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Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia — evidence for three subprovinces

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Abstract

This paper describes the distribution of fishes in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia. 48 842 fish representing 29 species (including one undescribed plotosid catfish) were recorded from 148 of the 171 sites sampled in 21 river systems throughout the Pilbara Drainage Division, i.e. from the Irwin River in the south to the DeGrey River in the north. Of these, 26 844 were from 13 native freshwater species (this total includes the catadromous Indian short-finned eel *Anguilla bicolor* McClelland 1844 and an undescribed plotosid catfish), 3 099 were from 12 marine/estuarine species and a further 18 899 were from four introduced species. In addition, the Pilbara Drainage Division contains two endemic cave fishes in the North West Cape (Humphreys & Adams 1991; Allen *et al*. 2002). The results of this study suggest that the Pilbara Drainage Division can be divided into three subprovinces, one for the westwards flowing rivers, i.e. from the Greenough to Lyndon (Southern Pilbara Subprovince), another for the northwards flowing rivers, i.e. from the Yannarie to the DeGrey (Northern Pilbara Subprovince), and a third for the subterranean waters of North West Cape (North West Cape Subprovince).

Key words: Pilbara Drainage Division, Western Australia, fish fauna

Introduction

The freshwater fish fauna of Australia is depauperate but highly endemic and lacks many families found elsewhere in the world (e.g. Whitley 1947; Lake 1971; Allen 1989; Unmack 2001). Based on the prevailing freshwater fish (and molluscan) fauna (Iredale & Whitley 1938) and hydrological data (Lake 1971) of the different regions, Australia has, with only minor modifications, long been categorised into a number of biogeographical zones, bioregions or provinces (see for example, Whitley 1947; Merrick & Schmida 1984;

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Allen *et al*. 2002). In the most recent discussions of these bioregions Unmack (2001), using contemporary statistical techniques, proposed that ten freshwater fish biogeographic provinces could be recognised, i.e. Southwestern, Pilbara, Kimberley, Northern, Central Australian, Eastern, Murray-Darling, Bass, Southern Tasmanian and Paleo.

The Pilbara Province extends from the Greenough River in the south to the DeGrey River in the north (Fig. 1) (Unmack 2001). It is one of the hottest regions in Australia with a mean rainfall of generally < 400 mm and in which perennial surface waters are scarce (Unmack 2001). However, a Mediterranean climate in the south, i.e. the region to the south of the Murchison River, and the effects of occasional monsoons in the north, i.e. the region to the north of the Yannarie River, ensures that whilst the region is exposed to extensive dry periods, with most of the region's rivers being intermittent for long periods, it is also subject to occasional flooding (winter in the south and summer in the north). It is worth noting that monsoonal and winter low pressure systems often extend far into the south and the north respectively, bringing with them unseasonal rainfall. As these low pressure systems rarely extend far inland, the inland sections of rivers receive even less and more erratic water than those of the coast. Furthermore, the central region between the Murchison and Ashburton rivers and the North West Cape receive even more erratic weather patterns often going several years without significant falls. However, whilst the North West Cape region is essentially desert with little, if any, perennial freshwater systems, it does have numerous caves that contain brackish waters and an associated stygofauna. To the north, the region is isolated from the Kimberley by the Great Sandy Desert, an extensive area with little or no surface run-off with the only records of fishes being those for the western rainbowfish *Melanotaenia australis* (Castelnau 1875) and the spangled perch *Leiopotherapon unicolor* (Günther 1859) from Sturt Creek (Unmack pers. comm.), whilst to the south there are no major catchments between the region and the first catchment of the Southwestern Division, i.e. the Arrowsmith River, *ca* 100 km to the south. The isolation of much of the region has resulted in only limited distributional fish faunal surveys being conducted. In 1947 Gilbert Whitley listed only three species known from the Pilbara (that he referred to as the Greyian Fluvifaunula) and stated that "We require more specimens for study, more exploration, and forbearance from introducing foreign types to the detriment of our native fauna". He did not, however, include the Murchison River hardyhead *Craterocephalus cuneiceps* Whitley 1944 in this list, which would have taken the total to four species. Since then, knowledge of the species composition of the region has been enhanced by Shipway (1950, 1953), Mees (1962, 1963), and Allen (1982). The most notable report of Pilbara fishes was that by Allen (1982) who reported on fish surveys by the Western Australian Museum in the 1970s. Masini (1998) conducted a limited fish survey of six species from between the Fortescue and DeGrey rivers, while Whitley (1945), Mees (1962), Humphreys and Adams (1991) and Humphreys (1994, 1999) provide notes on the subterranean fauna of the North West Cape. The above studies demonstrated that the Pilbara is home to five species of endemic freshwater fish

and, whilst sharing over half of it's species with the Kimberley, it shares none with the Southwestern Division (Allen *et al.* 2002).

In this paper we report on the results of a recent survey in which every major river system in the Pilbara Drainage Division was sampled for fish.

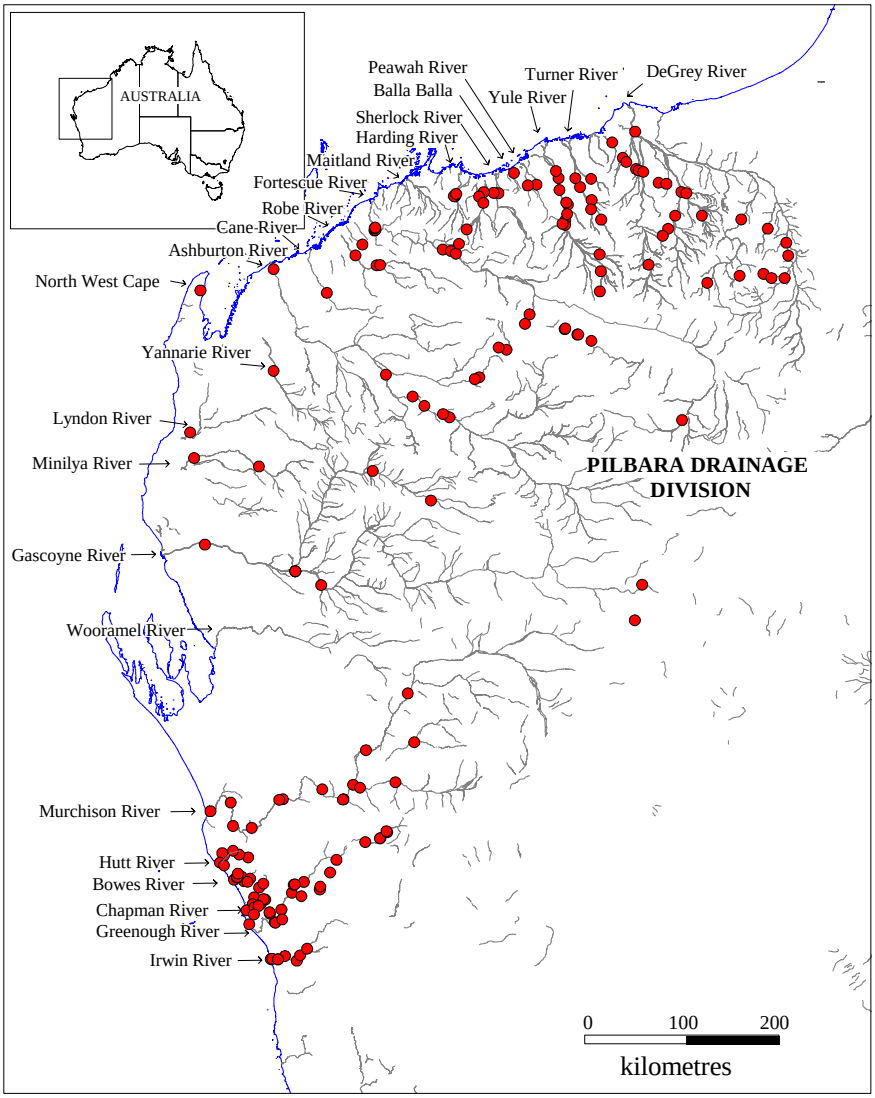

FIGURE 1. The sites in the Pilbara Drainage Division that were sampled for fish.

Materials and methods

Sampling for fish

Between December 2000 and November 2002 a total of 171 sites in the following rivers of the Pilbara Drainage Division were sampled for fish (see Fig. 1):

Irwin River (8 sites), Greenough River (21 sites), Chapman River (10 sites), Bowes River (8 sites), Hutt River (7 sites), Murchison River (15 sites), Gascoyne River (10 sites), Minilya River (2 sites), Lyndon River (1 site), Qualing and Charles Knife Rd pools (North West Cape) (2 sites), Yannarie River (1 site), Ashburton River (10 sites), Cane River (1 site), Robe River (4 sites), Fortescue River (16 sites), Harding River (3 sites), Sherlock River (6 sites), Balla Balla River (1 site), Peawah River (2 sites), Yule River (12 sites), Turner River (6 sites) and the DeGrey River (25 sites).

Sampling equipment included a variety of seine nets [1 m (1 mm mesh), 5, 10 and 15 m (all 3 mm mesh), 26 m (6 and 3 mm mesh) and 60 m (10 and 5 mm mesh)], gill nets (25 to 125 mm stretched mesh sizes), cast nets, masks and snorkels, and rods and lines.

Environmental variables

The salinity, temperature and pH were recorded at each sample site.

Species identification and maps

At each site, the fishes captured were identified, counted and a representative of each species photographed alive. The majority of fish were then released. However, some specimens were retained for positive identification and for the collections of the Western Australian Museum. Longitude and latitude were recorded at each site using a Global Positioning System (GPS). Species distribution maps were created using the above GPS data and MapInfo (MapInfo Corporation 1998).

Classification of sample sites, ordination of rivers and Analysis of Similarity (ANOSIM)

During the course of sampling our observations led us to propose that, based on it's freshwater fish fauna, the Pilbara Drainage Division should be more appropriately considered to be comprised of three subprovinces, i.e. a southern subprovince (Southern Pilbara) extending northwards to approximately the Minilya River, a North West Cape subprovince encompassing the cave fishes that are endemic to the otherwise dry and extremely arid North West Cape, and a northern subprovince (Northern Pilbara) including all rivers between the Yannarie River and the DeGrey River. In order to test this hypothesis a similarity matrix of the freshwater fish species present at each site in each river (captured during this study and from Western Australia Museum records) employing the Bray-Curtis similarity coefficient was constructed using the PRIMER package (Clarke & Gorley 2001). In the same package a dendogram was constructed to graphically display these data. A second analysis employing the pooled data for the sites from each river was also used to construct a similarity matrix of the freshwater fish species present in each river and an ordination plot using non-metric multidimensional scaling of these data generated. In order to test for significant differences between community structures of the proposed 'subprovinces', site and river data were subjected to one-way analysis of similarity (ANOSIM). ANOSIM is a non-parametric test that uses a permutation procedure applied to a

ranked similarity matrix, based on, in this case, a Bray-Curtis similarity matrix of species presence/absence data for sites or rivers. Firstly, the test statistic *R* is calculated. *R* is a measure of the discrimination between groups, with a value of 0 indicating no differences between groups, and a value of 1 indicating that each member within an *a priori* designated group is more similar to other members of the group than it is to members of any other group. Secondly, the samples (sites or rivers) are randomly sampled (with replacement) and assigned an arbitrary label (site or river descriptor) and the *R* statistic recalculated. This is performed a maximum of 999 times to produce a distribution of *R* values to which the original is compared and its probability of occurring by chance determined. Those rivers at which no native freshwater fish were caught were excluded from the analyses, e.g. the Irwin River was excluded as the only freshwater species caught was the introduced swordtail (*Xiphophorus hellerii* Heckel 1848).

Species presence-absence data were preferred to relative abundance data for a number of reasons; 1. Water levels, and thus sampling efficiency, varied greatly between the sample sites; 2. The level of sampling effort was governed by site characteristics, e.g. size and depth; 3. The requirement of a number of capture techniques to effectively sample the variety of species in the different sites, e.g. different meshed seine and gill nets, mask and snorkel only in clear waters, seine nets not as effective as gill nets or rod and line in capturing larger species (e.g. lesser salmon catfish); 4. Data from the Western Australian Museum gives no idea of sampling effort or total number of individuals captured. Thus, as estimates of relative abundance could not be standardised for all sites and as presence-absence data are generally more appropriate for biogeographic studies, comparisons utilising presence/absence data were employed.

Results and Discussion

Environmental variables

The conductivities of the rivers were generally low, but a number of systems in the southern part of the region were salt-affected. The salinity ranges for each species are provided in the individual species accounts. The pHs of the rivers sampled were always alkaline and ranged between 7.1 and 10.2. The water temperatures of the sites sampled ranged from 10.8 to 40.4°C. At some sites within Karijini National Park where the water temperatures were < 13°C in July all fish (*Neosilurus hyrtlii* Steindachner 1867 and *Leiopotherapon unicolor* (Günther 1859)) were dead. However, fish were found alive at nearby sites sampled during the same day where the water temperatures were >16°C. These data suggest that such low temperatures may be lethal to these tropical species.

Distribution of fishes in the Pilbara

A total of 48 842 fish representing 29 species were recorded from 148 of the 171 sites sampled in 22 river systems throughout the Pilbara Drainage Division, i.e. from the Irwin

River (a small river *ca* 30 km to the south of the Greenough River) in the south to the DeGrey River in the north (Tables 1–3). Of these, 26 844 were from 12 (possibly 13) native

TABLE 1. The native freshwater fishes collected in the rivers of the Pilbara (Indian Ocean) Drainage Division. N.B. WAM signifies that whilst this species was not collected during the current study it is listed as present in the Western Australian Museums records.

