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.*

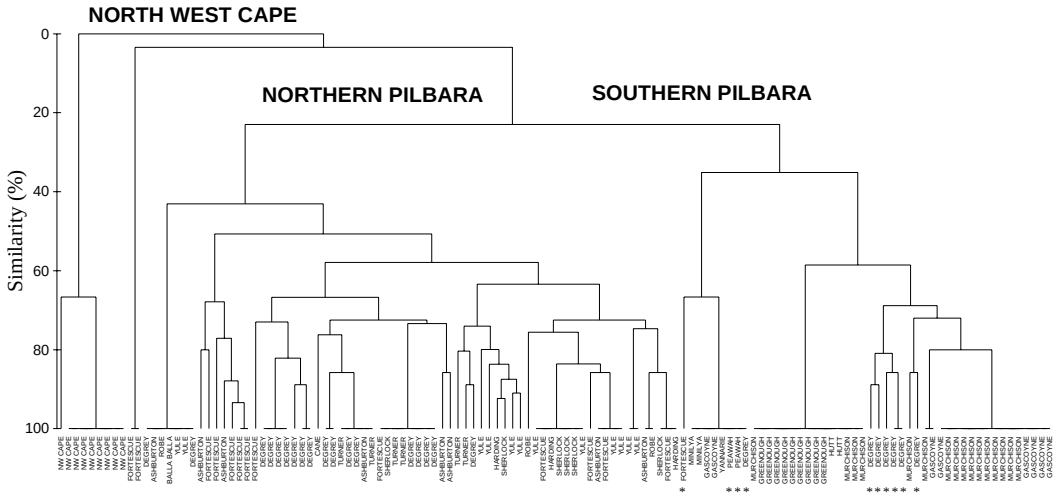

FIGURE 16. Classification of the presence/absence data of the native freshwater fish fauna for the sites sampled in the different rivers of the Pilbara Drainage Division. N.B. * signifies Northern river sites that group with Southern river sites.

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.

