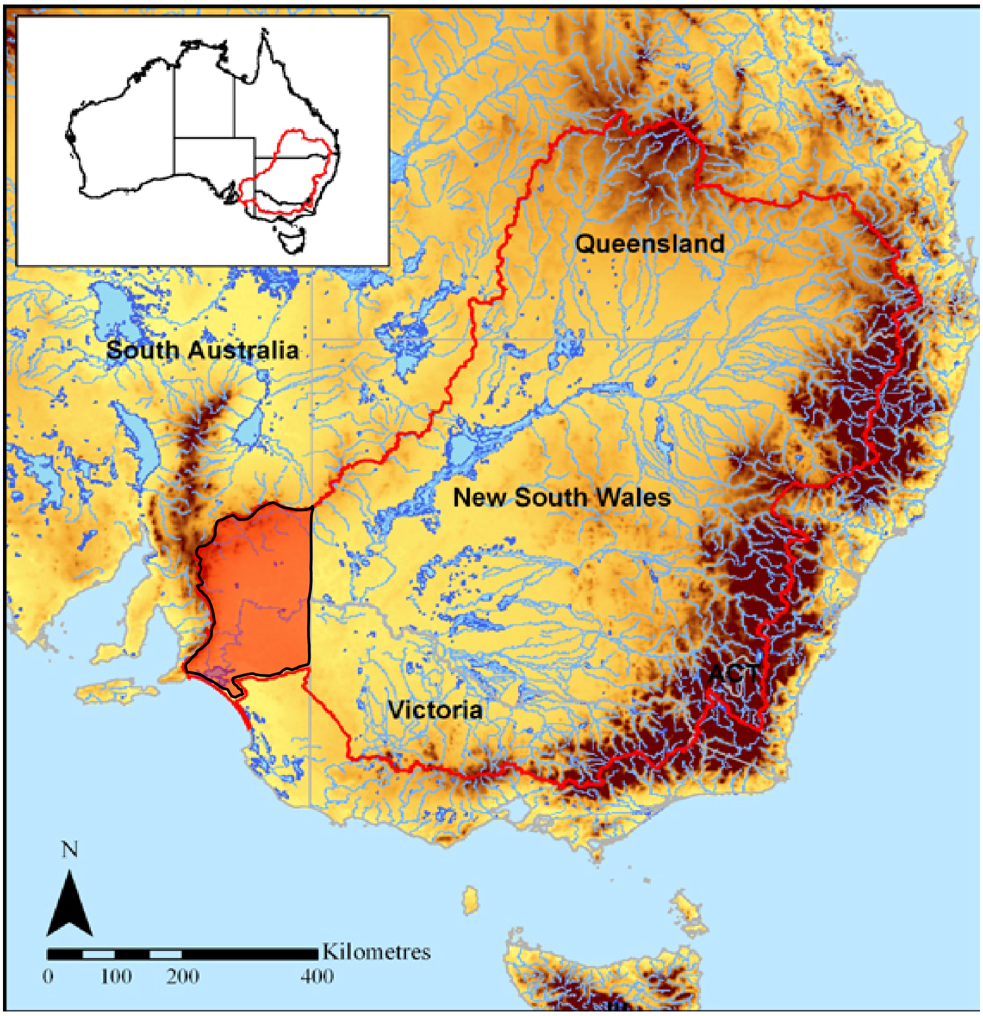
Mapping the current distribution of native and exotic freshwater fishes within the South Australian Murray-Darling Basin

Final Report to PIRSA Rural Solutions

SARDI Aquatic Sciences Publication number RD05/0031-1

SARDI Research Report Series number 119

- January 2006 -



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This publication should be cited as:
Smith, B. B. and Hammer, M. (2006). Mapping the current distribution of native and exotic freshwater fish within the South Australian Murray-Darling Basin. Final Report to PIRSA Rural Solutions, prepared by the South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 60 pp.

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SARDI Aquatic Sciences Publication number RD05/0031-1
SARDI Research Report Series number 119

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Date:	Tuesday 24th January 2006
Distribution:	PIRSA Rural Solutions, SARDI Aquatic Sciences
Circulation:	Unrestricted

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BACKGROUND

Anthropogenic degradation of the riverine environment, via myriad processes (i.e. river regulation, habitat destruction, overfishing, the introduction of exotic invasive fish), has resulted in significant declines in the diversity, range and abundance of freshwater fish throughout the Murray-Darling Basin (MDB) of southeastern Australia (Cadwallader, 1978). Expert opinion suggests that native fish populations in the Basin's rivers have declined under such processes to 10% of pre-European levels (MDBC, 2003).

In South Australia (SA), once abundant species such as chanda perch (*Ambassis agassizii*) and southern purple-spotted gudgeon (*Mogurnda adspersa*) are now thought to be extinct, and the range of trout cod (*Maccullochella macquarensis*), Murray galaxias (*Galaxias rostratus*) and Macquarie perch (*Macquaria australasica*) appears to have contracted out of SA (Hammer & Walker 2004). Of the 42 freshwater species found within the SA MDB, 35 are native and 7 are exotic invaders (Hammer & Walker 2004). Of the 35 native species, a recent assessment of conservation status amendments to the *National Parks and Wildlife Act 1972* lists 4 as Critically Endangered (CrEn) or Extinct (Ex), 7 as Endangered (En), 3 as Vulnerable (Vu) and 8 as Rare (R) – thus, >50% of all freshwater fish species in the SA-MDB are considered to be threatened (DEH, 2003). Eleven of these species are also concurrently protected under the South Australian *Fisheries Act 1982* or national legislation *EPBC Act 1999* (see Tab. 1).

With continuing local extinctions and range contractions, there is an urgent need to instigate environmental rehabilitation measures to help 'bring native fish back'. Documenting the current known distribution of native and exotic freshwater fish in South Australia will enable the identification of critical regions for management, and form a baseline against which the effectiveness of future rehabilitation efforts can be compared.

Table 1. List of native and exotic freshwater fish species known to occur (or have occurred) within the South Australian Murray-Darling Basin (after Hammer and Walker 2004). The conservation status of each species is indicated [State = DEH (2003) & *Fisheries Act 1982;* National = *EPBC Act 1999*]. Ex, Extinct; CrEn, Critically Endangered; En, Endangered; Vu, Vulnerable; R, Rare; (P), Protected under the *Fisheries Act 1982*. Species with no proposed conservation status are often abundant and/or widespread, however those marked with an (*) have a limited range within the Murray-Darling Basin. $^{\Psi}$ Recent surveys have found that unspecked hardyhead are widespread and abundant within the SA Murray (Holt *et al*. 2004, Smith 2006). Thus, their conservation status should remain unaltered.