Family Species	Common name	Total	Rivers
Anguillidae	Eels		
Anguilla bicolor	Indian short-finned eel	8	Fortescue, Yule, DeGrey (WAM)
Clupeidae	Herrings		
Nematalosa erebi	Bony bream	2 525	Ashburton, Cane, Robe, Fortescue, Maitland (WAM), Harding, Sherlock, Yule, Turner, Degrey
Ariidae	Fork-tailed catfishes		
Arius graeffei	Lesser salmon catfish	76	Ashburton, Fortescue, Harding, Sherlock, DeGrey
Plotosidae	Eel-tailed catfishes		
Neosilurus hyrtlii	Hyrtl's tandan	231	Ashburton (WAM), Fortescue, Maitland (WAM), Harding, Sherlock (WAM), Yule, DeGrey
Neosilurus sp.	Neosilurus species	1	Robe, Fortescue
Melanotaeniidae	Rainbowfishes		
Melanotaenia australis	Western rainbowfish	11 653	Ashburton, Robe, Fortescue, Maitland (WAM), Harding, Sherlock, Yule, Turner, DeGrey
Atherinidae	Silversides or hardyheads		
Craterocephalus cuneiceps	Murchison River hardyhead	8 128	Greenough, Hutt, Murchison, Wooramel (WAM), Gascoyne, DeGrey
Terapontidae	Grunters		
Amniataba percoides	Barred grunter	939	Ashburton, Robe, Fortescue, Maitland (WAM), Harding, Sherlock, Yule
Leiopotherapon aheneus	Fortescue grunter	792	Asburton, Robe, Fortescue
Leiopotherapon unicolor	Spangled perch	2 066	Murchison to DeGrey, Wooramel (WAM), Maitland (WAM)
Eleotridae	Gudgeons		
Hypseleotris aurea	Golden gudgeon	182	Murchison, Gascoyne
Hypseleotris compressus	Empire gudgeon	193	Chapman, Murchison, Robe (WAM), Fortescue, Harding, Sherlock, Yule, Turner, DeGrey
Gobiidae	Gobies		
Glossogobius giurus	Flathead goby	50	Ashburton, Fortescue, Maitland (WAM)
TOTAL		**26 844**	

freshwater species, 3 099 were from 12 marine/estuarine species and a further 18 899 were from four introduced species. In addition to the species captured during this study the Pilbara Drainage Division contains two endemic cave fishes in the North West Cape (Humphreys & Adams 1991; Allen *et al*. 2002). The five most abundant species were the introduced mosquitofish *Gambusia holbrooki* Girard (ex Agassiz) 1859 (16 510), and the following native species, western rainbowfish *Melanotaenia australis* (11 653), Murchison River hardyhead *Craterocephalus cuneiceps* (8 128), bony bream *Nematalosa erebi* (Günther 1868) (2 525) and spangled perch *Leiopotherapon unicolor* (2 066), which together accounted for ~85% of the total catch.

TABLE 2. The marine/estuarine fishes collected in the rivers of the Pilbara (Indian Ocean) Drainage Division.

Family Species	Common name	Total	Rivers
Elopidae	Tenpounders		
Elops hawaiiensis	Giant herring	70	Greenough, Harding, Yule
Megalopidae	Tarpon		
Megalops cyprinoides	Oxeye herring	102	Fortescue, Harding, Yule, DeGrey
Chanidae	Milkfish		
Chanos chanos	Milkfish	240	Ashburton, Fortescue, Yule, DeGrey
Mugilidae	Mullets		
Mugil cephalus	Sea mullet	605	Irwin, Greenough, Chapman, Bowes, Hutt, Murchison, Ashburton, Fortescue, Turner, DeGrey
Centropomidae	Giant perches		
Lates calcarifer	Barramundi	35	Ashburton, Harding, Sherlock, Yule, DeGrey
Lutjanidae	Snappers		
Lutjanus argentimaculatus	Mangrove jack	157	Ashburton, Fortescue, Harding, Sherlock, Yule, Turner, DeGrey
Sparidae	Bream		
Acanthopagrus butcheri	Black bream	123	Irwin, Greenough, Chapman, Hutt, Murchison
Gerreidae	Silver biddies		
Gerres filamentosus	Threadfin silver biddy	4	Turner, DeGrey
Gerres subfasciatus	Roach	11	Ashburton, Yule
Terapontidae	Grunters		
Amniataba caudavittata	Yellow-tail trumpeter	1 088	Greenough, Murchison, Yule, DeGrey
Scatophagidae	Scats		
Selenotoca multifasciata	Striped butterfish	6	Fortescue, DeGrey
Gobiidae	Gobies		
Pseudogobius olorum	Swan River goby	658	Irwin, Greenough, Chapman, Bowes, Hutt, Murchison
TOTAL		**3 099**	

TABLE 3. The introduced fishes collected in the rivers of the Pilbara (Indian Ocean) Drainage Division.

Family Species	Common name	Total	Rivers
Poeciliidae	Livebearers		
Gambusia holbrooki	Mosquitofish	16 510	Greenough, Chapman, Hutt, North West Cape
Poecilia reticulata	Guppy	150	North West Cape
Xiphophorus hellerii	Swordtail	232	Irwin
Cichlidae	Cichlids		
Oreochromis mossambicus	Tilapia	2 007	Chapman, Gascoyne, Minilya, Lyndon
TOTAL		**18 899**	

The following species accounts give details on the freshwater, marine/estuarine and introduced fishes that were captured during the project. For the purposes of this paper, freshwater species are those that are either restricted to freshwater, breed in freshwater or they spend the majority of their lives in freshwater. Marine and estuarine species are those that are predominantly found in the marine or estuarine environ but may enter freshwaters during their life, but do not breed in the fresh. It should be noted that the short-finned eel *Anguilla bicolor* McClelland 1844, which breeds in the sea, was included in the freshwater category as it must spend the majority of its juvenile and adult life in freshwaters. The lesser salmon catfish *Arius graeffei* Kner and Steindachner 1867, which is found in both fresh and salt waters, has also been included in the freshwater category because they will breed in freshwater.

Freshwater fishes of the Pilbara (Plate 1)

Indian short-finned eel (Anguillidae)
Anguilla bicolor McClelland 1844

The short-finned eel was the third least abundant species caught during the course of this study (Table 1). Only eight individuals were recorded at three sites in the Fortescue River (1 individual at each site) and at one site in the Yule River (Plate 1, Table 1, Fig. 2). Western Australian Museum records also report this species from a single site in each of the Fortescue and DeGrey rivers. This species was captured in salinities of between 0.5 and 1.3 ppt. It is the only anguillid known from Western Australia. The adults, which grow to ~100 cm total length (TL), migrate to marine waters to breed, small juveniles then migrating back into freshwaters where they spend the majority of their lives before returning to the sea to breed and die (Smith 1997).

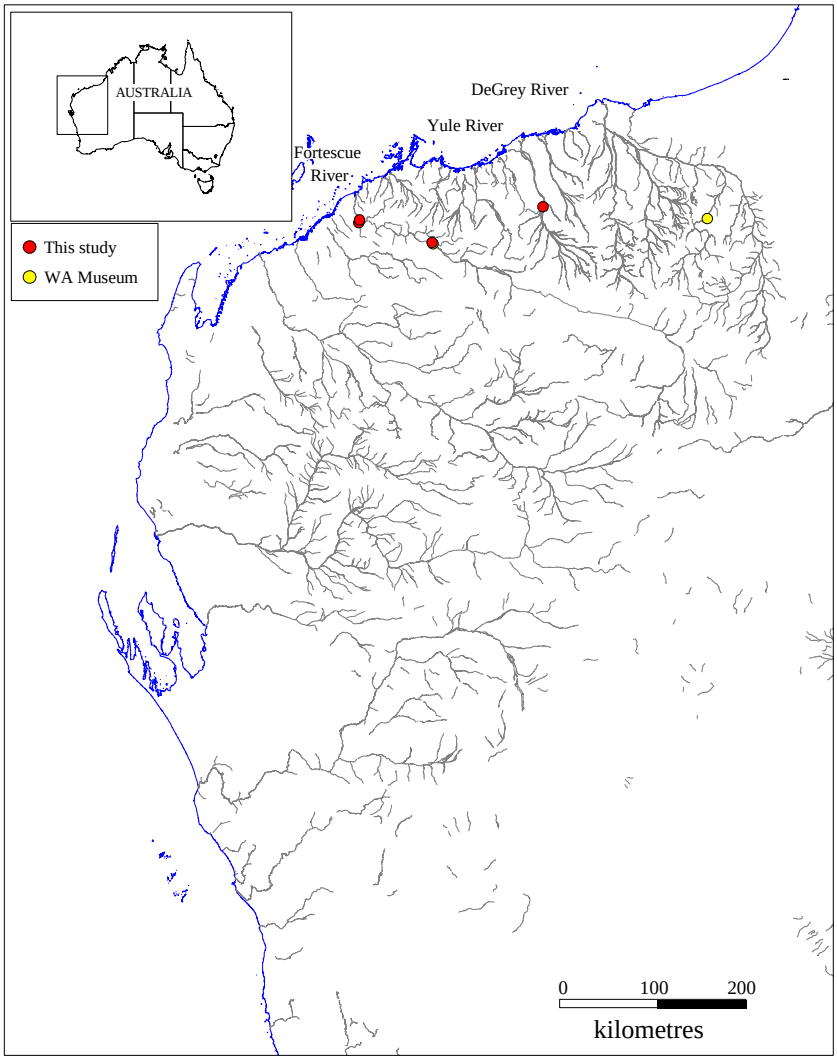

FIGURE 2. The sites in the Pilbara Drainage Division where the Indian short-finned eel (*Anguilla bicolor*) was captured. Also included are the Western Australian Museum records for the species.

Bony bream (Clupeidae)
Nematalosa erebi (Günther 1868)

The bony bream was the fourth most numerous species recorded during this study (Table 1). A total of 2 525 individuals were captured at 41 sites (at densities of up to 1.69 m^{-2}) in the majority of rivers between the Ashburton in the south and the DeGrey in the north (Plate 1, Table 1, Fig. 3). Western Australian Museum records report this species from the Ashburton, Robe, Fortescue, Maitland, Harding and DeGrey rivers. This species was captured in salinities between 0.1 and 2.3 ppt. This is one of Australia's most widespread

freshwater species occurring throughout other parts of northern Australia, including the drainages of the Kimberley, Northern Territory, Queensland, Murray-Darling and Lake Eyre (Allen *et al.* 2002). Attains a maximum size of ~30 cm TL and is one of only two Australian freshwater herrings. *Nematalosa erebi* may have a very protracted spawning period (i.e. at least May to December) in the Pilbara. In the Murray River (South Australia) it spawns in its second or third year of life during summer when water temperatures are 21–23°C (Puckridge and Walker 1990).

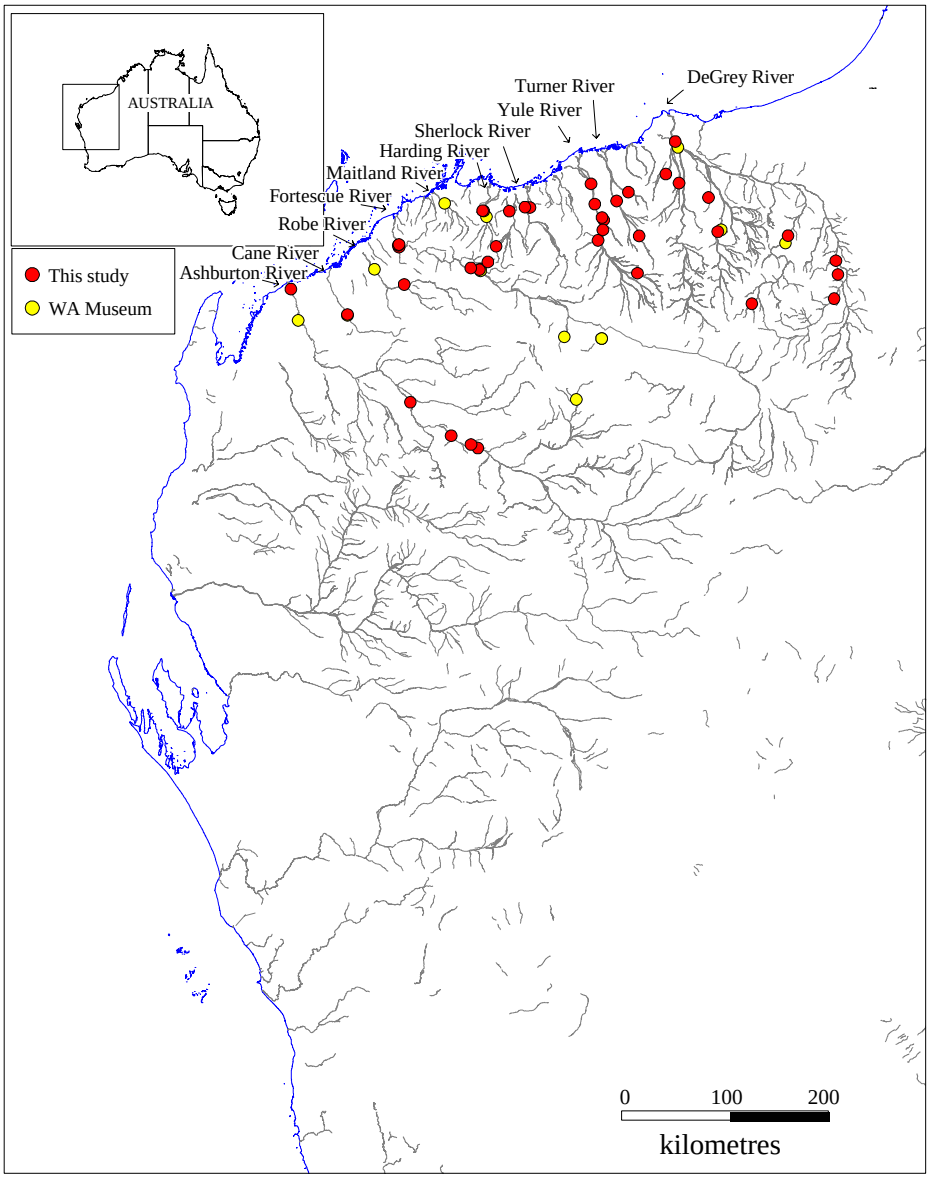

FIGURE 3. The sites in the Pilbara Drainage Division where the bony bream (*Nematalosa erebi*) was captured. Also included are the Western Australian Museum records for the species.

