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Aquatic fauna refuges in Margaret River and the Cape to Cape region of Australia's Mediterranean-climatic Southwestern Province

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SUMMARY

Margaret River and the Cape to Cape region in the extreme south-western tip of Australia are located between Cape Naturaliste in the north and Cape Leeuwin in the south and encompass all intervening catchments that drain westward to the Indian Ocean. The region has a Mediterranean climate and houses 13 native, obligate freshwater macrofauna species (i.e. fishes, decapod crustaceans and a bivalve mollusc), four of which are listed as threatened under State and/or Commonwealth legislation. The most imperiled species are the Margaret River Burrowing Crayfish (*Engaewa pseudoreducta*) and Hairy Marron (*Cherax tenuimanus*), both of which are endemic to the Margaret River catchment and listed as critically endangered (also by the IUCN), and Balston's Pygmy Perch (*Nannatherina balstoni*) which is vulnerable. The region also houses several fishes that may represent new, endemic taxa based on preliminary molecular evidence. Freshwater ecosystems in the region face numerous threats including global climate change, a growing human population, introduced species, destructive land uses, riparian degradation, water abstraction, declining environmental flows, instream barriers, and fire. Here we review the current knowledge of the considerable aquatic biodiversity values of the region to provide a contemporary checklist, and to highlight actions that may be considered to protect these values in the face of both current and future conservation threats.

Keywords: Threatened species; teleosts; decapod crustaceans; agnathans; mussels

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INTRODUCTION

The south-west of Western Australia is a global hotspot of species endemism that is influenced by a Mediterranean climate (Myers *et al.*, 2000; Olson & Dinerstein, 2002; Morgan *et al.*, 2014a). The aquatic fauna of the region is species impoverished, yet the region has the highest rate of species endemism of any major drainage division in Australia, with >90% of the native aquatic macrofauna (i.e. fishes, decapod crustaceans, and bivalve molluscs) being endemic to this region (Morgan *et al.*, 2011, 2014a). Some of these endemic species have suffered dramatic range declines during the past century, mainly due to impacts associated with deforestation and agricultural development, whilst others are naturally restricted to narrow ranges (Morgan *et al.*, 1998, 2011; Unmack, 2001; Allen *et al.*, 2002; Klunzinger *et al.*, 2015). While land clearing is now less prevalent, the entire regional aquatic fauna is becoming increasingly jeopardised by a number of anthropogenic stressors and environmental threats, not the least of which is human-induced global climate change (Suppiah *et al.*, 2007; Morrongiello *et al.*, 2011; Beatty *et al.*, 2014; IPCC, 2014; Morgan *et al.*, 2014a). Consequently, several of the region's endemic aquatic species are now imperiled and officially recognised as threatened under State and/or Commonwealth legislation (Morgan *et al.*, 2011, 2014a).

Situated within south-western Australia, the Cape to Cape region (CCR) (Figure 1) is globally recognised as a premier food and wine producing region, as well as a popular tourist destination. The population of the CCR has expanded in recent decades and land use patterns have shifted accordingly (CCG, 2005a, 2005b, 2006; DoW, 2009, 2010). For instance, agriculture has intensified (particularly viticulture), resulting in a growing demand for surface and subsurface water resources (CCG, 2005a, 2005b, 2006). In light of this, the Department of Water (Government of Western Australia) recently proclaimed several unregulated water resources in the CCR for allocation under license (DoW, 2009) and addressed the need for water management reform in the South West Regional Water Plan 2010 – 2030 (DoW, 2010). Balancing human water demands with ecological water requirements in a drying climatic region, where water demand is predicted to be at the limit of supply within 20 years, looms as a key management challenge (DoW, 2010). Moreover, the projected continuation of the current drying trend beyond this timeframe places further uncertainty on the long-term sustainability of some of the region's aquatic ecosystems (Suppiah *et al.*, 2007; CSIRO, 2009a, b; Morrongiello *et al.*, 2011).

The obligate freshwater macrofauna of the CCR comprises 13 native species (Morgan *et al.*, 2011), four of which are listed as threatened under the Wildlife Conservation Act 1950 and/or Environment Protection and Biodiversity Conservation (EPBC) Act 1999. Two additional species are listed as 'priority taxa' by the Department of Parks and Wildlife, Government of Western Australia (Morgan *et al.*, 2011, 2014a). The most imperiled are the Hairy Marron *Cherax tenuimanus* (Smith 1912) and the Margaret River Burrowing Crayfish *Engaewa pseudoreducta* Horwitz & Adams 2000, two range-restricted endemics that are listed as critically endangered under the EPBC Act 1999 (and also by the IUCN), while Balston's Pygmy Perch *Nannatherina balstoni* Regan 1906, and Carter's Freshwater Mussel *Westralunio carteri* (Iredale 1934) are either vulnerable (*N. balstoni*) or qualify as vulnerable (*W. carteri*) under the EPBC Act 1999 (Morgan *et al.*, 2014b, Klunzinger *et al.*, 2015). Notwithstanding the threat posed by climate change, these rare species also face a number of further specific threats (see Burnham *et al*., 2012; Duffy *et al*., 2014; Klunzinger *et al*., 2015).

With almost half of the CCR's native freshwater macrofauna recognised as threatened or requiring conservation management, freshwater ecosystems in the region have justifiably received considerable attention from natural resource managers, scientists and conservation organisations in recent years. Increasing resources have been channelled into conservation and landcare initiatives in the region, such as the construction of two rock ramp fishways on the Margaret River (Beatty *et al*., 2007), comprehensive foreshore assessments (e.g. CCG, 2005a, 2006, 2008), and research, monitoring and recovery work on the region's critically endangered species (e.g. Bunn, 2004; Bunn *et al*., 2008; Burnham *et al*., 2012; Duffy *et al*., 2014; Morgan *et al*., 2014b; Klunzinger *et al*., 2015). Given the burgeoning amount of unpublished literature pertaining to the catchments and resident aquatic macrofauna of the CCR, the aim of this review is to collate and interpret the available information and data, thus providing a framework for environmental managers to develop a conservation strategy that may be used to protect and enhance the region's aquatic biodiversity values.

STUDY AREA

This review focuses on the area between Cape Naturaliste (33.53° S, 115.00° E) and Cape Leeuwin (34.38° S, 115.14° E) and encompasses all intervening catchments draining westward to the Indian Ocean (Figure 1). The geology of the region features a coastal strip of sandy soil overlying limestone with occasional outcroppings of the underlying granitic and gneissic bedrock (Leeuwin Block), whilst further inland the topography is undulating and low-relief (20-100 m above sea level) with a mixture of gravelly and sandy soils in upland areas and alluvial sandy loams on drainage lines and floodplains (Tille & Lantzke, 1990; CCG, 2003).

The CCR has a Mediterranean climate characterised by hot, dry summers and mild, wet winters. Long-term mean annual precipitation at Margaret River is 1131 mm, and is similar at other weather stations in the vicinity, but considerably higher than areas to the region's north (BoM 2015). Precipitation decreases to around 900 mm further inland near the headwaters of the Margaret River catchment (BoM, 2015). On average, >75% of precipitation falls in the five months from May to September (BoM, 2015). Evaporation rates in the region are around 1.5 times higher than precipitation rates (Taylor & Tinley, 1999; BoM, 2015) resulting in highly seasonal flows, with most drainage systems becoming a series of isolated pools during the dry summer-autumn period.

CATCHMENT CONDITION IN THE CAPE TO CAPE REGION

Although small on a global scale, the Margaret River is the largest river system in the CCR, draining an area of 477 km2 and features extensive permanent pool habitats throughout the middle and upper reaches. The river is in relatively good condition and has not become impacted by secondary salinisation, unlike many other rivers in south-western Australia (Morgan *et al*., 2003; Beatty *et al*., 2011). Almost the entire upper Margaret River catchment and significant portions of the lower catchment are forested (Green *et al*., 2010) and only 21% of the catchment has been cleared of native vegetation (CCG, 2003; DoW, 2008). In contrast, other CCR catchments are much smaller and most have been cleared more extensively (Table 1). Agriculture (predominantly livestock and viticulture) is the dominant land use across the CCR, with the proportion of cleared land typically exceeding 60% (Table 1). Wilyabrup Brook is the most highly modified catchment in the CCR (Table 1) with unrestricted access of livestock to riparian habitats prevalent (CCG, 2006).