		Conservation Status	
Common Name	***Scientific Name***	*State*	*National*
Native fishes			
western blue-spot goby	*Pseudogobius olorum*	*	
small-mouthed hardyhead	*Atherinosoma microstoma*	*	
lagoon goby	*Tasmanogobius lastii*	*	
Murray-Darling golden perch	*Macquaria ambigua ambigua*		
flathead gudgeon	*Philypnodon grandiceps*		
common galaxias	*Galaxias maculatus*	*	
carp gudgeon complex	*Hypseleotris* spp.		
bony herring	*Nematalosa erebi*		
Australian smelt	*Retropinna semoni*		
Threatened native fishes			
unspecked hardyhead$^{\Psi}$	*Craterocephalus stercusmuscarum fulvus*	R	
Murray rainbowfish	*Melanotaenia fluviatilis*	R	
mountain galaxias	*Galaxias olidus*	R	
dwarf-flathead gudgeon	*Philypnodon* sp.	R	
congolli	*Pseudaphritis urvillii*	R	
silver perch	*Bidyanus bidyanus*	Vu	Vu
Murray hardyhead	*Craterocephalus fluviatilis*	En	Vu
Murray cod	*Maccullochella peelii peelii*	R	Vu
freshwater catfish	*Tandanus tandanus*	Vu (P)	
Yarra pygmy perch	*Nannoperca obscura*	En (P)	Vu
southern pygmy perch	*Nannoperca australis*	En (P)	
shortheaded lamprey	*Mordacia mordax*	En	
river blackfish	*Gadopsis marmoratus*	En (P)	
Exotic / Invasive fishes			
brown trout	*Salmo trutta*		
rainbow trout	*Oncorhynchus mykiss*		
redfin perch	*Perca fluviatilis*		
tench	*Tinca tinca*		
common carp x goldfish hybrid	*Cyprinid x Carassius* hybrid		
common carp	*Cyprinus carpio*		
goldfish	*Carassius auratus*		
eastern gambusia	*Gambusia holbrooki*		
Not represented in data			
climbing galaxias	*Galaxias brevipinnis*	Vu	
trout cod	*Maccullochella macquariensis*	Ex (P)	En
Macquarie perch	*Macquaria australasica*	Ex	En
estuary perch	*Macquaria colonorum*	En	
chanda perch	*Ambassis agassizii*	CrEn (P)	
southern purple-spotted gudgeon	*Morgurnda adspersa*	CrEn (P)	
shortfinned eel	*Anguilla australis*	R	
pouched lamprey	*Geotria australis*	En	
spangled grunter	*Leiopotherapon unicolor*		
Murray galaxias	*Galaxias rostratus*		

1. OBJECTIVES

The objectives of this project were to provide:

1. Individual and composite GIS map layers of the distribution of native and exotic fish species found within the SA MDB.
2. A brief summary of the risks associated with the primary exotic invasive freshwater fish species.
3. Highlight important knowledge gaps and research priorities for incorporation into a regional pest animal and pest plant plan for the SA-MDB Inland Natural Resource Management region.
4. Acknowledgments to agencies for the provision of fish distribution (presence) data.

2. SCOPE & ACKNOWLEDGEMENTS

Fish distribution data was collated from post-1999 surveys conducted by numerous government and research organisations (Tab. 2). Those organisations deserve special acknowledgement for their rapid and enthusiastic response to our requests for data. In total, 2888 data points from 20 surveys have been incorporated into 29 GIS maps regarding the current distribution of native and exotic freshwater fish within the SA-MDB[1]. The maps cover the five key regions of the SA-MDB (Riverland, Murray Gorge, Lower Swamps, Lower Lakes and Eastern Mount Lofty Ranges – Fig. 1, Tab. 2) and are grouped into four categories:

a) Native species – generally abundant and/or widespread,
b) Threatened native species – state and nationally listed,
c) Exotic invasive species, and
d) Composite maps of threatened native species and exotic invasive species, showing possible interactions and emphasising areas of species overlap.

[1] Given the short time frame allowed for the collation of data, generation of GIS maps and the completion of this report (10 working days), the authors acknowledge that data from some small-scale sampling and at least one larger-scale ongoing research project (i.e. Chowilla Fish Passage and Ecology – SARDI) was unavailable for inclusion in this report at the time of writing

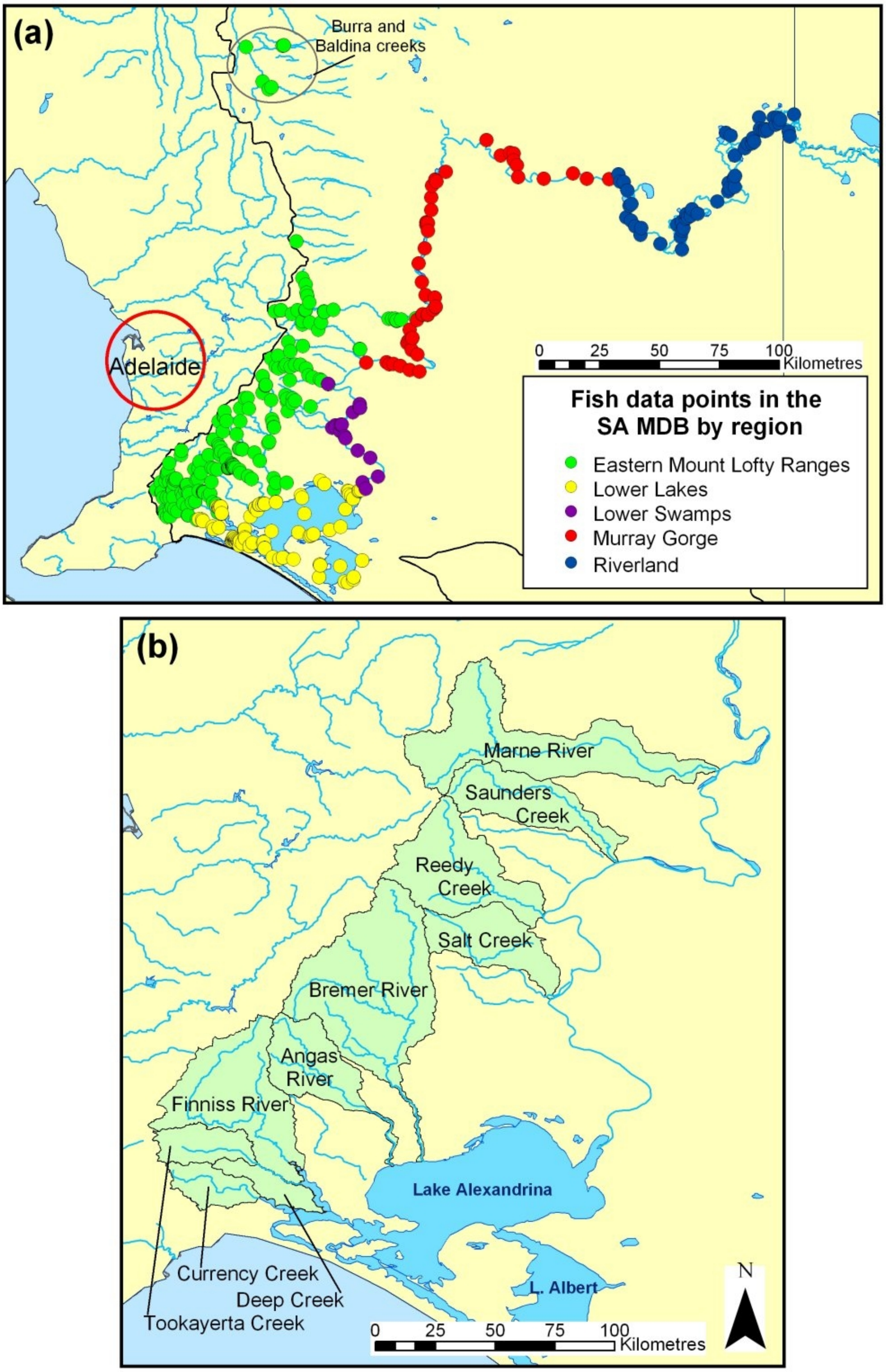


Figure 1. (a) Map showing the sampling locations from which information used in this report was collated. A key to regions (colours) within the South Australian Murray-Darling Basin is indicated. (b) Map showing the catchments and major rivers of the Eastern Mount Lofty Ranges

Table 2. Summary table listing the projects, research institutions and/or references from which these data were obtained for the compilation of the various distribution maps contained within this report.