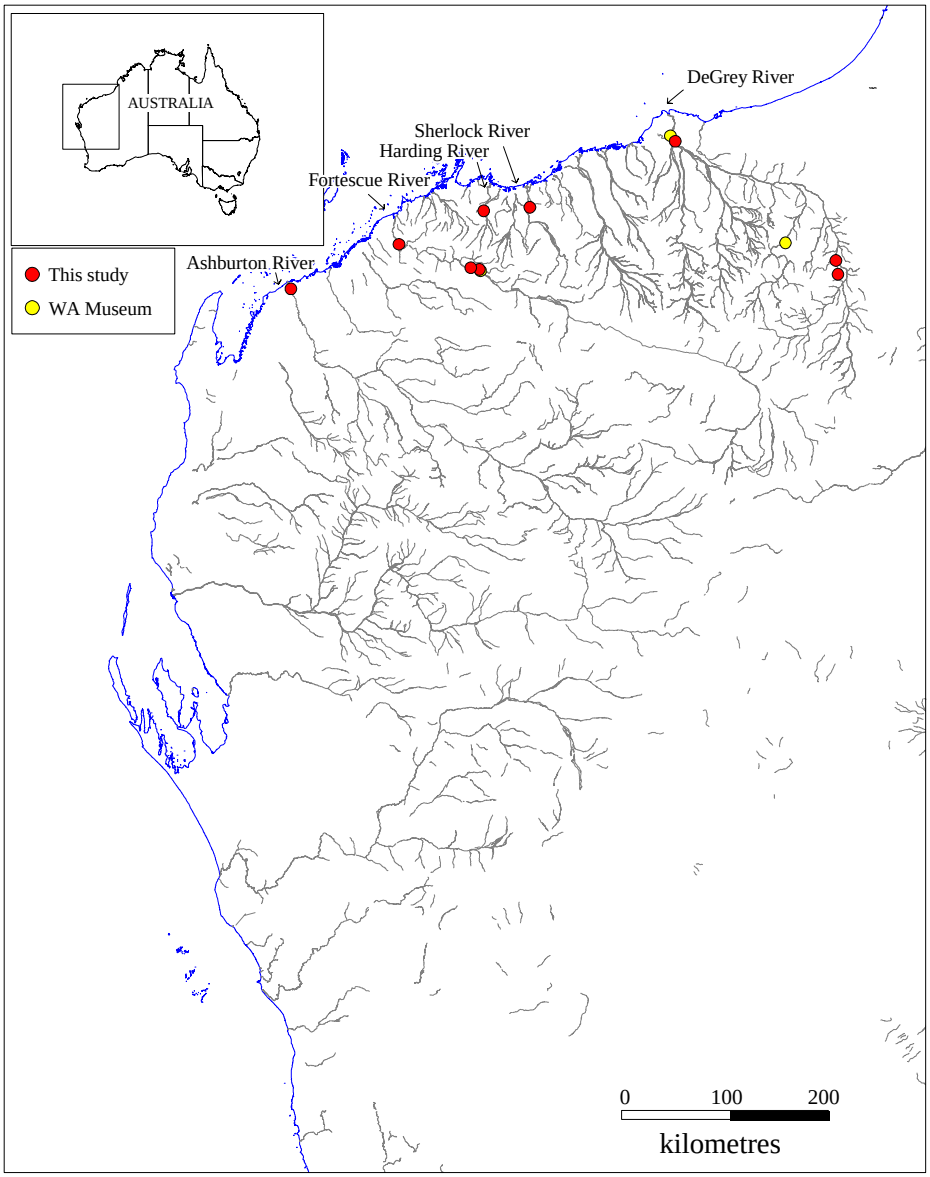

FIGURE 4. The sites in the Pilbara Drainage Division where the lesser salmon catfish (*Arius graeffei*) was captured. Also included are the Western Australian Museum records for the species.

Lesser salmon catfish (Ariidae)
Arius graeffei Kner and Steindachner 1867

Seventy six lesser salmon catfish were captured from 10 sites in the Ashburton, Fortescue, Harding, Sherlock and DeGrey rivers (Plate 1, Table 1, Fig. 4). Western Australian Museum records report this species from the Fortescue and DeGrey rivers. This species

was rarely abundant in the upper reaches of rivers, and although recorded at a density of 0.2 m^{-2} at one site it was found at densities of less than 0.05 m^{-2} at all other sites. This species was captured in salinities between 0.5 and 1.4 ppt. In Australia, *A. graeffei* has a coastal distribution from the Pilbara (Ashburton River) to New South Wales (Hunter River) where it is common in the estuarine reaches of rivers, however it can also survive and reproduce far upstream in riverine pools (Allen *et al.* 2002). Maximum size ~60 cm TL, based on our observations in the Kimberley spawning is likely to be during the wet season (summer).

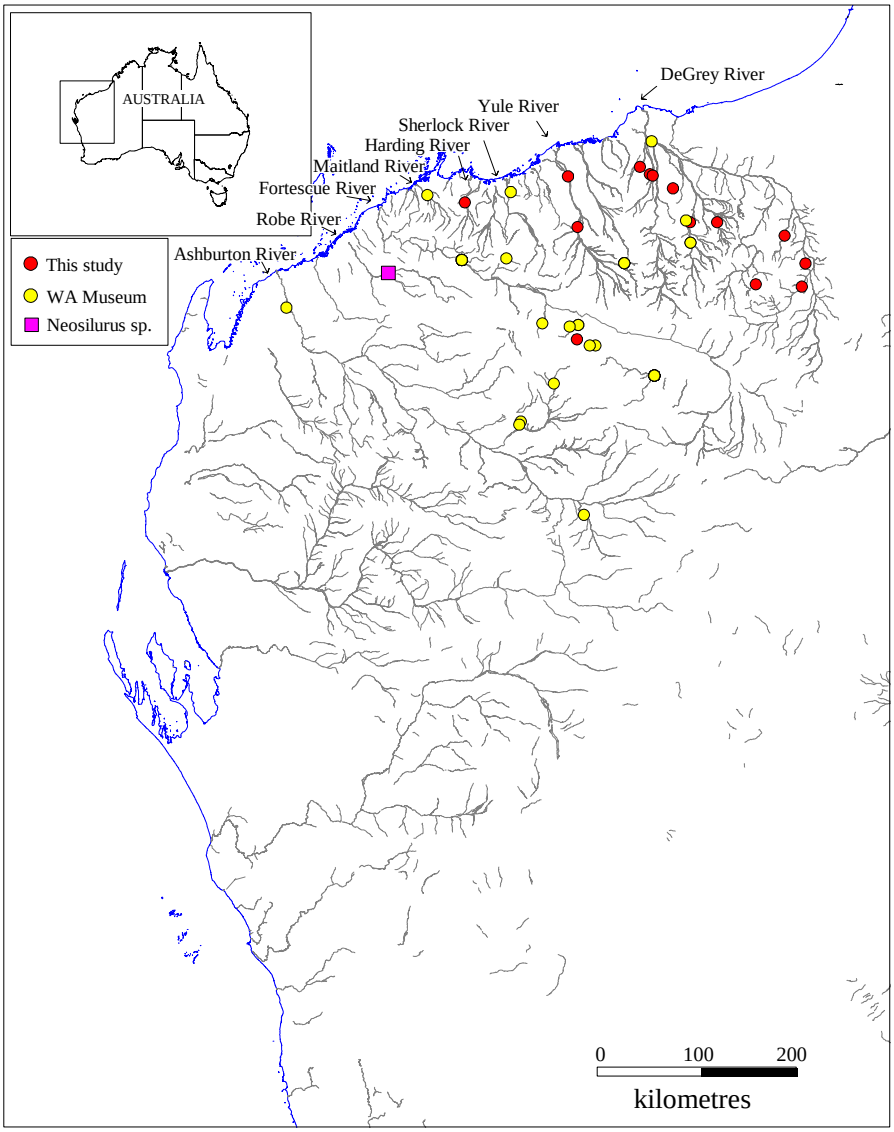

FIGURE 5. The sites in the Pilbara Drainage Division where Hyrtl's tandan (*Neosilurus hyrtlii*) and *Neosilurus* sp. were captured. Also included are the Western Australian Museum records for *N. hyrtlii*.

Hyrtl's tandan (Plotosidae)
Neosilurus hyrtlii Steindachner 1867

Two hundred and thirty one Hyrtl's tandan were captured from 14 sites in the Fortescue (0.4 ppt), Harding (0.5 ppt), Yule (0.3–0.4 ppt) and DeGrey (0.3–10.3 ppt) rivers (Plate 1, Table 1, Fig. 5). In the first three of these rivers densities never exceeded 0.05 m^{-2}. However, in those sites where it was captured in the DeGrey River it was often the third or fourth most abundant species with densities of up to 2.5 m^{-2}. Western Australian Museum records report this species from the Ashburton, Fortescue, Maitland, Sherlock, Yule and DeGrey rivers. *Neosilurus hyrtlii* is widespread across northern Australia from the Pilbara to the Brisbane River as well as Lake Eyre and the northern Murray-Darling basin (Allen *et al*. 2002). The species often forms very dense congregations in open water, which is presumably a defense mechanism to avoid predation. One specimen of what appears to be an undescribed species of *Neosilurus* was recorded at a single site in the Robe River (0.6 ppt). This latter 'species' is distinguishable from *N. hyrtlii* based on the fact that the head is proportionally larger and the snout length is longer (Plate 1). This species will be described in due course. The maximum size of *N. hyrtlii* is ~20 cm TL and it probably breeds during the wet (Allen *et al.* 2002).

Murchison River hardyhead (Atherinidae)
Craterocephalus cuneiceps Whitley 1944

The Murchison River hardyhead, with 8 128 individuals captured at 37 sites, was the third most numerous species encountered during the course of this study (Plate 1, Table 1, Fig. 6). However, while this species was found in the Greenough (0.2–32.1 ppt), Hutt (1.8–4.2 ppt), Murchison (0.1–13.9 ppt) and Gascoyne (0.9–2.7 ppt) rivers in the south and the DeGrey River (0.1–1.4 ppt) in the north, it has a disjunct distribution and was not found in any river between the Gascoyne and DeGrey rivers. This species was found at densities varying from 0.03 m^{-2} at a site in the DeGrey River to 25 m^{-2} at a site in the Murchison River. The Western Australian Museum has further records of this species from the Wooramel River. In the Murchison River population, breeding was extremely protracted with recruitment occurring throughout the year; the largest female and male specimens were 96 and 86 mm TL, respectively; sex ratio was 1.09 females :1 male; batch fecundity ranged from 46–454, and lengths at which 50 and 95% of females began maturation were 23.3 and 26.2 mm TL, respectively (Allen 2002).

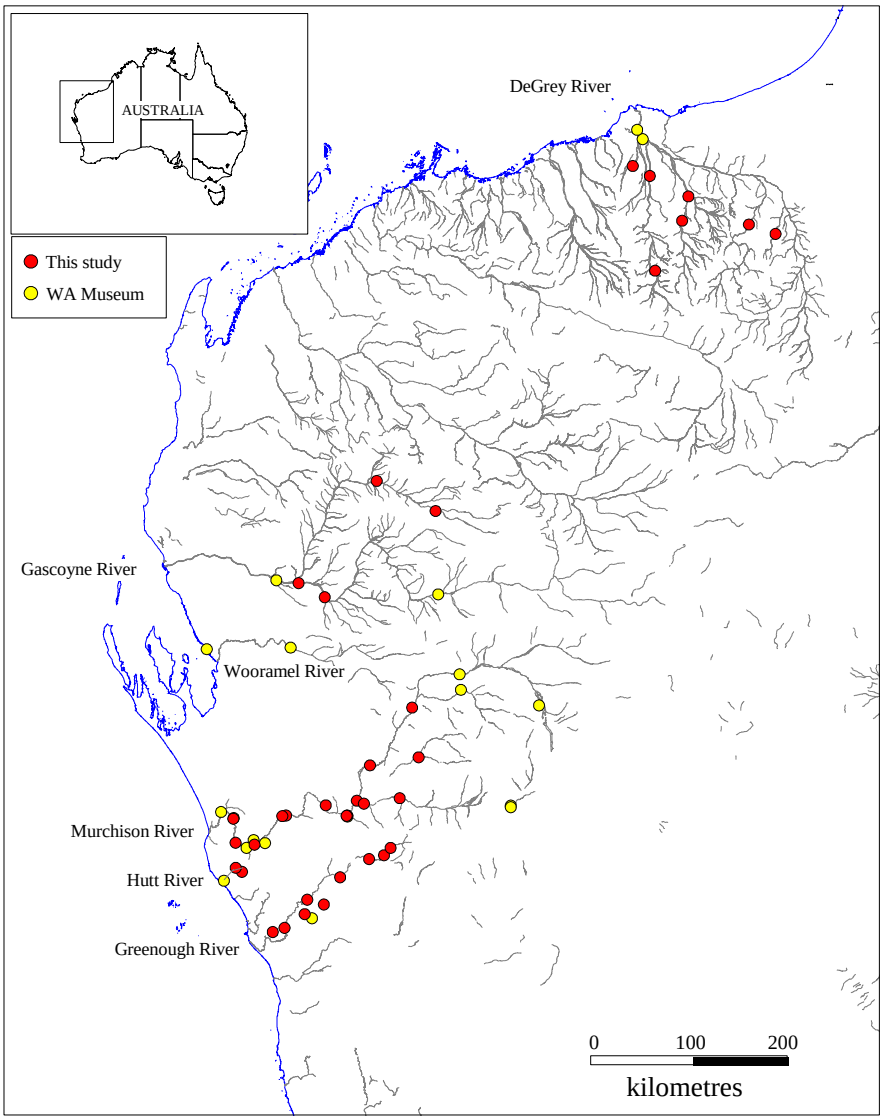

FIGURE 6. The sites in the Pilbara Drainage Division where the Murchison River hardyhead (*Craterocephalus cuneiceps*) was captured. Also included are the Western Australian Museum records for the species.

Western rainbowfish (Melanotaeniidae)
Melanotaenia australis (Castelnau 1875)

The western rainbowfish was the second most abundant species recorded during this study with 11 653 individuals captured from 72 sites in the Ashburton (0.1–9.9 ppt), Robe (0.5–0.6 ppt), Fortescue (0.4–1.4 ppt), Harding (0.5–0.6 ppt), Sherlock (0.2–1.4 ppt), Yule (0.3–1.1 ppt), Turner (1.0–2.3 ppt) and DeGrey (0.1–10.3 ppt) rivers at densities ranging

between 0.01 m^{-2} at a site in the Ashburton River in the south and 31.25 m^{-2} at a site in the DeGrey River in the north (Plate 1, Table 1, Fig. 7). Within the region densities of this species were generally higher towards the northern extent of its range. Western Australian Museum records note this species as present in the Ashburton, Fortescue, Maitland, Sherlock and DeGrey rivers. The range of this species extends from the Ashburton River in WA to the Victoria River in the Northern Territory (McGuigan *et al.* 2000; Allen *et al.* 2002). While only attaining a maximum size of ~10 cm TL, due to their extremely variable and vivid colour patterns they are highly regarded in the aquarium industry. The spawning period appears to be extremely protracted with temperatures above 20°C providing favourable conditions.

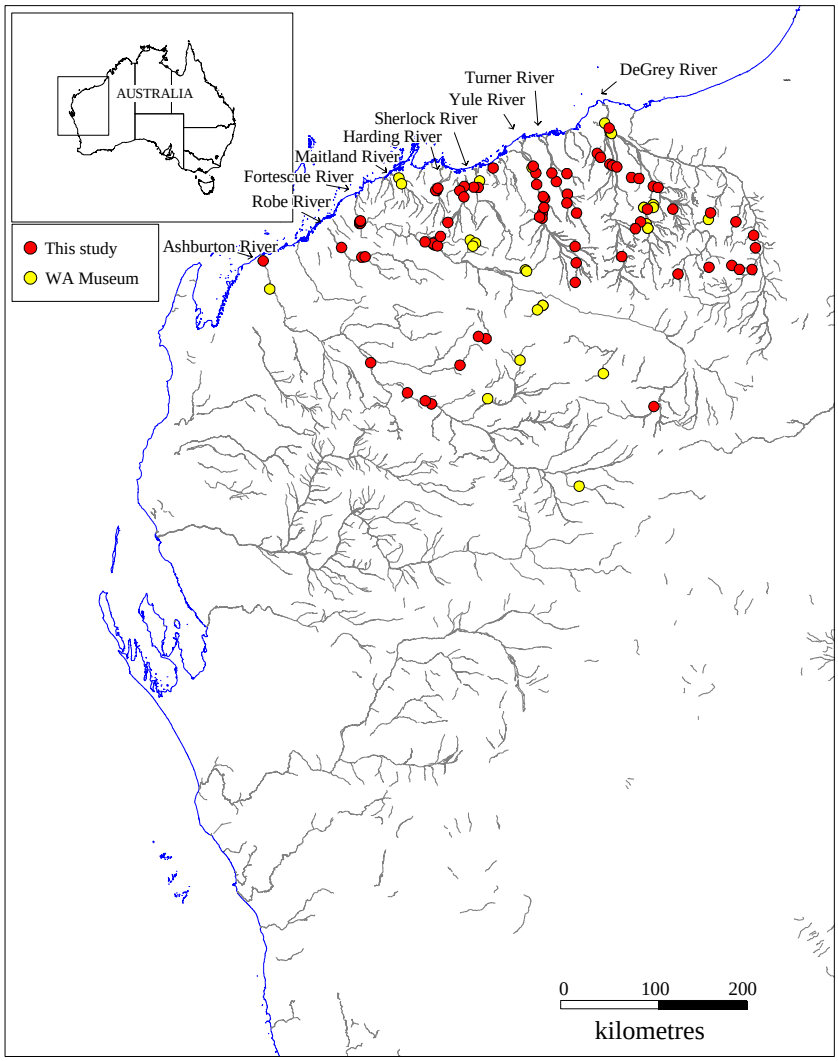

FIGURE 7. The sites in the Pilbara Drainage Division where the western rainbowfish (*Melanotaenia australis*) was captured. Also included are the Western Australian Museum records for the species.

