An overview of the 'freshwater fishes' of Western Australia

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Western Australia's non-tidal waters provide refuges to many unique fishes. Here we provide an overview to synthesise contemporary knowledge on these species with the aim of providing readers with an understanding of their biological, ecological and conservation significance. Western Australian inland aquatic ecosystems provide critical habitats for many obligate freshwater fishes as well as diadromous species that rely on fresh water to complete their life-cycle. Five of Australia's 10 ichthyological provinces are found within the State, three in their entirety. Notable species from evolutionary and biogeographic perspectives include the enigmatic Gondwanan relic *Lepidogalaxias salamandroides* (Salamanderfish) and the ancient jawless fish, the anadromous *Geotria australis* (Pouched Lamprey) in the Southwestern Province. The Pilbara Province supports Australia's only known obligate vertebrate stygofauna, including one of the world's largest stygofauna species, *Ophisternon candidum* (Blind Cave Eel), and two blind eleotrids (*Milyeringa* spp.). The freshwaters of the Kimberley region support three elasmobranchs including *Pristis pristis* (Largetooth or Freshwater Sawfish) and features high species richness and endemicity in the Terapontidae and Eleotridae. The Paleo Province encompasses much of the arid interior of the State, and has very few records of fishes. Western Australian rivers also provide habitat for a small number of euryhaline elasmobranchs that have become vulnerable to extinction elsewhere, and other fishes that utilise these habitats as nurseries. The State supports many fishes that are nationally and internationally listed as threatened or of conservation concern and an increasing number of alien fishes. We collated a total of 102 native fish species that are found within fresh waters of the State, of which 66 are obligate freshwater fish species, three are stygofauna, and a further two have amphidromous and potamodromous populations. In addition, several estuarine species are able to breed in fresh waters, the remainder being diadromous or 'wanderers' that are freshwater vagrants.

KEYWORDS: Kimberley, Pilbara, Southwestern, Paleo, Province, alien fish, endangered fish, endemic

INTRODUCTION

Covering nearly one-third of the Australian continent, Western Australia comprises 5 of Australia's 10 ichthyological provinces (Figure 1). The Southwestern, Pilbara, and Kimberley provinces are all wholly contained within Western Australia, whereas the western edge of the Northern Province and the western portion of the Paleo Province also occur in Western Australia (Unmack 2013). A broad variety of climatic regimes prevail in the provinces, including the temperate Mediterranean climate of the southwest, the sub-tropical and semi-arid climate of the Pilbara and southern Kimberley, the tropical northern Kimberley, and the arid Paleo Province. These climatic templates have undoubtedly influenced the evolution of many unique assemblages and species of fishes in the inland waters of the State.

Scientific contributions to our knowledge of Western Australia's fish fauna began largely during the middle of the last century, with many new species discovered and subsequently described from the 1940s (e.g. Whitley 1944, 1945), 1950s (Shipway 1953), 1960s (Mees 1961, 1962, 1963), and through the 1970s and 1980s (Allen 1975, 1978, 1982, 1989; Hutchins 1977, 1981; Vari 1978; Vari & Hutchins 1978; Ivantsoff *et al*. 1987). Numerous taxonomic, ecological and biogeographical studies followed these earlier works including those on the ecology, behaviour and physiology of the enigmatic *Lepidogalaxias salamandroides* (Salamanderfish) by McDowall & Pusey (1983), Allen & Berra (1989), Berra & Allen (1989, 1991), Pusey (1989, 1990), Pusey & Stewart (1989), Gill & Morgan (1999) and Morgan *et al*. (2000). A series of ecological descriptions of species and habitat associations in Western Australian fresh waters was also published by Pen & Potter (1990, 1991a, b, c), Pen *et al*. (1991, 1993), Humphreys & Feinberg (1995), Morgan *et al*. (1995, 1998), Pusey & Bradshaw (1996) and Gill & Morgan (1998), as were the first genetic studies on freshwater fishes in the State (Adams & Humphreys 1993; Storey *et al*. 1995). Taxonomic studies continued during the 1980s and 1990s, with several new Western Australian species described (McDowall & Frankenburg

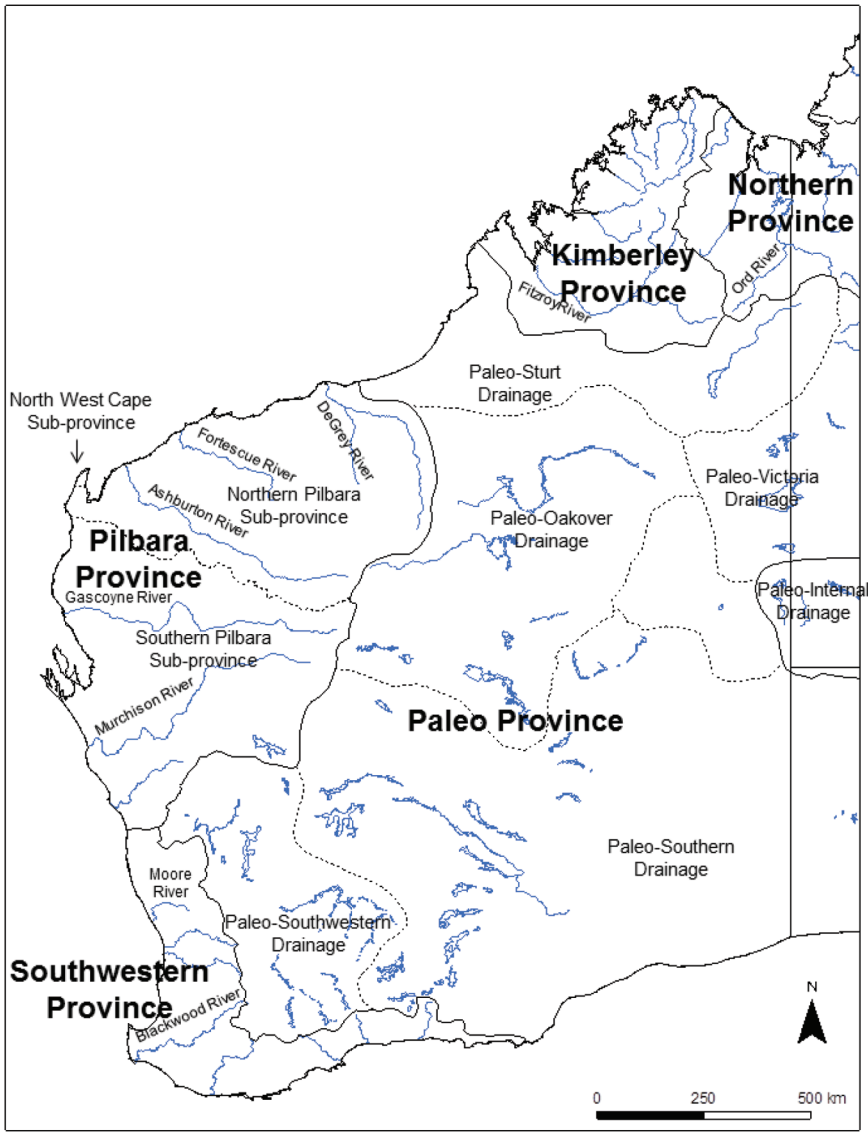

Figure 1 Freshwater fish biogeographical provinces of Western Australia adapted from Unmack (2013).

1981; Hoese & Allen 1983; Allen & Burgess 1990; Allen & Feinberg 1998; Allen & Jenkins 1999). The new millennium saw an increase in ecological and biogeographical studies in the State (Morgan *et al*. 2000, 2003, 2004a; Humphreys 2001; Unmack 2001, 2013; Smith *et al*. 2002; Morgan 2003, 2010; Allen *et al*. 2005; Gill *et al*. 2005; Beesley 2006; Chapman *et al*. 2006; Humphreys *et al*. 2006; Phillips *et al*. 2009; Beatty *et al*. 2010, 2011, 2013a, 2014; Davis *et al*. 2010, 2011, 2013; Ebner & Morgan 2013), culminating in the publication of reviews of fishes of each region (Allen *et al*. 2002; Morgan & Gill 2004; Morgan *et al*. 2004b, 2011a, b, 2014; Beatty & Morgan 2013). With the assistance of genetic tools, new species continue to be identified and described from inland waters of Western Australia, with two described in 2013 (Larson *et al.* 2013; Morgan *et al*. 2013) and many other new species recently identified and awaiting description (Unmack 2013).

Migration categories

For the purpose of this review, the term 'freshwater fishes' encompasses species belonging to the agnathans (jawless fishes), elasmobranchs (cartilaginous fishes) and teleosts (bony fishes) that are obligate inhabitants of fresh waters for some part of their life-cycle. Many teleost fishes that are found within Western Australian fresh waters are known to be, or are likely to be, potamodromous, i.e. they migrate wholly within fresh waters usually for the purpose of breeding, and complete their entire life-cycle within fresh waters (from Myers 1949). However, Myers (1949) discounts the use of this term for small or lateral breeding migrations, such as those "from the stream into the flooded forest during high water" or "the slight movement from a river channel to a shallow sand-bar for spawning". A number of Western Australian species, e.g. *Lepidogalaxias salamandroides*, *Galaxiella nigrostriata* (Black-stripe Minnow) and some populations of *Nannatherina balstoni* (Balston's Pygmy Perch) undertake short, lateral migrations from small pools into inundated riparian vegetation for the purpose of breeding (egg-deposition) (e.g. Pen *et al*. 1993; Morgan *et al*. 1995, 2000), but according to Myers' definition would not constitute being

categorised as potamodromous. With the exception of studies by Morgan & Beatty (2006) and Beatty *et al*. (2010, 2014), there are no further studies reporting on potamodromous migrations of fishes in this State. Accordingly, we are unable to assign the obligate freshwater fishes with migratory categories, and for the purpose of this review, they are tentatively labelled as potamodromous in that they all migrate within freshwater to some extent for breeding (Table 1).

Diadromy, a term that Myers (1949) coined for those fishes migrating between the sea and fresh water or at least between one of these biomes and the estuary, is not uncommon in Western Australian fishes and can be further subdivided into anadromy, catadromy or amphidromy (see also McDowall 1997). Anadromy involves an adult migration from the sea to rivers to spawn [e.g. *Geotria australis* (Pouched Lamprey) (Potter *et al*. 1979)], whereas catadromy involves a migration from fresh waters to marine waters for spawning e.g. *Lates calcarifer* (Barramundi). However, some populations of this species may be entirely marine (Moore & Reynolds 1982; Pender & Griffin 1996; McCulloch *et al*. 2005), and those in fresh water generally migrate to the estuary rather than the sea for spawning (categorised as semi-catadromous in Elliott *et al*. (2007)).