Project	Source	Regions of Study	Reference
1. 2004 River Murray Wetlands Baseline Survey	RMCWMB, SKM	R, MG, LS, LL	Holt *et al*. (2004)
2. 2005 River Murray Wetlands Baseline Survey	SARDI, RMCWMB	R, MG, LS, LL	Smith (2006, in press)
3. Lower Lakes Threatened Fish monitoring	SARDI, PIRSA	LL	Bice & Ye (2005)
4. Lower Lakes Drought Monitoring	SARDI, DWLBC	LL	Higham *et al.* (2004)
5. Sustainable Rivers Audit	SARDI	R, MG, LS, EMLR	MDBC (2006, in prep)
6. Murray River Fishway Assessments (Weirs 1-3)	SARDI, NSW DPI, VIC DSE	R, MG	NSW DPI (2005)
7. Commercial Fishers - reach data	SARDI	R, MG, LS, LL	n/a
8. Eastern Mount Lofty Ranges Fish Inventory	NFA (SA), RMCWMB	EMLR	Hammer (2004)
9. Opportunistic Eastern Mount Lofty Ranges sampling	NFA (SA), RMCWMB	EMLR	n/a
10. Lower Lakes Fish Inventory	NFA (SA)	LL	Wedderburn & Hammer (2003)
11. Freshwater Fish Survey of Baldina Creek	NFA (SA), Friends of Burra Parks Inc	EMLR	Hammer *et al.* (2005)
12. Freshwater Fishes of Wyndgate	DEH	EMLR	Hammer *et al.* (2002)
13-20. Other small-scale fish surveys along the South Australian Murray	PIRSA, DEH, RMCWMB	R, MG, LS, LL	ALT (2003), Nichols & Gilligan (2004), n/a

Key to Abbreviations:

Data Sources: **SARDI, South Australian Research and Development Institute (Aquatic Sciences); PIRSA, Primary Industries and Resources South Australia; SKM, Sinclair Knight Merz; NSW DPI, New South Wales Department of Primary Industries; VIC DSE, Victorian Department of Sustainability and Environments; DEH, Department for Environment and Heritage; RMCWMB, River Murray Catchment Water Management Board; NFA (SA), Native Fish Australia (SA); DWLBC, Department of Water Land and Biodiversity Conservation.**

Regions: **R, Riverland (SA/NSW/VIC border to Overland Corner); MG, Murray Gorge (Overland Corner to Mannum); LS, Lower Swamps (Mannum to Wellington); LL, Lower Lakes (Wellington to the Barrages including Lake Albert); EMLR, Eastern Mount Lofty Ranges (Upland and slopes streams draining into the River Murray or Lake Alexandrina).**

3. CAVEATS CONCERNING DATA INTERPRETATION & USE

Given the paucity of pre-1999 freshwater fish survey data, this report focuses only on data obtained from post-1999 surveys. Some species that are known from the region were excluded due to limited data, and whilst the projects from which this data was obtained used broadly similar fishing methods, the design and objectives of those surveys and the experience of the researchers varied. Thus, the intensity of sampling and construction of each gear type varied, making it impossible to standardise the data across surveys and habitats in terms of catch per unit effort (CPUE). As such, the maps only show the known current distribution of each species in terms of 'presence' data and suggest nothing about their relative abundance. Furthermore, whilst the authors consider that the distribution maps for each species provided in this report are accurate, the absence of a species from any given region must be interpreted with caution. It may well be that they are absent but they may also have been overlooked due to inappropriate survey methods, under-sampled or mis-identified.

This report relies on the compilation of copyright data from numerous research providers (Table 2); as such, the data remains the property of those original research providers.

4. DEFINITIONS

An **exotic species** is defined as one that is not native (indigenous) to the country under discussion. The term **introduced** refers to those exotic fish presently living in the wild in Australia. The term **translocated** refers to those fish both native and introduced, which have been transferred to waters outside their natural or previous distributional ranges within Australia. An **invasive species** or **pest species** is any species, though often an exotic species, that has a negative economic or ecological impact. Hence, the term **exotic invasive fish** describes any non-native species that presently causes harm, or has potential to cause harm to the native aquatic environment (definitions from MacKenzie et al., 2001; ABG, 2005). The definition of a 'freshwater fish', as used in this report, follows Hammer & Walker (2004), and a summary of all species recorded in the SA MDB and their status is presented in Table 1.

5. LAYOUT OF MAP PAGES

Figures 2-12 each contain a large-scale map showing overall fish distributions within the SA MDB (Map A), and a smaller-scale map focussing on those same distributions within the Eastern Mount Lofty Ranges, the Lower Lakes and the Lower Murray, for which there is more reliable survey data (Map B). Furthermore, the smaller-scale maps better identify regions of species overlap and help to evaluate complex patterns.

Figures 13-30 contain a single map, which covers the known distribution of each small-bodied threatened native fish species within the SA MDB. In this section (Section 7.4), readers should examine the paired maps (i.e. left and right pages) for significant regions of species overlap and possible interactions with the exotic invasive fish. That is, for each native species, the left page shows the native species versus eastern gambusia, common carp and goldfish (aggressive/habitat modifiers); the right page shows the same species versus redfin perch, brown trout and rainbow trout (large-bodied predatory invaders).