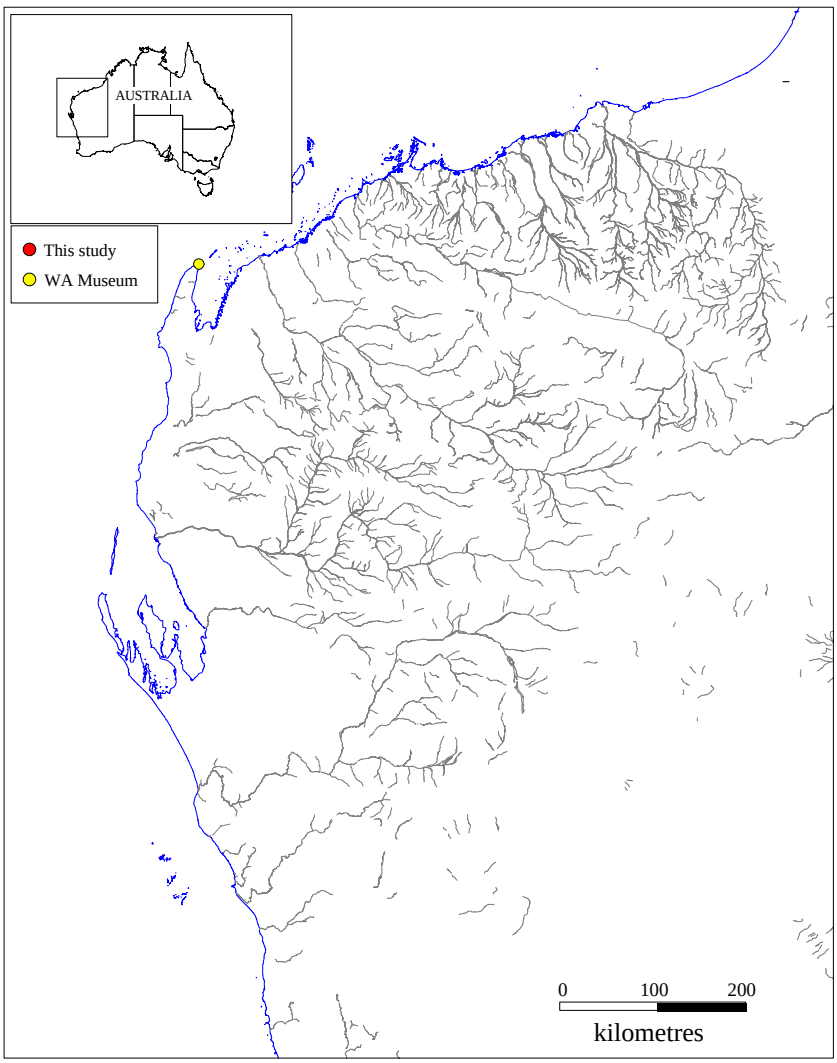

FIGURE 8. The site in the Pilbara Drainage Division where the Western Australian Museum has a record for the blind cave eel (*Ophisternon candidum*).

Blind cave eel (Synbranchidae)
Ophisternon candidum (Mees 1962)

Whilst not captured during this study, this species is endemic to the Pilbara and is restricted to the North West Cape (Fig. 8) (Humphreys & Adams 1991; Allen *et al*. 2002). This is undoubtedly one of Australia's most restricted and vulnerable fish species, a fact that has seen it listed as *VULNERABLE* in the Environment Protection and Biodiversity Conservation Act 1999. Only one other Western Australian freshwater fish species has been afforded the same listing, this being the blind gudgeon *Milyeringa veritas* Whitley

1945 (see below), a species also restricted to the North West Cape (and the adjacent Barrow Island).

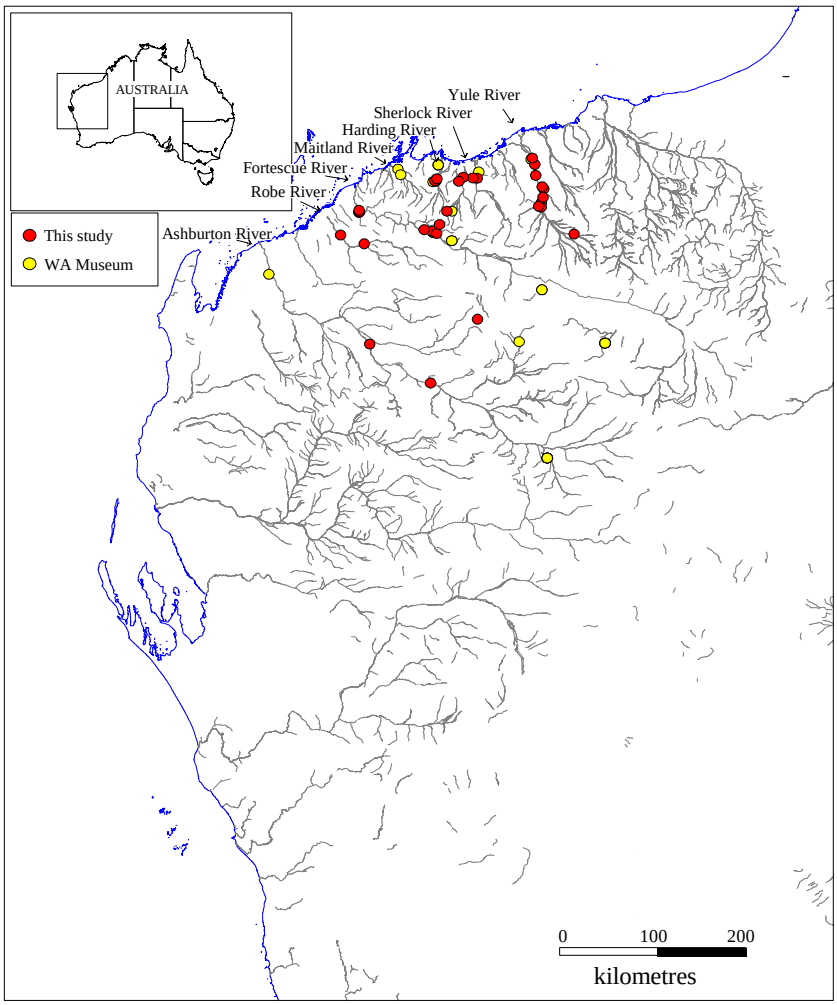

FIGURE 9. The sites in the Pilbara Drainage Division where the barred grunter (*Amniataba percoides*) was captured. Also included are the Western Australian Museum records for the species.

Barred grunter (Terapontidae)
Amniataba percoides (Günther 1864)

The barred grunter was the eighth most abundant species captured during this study, with 939 specimens caught in 26 sites at densities ranging from 0.01 m^{-2} in the Robe and Yule rivers to 0.97 m^{-2} in the Harding River (Plate 1, Table 1, Fig. 9). This species was caught in the Ashburton (1.0–9.9 ppt), Robe (0.5–0.6 ppt), Fortescue (0.4–3.4 ppt), Harding (0.5–

0.6 ppt), Sherlock (0.2–1.4 ppt) and Yule (0.3–1.1 ppt) rivers during this study, and is also documented in the Western Australian Museum records as being present in the Maitland River. While previously thought to be found in all of the major river systems of northern Australia north of the Ashburton (Allen *et al.* 2002) this species was not captured in the DeGrey River and no Western Australian Museum records exist for the species in this river. This species, which attains ~10 cm TL, forms loose schools in the shallows.

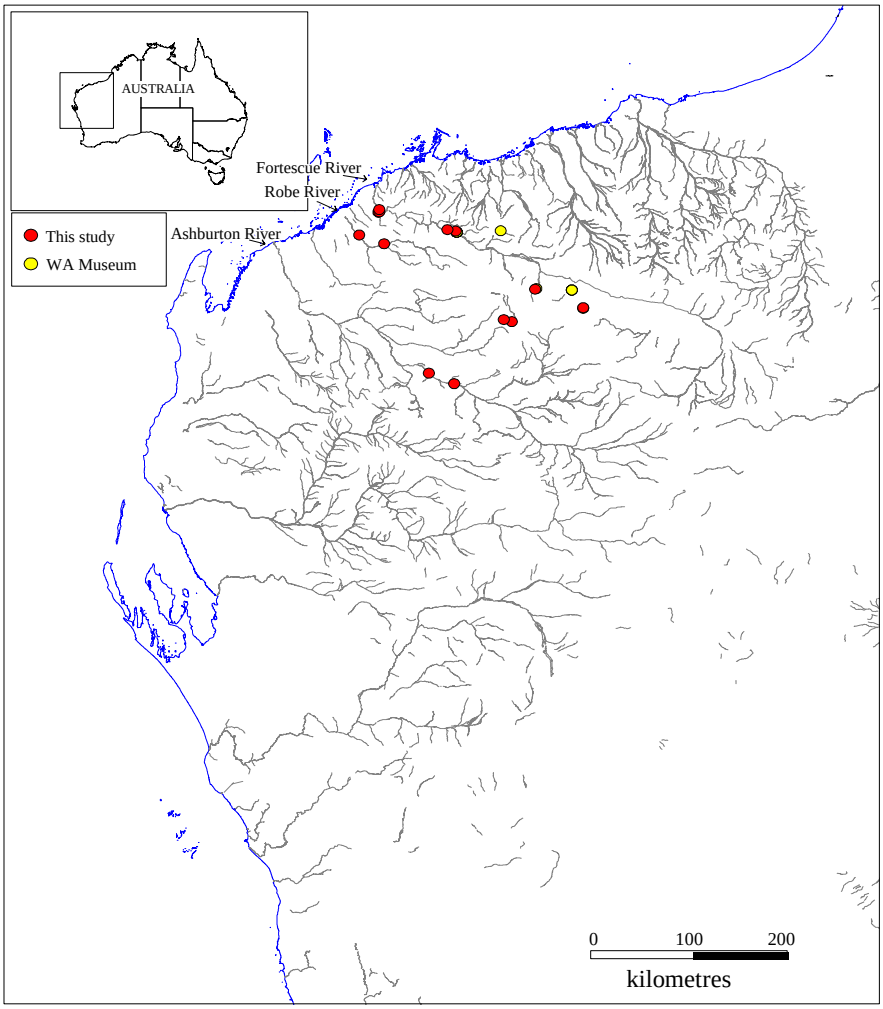

FIGURE 10. The sites in the Pilbara Drainage Division where the Fortescue grunter (*Leiopotherapon aheneus*) was captured. Also included are the Western Australian Museum records for the species.

Fortescue grunter (Terapontidae)
Leiopotherapon aheneus (Mees 1963)

First described in the 1960s and endemic to the Pilbara a total of 792 Fortescue grunters

were caught from seven sites in the Fortescue River (0.3–1.4 ppt) at densities varying from 0.03 to 0.19 m^{-2}, four sites in the Ashburton River (0.4–9.9 ppt) at densities ranging from < 0.01 to 0.13 m^{-2}, and two sites in the Robe River (0.5–0.6 ppt) at densities between 0.07 and 0.27 m^{-2} (Plate 1, Table 1, Fig. 10). This schooling species attains a maximum length of ~20 cm TL.

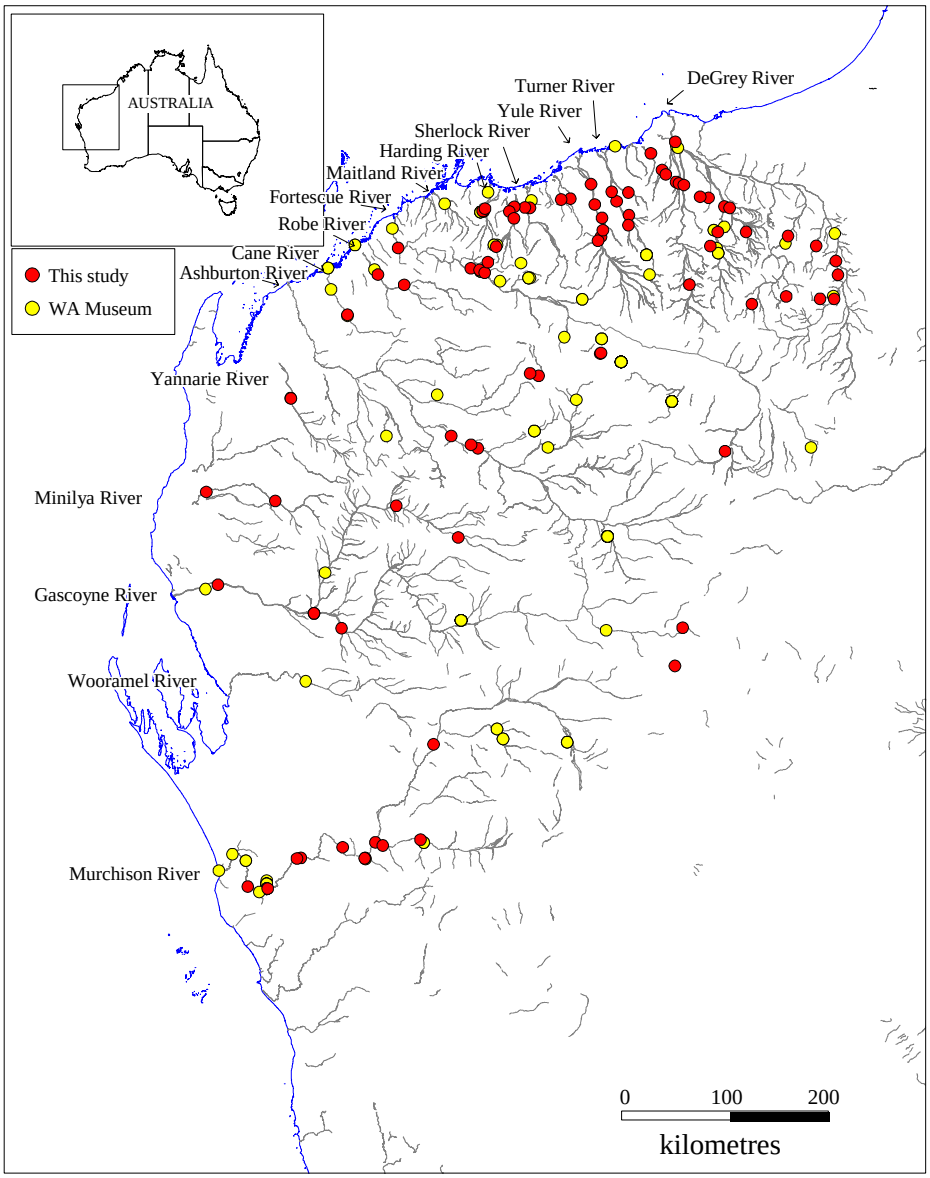

FIGURE 11. The sites in the Pilbara Drainage Division where the spangled perch (*Leiopotherapon unicolor*) was captured. Also included are the Western Australian Museum records for the species.