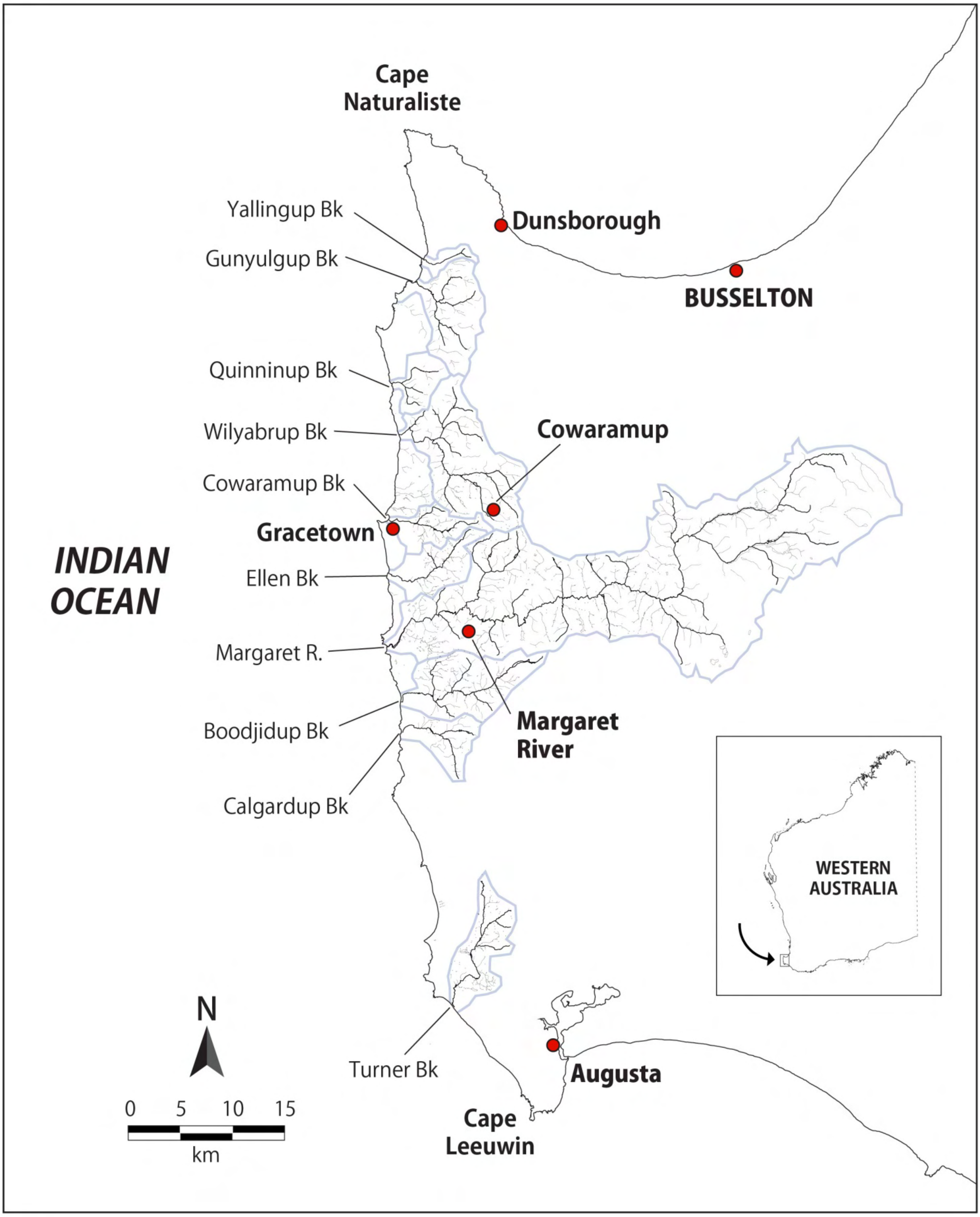

FIGURE 1. Major catchments and towns of the Mediterranean climatic Cape to Cape region of Western Australia.

TABLE 1. Attributes of major catchments of the Cape to Cape region, south-western Australia. The categorisation of foreshore condition (A – pristine; B – weedy; C – erosion prone/eroding; D - ditch) was derived from the application of methods developed by Pen and Scott (1995).

Catchment	Area (km^2)	Stream length (km)	Foreshore condition	Dominant land use types	Key environmental issues	References
Yallingup Brook	<10	5.5	Not available	Native vegetation (64%); agriculture (36%)	Erosion & sedimentation; degradation & destruction of riparian vegetation	Taylor & Tinley, 1999
Gunyulgup Brook	47	24.3	A <1%; B 29%; C 58%; D 6.5%	Agriculture (65%); native vegetation (35%)	Erosion & sedimentation; excessive livestock access to riparian zone; water abstraction / barriers (110 dams)	Hunt *et al.*, 2002; CCG, 2005b
Wilyabrup Brook	89	~100	A 6%; B 17%; C 22%; D 44%; Dams 11%	Agriculture (mainly livestock & viticulture) (84%); native vegetation (12%); residential (4%)	Excessive livestock access to riparian zone; intensification of land use; reduced flows / water abstraction / barriers (~100 dams)	Hunt *et al.*, 2002; CCG, 2006
Cowaramup Brook	24	30	A 15%; B 32%; C 25%; D 28%	Agriculture (mainly viticulture) (64%); native vegetation (36%)	Excessive livestock access to riparian zone; reduced flows /water abstraction / barriers (19 dams); sedimentation; salinisation of springs; limited refuge habitat	Hunt *et al.*, 2002; CCG, 2008
Ellen Brook	29	40	A 5%; B 29%; C 27%; D 37%; unassessed 2%	Agriculture (70%); native vegetation (30%)	Excessive livestock access to riparian zone; expanding human population; water abstraction / barriers (32 dams + 1 weir); algal blooms	Hunt *et al.*, 2002; CCG, 2005a
Margaret River	477	~250	Main channel: A 50%; B 45%; C 5%; D 0%. Lower tributaries: A 11%; B 46%; C 20%; D 23%. Bramley Brook: A 28%; B 31%; C 6%; D 35%	Forested (mostly native, some plantations) (79%); cleared (agriculture, residential) (21%)	Degradation & destruction of riparian vegetation; water abstraction / barrier (670 dams, 43 > 8 ML capacity); alien species introductions; pollution; livestock access to riparian zone	Pen, 1999; CCG, 2003, 2009a, 2011; DoW, 2008; Green *et al.*, 2010
Boodjidup Brook	60	55	A 15%; B 38%; C 30%; D 17%	Agriculture (49%); native vegetation (36%); rural residential (10%)	Excessive livestock access to riparian zone; reduced flows /water abstraction / barriers (90 dams); erosion / sedimentation	CCG, 2009b
Qunninup Brook	19	20.4	A 2%; B 41%; C 14%; D 43%	Agriculture (livestock & viticulture) (72%); native vegetation (27%)	Water abstraction / flow reductions/ barriers; degradation & destruction of riparian vegetation	Hunt *et al.*, 2002; CCG, 2013

The proliferation of on-stream dams is a key issue impacting catchments across the CCR (Table 1). Wilyabrup Brook, for instance, has ca 100 on-stream dams (CCG, 2006), and the density of dams is even higher in the Gunyulgup Brook and Boodjidup Brook catchments (Green *et al*., 2010; Table 1). The exception to this trend is the Margaret River main channel, which has only three low-level weirs, although there are 670 dams on its numerous tributaries including 43 of commercial size (i.e. >8 ML storage capacity) (Green *et al*., 2010; Table 1). Water is also pumped directly from the river in the middle and lower reaches for anthropogenic uses (Green *et al*., 2010). A report on the Ecological Water Requirements (EWR) in two representative reaches of the lower and middle section of Margaret River suggested that current levels of water abstraction were within ecologically sustainable limits but ongoing monitoring was required to ensure these limits would not be exceeded with future allocation of water licenses and climate change (Green *et al*., 2010). In Cowaramup Brook, however, a similar study found that water abstraction was already close to the ecologically sustainable yield, with only a limited capacity for the system to accommodate increased consumption (Donohue *et al*., 2010).