6. GIS MAPS

6.1 NATIVE SPECIES – GENERALLY ABUNDANT AND/OR WIDESPREAD

6.1.1 <u>Carp gudgeon species & smelt</u>

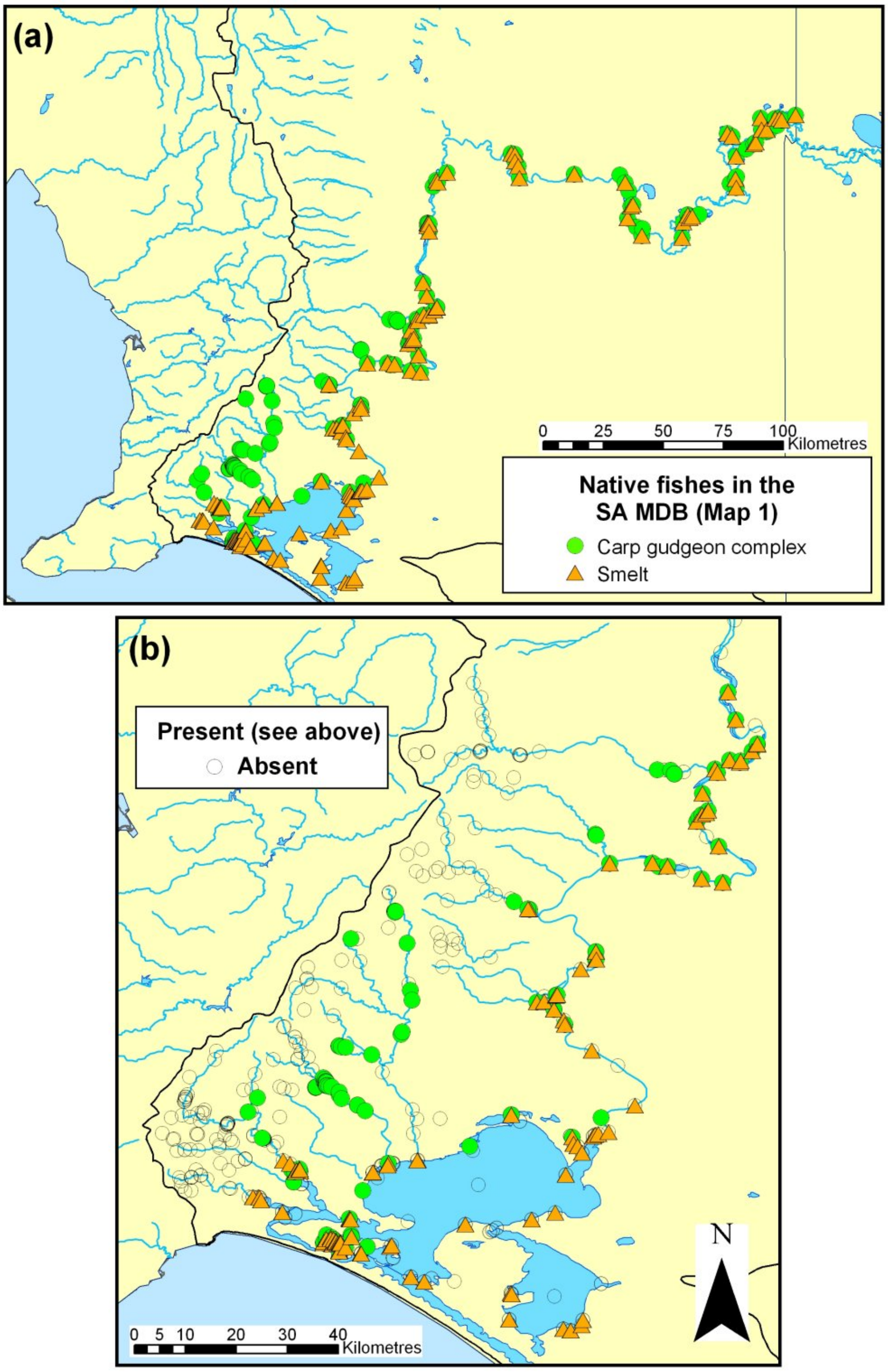


Figure 2. Map A shows the known current distribution of carp gudgeon species and Australian smelt within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.1.2 Bony herring and Murray-Darling golden perch

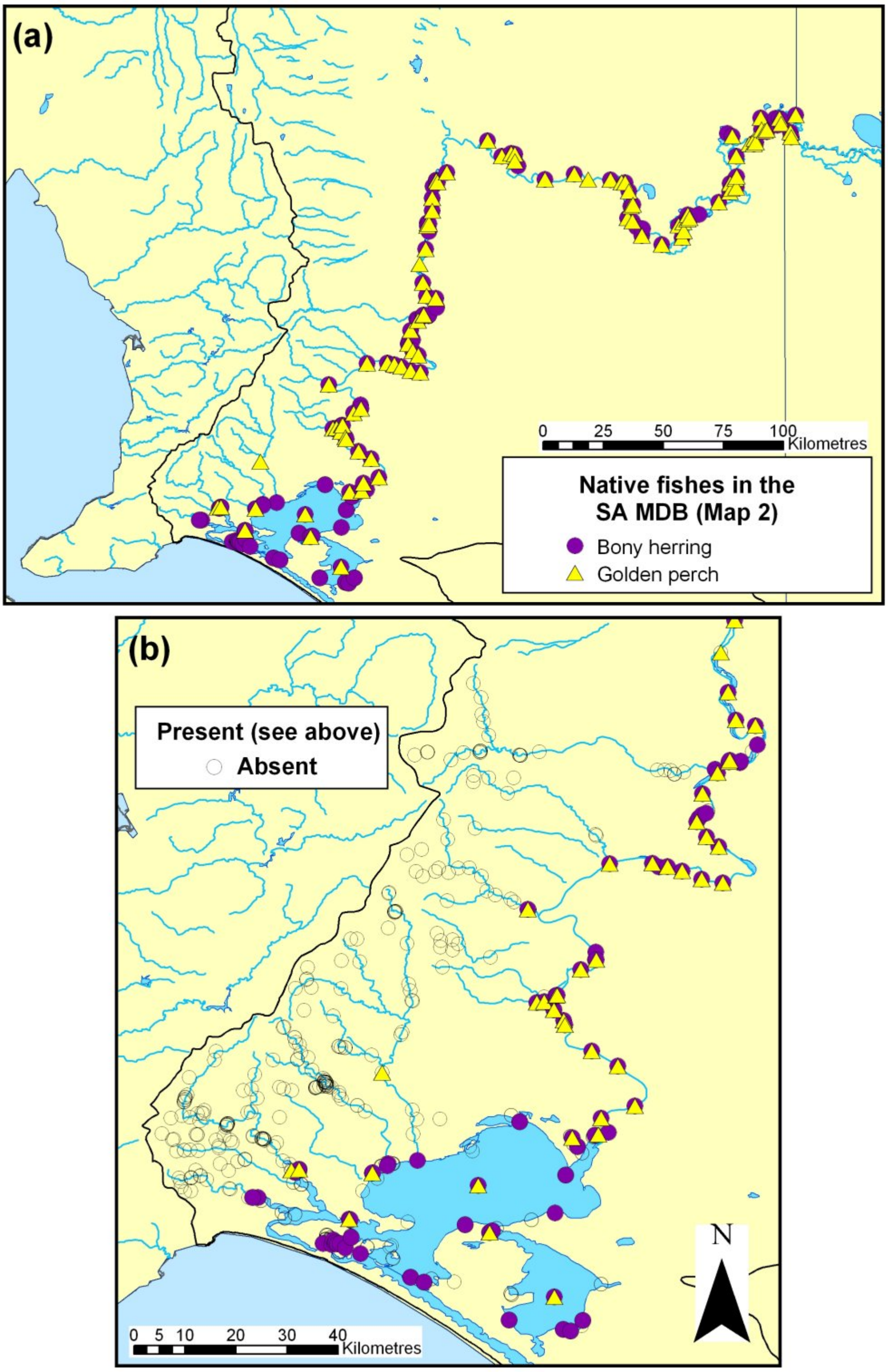


Figure 3. Map A shows the known current distribution of bony herring and Murray-Darling golden perch within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.1.3 Lagoon goby and blue-spot goby