Spangled perch (Terapontidae)
Leiopotherapon unicolor (Günther 1859)

This species had the most extensive range of any species encountered during this study, being found in every river system between the Murchison River in the south and the DeGrey River in the north (0.1–13.9 ppt) (Plate 1, Table 1, Fig. 11). Spangled perch was the fifth most abundant species found in the region, with a total of 2 066 specimens captured from 82 sites with a mean density of 0.08 m^{-2} across all sites sampled. Western Australian Museum records report the existence of this species in the Murchison, Wooramel, Gascoyne, Ashburton, Cane, Robe, Fortescue, Maitland, Harding, Sherlock, Yule, Turner and DeGrey rivers. Thus, this study reports the presence of *L. unicolor* in the Minilya and Yannarie rivers for the first time. Watson (1958) reports *L. unicolor* from the Greenough River, however those specimens, which are housed in the Western Australian Museum, are in fact yellow-tailed trumpeter *Amniataba caudavittata* (Richardson 1845) (see Mees 1963). Spangled perch is Australia's most widespread freshwater species, and ranges from the Murchison River in Western Australia north and east to the Murray-Darling and Lake Eyre drainage systems. The maximum size is ~30 cm TL and in the Murchison River mature males and females were captured in summer and larvae and small juveniles were captured in March. This very hardy and aggressive species had a diet in the Murchison River that was dominated by *C. cuneiceps* and aquatic macrophytes and it can thus be described as omnivorous.

Golden gudgeon (Eleotridae)
Hypseleotris aurea (Shipway 1950)

One hundred and eighty two golden gudgeon were caught from three sites in the Murchison River (0.7–0.9 ppt) and two sites in the upper reaches of the Gascoyne River (0.9–1.3 ppt), at densities ranging between 0.02 m^{-2} at a site in the former river and 3.75 m^{-2} at a site in the latter river (Plate 1, Table 1, Fig. 12). Western Australian Museum records document this species from an additional three sites in each of these rivers, whilst the Australian Museum has a record of this species from a single site in tributary of the Fortescue River (verified by ourselves and Dr D. Hoese of the Australian Museum). The restriction of this small species to just three river systems makes it vulnerable to ecological and hydrological changes within its environment. This is particularly relevant as one of the rivers in which this species is found, i.e. Gascoyne, is infested with the introduced, much larger and aggressive tilapia *Oreochromis mossambicus* (Peters 1852) (see below). Also pertinent is the salinisation of parts of the lower Murchison River. The salinity tolerance of the species is not known but in the Murchison River, where salinities ranged from 0.7 to 6.4 ppt, they were never captured in water >1.1 ppt.

PLATE 1 (a–h). Freshwater fishes of the Pilbara: (a) *Anguilla bicolor*, (b) *Nematalosa erebi*, (c) *Arius graeffei*, (d) *Neosilurus hyrtlii*, (e) *Neosilurus* sp., (f) *Melanotaenia australis*, (g) *Craterocephalus cuneiceps*, (h) *Ophisternon candidum*. **Photographs:** D. Morgan (a, d–f), M. Allen (b, c, g), G. Allen (h).

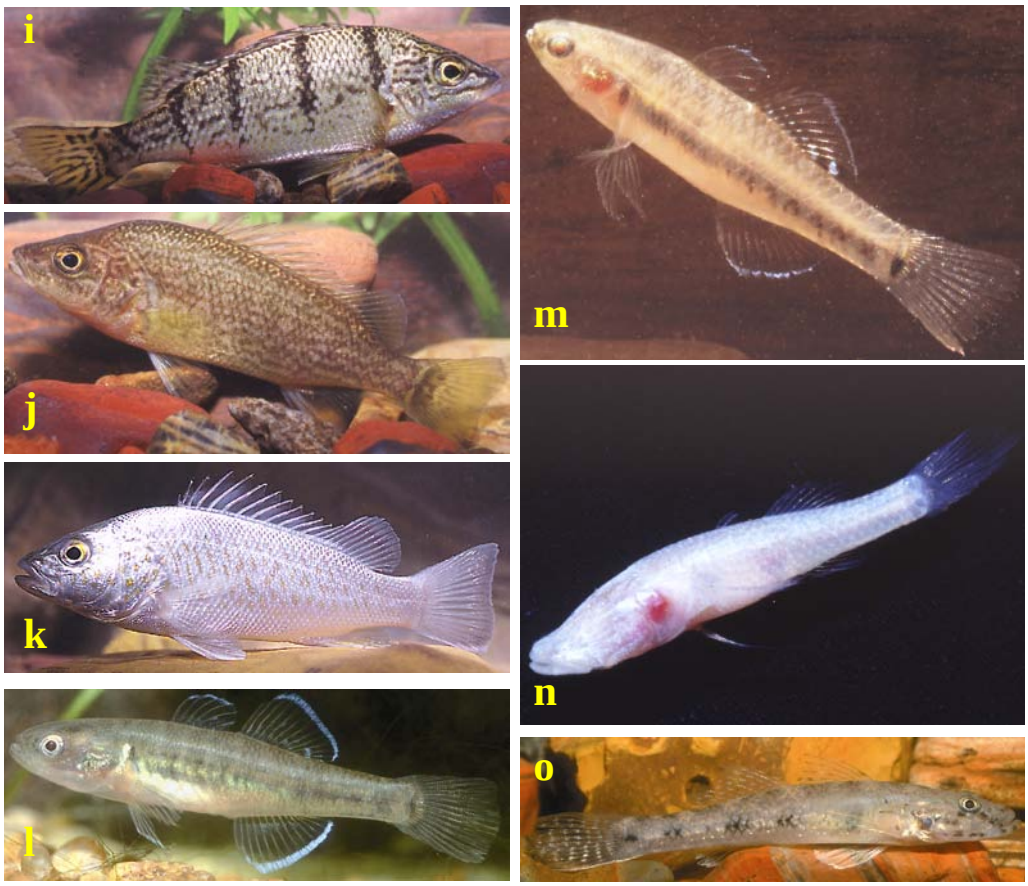

PLATE 1 (i–o). Freshwater fishes of the Pilbara: (i) *Amniataba percoides*, (j) *Leiopotherapon aheneus*, (k) *Leiopotherapon unicolor*, (l) *Hypseleotris aurea*, (m) *Hypseleotris compressus*, (n) *Milyeringa veritas* and (o) *Glossogobius giurus*. **Photographs:** D. Morgan (i, g, k, m), M. Allen (l, o) and G. Allen (n).

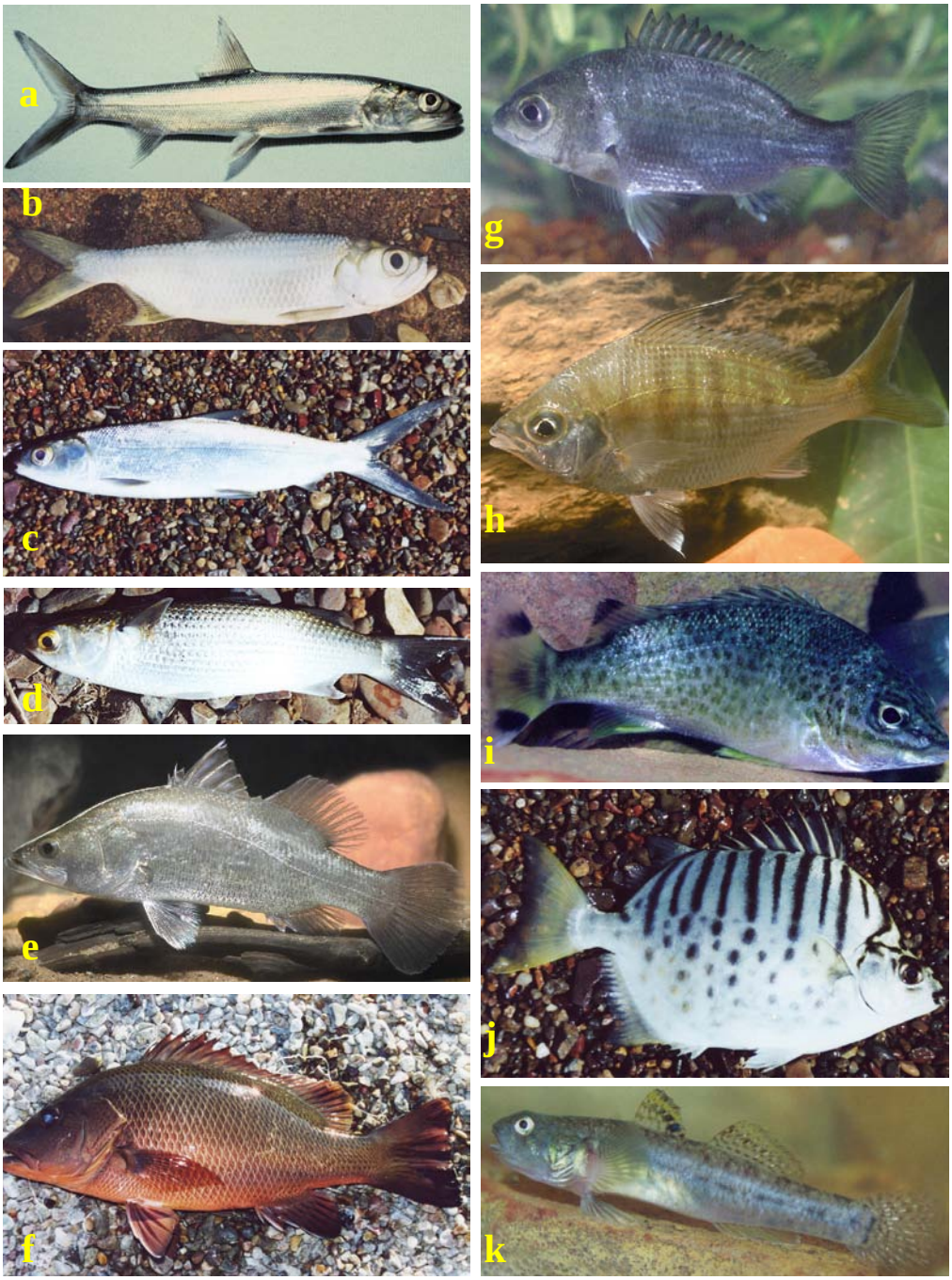

PLATE 2. Marine/estuarine fishes of Pilbara inland waters: (a) *Elops hawaiiensis*, (b) *Megalops cyprinoides*, (c) *Chanos chanos*, (d) *Mugil cephalus*, (e) *Lates calcarifer*, (f) *Lutjanus argentimaculatus*, (g) *Acanthopagrus butcheri*, (h) *Gerres filamentosus*, (i) *Amniataba caudavittata*, (j) *Selenotoca multifasciata*, (k) *Pseudogobius olorum*. **Photographs:** D. Morgan (b–d, f, g, i–k), M. Allen (e, h) and G. Allen (a).

PLATE 3. Introduced fishes of Pilbara inland waters: (a) *Gambusia holbrooki*, (b) *Poecilia reticulata*, (c) *Xiphophorus hellerii*, and (d) *Oreochromis mossambicus*. **Photographs:** D. Morgan.

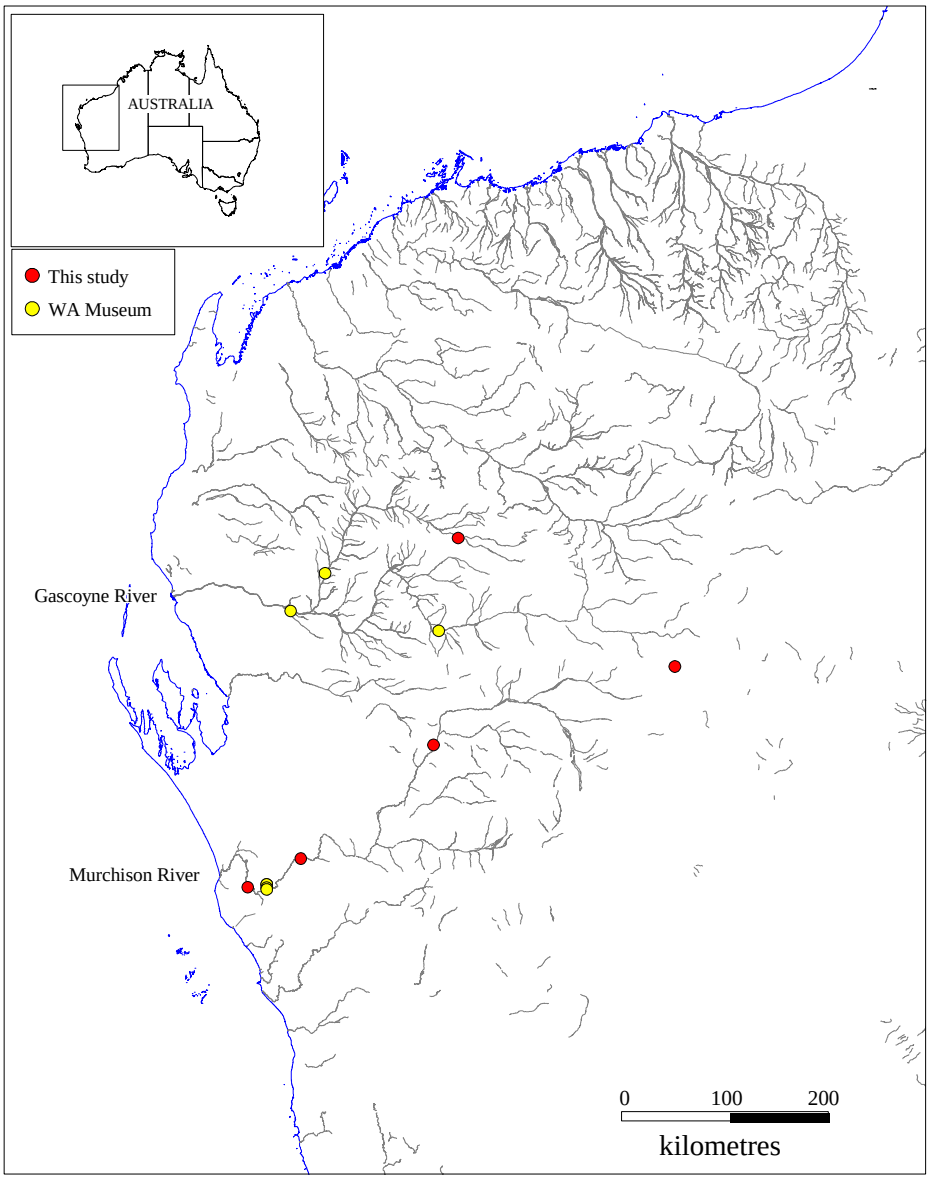

FIGURE 12. The sites in the Pilbara Drainage Division where the golden gudgeon (*Hypseleotris aurea*) was captured. Also included are the Western Australian Museum records for the species.