FRESHWATER MACROFAUNA OF THE CAPE TO CAPE REGION

The CCR houses a total of six native fish species (Table 2; Figure 2) including one agnathan, the Pouched Lamprey *Geotria australis* Gray 1851, and five teleosts, i.e. Western Minnow *Galaxias occidentalis* Ogilby 1899, Western Mud Minnow *Galaxiella munda* McDowall at1978, Balston's Pygmy Perch *N. balstoni*, Western Pygmy Perch *Nannoperca cf. vittata* and Nightfish *Bostockia cf. porosa*. Preliminary genetic analyses have revealed that the latter two taxa represent cryptic species that are as yet undescribed (Unmack, 2013; Morgan *et al*., 2014a). Additionally, five introduced teleost species have been recorded in fresh waters of the CCR, i.e. Rainbow Trout *Oncorhynchus mykiss* (Walbaum 1792), Goldfish *Carassius auratus* Linnaeus 1758, Common Carp *Cyprinus carpio* Linneaus 1758, Eastern Gambusia *Gambusia holbrooki* (Girard 1859) and Redfin Perch *Perca fluviatilis* Linnaeus 1758 (Table 2; Figure 3); although some of these species may no longer be present in the region (see below).

The CCR also houses nine decapod crustacean species (Table 3), seven of which are native (Figure 4), i.e. Hairy Marron *Cherax tenuimanus*, Gilgie *Cherax quinquecarinatus* Gray 1845, Restricted Gilgie *Cherax crassimanus* Riek 1967, Koonac *Cherax preissii* (Erichson 1846), Glossy Koonac *Cherax glaber* Riek 1967, Margaret River Burrowing Crayfish *Engaewa pseudoreducta*, Augusta Burrowing Crayfish *Engaewa similis* Riek 1967, and an additional two that have been introduced from elsewhere in Australia (Figure 3), i.e. Smooth Marron *Cherax cainii* Austin 2002 and Yabby *Cherax destructor* Clark 1936. The freshwater bivalve mollusc Carter's Freshwater Mussel (*Westralunio carteri*) also occurs in the CCR (Table 3, Figure 4).

A number of euryhaline species (e.g. *Leptatherina wallacei* (Prince, Ivantsoff & Potter 1982), *Pseudogobius olorum* (Sauvage 1880), *Afurcagobius suppositus* (Sauvage 1880)) have occasionally been reported from fresh waters of the CCR; however, these species generally only use freshwater habitats opportunistically and will not be covered further in this review.

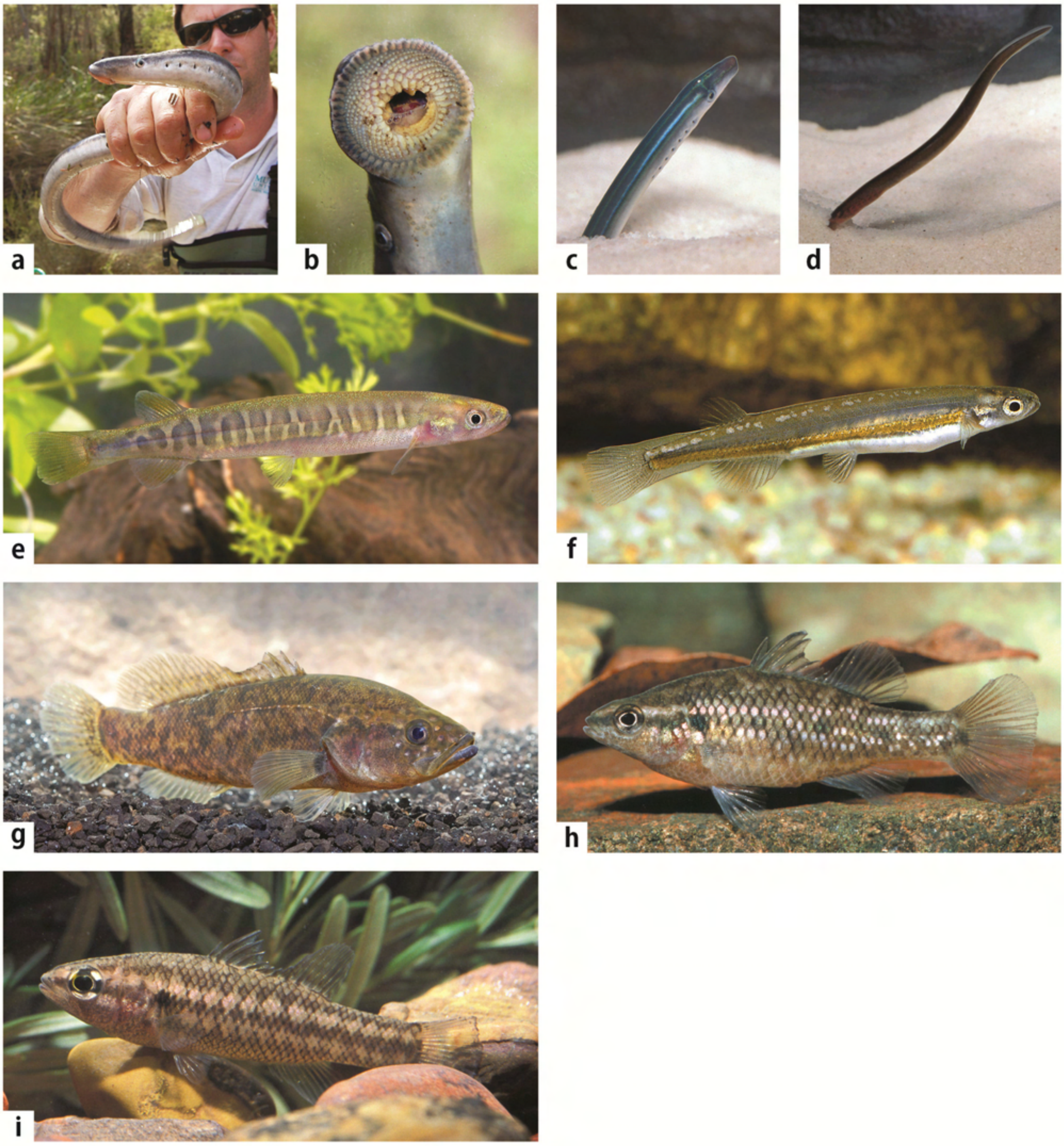

FIGURE 2. Native freshwater fishes of the Cape to Cape region: a) maturing Pouched Lamprey (*Geotria australis*) (image: S. Beatty); b) suctorial disc of sub-adult Pouched Lamprey (image: S. Beatty); c) metamorphosed juvenile or downstream migrant Pouched Lamprey (image: D. Morgan); d) larva (ammocoete) Pouched Lamprey (image: D. Morgan); e) Western Minnow (*Galaxias occidentalis*) (image: M. Allen); f) Western Mud Minnow (*Galaxiella munda*) (image: G. R. Allen); g) Nightfish (*Bostockia porosa*) (image: S. Beatty); h) Western Pygmy Perch (*Nannoperca vittata*) (image: M. Allen); i) Balston's Pygmy Perch (*Nannatherina balstoni*) (image: D. Morgan).