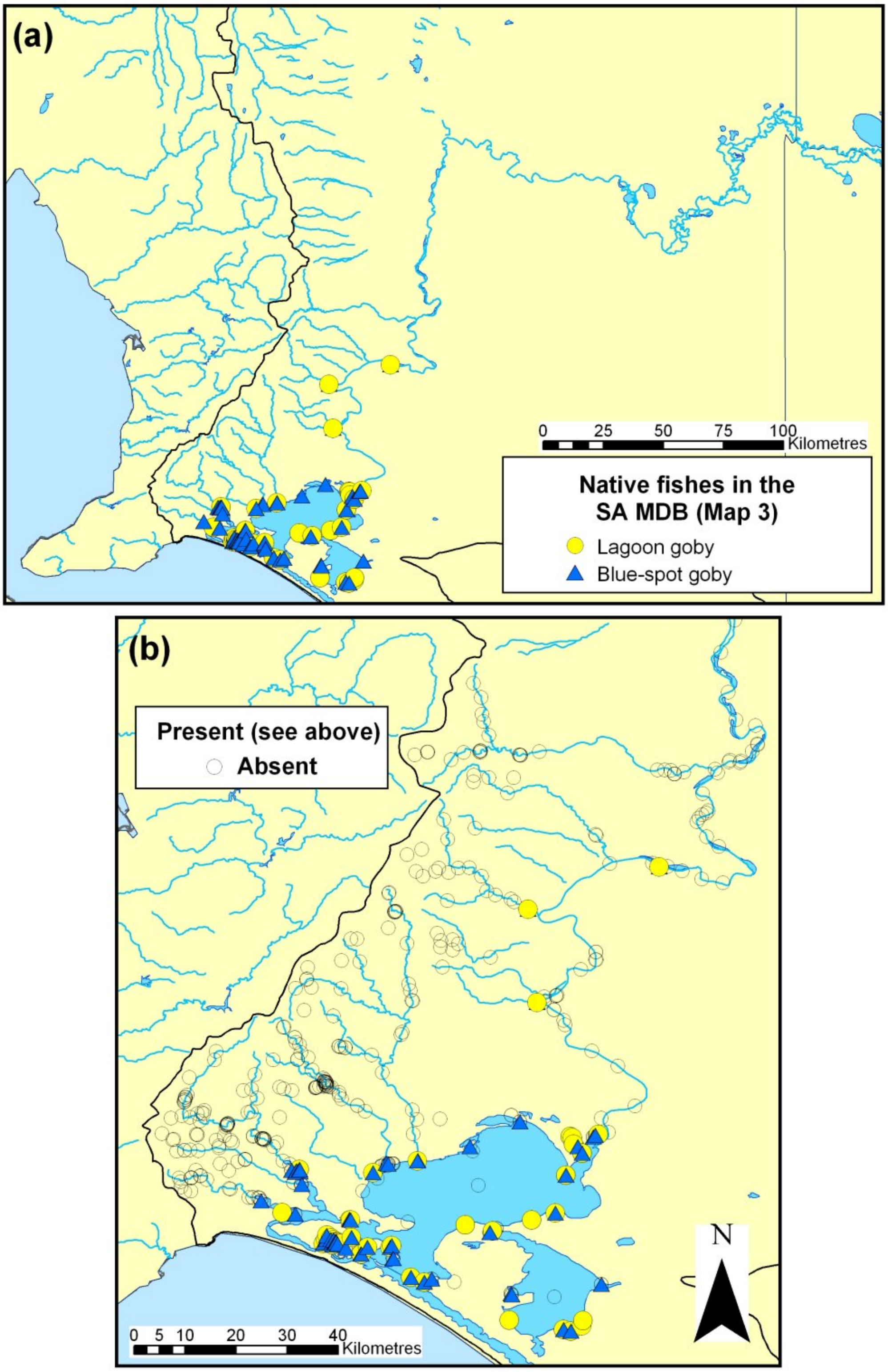


Figure 4. Map A shows the known current distribution of lagoon goby and blue-spot goby within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.1.4 Common galaxias and smallmouthed hardyhead

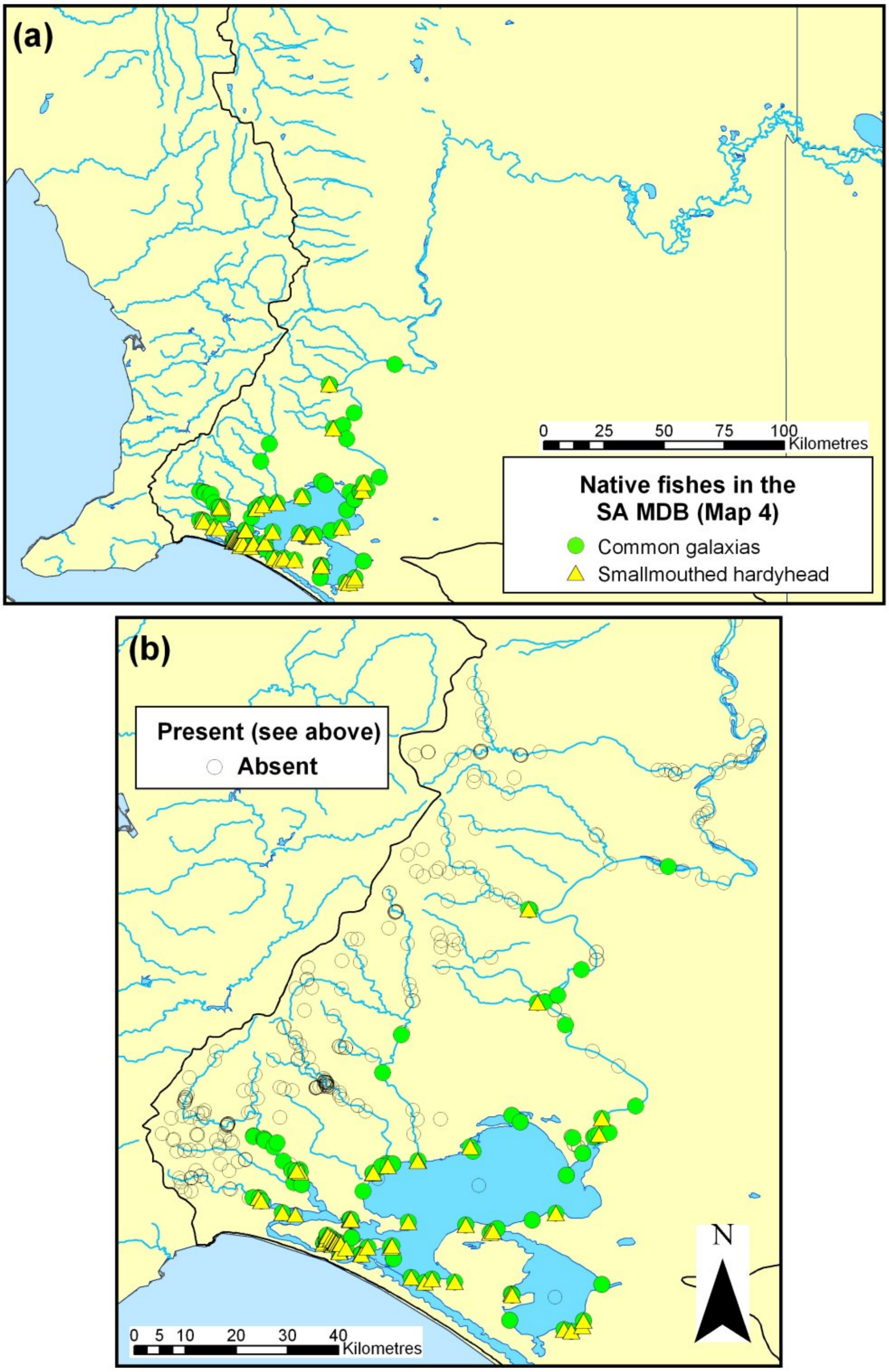


Figure 5. Map A shows the known current distribution of common galaxias and smallmouthed hardyhead within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.2 THREATENED NATIVE SPECIES – RARE OR DECLINING AND/OR WITH A RESTRICTED DISTRIBUTION