Amphidromy was a term developed by Myers (1949) for diadromous fishes "whose migration from fresh water to the sea, or *vice-versa*, is not for the purpose of breeding but occurs regularly at some other definite stage of the life-cycle". McDowall (1997, 2007) refined this definition to include only those fish that emigrate immediately to sea as newly hatched larvae where they grow and feed at sea for a period of a few weeks to months before returning to fresh water as juveniles [(e.g. *Galaxias maculatus* (Common Jollytail) (Chapman *et al*. 2006)]. It should be noted that in rare cases, fishes that are typically amphidromus may have populations that are land-locked and are potamodromous [e.g. *G. maculatus* and *Galaxias truttaceus* (Trout Minnow) see Morgan 2003; Chapman *et al.* 2006; Morgan & Beatty 2006)]. Euryhaline elasmobranchs that enter fresh waters as juveniles, which they use as nursery habitats [e.g. *Pristis pristis* (Thorburn *et al*. 2007; Whitty *et al*. 2009; Morgan *et al*. 2011b)], could be considered amphidromous according to the definition given by Myers (1949). However, based on McDowall's refinement, we note that the few elasmobranchs that mature at sea, pup in estuaries and undertake early juvenile growth in fresh water, do not have a free-swimming larval phase. In this review we categorise these species simply as euryhaline elasmobranchs.

Where available, species-specific life-cycle categories have been assigned to species from information collated from general texts (e.g. Allen *et al*. 2002) or from studies conducted on these species outside of Western Australia [e.g. the semi-anadromous *Megalops cyprinoides* in Coates (1987), Donaldson & Myers (2002), yet considered amphidromous by Myers (1949)]. Elliott *et al*. (2007) defined marine migrants as species that "spawn at sea and often enter estuaries in large numbers particularly as juveniles". Many species fall into this category in Western Australia, with a subset of these continuing their migration through estuaries and into fresh waters. Elliott *et al*. (2007) consider Mangrove Jack (*Lutjanus argentimaculatus*), Milkfish (*Chanos chanos*) and some members of the Mugilidae to be marine migrants; members of the Mugilidae and the above species often occur in fresh waters of Western Australia. 'Marine vagrants' or 'marine stragglers' are other species that spawn at sea and typically enter estuaries only in low numbers (Elliott *et al*. 2007), some of which are occasionally found in fresh waters in Western Australia. We cover the presence of such species within Western Australian freshwater habitats within this review for completeness. Additionally, a number of species that are typically estuarine (or complete their lives within the estuary) but on occasion enter fresh waters are covered in this review; we categorise these as 'estuarine vagrants'. It should be noted that several Western Australian estuarine species are able to complete their life-cycle within fresh waters.

Fishes of the inland waters of Western Australia

It is evident that the inland waters of Western Australia provide critical habitats to species that are found nowhere else. Below we review the current knowledge surrounding the fishes in each ichthyological province of Western Australia. This is important in light of the increasing anthropogenic stressors that this unique fauna is being challenged with, including the major loss of habitat through salinisation, dewatering, river regulation, agricultural activity and climate change (Morgan *et al.* 2003; Beatty *et al*. 2014) and from the impact of an ever increasing alien fauna (Morgan *et al*. 2004b; Beatty & Morgan 2013). This overview collates information from the large body of historical and recent research of the Western Australian 'freshwater fish' fauna, to serve as a reference point for current and future researchers.

Southwestern Province

The Southwestern Province hosts a unique and highly endemic fauna, the highest of any ichthyological province in Australia in terms of the proportions of endemic species (11 of 14), genera and families (Table 1, Figure 2) (Unmack 2013). The province is dominated by species with ancient lineages that are either unique to the south-west region or that have historical links to temperate eastern Australia that were severed due to increasing aridity and formation and uplift of the Nullarbor Plain (Unmack *et al*. 2011).

The most outstanding endemic species is *Lepidogalaxias salamandroides* which belongs to the Lepidogalaxiidae, an endemic family within the Southwestern Province. This remarkable species is one of the world's most unusual teleosts (e.g. Pusey 1989; Morgan *et al*. 2000) and the sole representative of an early divergent lineage within teleost evolution. Estimates put its mean age of divergence from its nearest relatives at ~230 million years ago (Ma) (Betancur *et al*. 2013).

One species of Plotosidae, '*Tandanus*' *bostocki* (Freshwater Cobbler) is the largest potamodromous fish of the region (reaching over 400 mm total length (TL)) (Beatty *et al*. 2010). This species, incorrectly placed in the genus *Tandanus*, represents an undescribed genus which is one of the earliest branching lineages within freshwater plotosids, and its divergence dates to the early Tertiary (Unmack *et al*. unpub. data). These two endemic groups (*Lepidogalaxias salamandroides* and *'Tandanus'*

Table 1 Native fishes (Agnatha, Chondrichthyes and Osteichthyes) found in the fresh waters of Western Australia. A Roman numeral after the species name indicates different taxa based on molecular data that are yet to be revised taxonomically. An * after the species name indicates that the current taxonomy is incorrect, but it remains unclear as to how many species are present and their distributions. Life-cycle category: An = anadromous fishes, EE = euryhaline elasmobranch, Am = amphidromous species, MM = marine migrants, MV = marine vagrants, EV = estuarine vagrants, C = catadromous fishes, Sc = semi-catadromous, and P = potamodromous fishes (but includes those freshwater obligatory species where migratory information is unavailable). Under Drainage Division, SW = Southwestern Province, P = Pilbara Province, K = Kimberley region, Pa = Paleo Province.

Species name	Common name	Life-cycle category	Drainage Division	Fig. 2 photo #
Geotriidae				
Geotria australis	Pouched Lamprey	An	SW	1
Carcharhinidae				
Carcharhinus leucas	Bull Shark	EE	SW/P/K	2
Pristidae				
Pristis pristis	Freshwater Sawfish	EE	P/K	3
Dasyatidae				
Himantura dalyensis	Freshwater Whipray	EE	K	4
Elopidae				
Elops hawaiiensis	Giant Herring	MV	SW/P/K	–
Megalopidae				
Megalops cyprinoides	Tarpon	MM	P/K	5
Anguillidae				
Anguilla bicolor	Indian Short-finned Eel	C	P/K	6
Clupeidae				
Nematalosa erebi I	Bony Bream	P	K	7
Nematalosa erebi II	Pilbara Bony Bream	P	P	–
Chandidae				
Chanos chanos	Milkfish	MV	P/K	–
Ariidae				
Neoarius graeffei	Lesser Salmon Catfish	MV/EV/P	P/K	8
Neoarius midgleyi	Silver Cobbler	P	K	9
Sciades leptaspis	Triangular Shield Catfish	EV	K	–
Plotosidae				
Anodontiglanis dahli I	Toothless Catfish	P	K	10
Anodontiglanis dahli II	Fitzroy Toothless Catfish	P	K	–
Neosilurus ater	Black Catfish	P	K	11
Neosilurus hyrtlii II	Hyrtl's Tandan	P	K/Pa	–
Neosilurus hyrtlii III	Kimberley Tandan	P	K	12
Neosilurus hyrtlii IV	Pilbara Tandan	P	P	–
Neosilurus sp.	Robe River Catfish	P	P	13
Neosilurus pseudospinosus I	False-spined Catfish	P	K	14
Neosilurus pseudospinosus II	Drysdale False-spined Catfish	P	K	–
Porochilus rendahli	Rendahl's Catfish	P	K	15
'Tandanus' bostocki	Freshwater Cobbler	P	SW	16
Galaxiidae				
Galaxias maculatus	Common Jollytail	Am/P	SW	17
Galaxias occidentalis	Western Minnow	P	SW	18
Galaxias truttaceus	Trout Minnow	Am/P	SW	19
Galaxiella munda	Western Mud Minnow	P	SW	20
Galaxiella nigrostriata	Black-stripe Minnow	P	SW	21
Lepidogalaxiidae				
Lepidogalaxias salamandroides	Salamanderfish	P	SW	22
Mugilidae				
Liza alata	Diamond Mullet	MM	K	–
Liza subviridis	Greenback Mullet	MM	P/K	–
Liza vaigiensis	Diamondscale Mullet	MM	P/K	–
Mugil cephalus	Sea Mullet	MM	SW/P/K	–
Melanotaeniidae				
Melanotaenia australis	Western Rainbowfish	P	P/K/Pa	23
Melanotaenia exquisita	Exquisite Rainbowfish	P	K	24
Melanotaenia gracilis	Slender Rainbowfish	P	K	25

Species name	Common name	Life-cycle category	Drainage Division	Fig. 2 photo #
Melanotaenia nigrans	Black-banded Rainbowfish	P	K	26
Melanotaenia pygmaea	Pygmy Rainbowfish	P	K	27
Melanotaenia sp. Bindoola	NA	P	K	–
Atherinidae				
Craterocephalus cuneiceps	Deep Hardyhead	P	P	28
Craterocephalus helenae	Drysdale Hardyhead	P	K	29
Craterocephalus lentiginosus	Prince Regent Hardyhead	P	K	30
Craterocephalus stramineus II	Strawman	P	K	31
Leptatherina wallacei	Western Hardyhead	EV/P	SW	32
Synbranchidae				
Ophisternon candidum	Blind Cave Eel	–	P	33
Belonidae				
Strongylura krefftii	Freshwater Longtom	P	K	34
Hemiramphidae				
Arrhamphus sclerolepis	Snub-nosed Garfish	MV/EV/P	P/K	35
Ambassidae				
Ambassis macleayi	Macleay's Glassfish	P	K	36
Ambassis sp. Northwest	Northwest Glassfish	P	K	37
Ambassis sp. Fitzroy	Fitzroy Glassfish	P	K	38
Parambassis gulliveri	Giant Glassfish	P	K	39
Latidae				
Lates calcarifer	Barramundi	Sc	P/K	40
Percichthyidae				
Bostockia porosa I	Nightfish	P	SW	41
Bostockia porosa II	Margaret River Nightfish	P	SW	–
Nannatherina balstoni	Balston's Pygmy Perch	P	SW	42
Nannoperca pygmaea	Little Pygmy Perch	P	SW	44
Nannoperca vittata I	Western Pygmy Perch	P	SW	43
Nannoperca vittata II	NA (Margaret River)	P	SW	–
Nannoperca vittata III	NA (South Coast)	P	SW	–
Apogonidae				
*Glossamia aprion**	Mouth Almighty	P	K	45
Leiognathidae				
Leiognathus equulus	Ponyfish	MV	K	–
Lutjanidae				
Lutjanus argentimaculatus	Mangrove Jack	MM	P	46
Gerreidae				
Gerres filamentosus	Threadfin Silverbiddy	MV/EV	P/K	–
Gerres subfasciatus	Roach	MV/EV	P/K	–
Sparidae				
Acanthopagrus butcheri	Black Bream	EV	SW	–
Sciaenidae				
Nibea squamosa	Scaly Croaker	MV	K	–
Toxotidae				
Toxotes chatareus	Seven Spot Archerfish	P	K	47
Toxotes kimberleyensis	Kimberley Archerfish	P	K	48
Terapontidae				
Amniataba caudavittata	Yellowtail Trumpeter	MV/EV/P	P	49
Amniataba percoides	Barred Grunter	P	P/K	50
Hannia greenwayi	Greenway's Grunter	P	K	51
Hephaestus epirrhinos	Long-nose Sooty Grunter	P	K	52
Hephaestus jenkinsi	Western Sooty Grunter	P	K	53
Leiopotherapon aheneus	Fortescue Grunter	P	P	54
Leiopotherapon macrolepis	Large-scaled Grunter	P	K	55
Leiopotherapon unicolor	Spangled Perch	P	P/K/Pa	56
Syncomistes butleri	Butler's Grunter	P	K	57
Syncomistes kimberleyensis	Kimberley Grunter	P	K	58
Syncomistes rastellus	Drysdale Grunter	P	K	59
Syncomistes trigonicus	Long-nose Grunter	P	K	60

Table 1 (cont.)