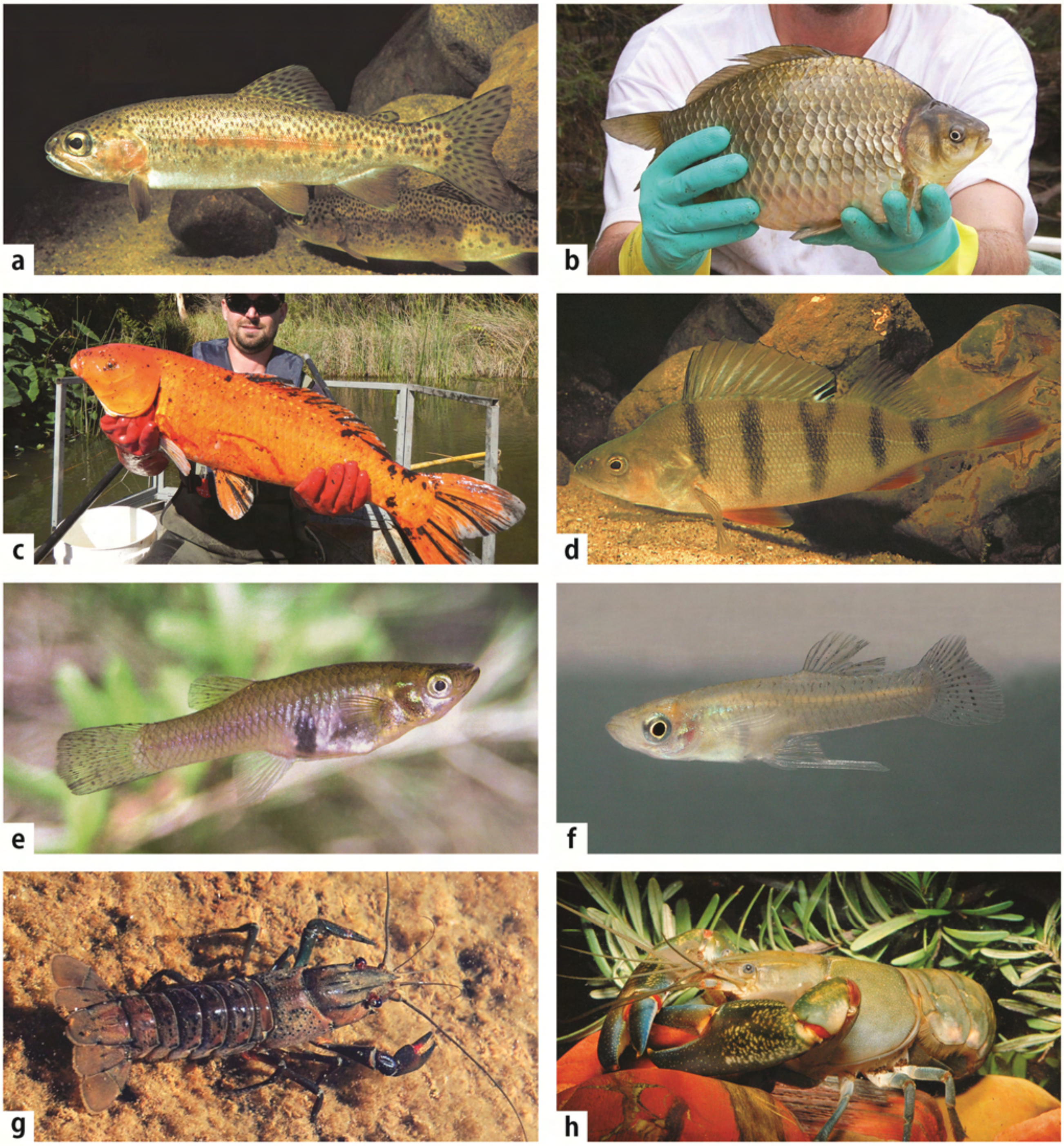

FIGURE 3. Introduced freshwater macrofauna species of the Cape to Cape region: a) Rainbow Trout (*Oncorhynchus mykiss*) (image: R. Kuiter); b) Goldfish (*Carassius auratus*) (image: S. Beatty); c) Common Carp (*Cyprinus carpio*) (image: S. Beatty); d) Redfin Perch (*Perca fluviatilis*) (image: R. Kuiter); e) female Eastern Gambusia (*Gambusia holbrooki*) (image: D. Morgan); f) male Eastern Gambusia (image: M. Allen); g) Smooth Marron (*Cherax cainii*) (image: D. Morgan); h) Yabby (*Cherax destructor*) (image: D. Morgan).

FIGURE 4. Native freshwater decapod crustaceans and bivalve molluscs in the Cape to Cape region: a) Margaret River Burrowing Crayfish (*Engaewa pseudoreducta*) (image: Q. Burnham); b) Augusta Burrowing Crayfish (*Engaewa similis*) (image: Q. Burnham); c) Hairy Marron (*Cherax tenuimanus*) (image: S. Visser); d) Gilgie (*Cherax quinquecarinatus*) (image: D. Morgan); e) Restricted Koonac (*Cherax crassimanus*) (image: S. Beatty); f) Koonac (*Cherax preissii*) (image: D. Morgan); g) Glossy Koonac (*Cherax glaber*) (image: R. McCormack); h) Carter's Freshwater Mussel (*Westralunio carteri*) (image: D. Morgan).

TABLE 2. Freshwater fish species present in the Cape to Cape region, south-western Australia. NB -* denotes an introduced species; ^ denotes a species that is presumed to have been locally extirpated from a catchment.

Family/Species	Common name	Catchments	References
Geotriidae			
Geotria australis	Pouched Lamprey	Margaret	Morgan *et al.*, 1998; Morgan & Beatty, 2003, 2004a, 2007a; Beatty & Morgan, 2008
Galaxiidae			
Galaxias occidentalis	Western Minnow	Margaret, Wilyabrup, Boodjidup, Turner	Morgan *et al.*, 1998, 2013; Morgan & Beatty, 2003, 2004a, 2005, 2007a, 2008; Beatty *et al.*, 2006, 2007, 2008; Beatty & Morgan, 2008; Beatty & Allen, 2008;
Galaxiella munda	Western Mud Minnow	Margaret, Wilyabrup, Boodjidup	Morgan *et al.*, 1998; Morgan & Beatty, 2003, 2004a, 2008; Beatty & Allen, 2008; Beatty *et al.*, 2008
Percichthyidae			
Bostockia porosa	Nightfish	Margaret, Wilyabrup, Ellen, Boodjidup, Turner^	Morgan *et al.*, 1998, 2013; Morgan & Beatty, 2003, 2004a, 2005, 2008; Beatty & Allen, 2008;
Nannoperca vittata	Western Pygmy Perch	Margaret, Wilyabrup, Ellen, Turner^	Morgan *et al.*, 1998, 2013; Morgan & Beatty, 2003, 2004a, 2005; Beatty *et al.*, 2006, 2008; Beatty & Allen, 2008
Nannatherina balstoni	Balston's Pygmy Perch	Margaret., Turner^	Morgan *et al.*, 1998, 2013; Morgan & Beatty, 2003
Salmonidae			
**Oncorhynchus mykiss*	*Rainbow Trout	Margaret, private farm dams throughout CCR	Morgan *et al.*, 1998; CCG, 2011
Cyprinidae			
**Carassius auratus*	*Goldfish	Margaret^, Wilyabrup	Beatty *et al.*, 2008; Allen *et al.*, 2013
**Cyprinus carpio*	*Common Carp	Margaret^, Wilyabrup^	R. Paice, pers. comm.; D. McKenzie, pers. comm.
Poeciliidae			
**Gambusia holbrooki*	*Eastern Gambusia	Margaret, Cowaramup, Ellen, Boodjidup, Turner	Morgan *et al.*, 1998, 2013; Morgan & Beatty, 2003, 2004a, 2005, 2008; Beatty & Morgan, 2008; Beatty *et al.*, 2008
Percidae			
**Perca fluviatilis*	*Redfin Perch	Margaret^	Morgan *et al.*, 1998

TABLE 3. Freshwater decapod crustaceans (Parastacidae) and bivalve mollusc (Hyriidae) species present in the Cape to Cape region, south-western Australia. NB -* denotes an introduced species; ^ denotes a species that is presumed to have been locally extirpated from a catchment; (?) denotes an unconfirmed record.

Family/Species	Common name	Catchments	References
Parastacidae			
Engaewa pseudoreducta	Margaret River Burrowing Crayfish	Margaret	Burnham *et al.,* 2012; DEC 2008
Engaewa similis	Augusta Burrowing Crayfish	Margaret, Boodjidup, Turner^	Horwitz & Adams 2000; Morgan *et al*. 2013; Q. Burnham pers. comm.
Cherax tenuimanus	Hairy Marron	Margaret	Austin & Ryan 2002; Bunn 2004; Molony *et al*. 2004; de Graaf *et al*. 2009
Cherax quinquecarinatus	Gilgie	Margaret, Wilyabrup, Ellen, Cowaramup, Gunyulgup, Boodjidup, Calgardup	Morgan & Beatty 2003, 2004a, 2005, 2008; Beatty *et al*. 2006, 2008; Beatty & Allen 2008;
Cherax crassimanus	Restricted Koonac	Margaret, Ellen, Turner^	Morgan & Beatty 2003, 2004a, 2005, 2008; Beatty *et al*. 2006, 2008; Beatty & Allen 2008;
Cherax preissii	Koonac	Margaret, Ellen, Calgardup, Turner	Morgan & Beatty 2005; Morgan *et al*. 2013
Cherax glaber	Glossy Koonac	Calgardup (?)	Austin & Knott 1996
**Cherax cainii*	*Smooth Marron	Margaret, Wilyabrup, Cowaramup, Ellen, Gunyulgup, Boodjidup	Morgan & Beatty 2005, 2008; Beatty *et al*. 2006; de Graaf *et al*. 2009
**Cherax destructor*	*Yabby	Margaret, Wilyabrup, Gunyulgup, Boodjidup, Turner	Morgan & Beatty 2005, 2008; Beatty *et al*. 2006, 2008; Beatty & Allen 2008; Allen *et al*. 2013; Morgan *et al*. 2013
Hyriidae			
Westralunio carteri	Carter's Freshwater Mussel	Margaret, Wilyabrup, Ellen, Boodjidup	Klunzinger *et al*. 2012