6.2.1 <u>Murray rainbowfish, unspecked hardyhead and Murray hardyhead</u>

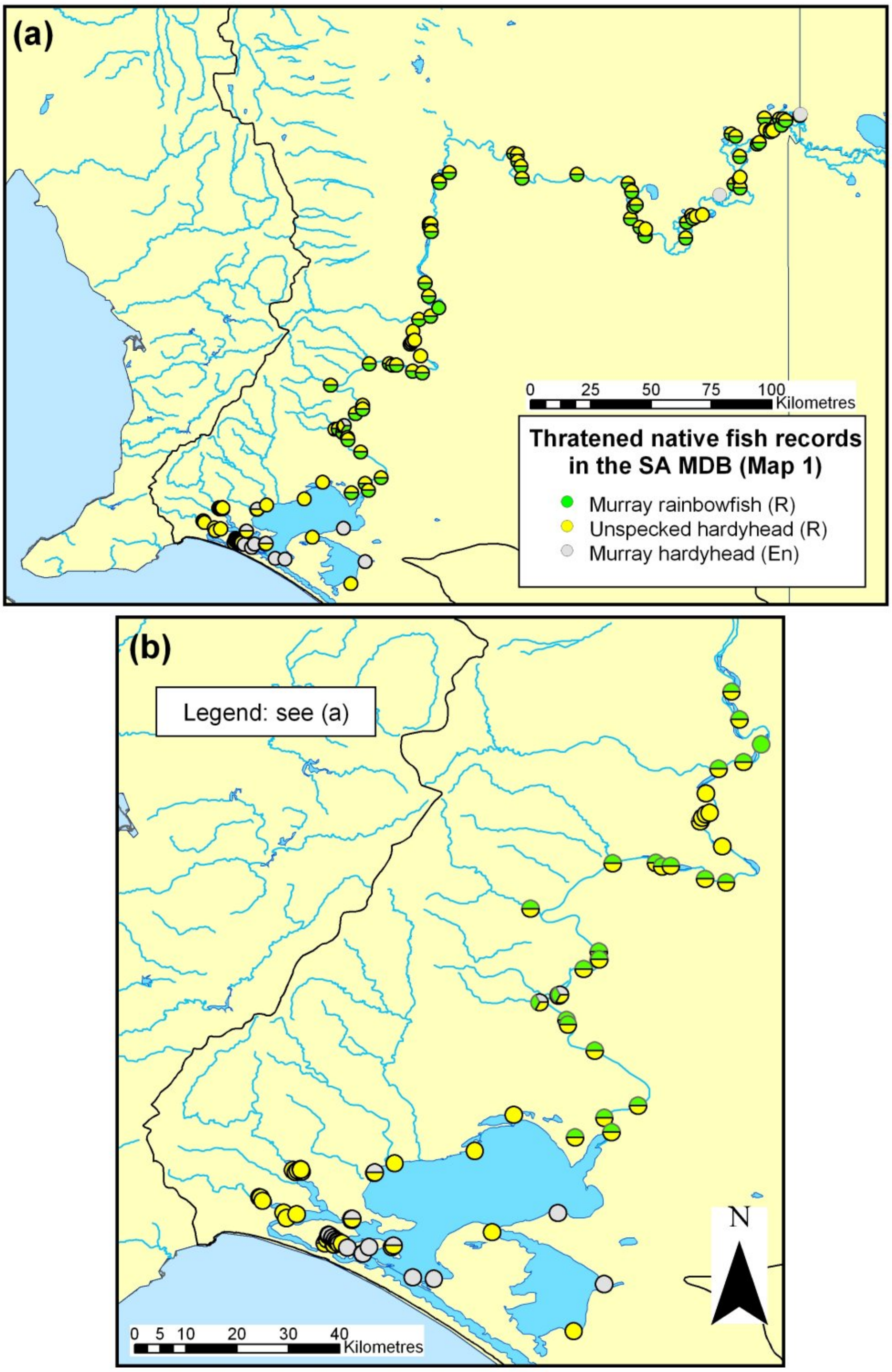


Figure 6. Map A shows the known current distribution of Murray rainbowfish, unspecked hardyhead and Murray hardyhead within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.2.2 Murray cod, silver perch and freshwater catfish

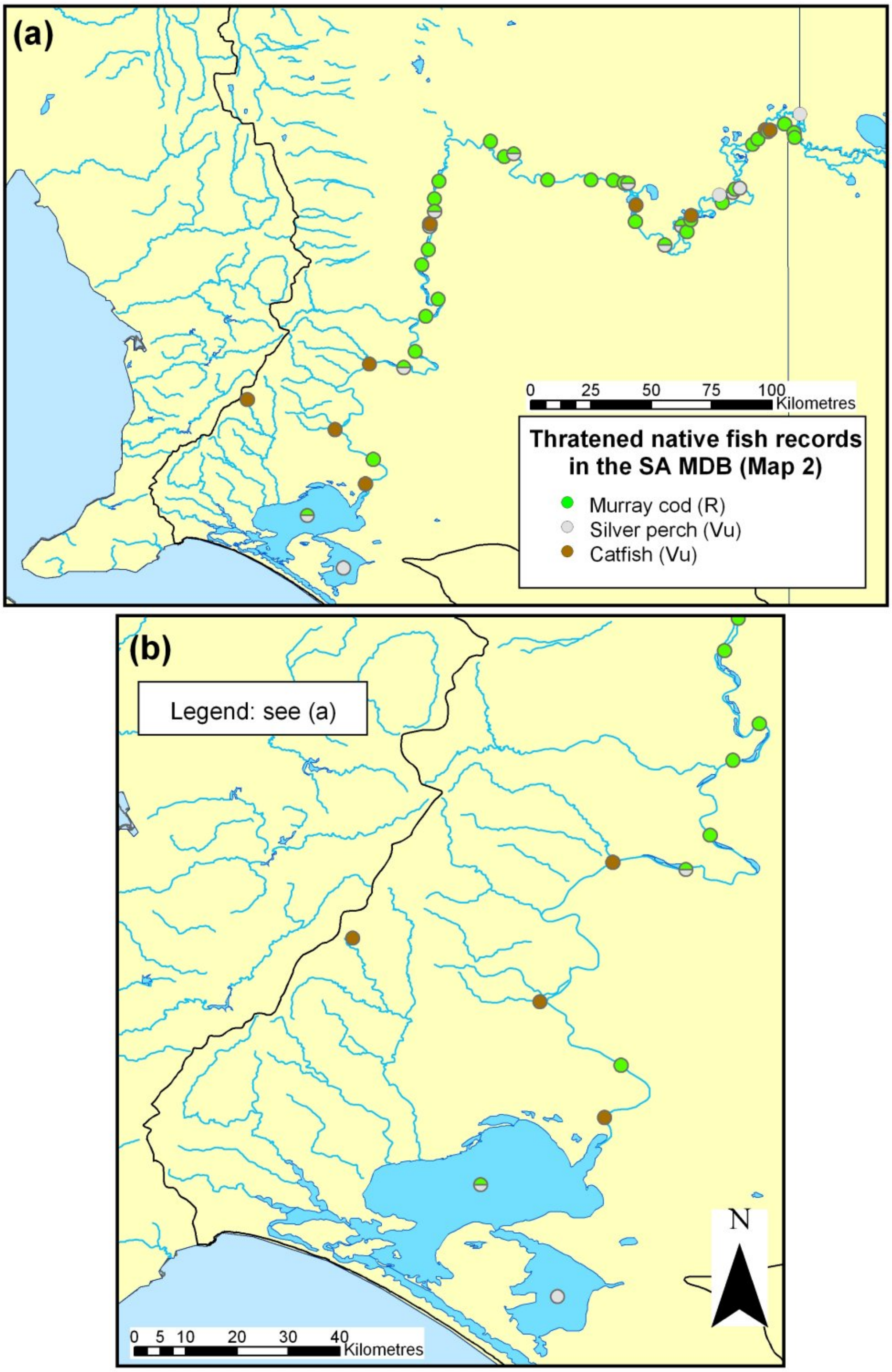


Figure 7. Map A shows the known current distribution of Murray cod, silver perch and freshwater catfish within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the Lower Murray, for which there is more reliable survey data, is shown in Map B.