Species name	Common name	Life-cycle category	Drainage Division	Fig. 2 photo #
Eleotridae				
Hypseleotris aurea	Golden Gudgeon	P	P	61
Hypseleotris compressa	Empire Gudgeon	EV/Am/P	P/K	62
Hypseleotris ejuncida	Slender Gudgeon	P	K	63
Hypseleotris kimberleyensis	Barnett River Gudgeon	P	K	64
Hypseleotris regalis	Prince Regent Gudgeon	P	K	65
Kimberleyeleotris hutchinsi	Mitchell Gudgeon	P	K	66
Kimberleyeleotris notata	Drysdale Gudgeon	P	K	–
Milyeringa veritas	Blind Gudgeon	–	P	67
Milyeringa justitia	Barrow Gudgeon	–	P	–
*Mogurnda mogurnda**	Northern Trout Gudgeon	P	K	68
*Mogurnda oligolepis**	Kimberley Mogurnda	P	K	69
Oxyeleotris lineolata	Sleepy Cod	P	K	70
Oxyeleotris selheimi	Giant Gudgeon	P	K	71
Kurtidae				
Kurtus gulliveri	Nurseryfish	EV	K	72
Gobiidae				
Afurcagobius suppositus	South-west Goby	EV/P	SW	73
Glossogobius giuris	Flathead Goby	P	P/K	74
Pseuogobius olorum	Blue-spot Goby	EV/P	SW/P	75
Scatophagidae				
Scatophagus argus	Spotted Scat	MV	P/K	–
Selenotoca multifasciata	Banded Scat	MV	P/K	–
Soleidae				
Leptachirus triramus	Tailed Sole	P	K	76
Tetraodontidae				
Marilyna meraukensis	Merauke Toadfish	MV/EV	K	–

bostocki) represent ancient and unusual lineages that have persisted in this Province and represent important legacies in the evolution of Australian fishes. Most other freshwater fishes in the Southwestern Province have old relationships to species in temperate eastern Australia that were severed due to the formation and uplift of the Nullarbor Plain and increasing aridity (Unmack *et al*. 2011). This includes seven endemic species of Percichthyidae (including two endemic genera, *Bostockia* and *Nannatherina*) and five species of Galaxiidae, three of which are endemic to the Province (Table 1).

Divergences among genera and species within the Southwestern Province span a range of dates. The origins of western percichthyids are estimated to be older than 40 Ma, with some genetic exchange between eastern and western Australian species occurring until around 14 Ma (Unmack *et al*. 2011). The galaxiid genus *Galaxiella* is represented by two species in the Province, *Galaxiella nigrostriata* and *Galaxiella munda* (Western Mud Minnow) which are estimated to have diverged from their eastern Australian relatives around 34 Ma (Unmack *et al*. 2012). The endemic *Galaxias occidentalis* (Western Minnow) diverged from eastern relatives around 15 Ma (Burridge *et al*. 2011). The split between the two endemic *Galaxiella* species has been dated at a mean age of 22.5 Ma (Unmack *et al*. 2012), while deeper divergences within the *Nannoperca vittata* (Western Pygmy Perch) species complex (comprising four species) began around 10 Ma (Unmack *et al*. 2011). Divergence between each species pair in the 'vittata' species complex, as well as the species pair within *Bostockia porosa* (Nightfish) occurred more recently at an estimated mean age of around 1–3 Ma (Unmack *et al*. unpub. data). One taxon belonging to the 'vittata' group was recently described as *Nannoperca pygmaea* (Little Pygmy Perch) and has a small biogeographical range compared to at least two of its congeners (Morgan *et al*. 2013).

The remaining species usually have some interactions between fresh and marine environments. The two remaining galaxiids, *Galaxias maculatus* and *Galaxias truttaceus*, both have an amphidromous life history in eastern Australia and whilst this is sometimes the case for *G. maculatus* in the Southwestern Province, a potamodromous life-cycle is more typical (Humphries 1989; Morgan 2003; Chapman *et al*. 2006; Morgan & Beatty 2006; Morgan *et al*. 2006).

The agnathan *Geotria australis* is anadromous; adults spawn in fresh water and the ammocoete larvae spend the first few years of their life in these habitats, before migrating into marine habitats feeding parasitically and growing (Potter *et al*. 1979). Some species that are typically estuarine species, such as *Leptatherina wallacei* (Western Hardyhead), *Pseudogobius olorum* (Blue-spot Goby) and *Afurcagobius suppositus* (South-west Goby) (Prince & Potter 1983; Potter & Hyndes 1999) have recently colonised many of the upstream reaches of the Province's larger river systems as a result of secondary salinisation (Morgan *et al.* 1998, 2003). However, each of these species also occurs naturally within a few fresh water coastal lakes and within the estuaries (Morgan *et al*. 1998). *Mugil cephalus* (Sea Mullet) is found in freshwater reaches of a few rivers, but generally only in

very low numbers compared to estuaries. *Acanthopagrus butcheri* (Black Bream), which we categorise as an 'estuarine vagrant', is only very occasionally found in the non-tidal waters of Western Australia, although it occurs in many estuaries of the region (Sarre *et al*. 2000).

There are a number of reports of *Carcharhinus leucas* (Bull Shark) from the estuaries of the Swan, Canning, Blackwood and Collie rivers, but none appear to make the transition into fresh waters, possibly due to seasonality of parturition in the species being different to the defined high flow regimes of the rivers resulting from the Mediterranean climate of the Province. Alternatively, natural and artificial barriers may play a role in limiting access to the upstream reaches of rivers. In recent times, a single *Hypseleotris compressa* (Empire Gudgeon) was found in a south-west river, although this record probably resulted from a southerly larval drift from the Pilbara Province, where this species is commonly encountered (Morgan & Gill 2004; Morgan & Beatty 2008). It remains to be seen whether this species naturally establishes populations in the Southwestern Province.

The highest species richness in the Province is found within the Blackwood River catchment (including the Scott River), which is also the largest river by discharge. It hosts the lamprey, six freshwater fishes and three estuarine species that have colonised large sections of this salinised system. The Margaret River is also an important basin which appears to have endemic species within the *Bostockia porosa* and *Nannoperca vittata* species groups (Unmack 2013). Most species in the Southwestern Province are concentrated in the coastal portion of the south-western most river basins in the region that experience the highest rainfalls, from approximately Albany to Perth. Outside this higher rainfall belt, species richness drops sharply with the fauna dominated by those species tolerant of drier, harsher environments such as *Nannoperca vittata*, *Galaxias occidentalis* and *Pseudogobius olorum*. These three species are the most widespread native fishes in the Southwestern Province; the first two species are found east to Waychinnicup River and north to Irwin River (south of Geraldton), while the latter species occurs east of Esperance and north into the Murchison River in the Pilbara Province.

Many of the native fishes of this region have undergone extensive range contractions, and in some catchments certain species have become restricted to a few remaining suitable habitats (Morgan *et al*. 1998; Galleotti *et al.* 2010; Beatty *et al.* 2014). Range declines were recently formally recognised with the listing of several species under both Federal and State endangered species legislation, and this Province has the highest proportion of threatened fishes in the State (Table 2). This is not surprising given that it is home to most of the State's human population and has the highest proportion of anthropogenic impacts. Anthropogenic stressors impacting fishes in the rivers and lakes of the region include salinisation, eutrophication, river regulation, alien fishes and, more recently, climate change (Morgan *et al*. 2003, 2004b; Beatty *et al*. 2011, 2013, 2014; Morrongiello *et al*. 2011; Beatty & Morgan 2013). Declining rainfall and surface flows, and subsequent reductions in groundwater levels, are impacting fishes, with the region one of the most seriously threatened by climate change (Beatty *et al*. 2014).

Pilbara Province

The Pilbara Province includes all river basins from the Irwin River in the south to the De Grey River in the north (Figure 1) (Morgan & Gill 2004). The northern boundary abuts the Great Sandy Desert which has largely isolated this Province from other parts of northern Australia. Consequently, the freshwater fishes in this province are either local endemics (6 species) or have extensive distributions across much of northern Australia (4 species; Table 1). There are no shared freshwater fish species with the Southwestern Province, although some estuarine species are shared, such as *Acanthopagrus butcheri* and *Pseudogobius olorum*, as far north as the Murchison River (Table 1). Distinct patterns in the distribution of fish species in the Pilbara Province resulted in the recognition of three sub-provinces, namely the Southern Pilbara, Northern Pilbara, and North West Cape (Figure 1) (Morgan & Gill 2004).

The most unusual endemic fishes of the Pilbara are found in the subterranean waters in North West Cape Sub-province. Two species of cave gudgeon occur allopatrically. *Milyeringa veritas* (Blind Gudgeon) occurs on the mainland at Cape Range Peninsula while the newly described *Milyeringa justitia* (Barrow Cave Gudgeon) is restricted to Barrow Island (Figure 2) (Humphreys & Adams 1991; Humphreys 1999, 2001; Humphreys *et al*. 2013; Larson *et al*. 2013). Both species share their habitat with *Ophisternon candidum* (Blind Cave Eel), although it is likely that the eels on Barrow Island also represent an additional endemic species given the divergence of the two *Milyeringa* species. There are also reports of additional *Ophisternon* populations in groundwater systems in the Robe basin (Larson *et al*. 2013). The subterranean habitats where these species occur are devoid of light except close to openings to the surface. There are freshwater caves as well as anchialine ecosystems which comprise fresh to brackish ground waters overlying sea water, some of which are tidal with salinities ranging from 0.3 to 34 ppt (Humphreys 2001). These unusual characteristics make it impossible to categorise the subterranean fauna as freshwater, estuarine or marine as they live under the terrestrial surface. This environment represents one of only a few examples of sympatric cave fish species in the world (Proudlove 2006).