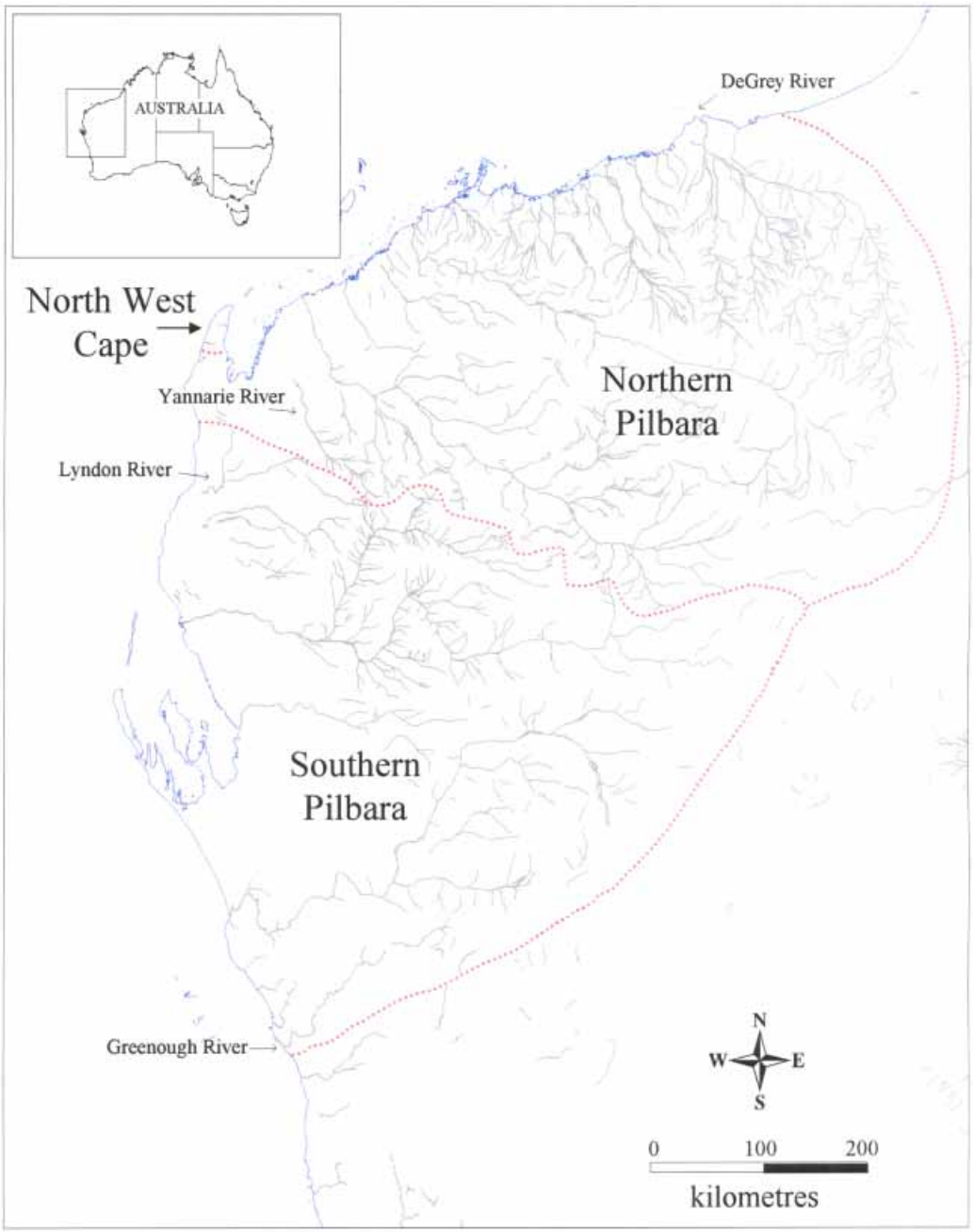

FIGURE 17. The subprovinces of the Pilbara Drainage Division, i.e. Southern Pilbara, North West Cape and Northern Pilbara.

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.

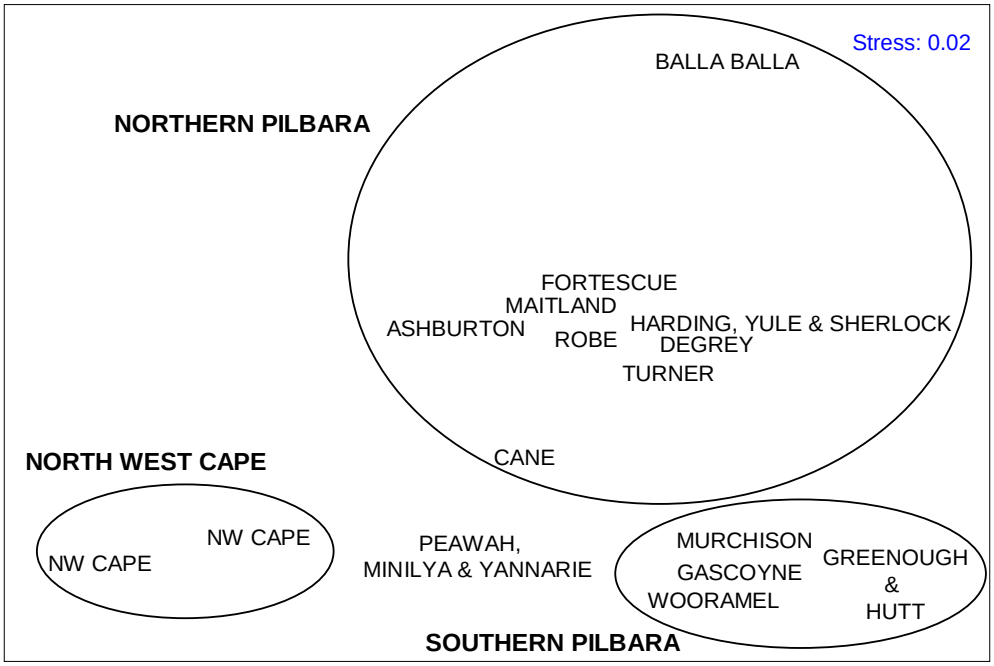

FIGURE 18. Ordination plot of the pooled presence/absence data for the different native freshwater fishes in the rivers of the Pilbara Drainage Division.

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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