Empire gudgeon (Eleotridae)
Hypseleotris compressus (Krefft 1864)

The empire gudgeon is another species that exhibited a disjunct distribution in this region. In the south, 25 and 11 specimens were caught in the Chapman (2.6 ppt) and Murchison rivers (0.1–2.5 ppt), respectively, and in the north, 36, one, six, 69, 13 and 32 individuals

were captured from sites in the Fortescue (0.5 ppt), Harding (0.5 ppt), Sherlock (0.7 ppt), Yule (0.3–0.5 ppt), Turner (1.1–2.3 ppt) and DeGrey (0.4–0.8 ppt) rivers, respectively (Plate 1, Table 1, Fig. 13). In addition, the Western Australian Museum records have documented the occurrence of this species at a single site in the Robe River. The record for the Chapman River represents a southerly range extension for the species. This southerly extension (and that of the mangrove jack *Lutjanus argentimaculatus* (Forsskål 1775) to the Murchison River (see below)) may parallel that of the mud crab *Scylla serrata* (Forsskål 1755) which Gopurenko *et al*. (2003) attributed to the recruitment of larvae via a particularly strong southerly flowing Leeuwin Current in 1999/2000.

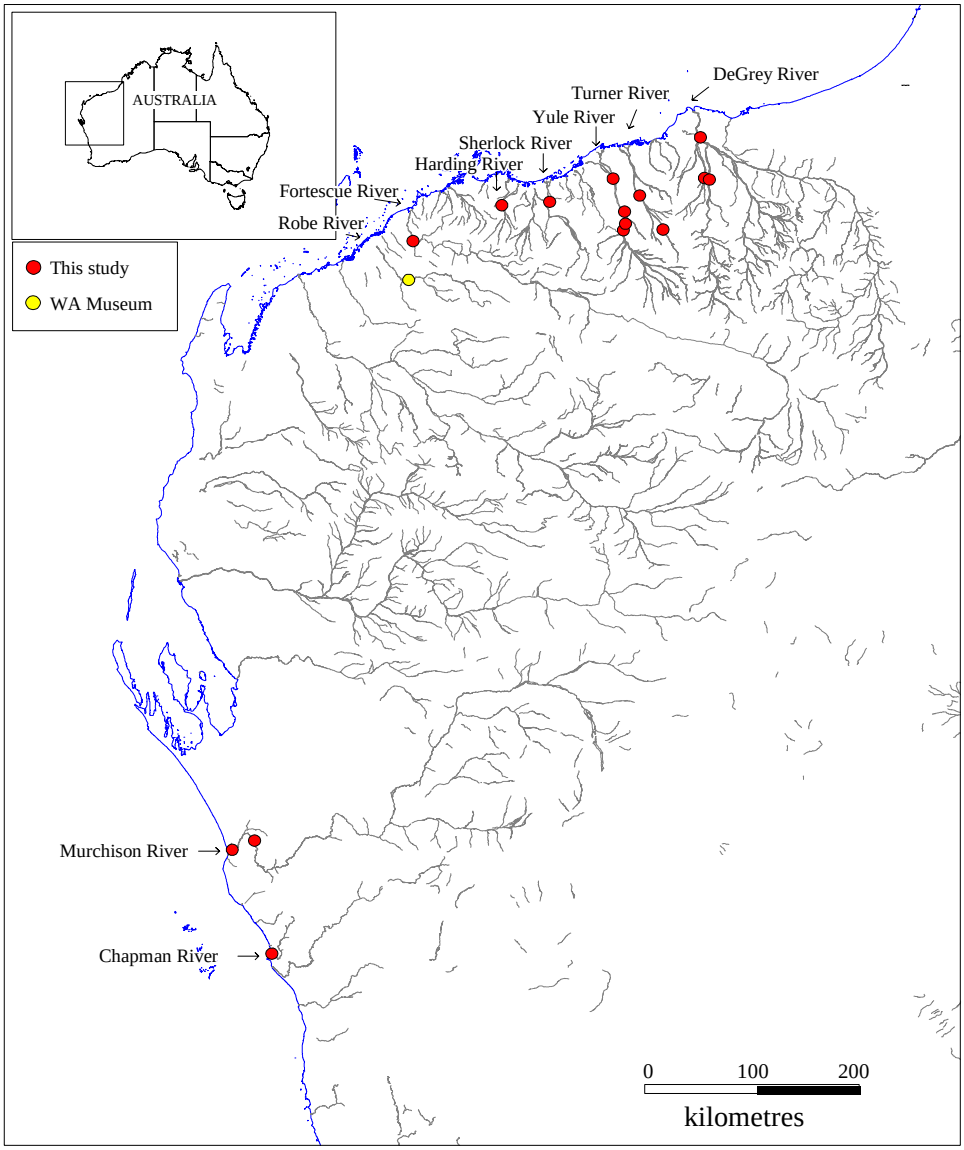

FIGURE 13. The sites in the Pilbara Drainage Division where the empire gudgeon (*Hypseleotris compressus*) was captured. Also included is the Western Australian Museum record for the species.

While not captured during this study, the species is endemic to the Pilbara and is restricted to the North West Cape and Barrow Island (Fig. 14) (Humphreys & Adams 1991; Allen *et al*. 2002). This is one of Australia's most restricted and vulnerable fish species, a fact that has seen it listed as *VULNERABLE* in the Environment Protection and Biodiversity Conservation Act 1999 and *DATA DEFICIENT* by the IUCN.

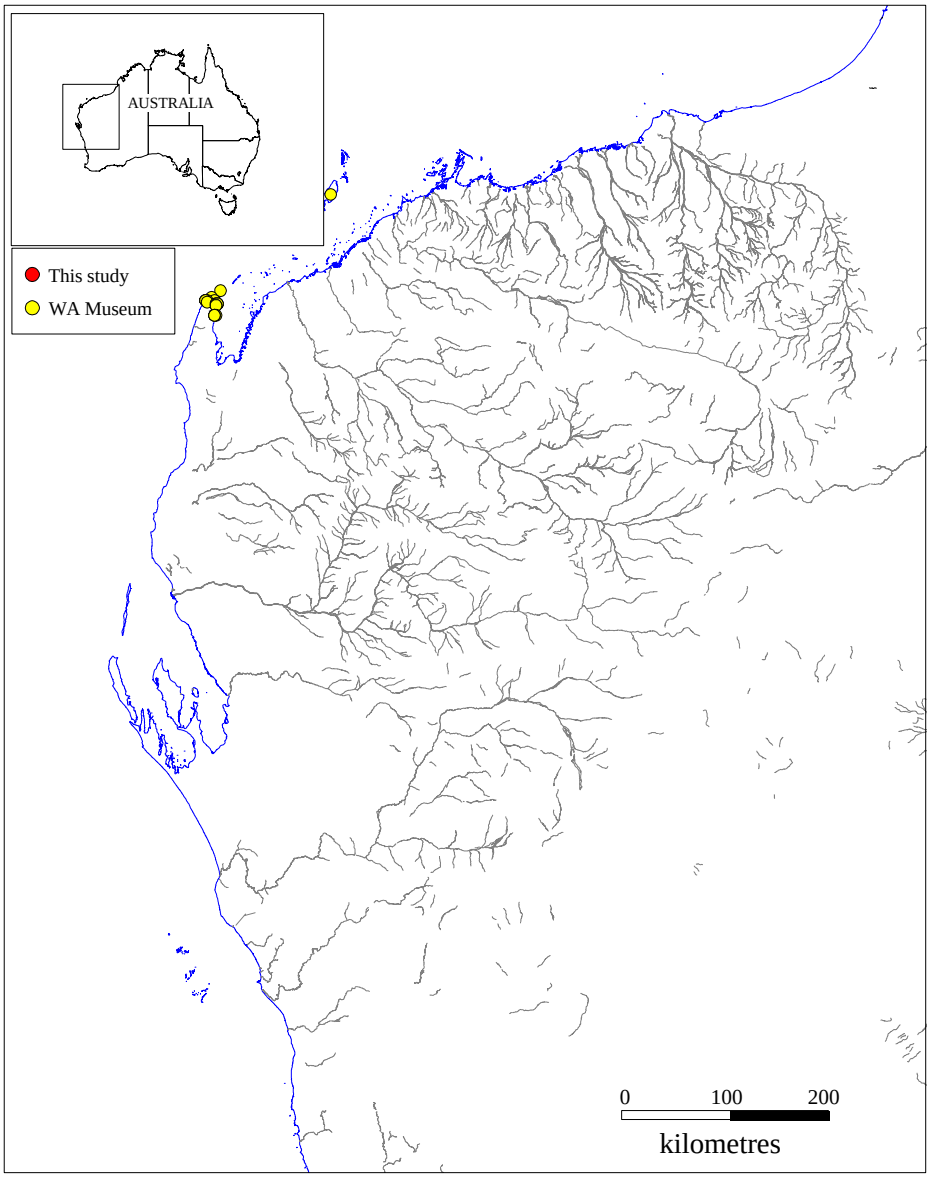

FIGURE 14. The sites in the Pilbara Drainage Division where the Western Australian Museum has records for the blind gudgeon (*Milyeringa veritas*).

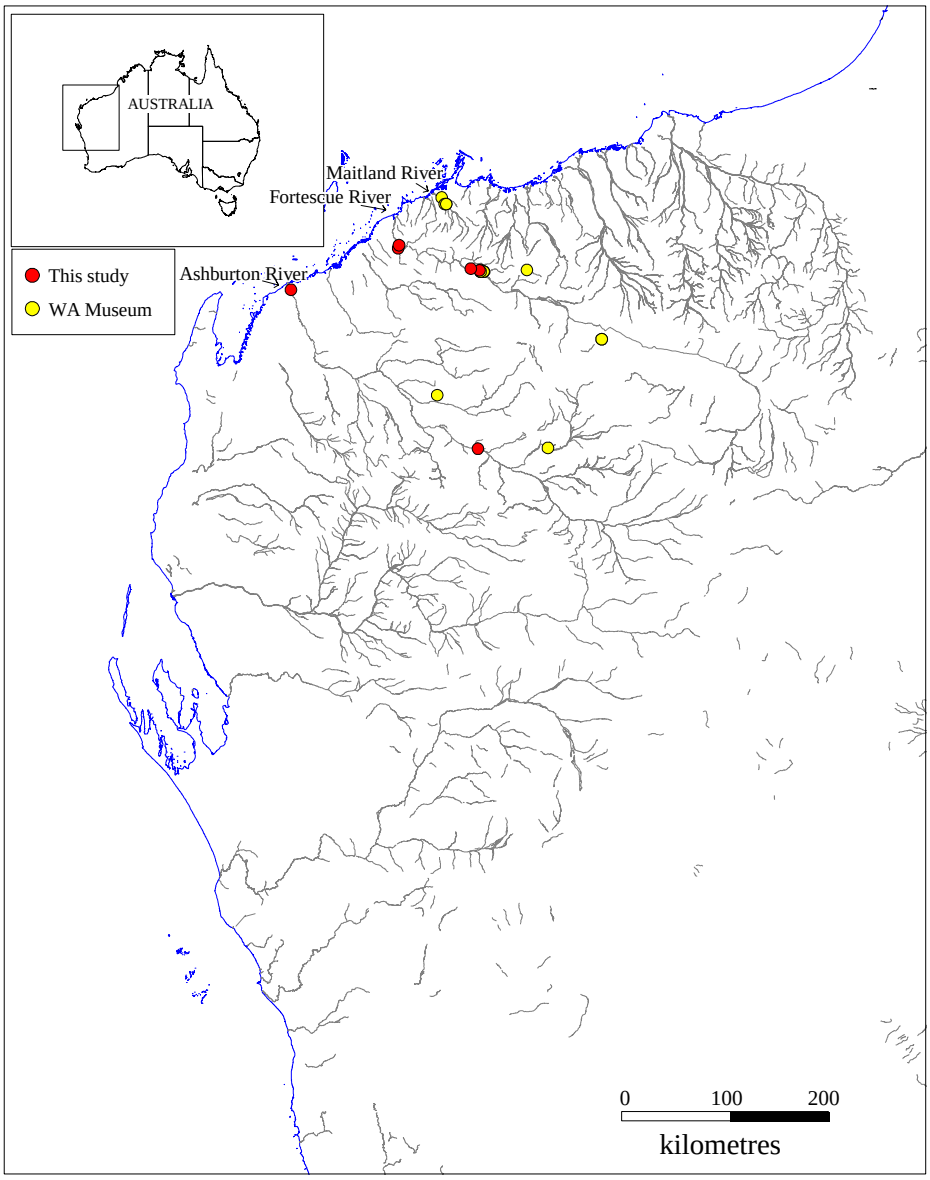

FIGURE 15. The sites in the Pilbara Drainage Division where the flathead goby (*Glossogobius giurus*) was captured. Also included are the Western Australian Museum records for the species.

Flathead goby (Gobiidae)
Glossogobius giurus (Hamilton 1822)

Eleven flathead gobies were caught at two sites in the Ashburton River (0.9–1.0 ppt) and a further 39 were captured at four sites in the Fortescue River (0.5–1.4 ppt) (Plate 1, Table 1, Fig. 15). This species is recorded at an additional two, four and two sites in the Ashburton,

Fortescue and Maitland rivers, respectively, in the Western Australian Museum records. It is widely distributed throughout northern Australia from the Ashburton River (WA) to the Burdekin River in North Queensland (Allen *et al.* 2002). It is also found throughout the Indo-West Pacific (Allen *et al.* 2002). The maximum size attained by the species is ~20 cm TL. Although this species is thought to have a marine larval stage (Allen *et al.* 2002), larvae, juveniles and adults were captured during this study in the freshwaters of the Pilbara and were also found in the headwaters of the Fitzroy River above waterfalls (Morgan *et al*. 2002, 2004).