The surface dwelling freshwater fish fauna is dominated by a relatively small number of species that can survive in the extreme environments of the Pilbara where rivers experience massive flooding following cyclones and limited water availability during dry times. The fauna consists of three fishes endemic to the province; *Craterocephalus cuneiceps* (Deep Hardyhead) and *Hypseleotris aurea* (Golden Gudgeon) are primarily restricted to southern rivers, but with the former having a disjunct northern population in the De Grey River (Morgan & Gill 2004; Allen *et al*. 2005), whilst *Leiopotherapon aheneus* (Fortescue Grunter) is restricted to a few Northern Sub-province rivers (Morgan and Gill 2004). A possible new species of *Neosilurus* catfish from the Robe River may also be endemic although it has not been captured for a number of years and the Robe River is predicted to have the highest freshwater fish extinction rate on the planet under future climate change scenarios (Tedesco *et al*. 2013).

Table 2 The fishes in non-tidal waters of Western Australia that are listed by: the International Union for the Conservation of Nature (IUCN); the Australian Federal Government (Environment Protection and Biodiversity Conservation Act (EPBC Act 1999)); or the Western Australian Government (Wildlife Conservation Act 1950 (WCA Act 1950) and the Fish Resources Management Act 1994 [FRMA 1994]). Also included is the Australian Society for Fish Biology's (ASFB) list. NT = near threatened, CE = critically endangered, DD = data deficient, LR/NT = lower risk/near threatened, LR/LC = lower risk/least concern, LC = least concern, V = vulnerable, Schedule 1 = fauna that is rare or is likely to become extinct, Priority 1 = poorly-known species (on threatened lands), Priority 2 = poorly-known species (on conservation lands), Priority 3 = poorly-known species (some on conservation estates), Priority 4 = rare, near threatened and other species in need of monitoring, FP = fully protected.

Species name	IUCN	EPBC 1999	WCA 1950	FRMA 1994	ASFB
Geotriidae					
Geotria australis	–	–	Priority 1	–	–
Carcharhinidae					
Carcharhinus leucas	NT	–	–	–	–
Pristidae					
Pristis pristis	CE	V	Priority 3	FP	CE
Dasyatidae					
Himantura dalyensis	DD	–	–	–	V
Anguillidae					
Anguilla bicolor	NT	–	–	–	–
Galaxiidae					
Galaxias truttaceus	–	CE	Schedule 1	–	CE
Galaxiella munda	LR/NT	–	Schedule 1	–	–
Galaxiella nigrostriata	LR/NT	–	Priority 3	–	–
Lepidogalaxiidae					
Lepidogalaxias salamandroides	LR/NT	–	–	–	–
Melanotaeniidae					
Melanotaenia exquisita	DD	–	–	–	–
Melanotaenia gracilis	LR/NT	–	–	–	–
Melanotaenia pygmaea	LR/NT	–	Priority 2	–	–
Atherinidae					
Craterocephalus helenae	LR/NT	–	Priority 2	–	–
Craterocephalus lentiginosus	LR/NT	–	Priority 2	–	–
Synbranchidae					
Ophisternon candidum	DD	–	Schedule 1	–	V
Ambassidae					
Ambassis macleayi	LC	–	–	–	–
Percichthyidae					
Nannatherina balstoni	DD	V	Schedule 1	–	V
Nannoperca pygmaea	–	–	–	–	CE
Terapontidae					
Hannia greenwayi	DD	–	Priority 1	–	–
Hephaestus epirrhinos	LR/NT	–	Priority 2	–	–
Leiopotherapon aheneus	LR/NT	–	Priority 4	–	–
Leiopotherapon macrolepis	LC	–	Priority 2	–	–
Syncomistes kimberleyensis	LR/NT	–	–	–	–
Syncomistes rastellus	LR/NT	–	Priority 2	–	–
Eleotridae					
Hypseleotris aurea	LR/LC	–	Priority 2	–	–
Hypseleotris ejuncida	LR/NT	–	–	–	–
Hypseleotris kimberleyensis	LR/NT	–	–	–	–
Hypseleotris regalis	LR/NT	–	–	–	–
Kimberleyeleotris hutchinsi	–	–	Priority 2	–	–
Kimberleyeleotris notata	–	–	Priority 2	–	–
Milyeringa justitia	–	–	Schedule 1	–	–
Milyeringa veritas	DD	V	Schedule 1	–	V
Kurtidae					
Kurtus gulliveri	LC	–	–	–	–

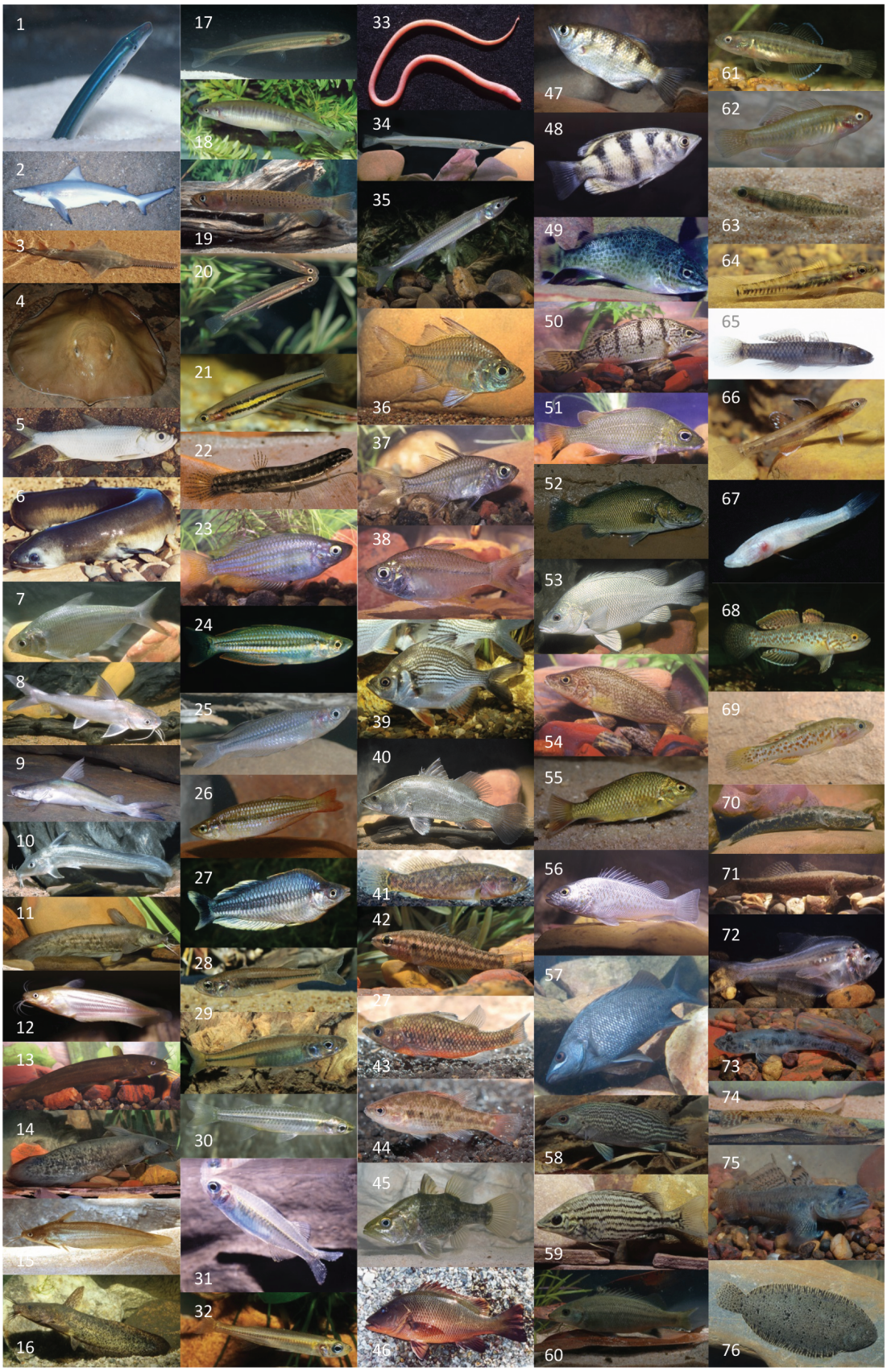

Figure 2 Fishes in fresh water habitats of Western Australia that spend all, or part of, their life-cycle in fresh water. Not pictured are the marine migrants, marine vagrants, estuarine vagrants, undescribed species, *Milyeringa justitia* or *Kimerleyeleotris notata*. Please refer to Table 1 for species names. Photographs by D. Morgan, M. Allen, G. Allen, S. Beatty, S. Visser and B. Ebner.

The remaining freshwater species are all widespread across northern Australia, although Pilbara populations tend to be genetically distinct with some differences sufficiently large to suggest they represent distinct (and thus endemic) species (Unmack 2013). For example, Pilbara populations of *Nematalosa erebi* (Bony Bream) and *Neosilurus hyrtlii* (Hyrtl's Tandan), two of Australia's most widespread freshwater fishes, both appear to be new species according to allozyme, mitochondrial and nuclear DNA studies (Unmack 2013; M. Adams & P. Unmack unpubl. data), and warrant closer morphological examination. Pilbara populations of *Melanotaenia australis* (Western Rainbowfish) are also genetically distinct to populations elsewhere in northern Australia (Young *et al*. 2011; Unmack *et al*. 2013). While most Pilbara fishes have phylogenetic relationships to other species from northern Australia, one exception is *Craterocephalus cuneiceps*, which, based on limited evidence, appears to be more closely related to central and eastern Australian *Craterocephalus* species than northern species (Unmack & Dowling 2010).

In contrast to the Southwestern Province, there are more estuarine and marine vagrants occurring in the non-tidal waters of the Pilbara Province (Table 1). At least 13 species of estuarine or marine vagrants are found in fresh waters of the Province, and in some habitats they have been recorded to comprise between 5 and 10% of the total fish numbers (see also Morgan & Gill 2004; Ebner & Morgan 2013). Some species also appear capable of breeding within either estuarine or fresh waters and are troublesome for simplistic migratory classification schemes; they could be classed as either estuarine vagrants that colonise fresh waters or as 'freshwater fishes' in the case of some populations. Examples include *Pseudogobius olorum* and *Hypseleotris compressa*.

Diadromous fishes of the Pilbara Province include *Lutjanus argentimaculatus* (Mangrove Jack), *Megalops cyprinoides* (Tarpon), *Carcharhinus leucas* and *Pristis pristis* (Morgan & Gill 2004; Ebner & Morgan 2013). The only confirmed records of the latter species are from the Ashburton River below a barrier built to stop the upstream incursion of tidal water, but they have also occasionally been reported from the De Grey River (Morgan unpubl. data). Catadromous species include *Anguilla bicolor* (Indian Short-finned Eel), while *Lates calcarifer* (Barramundi) is considered to be semi-catadromous.