THREATENING PROCESSES IN THE CAPE TO CAPE REGION

Climate change

South-western Australia has experienced a 10-15% reduction in rainfall since the mid-1970s with some parts of the region experiencing a 50% reduction in surface runoff during this time (Silberstein *et al.*, 2012). Global Climatic Models unanimously project further reductions in rainfall (ca 8%) and runoff (ca 24%), and an increase in the number of no-flow days (by up to 4 months) by 2030 (Suppiah *et al.*, 2007; CSIRO, 2009a, b; Barron *et al.*, 2012; Silberstein *et al.*, 2012). Compared with baseline period between 1986-2005, median estimates of average annual rainfall decrease for the region by 2090 are 12% under intermediate emissions scenario (RCP 4.5), and 18% under high emissions scenario (RCP 8.5); the latter could result in ca 65% reductions in annual runoff (Hope *et al.*, 2015). Drought periods and days of extreme heat are also projected to increase, which will cause higher evaporation rates (CSIRO, 2009a, b, Hope *et al.*, 2015). These changes are likely to have a profound impact on freshwater ecosystems in the region, in particular on the quantity and quality of available baseflow refuge habitat. The anticipated decline in biological carrying capacity of freshwater ecosystems due to climate change may lead to localised extirpations or even extinctions of the rarest and most vulnerable species (IPCC, 2013, 2014; DEC, 2008).

A recent survey of key baseflow refuge habitats in the Margaret River has revealed dramatic declines in the abundance of both Pouched Lamprey and Western Mud Minnow. Pouched Lamprey larvae (i.e. ammocoetes) were not found at 75% of previous known sites and not a single individual Western Mud Minnow was captured despite thorough sampling of sites where the species was previously common (see Morgan & Beatty, 2003). Land use and water quality in the Margaret River catchment have not changed markedly over this time period; indeed, the historical Western Mud Minnow sites were all located within a conservation reserve that was established many years prior to the initial fish survey. Whilst the spread of invasive Eastern Gambusia may be a factor in the decline of Western Mud Minnow (discussed in the Introduced species section below), a more likely explanation for the observed fish declines in the Margaret River is the sharp drop in annual stream discharge in recent years. Five of the lowest discharge years on record (since 1970 when record keeping commenced in the catchment) have occurred since 2006. Western Mud Minnow has been shown to spawn in temporarily flooded riparian zones and its recruitment success is likely to be linked to stream flow as has been demonstrated for other south-western Australian fishes including lampreys (Morgan *et al.*, 1998; Beatty *et al.*, 2007, 2014). Moreover, Western Mud Minnow typically has a short lifespan with most individuals spawning at age one and perishing shortly afterwards (Pen *et al.*, 1991), therefore population numbers are probably susceptible to dramatic inter-annual fluctuations depending on the suitability of environmental conditions from year to year. The prolonged drought conditions in recent years may account for the severe population decline of these species in Margaret River, as well as providing a bellwether of the potential for climate change to impact freshwater species in this system and throughout the south-west region.

The burrowing crayfishes (*Engaewa* spp.) are likely to be particularly vulnerable to climate change as they are restricted to ephemeral habitats that may cease to function effectively in the future due to rainfall reductions and declining water tables (Commander, 2000; DEC, 2008). It is unknown if these species will have the capacity to burrow to sufficient depths in order to withstand predicted water table declines in the region and interventionary actions may be required to maintain populations in their natural habitats. The Margaret River Burrowing Crayfish (*E. pseudoreducta*) is already critically endangered due to its small geographic range, limited dispersal capability, specialised ecological requirements and small population size (DEC, 2008). These attributes combine to make it the most imperiled aquatic species in the CCR (and arguably in the entire south-western Australian region), and its conservation warrants top priority. Captive breeding programs may need to be considered in the future to avoid extinction of this species (DEC, 2008).

Water abstraction

Groundwater abstraction can reduce flow from natural springs (CSIRO, 2009b), which has been shown to be vital in maintaining important aquatic refuges in some catchments in south-western Australia (Beatty *et al*., 2014). It will be critical to ensure that abstraction from major aquifers, particularly the south-west Yarragadee and Leederville, does not exacerbate the effects of climate change in reducing the amount and quality of baseflow refuge pools; particularly those in the upper Margaret River. Other water abstraction issues include the illegal pumping of river water, non-compliance by private land holders in the installation and use of flow-bypass valves in dams, and the impact of timber plantations intercepting run-off and causing draw-down of water tables (DoW, 2009). In the Cowaramup Brook catchment, water abstraction is already very close to the maximum sustainable level necessary to maintain aquatic ecological functions (Donohue *et al*., 2010). Further EWR studies would be beneficial in order to determine if water use is encroaching on ecologically sustainable limits in other catchments of the region. The State Government's water authorities have embarked on a massive public educational campaign to raise awareness of the precarious state of potable water supplies in south-western Australia and to encourage strategies for limiting water wastage. Clearly, authorities will need to closely monitor and, where required, impose restrictions on human water use in the CCR and across the broader region in order to balance human demands with ecological requirements as the region continues its transition to drier and warmer climatic conditions.

Introduced species

Over the past 40 years, the rate of species introductions has soared (75% increase since 1970) in fresh waters of south-western Australia (Beatty & Morgan, 2013). The earliest introductions were government sanctioned for the purpose of creating enhanced recreational angling opportunities (e.g. Redfin Perch, Rainbow Trout) and for the biological control of mosquitos (i.e. Eastern Gambusia). More recently, popular aquarium and aquaculture species (e.g. Goldfish, Carp, Yabby, Smooth Marron) have become established in natural waterways via the dumping of unwanted animals or via their escape from ponds and dams during flooding (Morgan & Beatty, 2004b, 2007b; Morgan *et al*., 2004, 2011; Beatty & Morgan, 2013). Invasive aquatic species have been shown to have adverse impacts on Australian native species through predation, competition for food and space resources, agonistic behaviour, habitat degradation, and as vectors of diseases and parasites (e.g. Fletcher *et al*., 1985; Horwitz, 1990; Gill *et al*., 1999; Morgan *et al*., 2002, 2004; Morgan & Beatty, 2007b; Tay *et al*., 2007; Lymbery *et al*., 2010; Beatty & Morgan, 2013).

Six introduced aquatic macrofauna species have been recorded in fresh waters of the CCR (Tables 2; 3). Additionally, despite being a south-western Australian endemic, translocation of Smooth Marron into the Margaret River catchment has pushed the Hairy Marron to the brink of extinction (Bunn, 2004; de Graaf *et al*., 2009; Duffy *et al*., 2014). In response, the Department of Fisheries, Government of Western Australia, has established a captive breeding program of genetically validated pure-strain Hairy Marron for supplementation of wild stocks (de Graaf *et al*., 2009; Duffy *et al*., 2014), and has overseen the removal of large numbers of Smooth Marron and hybrid specimens from the upper Margaret River since 2004, which has slowed but not reversed the overall decline of Hairy Marron in this system (de Graaf *et al*., 2009).

Generally, once established, introduced species prove impossible to eradicate from the wild (Horwitz, 1990; Rowe *et al.*, 2008). On the one hand, Smooth Marron and Eastern Gambusia have become well established and widespread in the CCR (Figures 5 and 6), with the latter species recently being discovered for the first time in Canebrake Pool, one of the most important baseflow refuge habitats in the Margaret River (Allen *et al.*, 2015). This noxious pest species has rapidly become one of the most abundant fishes at this site, underlining its highly invasive traits. Its impact on the native aquatic fauna has been significant, with >90% of native percicthyids captured from this site showing signs of caudal fin damage due to fin-nipping by Eastern Gambusia (Figure 7). Its establishment in Canebrake Pool may have also contributed to the decline of Western Mud Minnow at this site. However, as the abundance of Western Mud Minnow has also dropped to undetectable levels in refuge pools further upstream that are not yet colonised by Eastern Gambusia, the decline is more likely attributable to climate change driven flow reductions.