Marine/estuarine fishes of the Pilbara (Plate 2)

Many Australian marine species utilise estuaries, and to a lesser extent freshwaters of rivers, as nursery grounds as they are relatively 'safe' and protected habitats (Potter *et al.* 1988; Gaughan *et al* 1990). During this study 12 species of marine fishes were found in the riverine (freshwater) environment (see Plate 1) and included giant herring *Elops hawaiiensis* Regan 1909 (Elopidae), tarpon or oxeye herring *Megalops cyprinoides* (Broussonet 1782) (Megalopidae), milkfish *Chanos chanos* (Forsskål 1775) (Chanidae), sea mullet *Mugil cephalus* Linnaeus 1758 (Mugilidae), barramundi *Lates calcarifer* (Bloch 1790) (Centropomidae), mangrove jack *Lutjanus argentimaculatus* (Lutjanidae), black bream *Acanthopagrus butcheri* (Munro 1949) (Sparidae), whipfin silver-biddy *Gerres filamentosus* Cuvier 1829 (Gerreidae), roach *Gerres subfasciatus* Cuvier 1829 (Gerreidae), yellow-tail trumpeter *Amniataba caudavittata* (Richardson 1845) (Terapontidae), striped butterfish *Scatophagus multifasciatus* Richardson 1845 (Scatophagidae) and Swan River goby *Pseudogobius olorum* (Sauvage 1880) (Gobiidae). Whilst many of these species utilise the river as a nursery (e.g. mullet and mangrove jack), some individuals of species, such as barramundi and oxeye herring, appear to spend extensive periods (if not years) in the river well beyond their juvenile stage. Other salt water species encountered in the river can be referred to as 'marine or estuarine stragglers' and this group comprises those species that are usually found within the marine or estuarine environment but may occasionally enter rivers (e.g. giant herring, striped butterfish, whipfin silver-biddy and roach). A number of other marine/estuarine species were captured at the estuarine/freshwater interface, i.e. upper tidal limit, but have not been included in this paper, e.g. Blackburn's herring *Herklotsichthys blackburni* (Whitley 1946) (Clupeidae), crescent perch *Terapon jarbua* (Forsskål 1775) (Terapontidae) and Telkara perchlet *Ambassis vachellii* Richardson 1846 (Ambassidae).

Giant herring (Elopidae)
Elops hawaiiensis Regan 1909

Three, two and 65 giant herring were caught at a single site in each of the Greenough (33.7 ppt), Harding (0.5 ppt) and Yule (0.3 ppt) rivers, respectively (Plate 2, Table 2). This species is common and widespread throughout sub-tropical and tropical waters of Australia and throughout much of the Indo-Pacific (Allen *et al.* 2002).

Oxeye-herring or tarpon (Megalopidae)
Megalops cyprinoides (Broussonet 1782)

Twenty three, 10, 51 and 18 oxeye herring were caught at two, one, two and four sites in the Fortescue (0.6 ppt), Harding (0.5 ppt), Yule (0.3–0.4 ppt) and DeGrey (1.1 ppt) rivers, respectively (Plate 2, Table 2). The adults are usually associated with coastal seas while the juveniles and small adults are often found long distances up rivers (e.g. DeGrey River) (Allen *et al*. 2002).

Milkfish (Chanidae)
Chanos chanos (Forsskål 1775)

The milkfish was only caught in the lowermost reaches of the Ashburton (1, 0.9 ppt), Fortescue (164, 0.6 ppt), Yule (50, 0.3 ppt) and DeGrey (25, 1.1 ppt) rivers (Plate 2, Table 2). All of the 240 milkfish captured were less than 40 cm TL.

Sea mullet (Mugilidae)
Mugil cephalus Linnaeus 1758

A total of 605 sea mullet was captured in the lower reaches of the Irwin (2.3–13.7 ppt), Greenough (33.7 ppt), Chapman (2.6 ppt), Bowes (0.1 ppt), Hutt (3.1 ppt), Murchison (0.1–1.4 ppt), Ashburton (0.9 ppt), Fortescue (0.6 ppt) and DeGrey (1.1 ppt) rivers, and at an upstream site in the Turner River (1.1 ppt) (Plate 2, Table 2). This species is widespread throughout tropical, subtropical and warm temperate waters of the world (Harrison & Senou 1999).

Barramundi (Centropomidae)
Lates calcarifer (Bloch 1790)

A total of 35 barramundi was captured in the lower reaches of the Ashburton (0.9 ppt), Harding (0.5–0.6 ppt), Sherlock (0.7 ppt), Yule (0.3 ppt) and DeGrey (1.1 ppt) rivers (Plate 2, Table 2). Although this species was not found great distances inland during the course of this study, it has been reported from the headwaters of the DeGrey River and occurs over 400 km from the coast in the Fitzroy River in the Kimberley (Morgan *et al.* 2002, 2004).

Mangrove jack (Lutjanidae)
Lutjanus argentimaculatus (Forsskål 1775)

A total of 157 mangrove jack was caught in the lower reaches of the Ashburton (0.9 ppt), Fortescue (0.5–1.3 ppt), Harding (0.5 ppt), Sherlock (0.7 ppt), Yule (0.3 ppt) and DeGrey (1.1 ppt) rivers, and the middle to upper regions of the Fortescue and Turner (1.1 ppt) rivers (Plate 2, Table 2). This species generally utilises mangroves, estuaries and the lower reaches of freshwater streams as a nursery with the adults migrating to offshore reefs (Anderson & Allen 2001). In Western Australia it has recently been found as far south as the Murchison River by recreational fishers.

Black bream (Sparidae)
Acanthopagrus butcheri (Munro 1949)

A total of 123 black bream was recorded from the lower reaches of the Irwin (0.3 ppt), Greenough (33.7 ppt), Chapman (2.6 ppt), Hutt (3.1 ppt) and Murchison (1.1 ppt) rivers (Plate 2, Table 2). This species is generally restricted to the estuaries of southern Australia (Sarre *et al.* 2000).

Whipfin silver-biddy (Gerreidae)
Gerres filamentosus Cuvier 1829

A total of only four whipfin silver-biddies were captured from one site in the Turner River (1.1 ppt) and two sites in the DeGrey River (0.5–1.1 ppt) (Plate 2, Table 2). It is widespread throughout warm waters of the Indo-Pacific where it usually occurs in coastal waters, but sometimes penetrates freshwater streams (Woodland 2001; Allen *et al.* 2002).

Roach (Gerreidae)
Gerres subfasciatus Cuvier 1829

A total of 11 roach were caught from single sites in both of the Ashburton (0.9 ppt) and Yule (0.3 ppt) rivers (Table 2). Found throughout temperate and tropical waters of Australia (Woodland 2001).

Yellow-tail trumpeter (Terapontidae)
Amniataba caudavittata (Richardson 1845)

While generally considered an estuarine species in south-western Australia, *A. caudavittata* is typically marine in northern Australia (Vari 1978). In contrast, within the Murchison (0.1–13.9 ppt) and Greenough (1.6–17.0 ppt) rivers this species occurs considerable distances inland (Plate 2, Table 2). Riverine populations however, exhibited a disjunct distribution in this region. Thus, whilst a total of 950 and 117 individuals were captured from three and eight sites in the Greenough and Murchison rivers, respectively, and a further 20 and one specimens were caught from one site in each of the Yule (0.3 ppt) and DeGrey (1.1 ppt) rivers, respectively, this species was not captured in any of the rivers in between. This species is found from south-western Western Australia north to north-eastern Australia and southern Papua New Guinea (Vari 2001).

Striped butterfish (Scatophagidae)
Scatophagus multifasciatus Richardson 1845

One striped butterfish was caught in the lower Fortescue River (0.6 ppt) and five were captured at a single site in the lower DeGrey River (1.1 ppt) (Plate 2, Table 2). This species is generally found in mangrove areas of northern and eastern Australia (Shark Bay to Sydney), southern New Guinea and New Caledonia (Allen *et al.* 2002).

Swan River goby (Gobiidae)
Pseudogobius olorum (Sauvage 1880)

Six hundred and fifty eight specimens of the Swan River goby were caught from 19 sites in the Irwin (0.3–13.7 ppt), Greenough (3.6–33.7 ppt), Chapman (2.6 ppt), Bowes (0.1–2.4 ppt), Hutt (1.8–4.2 ppt) and Murchison (0.1–13.9 ppt) rivers (Plate 2, Table 2). Western Australian Museum records also note the existence of this species in the latter three of these rivers. This species was often captured a long way inland, particularly in the salt-

affected Greenough River. It is also now found long distances inland in the salt-affected rivers of south-western Australia (Morgan *et al.* 1998, 2003).

Introduced fishes of the Pilbara (Plate 3)

Four species of introduced fish were captured in the Pilbara Drainage Division during this study (Table 3). Three are livebearers and belong to the Poeciliidae, i.e. mosquitofish *Gambusia holbrooki*, guppies *Poecilia reticulata* Peters 1859 and swordtails *Xiphophorus hellerii*, and one mouthbrooding species belonging to the Cichlidae, i.e. tilapia or Mossambique mouthbrooder *Oreochromis mossambicus*. These species were restricted to the southern half of the Pilbara Drainage Division and no introduced species have been recorded north of the Lyndon River. The Murchison River (and possibly the Wooramel River which was not sampled during this study) is the only river south of the Gascoyne River in the Pilbara Drainage Division that is free from introduced species. The impacts of introduced fishes on native freshwater species within Western Australia has previously been shown to range from predation and agonistic behaviour to competition for food and space (see for example, Gill *et al*. 1999; Morgan *et al*. 1998, 2002). These impacts are likely to be exacerbated in such an arid region as the Pilbara, where rivers tend to be made up of a series of small billabongs and pools during extended dry periods. These pools would normally act as refugia for the native fishes, however their species compositions are often compromised by ferals.

Mosquitofish (Poeciliidae)
Gambusia holbrooki Girard (ex Agassiz) 1859

Whilst the mosquitofish was the most abundant species captured (16 510, 0.3 to 100 m^{-2} overall) during the course of this study it was present in only three out of the 21 rivers sampled, i.e. the Greenough (1.6–33.7 ppt), Chapman (0.2–2.6 ppt) and Hutt (3.1–4.2 ppt) rivers, but was also found in a small pool on the North West Cape (Table 3). Thus, when captured it is often very abundant and every effort should be made to ensure that this nuisance species does (is) not spread to other parts of the Pilbara Drainage Division. This extremely aggressive species native to Atlantic and Gulf Slope drainages of the USA (Fuller *et al*. 1999) was introduced into Western Australia in the 1930s for mosquito control and is known to seriously impact on native Australian fishes in the form of agonistic behaviour through fin-nipping and predation (Howe *et al*. 1997; Gill *et al*. 1999; Aarn & Ivantsoff 2001). *Gambusia holbrooki* was captured with *C. cuneiceps* in the Greenough and Hutt rivers and is by far the more abundant of the two in the Hutt River, but the roles are reversed in the Greenough River. However, of the 21 sites sampled in the latter river

during the study, these species were found together at only one site. These observations suggest that some degree of intraspecific competition may be occurring. As *G. holbrooki* is essentially a carnivore (Pen *et al.* 1993) and *C. cuneiceps* is a detritivore/omnivore (Allen 2002), it is unlikely that dietary competition has resulted in the above observation. A more likely explanation is that *C. cuneiceps* has been excluded from sites in which *G. holbrooki* occurs due to the aggressive nature of this introduced species and the fact that both species attain a similar size and utilise the shallows as nursery and feeding grounds. As noted above, *G. holbrooki* has been shown to prey on fish larvae and have deleterious impacts on fin condition, reproductive success and survival rate of similar-sized Australian fish species (Howe *et al*. 1997; Gill *et al*. 1999; Aarn & Ivantsoff 2001).

Guppy (Poeciliidae)
Poecilia reticulata Peters 1859

Guppies were captured from a single small pool on Charles Knife Road on the North West Cape (Table 3). This is the only known record of this species from Western Australia and, in conjunction with the Department of Fisheries Western Australia and the Department of Conservation and Land Management Exmouth, every effort was made to eliminate this species from the pool. In this pool this species was found with the introduced *G. holbrooki* and some introduced gastropods (*Helisoma* sp. and *Physa* sp.), suggesting that the occurrence of these species was the result of a deliberate 'dumping' of unwanted aquarium pets. This species is originally from South America and is now widespread in coastal drainages of northeastern Australia.

Swordtail (Poeciliidae)
Xiphophorus hellerii Heckel 1848

Two hundred and thirty two swordtails were captured at five sites in the Irwin River (0.6–2.4 ppt) (Table 3). Their presence in Western Australia in the Irwin River, that they now dominate, was first reported by Morgan and Gill (2001). Their introduction is presumably from a deliberate release. Of alarm is the fact that the individuals of this species have the ability to outcompete *G. holbrooki* (Milton & Arthington 1983), and as they only apparently cease reproductive activity when water temperatures are <15°C (Milton & Arthington 1983) they are capable of reproducing for most of the year throughout northern Western Australia. For example, Milton and Arthington (1983) found that in the Brisbane region, i.e. similar latitude to the Irwin River, over 30% of females were pregnant in all months of the year except June and that new recruits also appeared in all months. Furthermore, individuals have a short gestation, a higher mean fecundity than the extremely suc-

cessful *G. holbrooki*, can tolerate a wide range of salinities and temperatures and can survive at low oxygen concentrations by gulping air at the air-water interface (Arthington *et al*. 1983). A study of the biology of this species in the region is currently being undertaken by the authors. So far the study suggests: that mean length of pregnant females from spring and summer was 41.6 mm SL with a mean fecundity of 30.1; the length at 50 (L_{50}) and 95% (L_{95}) first maturation was 30.2 and 40.3 mm SL, respectively; the predicted values for L_{50} and L_{95} for males were slightly larger at 33.1 and 49.7 mm SL, respectively; all size classes were omnivorous and ingested a wide variety of food types.

Tilapia or Mozambique mouthbrooder (Cichlidae)
Oreochromis mossambicus (Peters 1852)

An African species, tilapia was captured at a total of nine sites from the Chapman (2.6 ppt), Gascoyne (0.9–2.7 ppt), Minilya (1.3–2.2 ppt) and Lyndon (80.6–95.0 ppt) rivers (Table 3). Since the first record at a single site in the Gascoyne River in the early 1980's, the species has spread throughout the Gascoyne River and into the other three rivers noted above and was, with 2 007 individuals captured during the course of this study, the sixth most abundant species recorded. This species is extremely halotolerant and during the study was found living at a salinity of ~95 ppt (seawater = 35 ppt) in a pool of the Lyndon River. The relative abundance of *C. cuneiceps* and *H. aurea* in the Gascoyne River is much lower than in the nearby Murchison River, a river that is free from introduced fishes. This variation suggests a deleterious impact of tilapia on the population of *C. cuneiceps* and *H. aurea* in the Gascoyne system. Such an impact may be due to both the agonistic territorial behaviour that mature male tilapia exhibit during the breeding season (Turner 1986), and the high degree of dietary overlap, i.e. that all of these species ingest detritus, fungal and bacterial mats and invertebrates (Bruton & Boltt 1975; Morgan & Gill unpublished data). Unfortunately, in the absence of data for the relative abundance of *C. cuneiceps* and *H. aurea* in the Gascoyne River prior to the introduction of tilapia, the presumed negative impact of this introduced species cannot be confirmed. Particularly worrying is the fact that tilapia is now present in rivers both north (i.e. in the Gascoyne, Minilya and Lyndon rivers) and south (i.e. in the Chapman River) of the Murchison River. It is important that every possible measure is taken to ensure that this river, and other Pilbara rivers north of those mentioned above, remain pest free.