Future impacts to the habitats and fishes of the region are likely to result from the impacts of climate change and from dewatering of habitats during mining and through water abstraction (Tedesco *et al*. 2013). As an example, Tedesco *et al*. (2013) predicted that freshwater fish extinction rates within river basins within the Northern Pilbara Sub-province will be amongst the highest on the globe. Incredibly, the authors predicted that six of the rivers within the Northern Pilbara Sub-province will be in the top 12 rivers globally to suffer the highest extinction rates due to water availability shrinkage from climate change. These include the Robe (ranked 1), Sherlock (3), Fortescue (4), Yule (6), Ashburton (7) and De Grey (12) rivers. Therefore, the Pilbara warrants far more research and management attention than it is receiving to halt imminent (and possibly additional) extinctions.

Kimberley and Northern Provinces

For the sake of convenience we discuss the fauna of these two provinces together as the "Kimberley region" as only a limited portion of the Northern Province occurs within Western Australia (Figure 1). The division of these two provinces is primarily based on the presence of a number of fishes endemic to the Kimberley Province (19 species), rather than species present in the Northern Province but absent from Kimberley Province [with a couple of key exceptions, i.e. *Craterocephalus stramineus* (Strawman) and *Parambassis gulliveri* (Giant Glassfish)]. Furthermore, the boundary between the two provinces is somewhat arbitrary, as currently defined river basins such as the King George and Berkeley remain poorly sampled, such that the boundary cannot be more reliably determined (Morgan *et al*. 2011a; Unmack 2013).

The Kimberley region is a poorly known area of high fish species richness (48 species; Table 1). Many rivers are difficult to access or access is only available to a limited portion of the river basin. As a result, the taxonomy of many Kimberley fishes is uncertain. Many groups appear to contain multiple cryptic species, some of which are widespread while others have highly restricted distributions. High endemicity in the Kimberley is likely a result of the rugged topography; many rivers are characterised by deep gorges and waterfalls which limit migratory movement and exclude diadromous species.

The Kimberley region lacks any highly unusual or particularly old relictual endemic freshwater groups (as is the case in most of northern and eastern Australia). Only two genera are endemic (*Hannia* and *Kimberleyeleotris*). However, many families have high species richness and endemism compared to most regions of the continent. The major families include the Terapontidae (10 species), Eleotridae (10 species), Plotosidae (8 species), Melanotaeniidae (6 species), Ambassidae (4 species), and Toxotidae (2 species) (Table 1, Figure 2) (Morgan *et al*. 2011a; Unmack 2013). Although all groups appear to be primarily related to species found across northern Australia, a key difference is that much of northern Australia east of Darwin was potentially more interconnected during low sea levels, as were basins such as the Daly, Victoria and Ord (Unmack 2001). The shorter catchments and rugged topography around the Kimberley Province appears to have isolated elements of the fauna from eastern regions, leading to divergence through isolation over long time periods. Few molecular clock approaches or phylogenies have been published on Kimberley region fishes, but a mean divergence of 20.5 Ma has been estimated to have occurred between the sister species *Craterocephalus helenae* (Drysdale River Hardyhead) and *Craterocephalus marianae* (from western Arnhemland) which represents the earliest branching lineage (mean age of 37.5 Ma) within the "eyresii group" (Unmack & Dowling 2010). In rainbowfishes, the "nigrans" group (which is endemic to northern Australia) had its mean divergence from its sister lineage (the "australis" group) 12 Ma, with modern species diversifying over the last 6 Ma. Within the "nigrans" group, species endemic to the Kimberley Province such as *Melanotaenia pygmaea* (Pygmy Rainbowfish) and *Melanotaenia gracilis* (Drysdale Rainbowfish) diverged from their sister lineages/species around 5 and 1.5 Ma, respectively (Unmack *et al*. 2013).

The total number of obligate freshwater fish species in this region currently stands at 48 species, but is likely to increase with further exploration and the implementation of genetic studies, especially in groups like *Mogurnda* and *Glossamia*. Numerous diadromous fishes are found within the Kimberley region, including seven that are shared with the Pilbara Province and additionally *Himantura dalyensis* (Freshwater Whipray) (Morgan *et al*. 2004a; Marzullo *et al*. 2011). The catadromous (i.e. *Anguilla bicolor*) and semi-catadromous (i.e. *Lates calcarifer*) fishes found in the Pilbara are also found within the Kimberley, and these provinces comprise the Australian range of *Anguilla bicolor* (Morgan & Gill 2004; Morgan *et al*. 2004a, 2011a). We document 15 marine and estuarine vagrants or marine migrants within the Kimberley region and a further two species that are able to breed within either marine, estuarine or fresh waters (Table 1). A further two conservation dependent euryhaline elasmobranchs [*Glyphis garricki* (Northern River Shark) and *Glyphis glyphis* (Speartooth Shark)] are known from Western Australian estuaries, but neither of these have been recorded within non-tidal inland waters in Western Australia (see Thorburn & Morgan 2004; Morgan *et al*. 2011b).

Paleo Province

Very little is known about the fishes of the Paleo Province. This vast area covers almost half of Australia, although none of it drains to the ocean due to arid conditions and a lack of larger coordinated drainages (Figure 1). The Paleo Province is divided up into sub-provinces or "drainages" based on likely former connections and drainage directions that have had limited connectivity from at least the mid Miocene (Van de Graaff *et al*. 1977; Unmack 2001, 2013). Despite this apparent extreme isolation and the aridity of the region, some records of fish exist, including three species in the Sturt Creek/Lake Gregory system [Paleo Sturt Drainage; *Leiopotherapon unicolor* (Spangled Perch), *Melanotaenia australis* and *Neosilurus hyrtlii*)] (Walker 2009). Populations of the latter two species are genetically related to populations from adjacent Kimberley drainages (Unmack *et al*. unpubl. data). Museum databases indicate that *Leiopotherapon unicolor* and *Melanotaenia australis* have been collected from the Ruddall River system (Paleo Oakover Drainage). There are also records of *Leiopotherapon unicolor* in the Lake Boonderroo/Ponton Creek system (Paleo Southern Drainage), and the introduced *Gambusia holbrooki* and *Carassius auratus* (Goldfish) from several other locations within the Paleo Province (see Morgan *et al*. 2004b). The introduced crayfish *Cherax destructor* (Yabby) is found in a few localities (see Beatty *et al*. 2005). Specific areas within the Paleo Province require dedicated survey and study due to the paucity of data that exists for this area.

Threatened fishes of Western Australia

Western Australian fishes are placed on various conservation lists at international (1), national (2) and state level (3) (see Table 2), but there is little consistency between the different lists and categories. Only one species from WA appears on all five lists (*Pristis pristis*), and three species appear on at least one list at the international, national and state levels (Table 2). Many freshwater fish species in Western Australia are imperilled as evidenced by the total of 33 listed species (Table 2), including two Critically Endangered species, *Pristis pristis* and *Galaxias truttaceus*, according to the IUCN and EPBC lists, respectively. It is important to consider that many of Western Australia's freshwater fishes are naturally rare or have very restricted distributions, mainly as a consequence of evolving in systems that became isolated long ago, e.g. *Melanotaenia pygmaea* (Pygmy Rainbowfish), *Hypseleotris ejuncida* (Slender Gudgeon), *Hypseleotris kimberleyensis* (Barnett River Gudgeon) and *Hypseleotris regalis* (Prince Regent Gudgeon). There is also a disconnect between the true status of some species and their categorisation on conservation lists, e.g. *Kimberleyeleotris notata* (Drysdale Gudgeon), is known only from two specimens at a single locality, but is only acknowledged as a Priority 2 species under the State's Wildlife Conservation Act 1950. Of the two fishes that were first described in 2013 (*Milyeringa justitia* and *Nannoperca pygmaea*), both of which are extremely rare, range restricted and threatened by anthropogenic stressors, only *M. justitia* is officially recognised as threatened, but only on one government list, while *N. pygmaea* is listed as Critically Endangered by the Australian Society for Fish Biology (Lintermans 2013). Unless nominations are submitted, or species are reviewed, these lists may only serve as a reminder of the threatened nature of many species.

Alien fishes in Western Australia

Regrettably, the Southwestern Province now supports a range of alien fishes that compete with native species for habitat and resources, and the number is likely to increase with new species being reported and existing alien fishes (and their associated alien parasites) spreading naturally and through human activities (Morgan & Gill 2001; Morgan *et al*. 2002, 2004b; Morgan 2003; Lymbery *et al*. 2010, 2014; Beatty & Morgan 2013; Duffy *et al*. 2013). In a recent review by Beatty & Morgan (2013), 13 species were identified as having developed self-maintaining populations from wild systems in the Southwestern Province. This study identified that the majority were 'climatically mismatched' and 80% of recent introductions were aquarium species. They projected that this trend was likely to continue due to projected climate change. Indeed, consistent with their prediction, another tropical aquarium cichlid species was recently reported by Duffy *et al*. (2013).

To the best of our knowledge, the Northern Pilbara Sub-province is currently free of introduced fishes. Within the North West Cape Sub-province *Poecilia reticulata* (Guppy) has been introduced into some sites housing cave fishes, while the Southern Pilbara now houses *Oreochromis mossambicus* (Mozambique Mouthbrooder or Tilapia) in estuarine and freshwaters of the Chapman, Gascoyne, Minilya and Lyndon rivers (Morgan & Gill 2004; Morgan *et al*. 2004b; Maddern *et al*. 2007). *Gambusia holbrooki* (Eastern Mosquitofish) plagues rivers south of, but not including the Murchison River, while *Xiphophorus hellerii* (Swordtail) occurs within the Irwin River (Morgan & Gill 2001; Maddern *et al*. 2011).

The only record of alien fish in the Kimberley region is *Gambusia holbrooki* near Beagle Bay (Morgan *et al*. 2004b). The crustacean *Cherax quadricarinatus* (Redclaw Crayfish), which is otherwise widespread across

northern Australia, has been introduced within the Ord River in the Northern Province (Doupé *et al*. 2004) and more recently into the Harding River of the Pilbara Province (Morgan *et al*. 2014). The recent colonisation by the cane toad (*Rhinella marina*) from the Northern Province will undoubtedly have adverse effects on aquatic fauna in the Kimberley region.

PRIORITIES FOR RESEARCH AND MANAGEMENT

The non-tidal inland waters of Western Australia contain 102 indigenous species of fish, of which one is a jawless fish of the Agantha, three are cartilaginous Elasmobranchii, and the remainder are bony fishes (Teleostei). The agnathan has a circum-polar distribution in the Southern Hemsiphere, and in Western Australia is restricted to the cooler, non-salinised streams of the Southwestern Province. Two of the elasmobranchs are widespread in temperate and tropical waters of the world (*Pristis pristis* and *Carcharhinus leucas*) (Last & Stevens 2009; Morgan *et al.* 2011b), whereas the third species, *Himantura dalyensis*, appears to have a patchy distribution within northern Australian and southern Papua New Guinea waters that are north and west of (and inclusive of) the Fitzroy River in the Kimberley (Morgan *et al*. 2004a; Last & Manjaji-Matsumoto 2008). A further two endangered euryhaline elasmobranchs are known from Western Australian estuaries (i.e. *Glyphis* spp.) but as yet have not been recorded in non-tidal inland waters in the State (Thorburn & Morgan 2004; Morgan *et al*. 2011b).