6.2.3 Dwarf flathead gudgeon, congolli, mountain galaxias, shortheaded lamprey

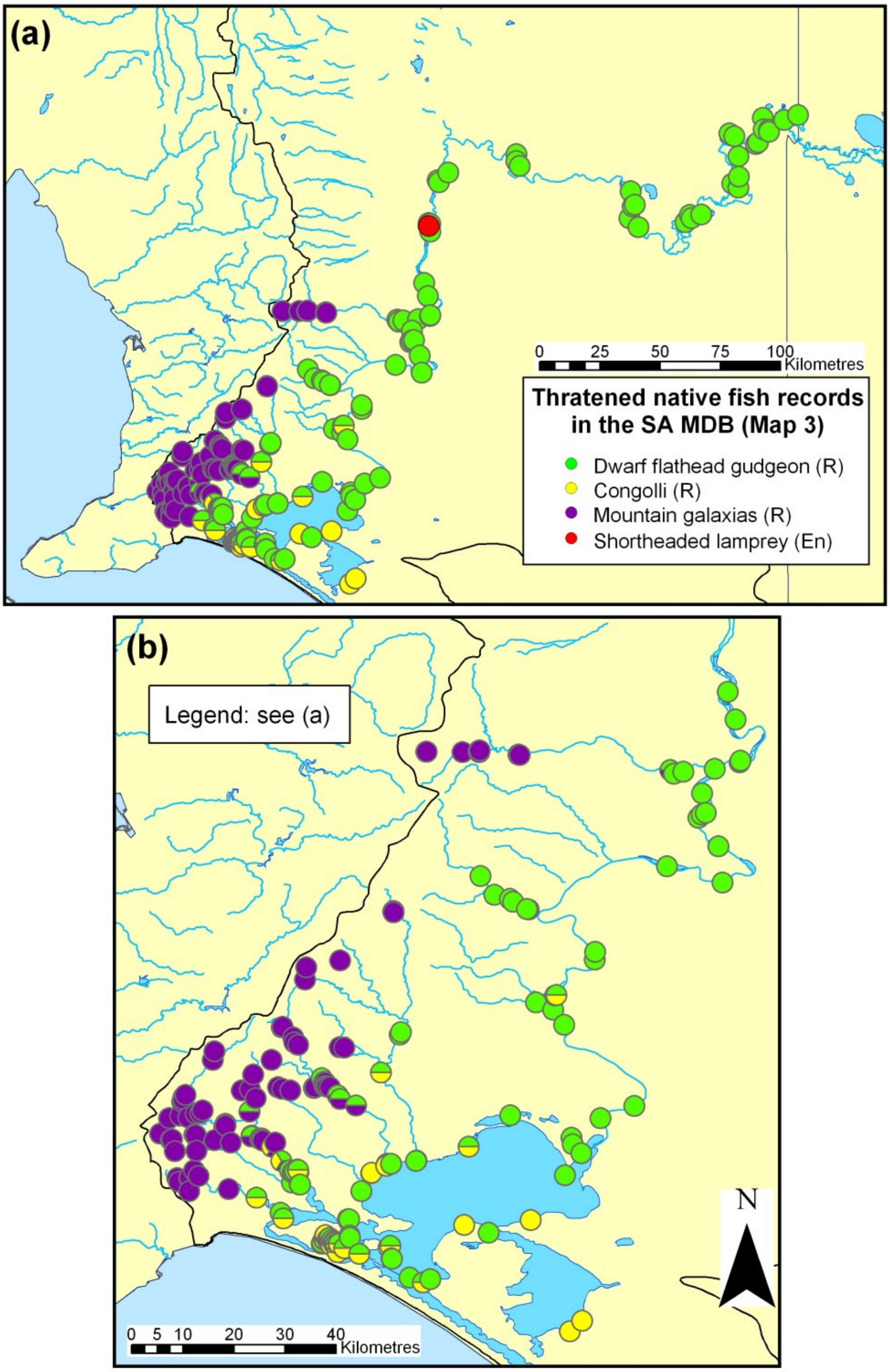


Figure 8. Map A shows the known current distribution of dwarf flathead gudgeon, congolli, mountain galaxias and shortheaded lamprey within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the Lower Murray, for which there is more reliable survey data, is shown in Map B.

6.2.4 Yarra pygmy perch, southern pygmy perch and river blackfish

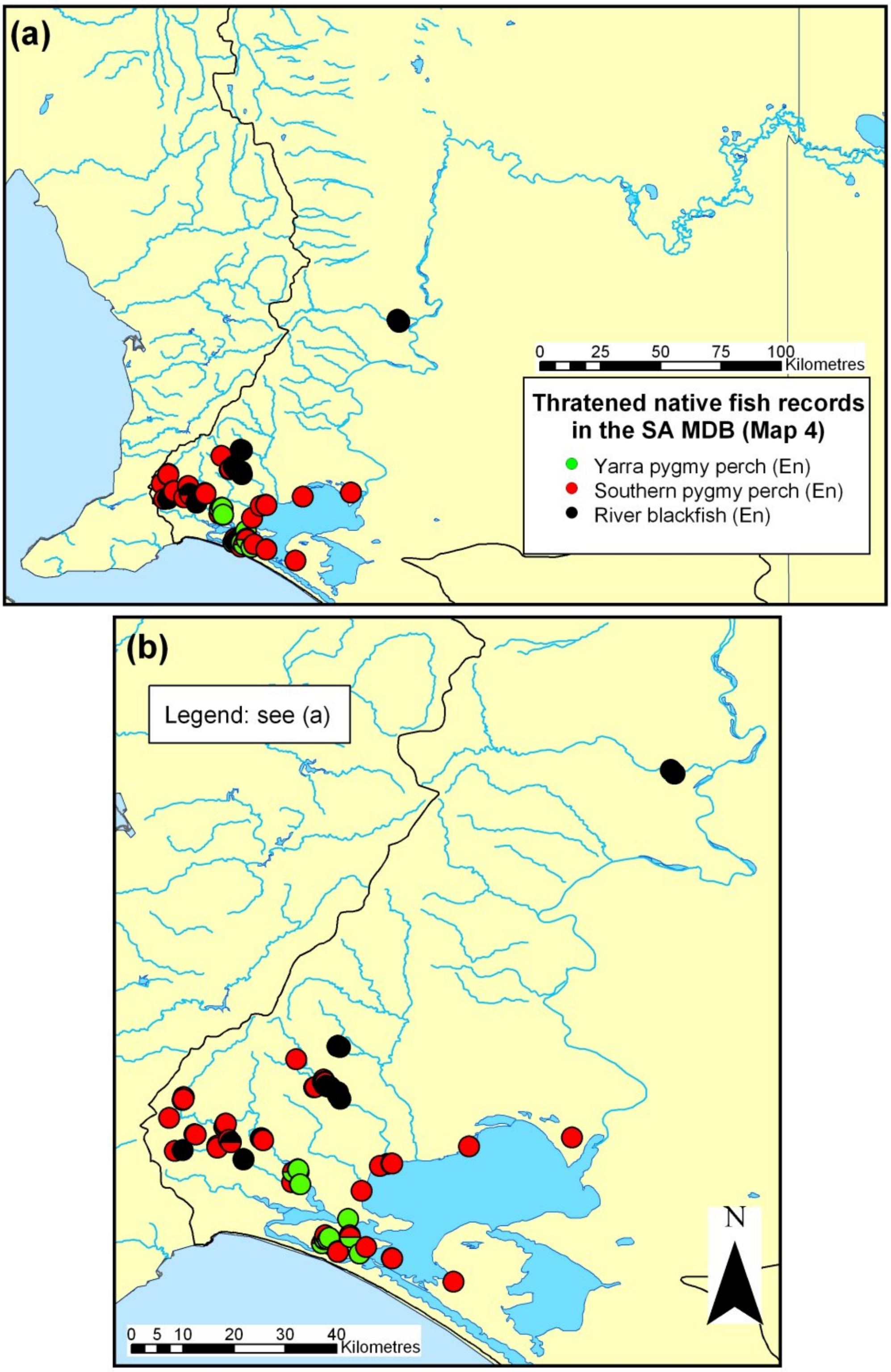


Figure 9. Map A shows the known current distribution of Yarra pygmy perch, southern pygmy perch and river blackfish within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the Lower Murray, for which there is more reliable survey data, is shown in Map B.