The Pilbara Drainage Division, evidence for three subprovinces of freshwater fishes

Classification of the individual sites in the rivers of the Pilbara, utilising presence/absence data for the freshwater species, essentially divides the drainage division into three groups,

i.e. the first contains all the Museum of Western Australia records for the cave fishes of North West Cape (North West Cape Subprovince), another group which comprises those sites in the westwards flowing rivers, i.e. those south of (and including) the Minilya River (Southern Pilbara Subprovince), and the remaining group that comprises those sites in the northwards flowing rivers, i.e. those north of (and including) the Yannarie River (Northern Pilbara Subprovince) (Figs 16, 17). The ten northern river sites that are included in the southern river grouping are placed there due to the capture of, either only *L. unicolor* (Peawah and DeGrey rivers), or *L. unicolor* and the undescribed catfish (Fortescue River) or are those sites in the DeGrey River that harboured *C. cuneiceps.*

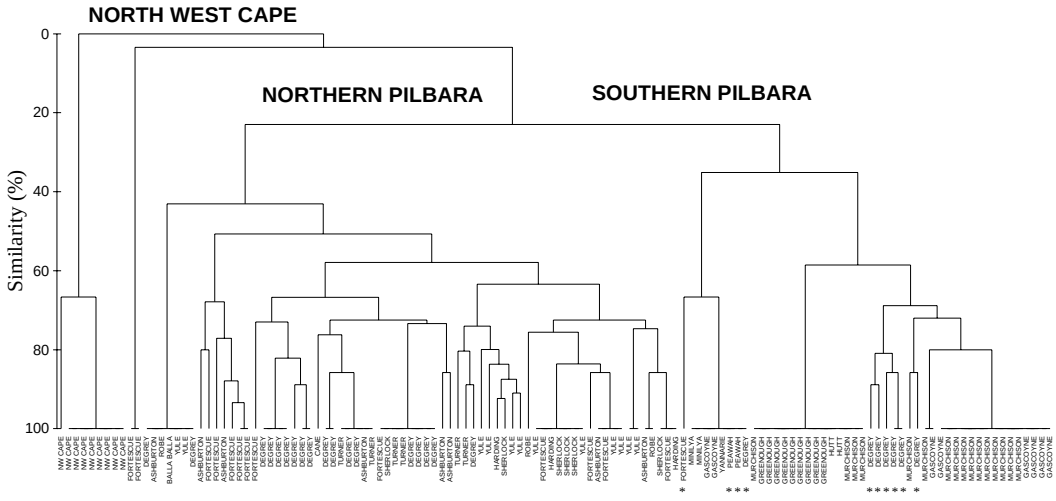

FIGURE 16. Classification of the presence/absence data of the native freshwater fish fauna for the sites sampled in the different rivers of the Pilbara Drainage Division. N.B. * signifies Northern river sites that group with Southern river sites.

The ordination plot of the site data pooled within rivers of the Pilbara (Fig. 18), utilising presence/absence data for the freshwater species, essentially shows a division of the drainage division into three major groups, i.e. one group on the lower-right of the plot that comprises those rivers south of (and including) the Gascoyne River, another group above these that comprises those systems north of (and including) the Ashburton River, and thus parallels the classification of data for individual sites, and a third group in the lower-left of the plot comprising the North West Cape sites. The grouping of the Minilya, Yannarie, and Peawah rivers as a sub-group between these groups is due to the fact that the few sites that were sampled in these systems only yielded *L. unicolor.* Thus, these rivers were grouped on an absence of other species, rather than the presence of distinguishing species. ANOSIM demonstrated a significant difference in the fauna of the three regions, i.e., *R*-statistics of between 0.691 and 0.930, $p < 0.001$ for sites; *R*-statistic of between 0.651 and 0.976, $p \leq 0.002$ for rivers.

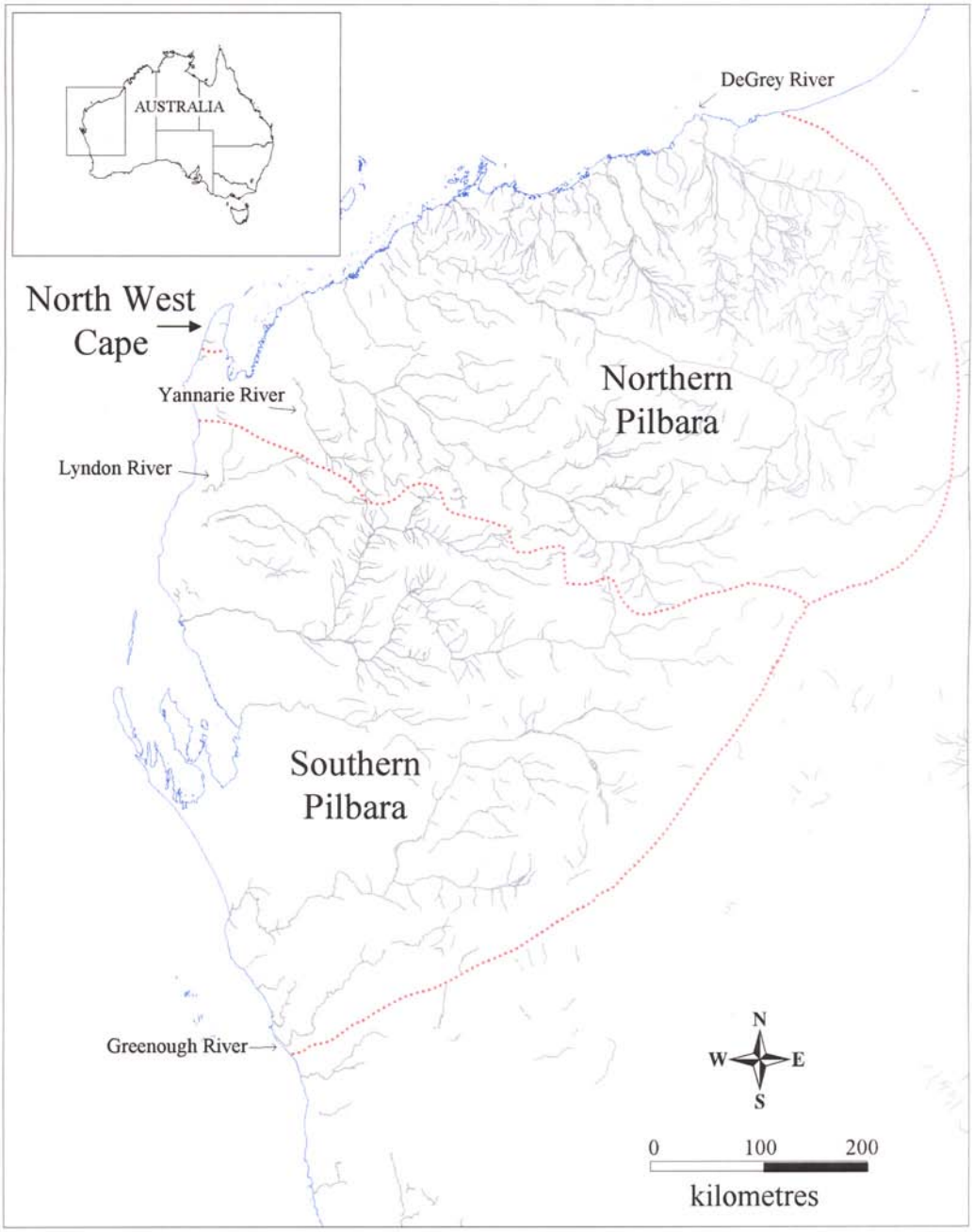

FIGURE 17. The subprovinces of the Pilbara Drainage Division, i.e. Southern Pilbara, North West Cape and Northern Pilbara.

The reasons for these major distinctions between both the Southern Pilbara and the Northern Pilbara, and these regions and North West Cape lie in the very different fish faunas of these three regions (Figs 16, 17, 18). The rivers of the Southern Pilbara are very

depauperate, collectively containing only four species, i.e. *C. cuneiceps,* a species that was found in all of the rivers in the Southern Pilbara that contained freshwater fish, but in the Northern Pilbara was only found in the DeGrey River; the cosmopolitan *L. unicolor,* a species found across the north and east of Australia, and as far south-west as the Murchison River; *H. aurea,* a rare species currently known only from the Murchison and Gascoyne rivers in the Southern Pilbara and one site in a tributary of the Fortescue River in the Northern Pilbara; and *H. compressus* found in the Chapman and Murchison rivers in the Southern Pilbara and six rivers in the Northern Pilbara. In contrast, the Northern Pilbara is comparatively rich in freshwater (and catadromous) species, it's waters collectively housing 11 species, i.e. *L. aheneus,* a species endemic to the Northern Pilbara; *A. bicolor, A. graeffei, N. hyrtlii, M. australis, A. percoides* and *G. giurus,* species that within the Pilbara are only found in the rivers of the Northern Pilbara but are also found in other freshwaters across the north of Australia; *L. unicolor* and *H. compressus* that are shared with the Southern Pilbara and rivers across northern and eastern Australia and *C. cuneiceps* and *H. aurea* that, as noted previously, have disjunct distributions with populations only in the DeGrey (*C. cuneiceps*) and Fortescue rivers (*H. aurea*) in the Northern Pilbara and several rivers in the Southern Pilbara. The third region, i.e. North West Cape, contains little permanent fresh water and no native stream or lake dwelling fishes, it does however have significant cave formations that contain brackish waters that are the home to two cave fishes (*O. candidum* and *M. veritas*) endemic to the Cape.

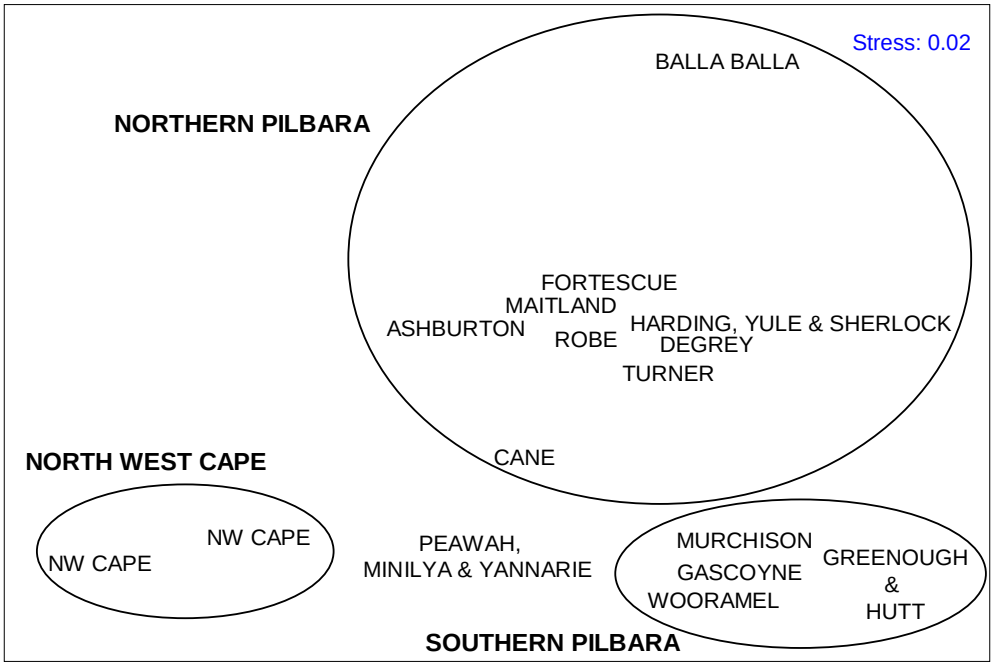

FIGURE 18. Ordination plot of the pooled presence/absence data for the different native freshwater fishes in the rivers of the Pilbara Drainage Division.

Whilst Unmack (2001) changed several of the traditional freshwater ichthyofaunal provinces previously recognised in Australia, for example he recognised a distinct Kimberley Province that he further divided into two subprovinces, he maintained the Pilbara as a single province, noting major differences between it and the provinces to the south and north. Our current analyses strongly support the recognition of three subprovinces within the Pilbara Province, i.e. a Southern Pilbara Subprovince, a North West Cape Subprovince and a Northern Pilbara Subprovince. The freshwaters of the first contain only four freshwater fishes, the second has no surface dwelling fishes but does have a well documented stygofauna that includes two fishes, whilst the third region's ichthyofauna has one endemic species and is dominated by essentially tropical groups that are found across northern Australia but, with the exception of *L. unicolor*, are not found in either of the other two subprovinces of the Pilbara. The paucity of freshwater fishes in the North West Cape is likely a direct consequence of the fact that there is very little permanent surface water in that region. The poor representation of freshwater fishes in the Southern Pilbara is probably a reflection of the fact that inland it has been separated from the Northern Pilbara by the highest mountain ranges in Western Australia, i.e. the Chichester, Hamersley, Collier ranges, for at least 12 million years and possibly for up to 55 million years (van de Graaff *et al*. 1977) whilst the lack of permanent water in the North West Cape and the narrowest section of the continental shelf occurring just off the Cape is likely to act as a barrier to the movement of freshwater fishes down the coast.

Summary

Numerically, the freshwaters of the Pilbara Drainage Division are dominated by native freshwater species (representing ~55% of captures). However, introduced fishes contributed to ~39% of fish captured and these were largely dominated by *G. holbrooki* from the Greenough, Chapman and Hutt rivers in the south of the Pilbara Drainage Division and *O. mossambicus* in the Chapman, Gascoyne, Minilya and Lyndon rivers. Species categorised as being of marine or estuarine origin represented ~6% of fish caught. Importantly, there were no introduced species captured in the any river north of the Lyndon River, and thus many of the river systems of the Pilbara remain free of introduced species. We propose that *G. holbrooki* and *O. mossambicus*, and possibly *X. hellerii*, have contributed to the decline in native fishes in the rivers where these feral pests are found (see species synopses). Furthermore, the results of this study suggest that although the Pilbara Drainage Division has long been considered one bioregion/province (e.g. Whitley 1959; Lake 1971; Unmack 2001), the fish faunas of the southern and northern rivers and the caves of North West Cape are very dissimilar and, in recognition of this fact, it is appropriate that the province be divided into three subprovinces, i.e. one for the westwards flowing rivers from the Greenough River to the Lyndon River in the south (Southern Pilbara), a second for the

caves of North West Cape and a third for the northwards flowing rivers between the Yannarie River and the DeGrey River (Northern Pilbara).

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