Conservation of Western Australia's inland fishes

Almost one-third of fishes that are found in Western Australian inland waters are listed as Threatened or Data Deficient. Importantly, no fish species is known to have gone extinct in the wild in Western Australia, but populations have been lost, which is an irreversible trend when noting the genetic isolation of many populations. For example, *Nannatherina balstoni* has been extirpated from a number of river systems, and to 're-stock' from elsewhere is not necessarily going to revive the species, for reasons that are beyond the scope of this overview, but which may include compromising genetic lineages, introductions of parasites, or most importantly that the stressors on those systems that led to the decline of the species in the first instance (from declines in habitat and water quality, and introduced species) render them unsuitable for re-establishment. The streamlining of threatened species lists and assessments is required, which will lead to a better understanding of the priority species, and the threats to each.

Migration patterns, habitats and priorities for research and management

Although the information on individual species migration patterns is limited, it is clear that the Pilbara and Kimberley provinces are utilised to a higher degree by diadromous fishes than the Southwestern Province. Furthermore, marine vagrants and marine migrants are also more likely encountered in the fresh waters of the more northerly rivers of Western Australia. Importantly from a global perspective, parts of the Kimberley are important nursery areas for endangered euryhaline elasmobranchs, with many such habitats having been lost elsewhere in these species' distributional ranges. Several teleost species are able to complete their life-cycle in either fresh, estuarine or marine waters. An example is *Neoarius graeffei* (Lesser Salmon Catfish), which is common in coastal waters, estuaries and fresh waters in the Kimberley and Pilbara provinces. Others, which may be considered to be amphidromous in some populations, are known to have potamodromous 'landlocked' populations in the Southwestern Province, namely, *Galaxias maculatus* and *Galaxias truttaceus* (Morgan 2003; Chapman *et al*. 2006; Morgan & Beatty 2006). Some species are known to occupy very small disjunct habitats and do not appear to migrate far; the scale of their migrations can probably be defined in metres [e.g. *Lepidogalaxias salamandroides* and *Galaxiella nigrostriata* are two species that aestivate and appear to remain in isolated ephemeral peat swamps (Pusey 1989; Morgan *et al*. 2000; Smith *et al*. 2002; Galleotti *et al*. 2010)].

Approximately 70% of the species listed in inland Western Australian waters are restricted to fresh waters. Many of these are endemic to the State, with the Southwestern Province having the highest proportion of endemic freshwater fishes on the continent, and the proportion of endemic fishes is set to rise following the descriptions of cryptic species (Unmack 2013). The region, however, also has a high concentration of alien

Table 3 Established alien fishes of Western Australian wild ecosystems. SW = Southwestern Province, P = Pilbara Province, K = Kimberley Province, Pa = Paleo Province (after Allen *et al*. 2002; Morgan *et al*. 2004b; Beatty & Morgan 2013; Duffy *et al*. 2013; Unmack 2013).

Species name	Common name	Drainage Division
Plotosidae		
Tandanus tandanus	Freshwater Catfish	SW
Salmonidae		
Oncorhynchus mykiss	Rainbow Trout	SW
Salmo trutta	Brown Trout	SW
Cyprinidae		
Carassius auratus	Goldfish	SW/Pa
Cyprinus carpio	Carp	SW
Puntius conchonius	Rosy Barb	SW
Poeciliidae		
Gambusia holbrooki	Eastern Mosquitofish	SW/P/K/Pa
Phalloceros harpagos	One-spot Livebearer	SW
Poecilia reticulata	Guppy	P
Xiphophorus hellerii	Swordtail	SW/P
Percidae		
Perca fluviatilis	Redfin Perch	SW
Cichlidae		
Geophagus brasiliensis	Pearl Cichlid	SW
Oreochromis mossambicus	Mozambique Mouthbrooder	P
Percichthyidae		
Macquaria ambigua	Golden Perch	SW
Terapontidae		
Bidyanus bidyanus	Silver Perch	SW
Leiopotherapon unicolor	Spangled Perch	SW

fishes (Table 3) and this is a figure that will also inevitably increase with further incursions. While escapees from the ornamental industry have contributed to most new species introductions in Western Australia in recent times, there is growing pressure to increase aquaculture and recreational fishing opportunities; noting that one such example is the historial, ongoing, yet controversial stocking of Northern Hemisphere salmonids into Southwestern Province ecosystems.

A list of broad priorities for research and management of Western Australia's inland fishes include:

- Conservation of fishes in the Southwestern Province, particularly with regard to anthropogenic stressors and climate change.
- Conservation of fishes in the Pilbara Province, particularly with regard to climate change, water extraction, mining and alien fishes.
- Conservation of euryhaline elasmobranchs, particularly in the Kimberley which supports globally significant habitats for the Freshwater Sawfish (*Pristis pristis*)
- Audits of drainages lacking sufficient biodiversity surveys, e.g. Paleo Province, much of the Kimberley Province and parts of the Pilbara Province.
- Aligning threatened species lists, and developing a process for streamlining faunal assessments.
- Description of new taxa in the Southwestern, Pilbara and Kimberley provinces.
- Developing a strategy for the targeted control of alien or translocated fishes.

CONCLUSIONS

Of the 102 species of fish found in Western Australia's freshwater ecosystems, some 66 are obligate species, while many diadromous fishes also occur here. Many species are imperilled, and it is clear that in time, new species will be described, including, but by no means limited to, those species highlighted here as being new to science, e.g. *Nannoperca* spp., *Nematalosa* sp. and *Neosilirus* sp. What is also clear is that habitats will be lost and there will be incursions of alien species, none of which will be beneficial to maintaining the status quo of our unique yet often unheralded 'freshwater' fish fauna. Much more attention is warranted in terms of research and management on the fishes outside of the Southwestern Province, particularly the Pilbara, to help prevent extirpations of the more unique fishes.

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REFERENCES

Adams M & Humphreys W F 1993. Patterns of genetic diversity within selected subterranean fauna of the Cape Range peninsula, Western Australia: systematic and biogeographical implications. *Records of the Western Australian Museum* **45**, 145–164.

Allen G R 1975. A preliminary checklist of the freshwater fishes of the Prince Regent River Reserve north-west Kimberley, Western Australia. In, Miles, J.M. and Burbidge, A.A. (eds), A biological survey of the Prince Regent River Reserve North-west Kimberley, Western Australia in August, 1974. *Wildlife Research Bulletin of Western Australia* **3**, 1–116.

Allen G R 1978. The rainbowfishes of northwestern Australia (Family Melanotaeniidae). *Ichthyology* **26**, 91–102.

Allen G R 1982. *Inland fishes of Western Australia*. Western Australian Museum, Perth.

Allen G R 1989. *Freshwater fishes of Australia*. T.F.H. Publications, Brookvale.

Allen G R & T M Berra 1989. Life history aspects of the West Australian salamanderfish, *Lepidogalaxias salamandroides* Mees. *Records of the Western Australian Museum* **14**, 253–267.

Allen G R & Burgess W E 1990. A review of the glassfishes (Chandidae) of Australia and New Guinea. *Records of the Western Australian Museum* Supplement **34**, 139–206.

Allen G R & Feinberg M N 1998. Descriptions of new genus and four new species of freshwater catfishes (Plotosidae) from Australia. *Aqua, Journal of Ichthyology and Aquatic Biology* **3**, 141–156.

Allen G R & Jenkins A P 1999. A review of the Australian freshwater gudgeons, genus *Mogurnda* (Eleotridae) with descriptions of three new species *Aqua, Journal of Ichthyology and Aquatic Biology* **3**, 9–18.

Allen G R, Midgley S H & Allen M 2002. *Field Guide to the Freshwater Fishes of Australia*. CSIRO/Western Australian Museum, Perth, Australia.

Allen M, Morgan, D L & Gill H S 2005. Distribution, zoogeography and biology of the Murchison River hardyhead (*Craterocephalus cuneiceps* Whitley, 1944), an atherinid endemic to the Indian Ocean (Pilbara) Drainage Division of Western Australia. *Ecology of Freshwater Fish* **14**, 209–224.

Beatty S J & Morgan D L 2013. Introduced freshwater fishes in a global endemic hotspot and implications of habitat and climatic change. *BioInvasions Records* **2**, 1–9.

Beatty S J, Morgan D L & Gill H S 2005. Role of life history strategy in the colonisation of Western Australian aquatic systems by the introduced crayfish *Cherax destructor* Clark, 1936. *Hydrobiologia* **549**, 219–237.

Beatty S J, Morgan D L, Keleher J, Allen M G & Sarre G A 2013. The tropical South American cichlid, *Geophagus brasiliensis* in Mediterranean climatic south-western Australia. *Aquatic Invasions* **8**, 21–36.

Beatty S J, Morgan D L & Lymbery A J 2014. Implications of climate change for potamodromous fishes. *Global Change Biology* **20,** 1794–1807.

Beatty S J, Morgan D L, McAleer F J & Ramsay A R 2010. Groundwater contribution to baseflow maintains habitat connectivity for *Tandanus bostocki* (Teleostei: Plotosidae) in a south-western Australian river. *Ecology of Freshwater Fish* **19**, 595–608.

Beatty S J, Morgan D L, Rashnavidi M & Lymbery A J 2011. Salinity tolerances of endemic freshwater fishes of south-western Australia: implications for conservation in a biodiversity hotspot. *Marine & Freshwater Research* **62**, 91–100.

Beesley L 2006. *Environmental stability: Its role in structuring fish communities and life history strategies in the Fortescue River, Western Australia*. PhD thesis, University of Western Australia.

Berra T M & Allen G R 1989. Burrowing, emergence, behaviour, and functional morphology of the Australian salamanderfish, *Lepidogalaxias salamandroides*. *Fisheries* **14**, 2–10.

Berra T M & Allen G R 1991. Population structure and development of *Lepidogalaxias salamandroides* (Pisces: Salmoniformes) from Western Australia. *Copeia* **1991**, 845–850.

Betancur R R, Broughton R E, Wiley E O, Carpenter K, Lopez J A, Li C, Holcroft N I, Arcila D, Sanciangco M, Cureton J, Zhang F, Buser T, Campbell M, Rowley T, Ballesteros J A, Lu G, Grande T, Arratia G, & Ortí G 2013. The tree of life and a new classification of bony fishes. PLoS Currents Tree of Life 2013 Apr 18. Edition 1.

Burridge C P, McDowall R M, Craw D, Wilson M V H & Waters J M 2011. Marine dispersal as a pre-requisite for Gondwanan vicariance among elements of the galaxiid fish fauna. *Journal of Biogeography* **39**, 306–321.

Chapman A, Morgan D L, Beatty S J & Gill H S 2006. Variation in life history of land-locked lacustrine and riverine populations of *Galaxias maculatus* (Jenyns 1842) in Western Australia. *Environmental Biology of Fishes* **77**, 21–37.