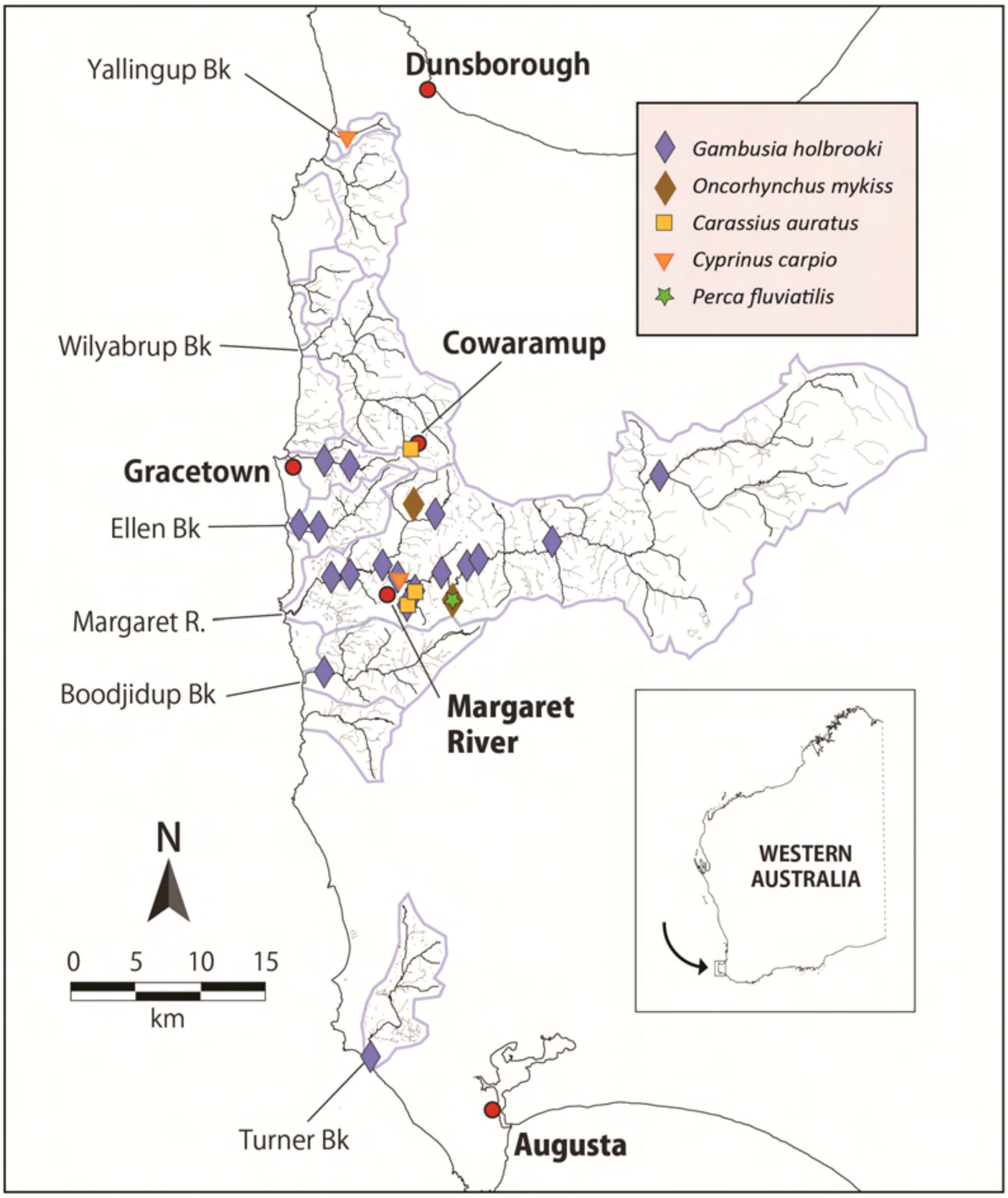

FIGURE 5. Distribution of introduced fishes in the Cape to Cape region of Western Australia.

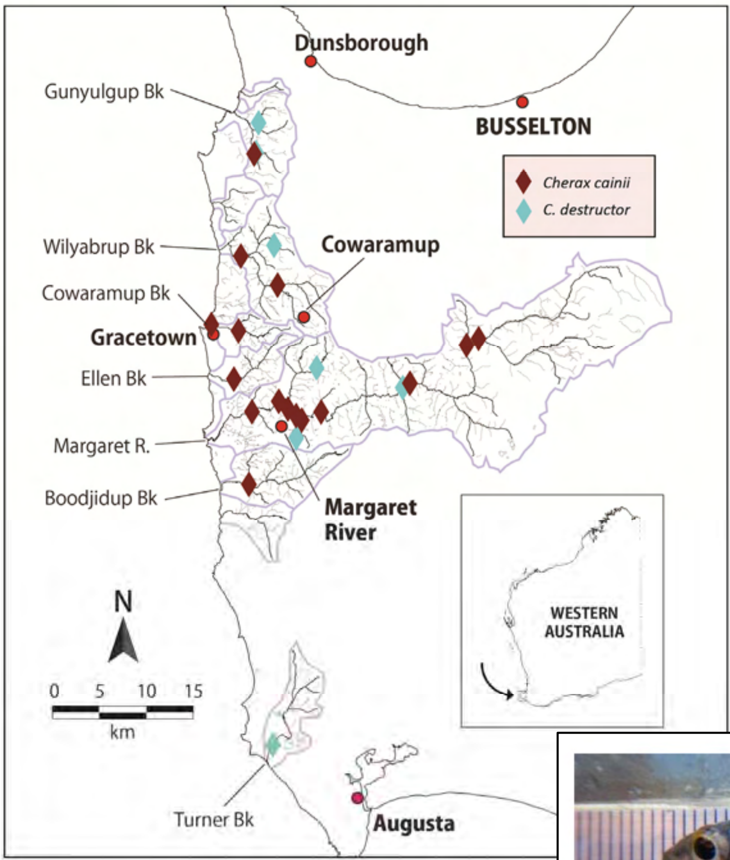

FIGURE 6. Distribution of introduced crayfishes in the Cape to Cape region of Western Australia.

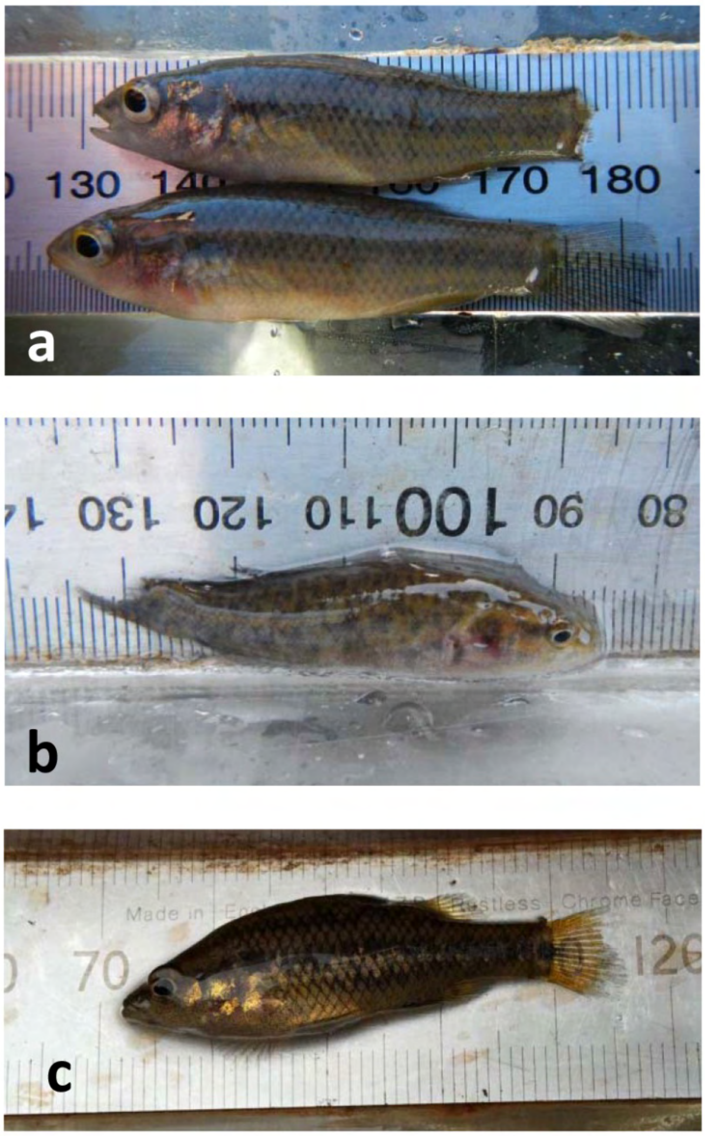

FIGURE 7. Caudal fin damage on percichthyids captured from Canebrake Pool, Margaret River (March-April 2015) caused by agonistic behaviour of Eastern Gambusia; a) Balston's Pygmy Perch (damaged tail above, undamaged tail below); b) Nightfish; c) Western Pygmy Perch (images: M. Allen).