Coates D 1987. Observations on the biology of the Tarpon, *Megalops cyprinoides* (Broussonet) (Pisces:Megalopidae) in the Sepik River, Northern Papua New Guinea. *Australian Journal of Marine and Freshwater Research* **38**, 529–535.

Davis A M, Pearson R G, Pusey B J, Perna C, Morgan D L & Burrows D 2011. Trophic ecology of northern Australia's terapontids: ontogenetic dietary shifts and feeding classification. *Journal of Fish Biology* **78**, 265–286.

Davis A M, Pusey B J, Thorburn D C, Dowe J L, Morgan D L & Burrows D 2010. Riparian contributions to the diet of terapontid grunters (Pisces: Terapontidae) in wet-dry tropical rivers. *Journal of Fish Biology* **76**, 862–879.

Davis A M, Unmack P J, Pusey B J, Pearson R G & Morgan D L 2013. Ontogenetic development of intestinal length and relationships to diet in an Australasian fish family (Terapontidae). *BMC Evolutionary Biology* **13**, 53.

Donaldson T J & Myers R F 2002. Insular freshwater fish faunas of Micronesia: patterns of species richness and similarity. *Environmental Biology of Fishes* **65**, 139–149.

Doupé R G, Morgan D L, Gill, H S & Rowland A J 2004. Introduction of redclaw crayfish *Cherax quadricarinatus* (von Matrens) to Lake Kununurra, Ord River, Western Australia: prospects for a 'yabby' in the Kimberley. *Journal of the Royal Society of Western Australia* **87**, 187–191.

Duffy R, Snow M & Bird C 2013. The convict cichlid *Amatitlania nigrofasciata* (Cichlidae): first record of this non-native species in Western Australian waterbodies. *Records of the Western Australian Museum* **28**, 7–12.

Ebner B C & Morgan D L 2013. Using remote underwater video to estimate freshwater fish species richness. *Journal of Fish Biology* **82**, 1592–1612.

Elliott M, Whitfield A K, Potter I C, Blaber S J M, Cyrus D P, Nordie F G & Harrison T D 2007. The guild approach to categorizing estuarine fish assemblages: a global review. *Fish & Fisheries* **8**, 241–268.

Galeotti D M, McCullough C D & Lund M A 2010. Black-stripe minnow *Galaxiella nigrostriata* (Shipway 1953) (Pisces: Galaxiidae), a review and discussion. *Journal of the Royal Society of Western Australia* **93**, 13–20.

Gill H S & Morgan D L 1998. Larval development of *Nannatherina balstoni* Regan (Nannopercidae), with a description of ontogenetic changes in diet. *Ecology of Freshwater Fish* **7**, 132–139.

Gill H S & Morgan D L 1999. Larval development in the salamanderfish, *Lepidogalaxias salamandroides*. *Copeia* **1999**, 219–224.

Gill H S, Morgan D L, Doupé R G & Rowland A J 2005. The fishes of Lake Kununurra, a highly regulated section of the Ord River in northern Western Australia. *Records of the Western Australian Museum* **23**, 1–6.

Hoese D F & Allen G R 1983. A review of the gudgeon genus *Hypseleotris* (Pisces: Eleotridae) of Western Australia, with descriptions of three new species. *Records of the Western Australian Museum* **10**, 243–261.

Humphreys W F 1999. The distribution of the Australian cave fishes. *Records of the Western Australian Museum* **19**, 469–472.

Humphreys W F 2001. *Milyeringa veritas* Whitley 1945 (Eleotridae), a remarkably versatile cave fish from the arid tropics of northwestern Australia. *Environmental Biology of Fishes* **62**, 297313.

Humphreys W F & Adams M 1991. The subterranean aquatic fauna of the North West Cape peninsula, Western Australia. *Records of the Western Australian Museum* **15,** 383–411.

Humphreys G, Alexander J, Harvey M S & Humphreys W F 2013. The subterranean fauna of Barrow Island, north-western Australia: 10 years on. *Records of the Western Australian Museum*, Supplement **83**, 145–158.

Humphreys W F & Feinberg M N 1995. Food of the blind cave fishes of northwestern Australia. *Records of the Western Australian Museum* **17**, 29–33.

Humphreys W F, Shiao J C, Iizuka Y & Tzeng W N 2006. Can otolith microchemistry reveal whether the blind cave gudgeon, *Milyeringa veritas* (Eleotridae), is diadromous within a subterranean estuary. *Environmental Biology of Fishes* **75**, 439–453.

Humphries P 1989. Variation in the life history of diadromous and landlocked populations of the spotted galaxias, *Galaxias truttaceus* Valenciennes, in Tasmania. *Ecology of Freshwater Fish* **40**, 501–18.

Hutchins J B 1977. The freshwater fish fauna of the Drysdale River National Park North Kimberley, Western Australia. In, Kabay, E.D. and Burbidge, A.A. (eds), *A biological survey of the Drysdale River National Park North Kimberley, Western Australia in August, 1975*. *Wildlife Research Bulletin of Western Australia* **6**, 1–133.

Hutchins J B 1981. Freshwater fish fauna of the Mitchell Plateau Area, Kimberley, Western Australia. In, *Biological survey of Mitchell Plateau and Admiralty Gulf, Kimberley, Western Australia*. Western Australian Museum, Perth.

Ivantsoff W, Crowley L E L M & Allen G R 1987. Descriptions of three new species and one subspecies of freshwater hardyhead (Pisces: Atherinidae: *Craterocephalus*) from Australia. *Records of the Western Australian Museum* **13**, 171–88.

Larson H K, Foster R, Humphreys W F & Stevens M I 2013. A new species of the blind cave gudgeon (Pisces: Gobioidei, Eleotridae) from Barrow Island, Western Australia, with a redescription of *M. veritas* Whitley. *Zootaxa* **3616**, 135–150.

Last P R & Manjaji-Matsumoto B M 2008. *Himantura dalyensis* sp. nov., a new estuarine whipray (Myliobatoidei: Dasyatidae) from northern Australia. In: *Descriptions of new Australian Chondrichthyans*. CSIRO Marine and Atmospheric Research Paper No. **022**, 283–291.

Last P R & Stevens J D 2009. *Sharks and Rays of Australia*. CSIRO Publishing: Collingwood, VIC.

Lintermans M 2013. Conservation and management. *In*: Humphries, P & Walker, K (eds), *Ecology of Australian freshwater fishes*, pp. 283–316. CSIRO Publishing, Victoria.

Lymbery A J, Hassan M, Morgan D L, Beatty S J & Doupe R G 2010. Parasites of native and exotic freshwater fishes in south-western Australia. *Journal of Fish Biology* **76**, 1770–1785.

Lymbery A J, Morine M, Kanani H G, Beatty S J & Morgan D L 2014. Co-invaders: The effects of alien parasites on native

hosts. *International Journal for Parasitology: Parasites and Wildlife htpp://*dx.doi.org/10.1016/j.ijppaw.2014.04.002

Maddern M G, Gill H S & Morgan D L, 2011. Biology and invasive potential of the introduced swordtail *Xiphophorus hellerii* Heckel (Poeciliidae) in Western Australia. *Aquatic Conservation: Marine and Freshwater Ecosystems* DOI: 10.1002/aqc.118.

Maddern M G, Morgan D L & Gill H S 2007. Distribution, diet and potential impacts of the introduced Mozambique mouthbrooder *Oreochromis mossambicus* Peters (Pisces: Cichlidae) in Western Australia. *Journal of the Royal Society of Western Australia* **90**, 203–214.

McCulloch M, Cappo M, Aumend J & Müller W 2005. Tracing the life history of individual barramundi using laser ablation MC-ICP-MS Sr-isotopic and Sr/Ba rations in otoliths. *Marine and Freshwater Research* **56**, 637–644.

McDowall R M 1997. The evolution of diadromy in fishes (revisited) and its place in phylogenetic analysis. *Reviews in Fish Biology and Fisheries* **7**, 443–462.

McDowall R M 2007. On amphidromy, a distinct form of diadromy in aquatic organisms. *Fish and Fisheries* **8**, 1–13.

McDowall R M & Pusey B J 1983. *Lepidogalaxias salamandroides* Mees – a redescription, with natural history notes. *Records of the Western Australian Museum* **11**, 11–23.

McDowall R M & Frankenberg R S 1981. The galaxiid fishes of Australia. *Records of the Western Australian Museum* **33**, 443–605.

Marzullo T A, Wueringer B E, Squire L & Collin S P 2011. Description of the mechanoreceptive lateral line and electroreceptive ampullary system in the freshwater whipray, *Himantura dalyensis*. *Marine and Freshwater Research* **62**, 771–779.

Mees G F 1961. Description of a new fish of the family Galaxiidae from Western Australia. *Journal of the Royal Society of Western Australia* **44**, 33–38.

Mees G F 1962. The subterranean freshwater fauna of Yardie Creek Station, North West Cape, Western Australia. *Journal of the Royal Society of Western Australia* **45**, 24–32.

Mees G F 1963. Description of a new freshwater fish of the family Theraponidae from Western Australia. *Journal of the Royal Society of Western Australia* **46**, 1–4.

Moore R & Reynolds L F 1982. Migration patterns of barramundi *Lates calcarifer* (Bloch), in Papua New Guinea. *Australian Journal of Marine & Freshwater Research* **33**, 671–682.

Morgan D L 2003. Distribution and biology of *Galaxias truttaceus* (Galaxiidae) in south-western Australia, including first evidence of parasitism of fishes in Western Australia by *Ligula intestinalis*. *Environmental Biology of Fishes* **66**, 155–167.

Morgan D L 2010. Fishes of the King Edward River in the Kimberley region, Western Australia. *Records of the Western Australian Museum* **25,** 351–368.

Morgan D L, Allen G R, Pusey B J & Burrows D W 2011a. A review of the freshwater fishes of the Kimberley region of Western Australia. *Zootaxa* **2816**, 1–64.

Morgan D L, Allen M G, Beatty S J, Ebner B C & Keleher J J 2014. *A field guide to the freshwater fishes of Western Australia's Pilbara Province.* Freshwater Fish Group, Murdoch University, Murdoch, Western Australia.

Morgan D L, Allen M G, Bedford P & Horstman M 2004a. Fish fauna of the Fitzroy River in the Kimberley region of Western Australia – including the Bunuba, Gooniyandi, Ngarinyin, Nyikina and Walmajarri Aboriginal names. *Records of the Western Australian Museum* **22**, 147–161.

Morgan D L & Beatty S J 2006. Use of a vertical-slot fishway by galaxiids in Western Australia. *Ecology of Freshwater Fish* **15**, 500–509.

Morgan D L & Beatty S J 2008. Fishes and freshwater crayfishes of major catchments of the Leschenault Estuary: Preston and Brunswick River, including first record of a freshwater gudgeon (Eleotridae) from south-western Australia. *Journal of the Royal Society of Western Australia* **91**, 155–161.

Morgan D L, Beatty S J & Adams M 2013. *Nannoperca pygmaea*, a new species of pygmy perch (Teleostei: Percichthyidae) from Western Australia. *Zootaxa* **3637**, 401–411.

Morgan D L, Chapman A, Beatty S J & Gill H S 2006. Distribution of the spotted minnow (*Galaxias maculatus* (Jenyns, 1842)) (Teleostei: Galaxiidae) in Western Australia including range extensions and sympatric species. *Records of the Western Australian Museum* **23**, 7–11.

Morgan D L & Gill H S 2001. The green swordtail *Xiphophorus helleri* Heckel (Poeciliidae): another aquarium fish established in the wild in Western Australia. *Records of the Western Australian Museum* **20**, 349–352.

Morgan D L & Gill H S 2004. Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia – evidence for three subprovinces. *Zootaxa* **636**, 1–43.

Morgan D L, Gill H S, Maddern M G & Beatty S J 2004b. Distribution and impacts of introduced freshwater fishes in Western Australia. *New Zealand Journal of Marine and Freshwater Research* **38**, 511–523.

Morgan D L, Gill H S & Potter I C 1995. Life cycle, growth and diet of Balston's pygmy perch in its natural habitat of acidic pools. *Journal of Fish Biology* **47**, 808–825.

Morgan D L, Gill H S & Potter I C 1998. Distribution, identification and biology of freshwater fishes in south-western Australia. *Records of Western Australian Museum* **Supplement 56,** 1–97.

Morgan D L, Gill H S & Potter I C 2000. Age composition, growth and reproductive biology of the salamanderfish *Lepidogalaxias salamandroides*: a re-examination. *Environmental Biology of Fishes* **57**, 191–204.

Morgan D L, Hambleton S J, Gill H S & Beatty S J 2002. Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*) (Percidae) in Western Australia. *Marine & Freshwater Research* **53**, 1211–1221.

Morgan D L, Thorburn D C & Gill H S 2003. Salinization of south-western Western Australian rivers and the implications for the inland fish fauna – the Blackwood River, a case study. *Pacific Conservation Biology* **9**, 161–171.

Morgan D L, Whitty J M, Phillips N M, Thorburn D C, Chaplin J A & McAuley R 2011b. North-western Australia as a hotspot for endangered elasmobranchs, with particular reference to sawfishes and the Northern River Shark. *Journal of the Royal Society of Western Australia* **94**, 345–358.

Morrongiello J R, Beatty S J, Bennett J C, Crook D A, Ikedife D N E N, Kennard M J, Kerezsy A, Lintermans M, McNeil D G, Pusey B J & Rayner T 2011. Climate change and its implications for Australia's freshwater fish. *Marine and Freshwater Research* **62**, 1082–1098.

Myers G S 1949. Use of anadromous, catadromous and allied terms for migratory fishes. *Copeia* **1949**, 89–97.

Pen L J, Gill H S, Potter I C & Humphries P 1993. Growth, age composition, reproductive biology and diet of the black-stripe minnow *Galaxiella nigrostriata* (Shipway), including comparisons with the other two *Galaxiella* species. *Journal of Fish Biology* **43**, 847–863.

Pen L J & Potter I C 1990. Biology of the nightfish, *Bostockia porosa* Castelnau, in south-western Australia. *Australian Journal of Marine & Freshwater Research* **41**, 627–645.

Pen L J & Potter I C 1991a. Biology of the western minnow, *Galaxias occidentalis* Ogilby (Teleostei: Galaxiidae), in a south-western Australian river. 2. Size and age composition, growth and diet. *Hydrobiologia* **211**, 89–100.

Pen L J & Potter I C 1991b. The biology of the western pygmy perch, *Edelia vittata*, and comparisons with two other teleost species endemic to south-western Australia. *Environmental Biology of Fishes* **31**, 365–380.

Pen L J & Potter I C 1991c. Biology of the western minnow,

Galaxias occidentalis Ogilby (Teleostei: Galaxiidae), in a south-western Australian river. 1. Reproductive biology. *Hydrobiologia* **211**, 77–88.

Pen L J, Potter I C & Hilliard R W 1991. Biology of *Galaxiella munda* McDowall (Teleostei: Galaxiidae), including a comparison of the reproductive strategies of this and three other local species. *Journal of Fish Biology* **39**, 717–731.

Pender P J & Griffin R K 1996. Habitat history of barramundi *Lates calcarifer* in a northern Australian river system based on barium and strontium levels in scales. *Transactions of the American Fisheries Society* **125**, 679–689.

Phillips R D, Storey A W & Johnson M S 2009. Genetic structure of *Melanotaenia australis* at local and regional scales in the east Kimberley, Western Australia. *Journal of Fish Biology* **74**, 437–451.

Potter I C & Hyndes G A 1999. Characteristics of the ichthyofauna of southwestern Australian estuaries, including comparisons with holarctic estuaries and estuaries elsewhere in temperate Australia. *Australian Journal of Ecology* **24**, 395–421.

Potter I C, Prince P A & Croxall J P 1979. Data on the adult marine and migratory phases in the life cycle of the Southern Hemisphere lamprey, *Geotria australis* Gray. *Environmental Biology of Fishes* **4**, 65–69.

Prince J D & Potter I C 1983. Life-cycle duration, growth and spawning times of five species of Atherinidae (Teleostei) found in a Western Australian estuary. *Australian Journal of Marine and Freshwater Research* **34**, 287–301.

Proudlove G S 2006. *Subterranean fishes of the world. An account of the subterranean (hypogean) fishes described to 2003 with a bibliography 1541–2004*. International Society for Subterranean Biology, Moulis, France.

Pusey B J 1989. Aestivation in the teleost fish *Lepidogalaxias salamandroides* Mees. *Comparative Biochemistry and Physiology* **92A**, 137–138.

Pusey B J 1990. Seasonality, aestivation and the life history of the salamanderfish *Lepidogalaxias salamandroides* (Pisces: Lepidogalaxiidae). *Environmental Biology of Fishes* **29**, 15–26.

Pusey B J & Bradshaw S D 1996. Diet and dietary overlap in fishes of temporary waters of southwestern Australia. *Ecology of Freshwater Fish* **5**, 183–194.

Pusey B J & Stewart T 1989. Internal fertilization in *Lepidogalaxias salamandroides* Mees (Pisces: Lepidogalaxiidae). *Zoological Journal of the Linnean Society* **97**, 69–79.

Sarre G A, Platell M E & Potter I C 2000. Do the dietary compositions of *Acanthopagrus butcheri* in four estuaries and a coastal lake vary with body size and season and within and amongst these water bodies? *Journal of Fish Biology* **56**, 103–122.

Shipway B 1953. Additional records of fishes occurring in the fresh waters of Western Australia. *Western Australian Naturalist* **3**, 173–177.

Smith K D, Pen L J & Knott B 2002. Genetic and morphological study of the black-stripe minnow, *Galaxiella nigrostriata* (Salmoniformes: Galaxiidae), including a disjunct population near Perth, Western Australia. *Records of the Western Australian Museum* **21**, 285–290.

Storey A W, Edwards D H D, Watts R J & Hebbert D R 1995. Genetic and Morphological differences between populations of the Western Minnow, *Galaxias occidentalis*, from two river systems in south-western Australia. *Marine and Freshwater Research* **46**, 769–777.

Tedesco P A, Oberdorff T, Cornu J -F, Beauchard O, Brosse S, Durr H H, Grenouillet G, Leprieur F, Tisseuil C, Zaiss R & Hugueny B 2013. A scenario for impacts of water availability loss due to climate change on riverine fish extinction rates. *Journal of Applied Ecology* **50**, 1105–1115.

Thorburn D C, Morgan D L, Rowland A J & Gill H S 2007. Freshwater Sawfish *Pristis microdon* Latham, 1794 (Chondrichthyes: Pristidae) in the Kimberley region of Western Australia. *Zootaxa* **1471**, 27–41.

Thorburn D C & Morgan D L, 2004. The northern river shark *Glyphis* sp. C (Carcharhinidae) discovered in Western Australia. *Zootaxa* **685**, 1–8.

Unmack P J 2001. Biogeography of Australian freshwater fishes. *Journal of Biogeography* **28**, 1053–1089.

Unmack P J 2013. Biogeography. *In*: Humphries P & Walker K (eds), *Ecology of Australian freshwater fishes* pp. 25–48. CSIRO Publishing, Victoria.

Unmack P J, Allen G R & Johnson J B 2013. Phylogeny and biogeography of rainbowfishes (Teleostei: Melanotaeniidae). *Molecular Phylogenetics and Evolution* **67**, 15–27.

Unmack P J, Bagley J C, Adams M, Hammer M P & Johnson J B 2012. Molecular phylogeny and phylogeography of the Australian freshwater fish genus *Galaxiella*, with an emphasis on dwarf galaxias (*G. pusilla*). *Plos One* **7**, e38433.

Unmack P J & Dowling T E 2010. Biogeography of the genus *Craterocephalus* (Teleostei: Atherinindae) in Australia. *Molecular Phylogenetics and Evolution* **55**, 968–984.

Unmack P J, Hammer M P, Adams M, Dowling T E 2011. A phylogenetic analysis of pygmy perches (Teleostei: Percichthyidae) with an assessment of the major historical influences on aquatic biogeography in southern Australia. *Systematic Biology* **60**, 797–812.

Van de Graaff W E, Crowe R W, Bunting J A & Jackson M J 1977. Relict early Cainozoic drainages in arid Western Australia. *Zeitschrift für Geomorphologie* **21**, 379–400.

Vari R P 1978. The terapon perches (Percoidei, Teraponidae). A cladistic analysis and taxonomic revision. *Bulletin of the American Museum of Natural History* **159**, 175–340.

Vari R P & Hutchins J B 1978. New species of terapon perches (Percoidei, Teraponidae) from Australia. *American Museum Novitates* No. **2654**, 1–8.

Walker S 2009. When the worms turn: *Eustrongylides* in spangled perch (*Leiopotherapon unicolor*) at Paruku (Lake Gregory), Western Australia. Honours Thesis, University of Canberra, ACT.

Whitley G P 1944. New sharks and fishes from Western Australia. *Australian Zoologist* **10**, 252–273.

Whitley G P 1945. New sharks and fishes from Western Australia. Part 2. *Australian Zoologist* **11**, 1–42.

Whitty J M, Morgan D L, Peverell S C, Thorburn D C & Beatty S J 2009. Ontogenetic depth partitioning by juvenile freshwater sawfish (*Pristis microdon*: Pristidae) in a riverine environment. *Marine and Freshwater Research* **60**, 306–316.

Young M J, Evans J P & Simmons L W 2011. Population genetic structure and a possible role for selection in driving phenotypic divergence in a rainbowfish (Melanotaeniidae). *Biological Journal of the Linnean Society* **102**, 144–160.