The Yabby is also in the early stages of establishing itself in the region (Figure 6). Unfortunately, this species is very adaptable to local conditions and eradication is unlikely via conventional control methods. The Yabby is of particular concern as it occupies an equivalent ecological niche to endemic *Cherax* spp. and directly competes with them for food and habitat resources (Beatty, 2006; Lynas *et al*., 2007). It is also capable of breeding multiple times per year, allowing it to rapidly colonise habitats and potentially outnumber native species (Beatty *et al*., 2005).

The remaining alien species have either failed to establish self-sustaining populations (e.g. Rainbow Trout and Redfin Perch), or their spread in the region has, thus far, been effectively contained through targeted fishing (e.g. Goldfish and Common Carp). Goldfish have been eradicated from Darch Brook (a tributary of Margaret River) via a combination of habitat dewatering, netting and chemical icthyocide (rotenone) application (Allen *et al*., 2013). As far as the authors are aware, this represents the first successful eradication of the species from an aquatic system in Western Australia. The only other record of Goldfish in the CCR is from an artificial pond in the Wilyabrup Brook catchment near Cowaramup, where >1,000 individuals were removed in 2011 (Freshwater Fish Group, Murdoch University, unpubl. data). However the species remains at liberty in the catchment.

The strategy of targeted fishing effort has had mixed success in mitigating the environmental risks of introduced freshwater species in the CCR, but undoubtedly a more cost-effective and practical strategy would be to prevent further introductions from occurring in the first instance. This is probably best achieved through educational programs designed to raise awareness and appreciation of native biodiversity whilst also emphasising the negative impacts that introduced species can have on native wildlife. The biosecurity branch of the Department of Fisheries (Government of Western Australia) has recently launched an educational campaign to address this growing threat.

Instream barriers

Artificial barriers on waterways (e.g. dams, weirs, road crossings) can impact on aquatic species in a number of ways. Most crucially, they reduce longitudinal connectivity in lotic systems, which blocks or restricts the access of migratory species to vital habitats such as breeding grounds, seasonal feeding areas, or nurseries (Lucas & Baras, 2001; Morgan & Beatty, 2003; Koehn & Crook, 2013). For example, a number of native freshwater fishes (e.g. Western Minnow, Nightfish) move upstream to spawn in lower order tributaries with the onset of winter flows (Beatty *et al*., 2014). Not only do instream barriers restrict the migration of such species through physical blockage, they also delay the onset of seasonal flows that provide spawning cues, thus shortening the duration of the breeding season. In the CCR, hundreds of instream barriers (mainly gully dams) have been installed in recent decades (e.g. CCG, 2005a, 2006), yet only three fish passage structures have been built during this time (Beatty *et al*., 2007; Beatty & Allen, 2008). Furthermore, these fishways have been shown to effectively allow passage of only a subset of the resident fish fauna (i.e. Western Minnow, Pouched Lamprey and Western Pygmy Perch) while blocking upstream passage of other fishes (Morgan & Beatty, 2004; Beatty & Allen, 2008; Beatty & Morgan, 2008). Thus, there is a need for further research into modifications or alternative designs that will allow the full suite of migratory native aquatic species to bypass instream barriers in the CCR and more broadly throughout south-western Australia.

A simpler and more effective means of mitigating the impacts of instream barriers on migratory species may be the decommissioning and removal of artificial barriers (see Beatty *et al*., 2013). However, these structures are rarely redundant and may even provide ecological benefits such as the provision of permanent refuge habitats in their associated impoundments (an ecological function that will become increasingly valuable in a drying climatic region), or by limiting the dispersal of introduced species. In Boodjidup Brook for instance, the absence of Eastern Gambusia from the majority of the upper catchment is presumably due to the presence of an instream barrier, which may, in part, explain why the Western Mud Minnow persists in reasonable numbers in this system (Morgan & Beatty, 2008).

Loss and degradation of riparian vegetation

Riparian vegetation provides multiple benefits for both terrestrial and aquatic fauna and plays a vital role in maintaining aquatic ecosystem function and health (Pen, 1999). In the past, riparian vegetation was commonly destroyed during the development of agricultural land. The infamous case of the extirpation of a population of critically endangered Margaret River Burrowing Crayfish at the type locality in 1985 following the construction of a dam and establishment of a timber plantation (DEC, 2008) highlights the severity of the impact that such practices can have on aquatic macrofauna. Although the rate of clearing of riparian vegetation has declined in recent years, degradation of remnant vegetation is an ongoing issue across the region, mainly due to unfettered access of livestock to stream lines and this threatens aquatic ecosystems through processes of erosion, sedimentation and increased nutrient inputs.

Mature overstorey vegetation is vital in moderating water temperature and evaporation rates through shading (Pen, 1999; Davies *et al*., 2007), and provides instream habitat for native aquatic species such as Nightfish and Marron in the form of woody debris (Pen, 1999). Additionally, the leafy material that falls into the water is a vital source of carbon that drives aquatic food webs in a region where primary productivity in streams is naturally low (Pen, 1999). Deep rooted riparian vegetation also keeps salt-ladened groundwater at a sufficient depth to prevent secondary salinisation of streams, which has led to the extirpation of native species in some of the major rivers of south-western Australia (Pen, 1999; Morgan *et al*., 1998, 2003).

Much riparian rehabilitation and fencing work has already been undertaken in the region (D. McKenzie, Cape to Cape Catchments Group pers. comm.) and our review revealed that further work is needed. From the standpoint of conserving aquatic fauna, future works should focus on sites that house threatened or rare aquatic species, particularly Burrowing Crayfishes (*Engaewa* spp.), Balston's Pygmy Perch, and Western Mud Minnow.

Fire

Native vegetation has long been burnt on a multi-annual rotational schedule as a land management tool for reducing fuel loads and associated risk of destructive wildfires, and to stimulate native plant growth and reproduction (Christensen & Kimber, 1975). Given the prevalence of fire in the Australian landscape (and particularly in the south-west of Australia); it is surprising that its impact on aquatic ecosystems has not yet been studied in detail. Concerns have been raised about the impact of fire on *Engaewa* spp., especially the highly restricted *E. pseudoreducta* (DEC, 2008). The restricted range of this species leaves it extremely vulnerable to habitat disturbance that may occur during fire management activities such as the clearing of firebreaks and containment lines, or in the use of fire retardant chemicals (DEC, 2008). In the *Engaewa* Recovery Plan it was stated that there was an "urgent need to improve the understanding of the effects of fire on *Engaewa* spp." (DEC, 2008) but little has been done to address this knowledge gap, and we contend that the same applies to other native aquatic species, and aquatic ecosystem more generally, as well. The threat of wild fires is likely to escalate as the region's climate becomes hotter and drier; therefore managing associated risks is likely to become more prevalent in the future.

CONCLUSIONS

The Cape to Cape Region is an iconic part of Mediterranean climatic Australia. It has an expanding population and is also one of the premier tourist destinations in Western Australia due to the climate and natural beauty. This review has highlighted that the aquatic macrofauna of the region, whilst depauperate, has exceptional rates of endemism and contains a number of threatened species. We recommend that sites within the CCR known to house these species (Figures 8 and 9) be monitored on a regular basis in order to maintain an up-to-date knowledge of the conservation status of threatened populations and their habitats so that immediate threats can be identified and addressed (e.g. riparian zone degradation, water quality issues, novel species introductions). The importance of such monitoring was highlighted during the recent survey of baseflow refuge pools in Margaret River, where a severe decline in abundance of both Western Mud Minnow and Pouched Lamprey was detected, as was the spread of invasive Eastern Gambusia into the upper Margaret River (Allen *et al.*, 2015).

One of the major environmental challenges faced in the region is finding a balance between human water demands and those of the environment. Many of the aquatic ecosystems in the region are degraded, while the areas that remain near pristine face a number of serious threats. The work on improving the management of aquatic ecosystems in the CCR to date has been commendable, but our review reveals a clear need for ongoing and adaptive management, as well as further monitoring and onground works that will contribute to the protection of the aquatic fauna values of the CCR.

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AUTHOR CONTRIBUTIONS

Each of the authors contributed to the collection of data, and writing of the manuscript

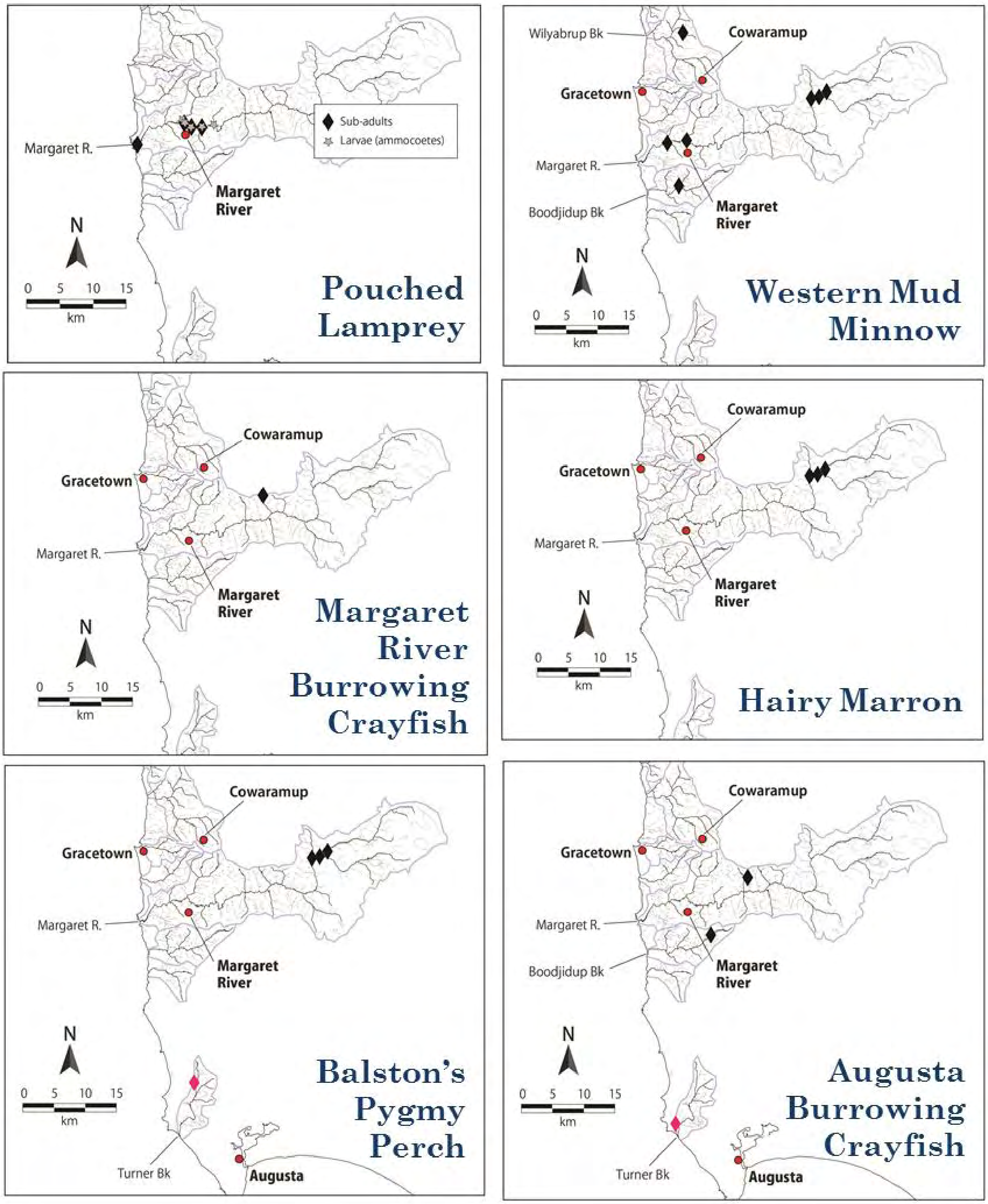

FIGURE 8. Distribution of threatened fish and crayfish species in the Cape to Cape region, Western Australia. Black diamonds indicate known sites where the species is likely to remain extant; pink diamonds indicate historical sites where species is presumed to have been lost.

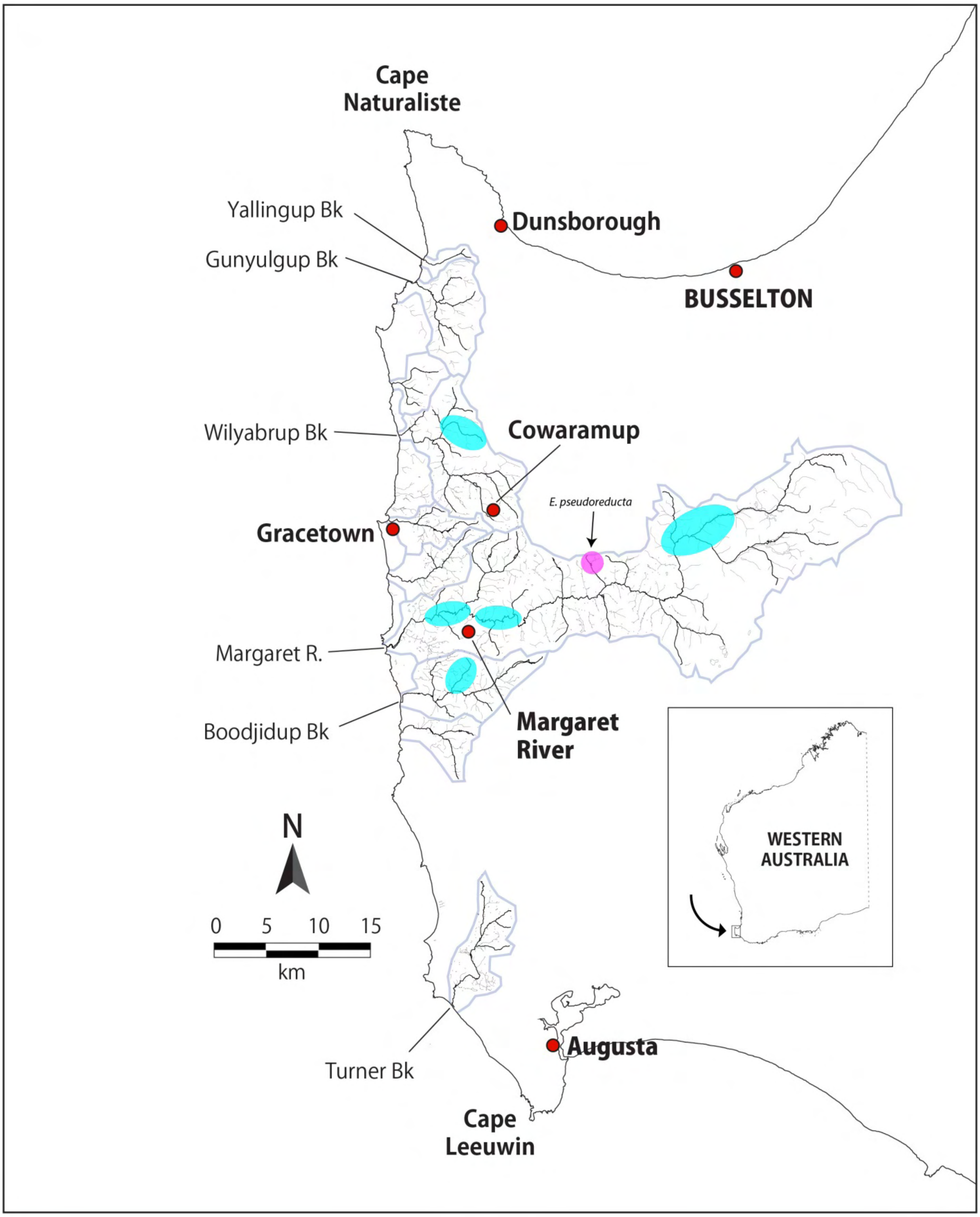

FIGURE 9. Conservation priority areas in the Cape to Cape region housing threatened, endangered and priority species (i.e. Hairy Marron, Margaret River Burrowing Crayfish, Balston's Pygmy Perch, Western Mud Minnow, and Pouched Lamprey)

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