6.3 EXOTIC INVASIVE SPECIES

6.3.1 Common carp, goldfish, common carp x goldfish hybrids and tench

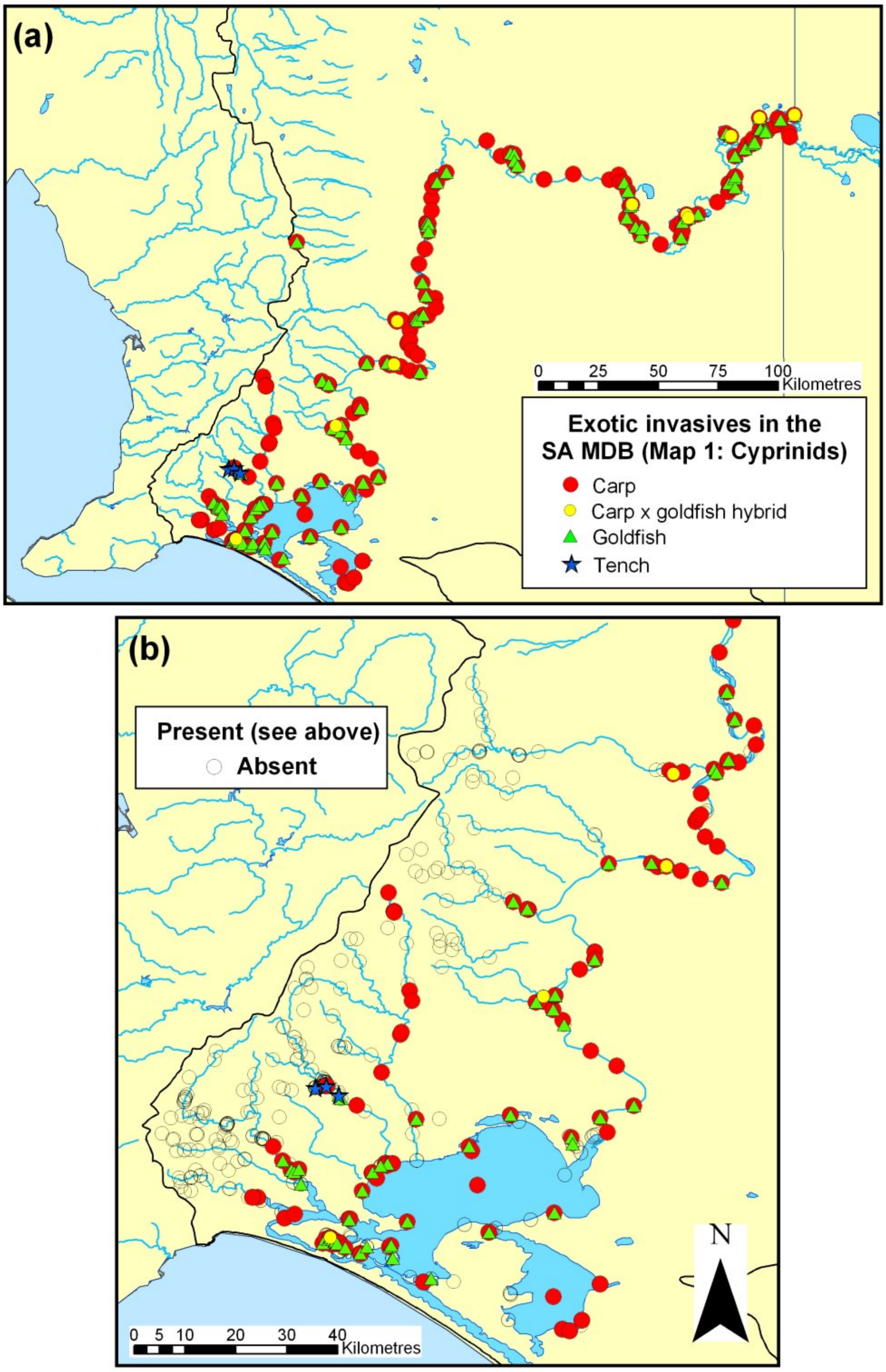
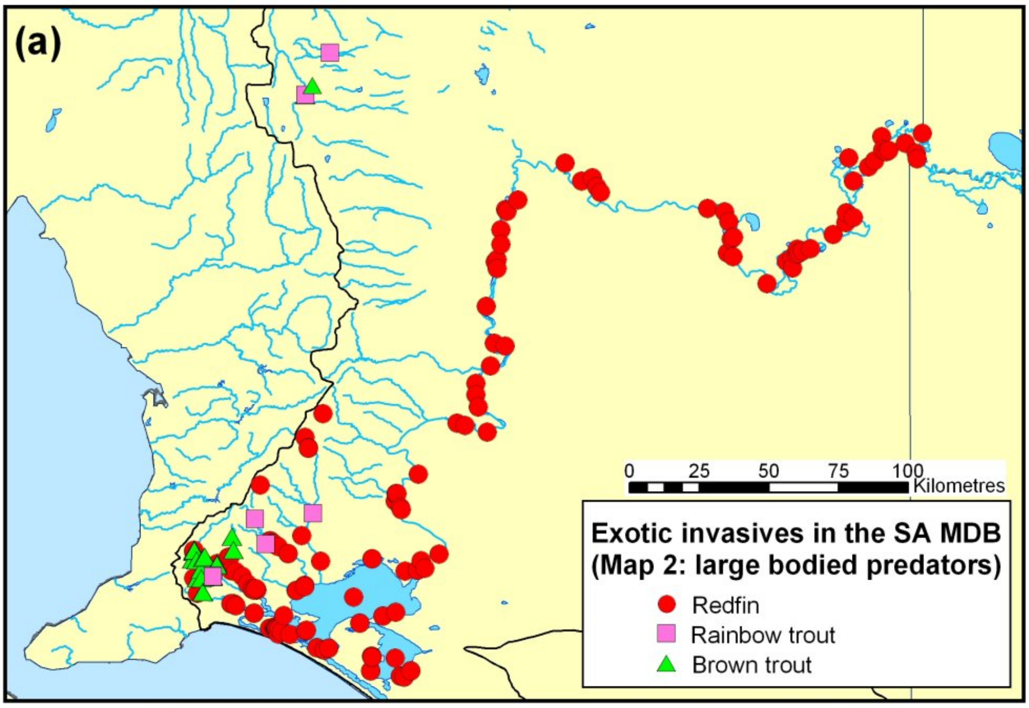


Figure 10. Map A shows the known current distribution of common carp, goldfish, common carp x goldfish hybrids and tench within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the Lower Murray, for which there is more reliable survey data, is shown in Map B.

6.3.2 Redfin perch, rainbow trout and brown trout



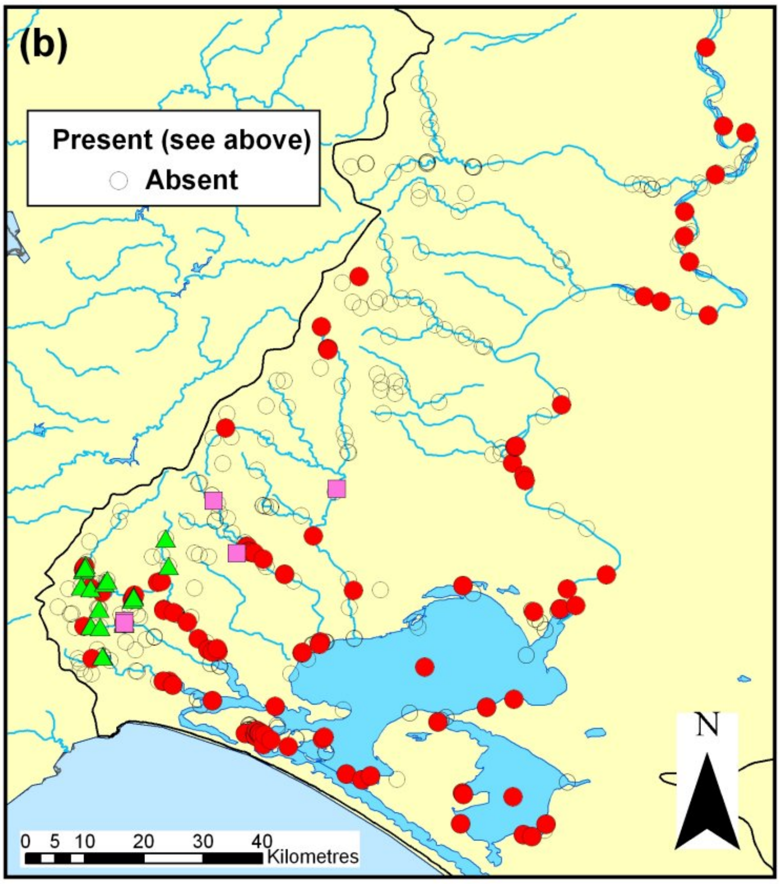
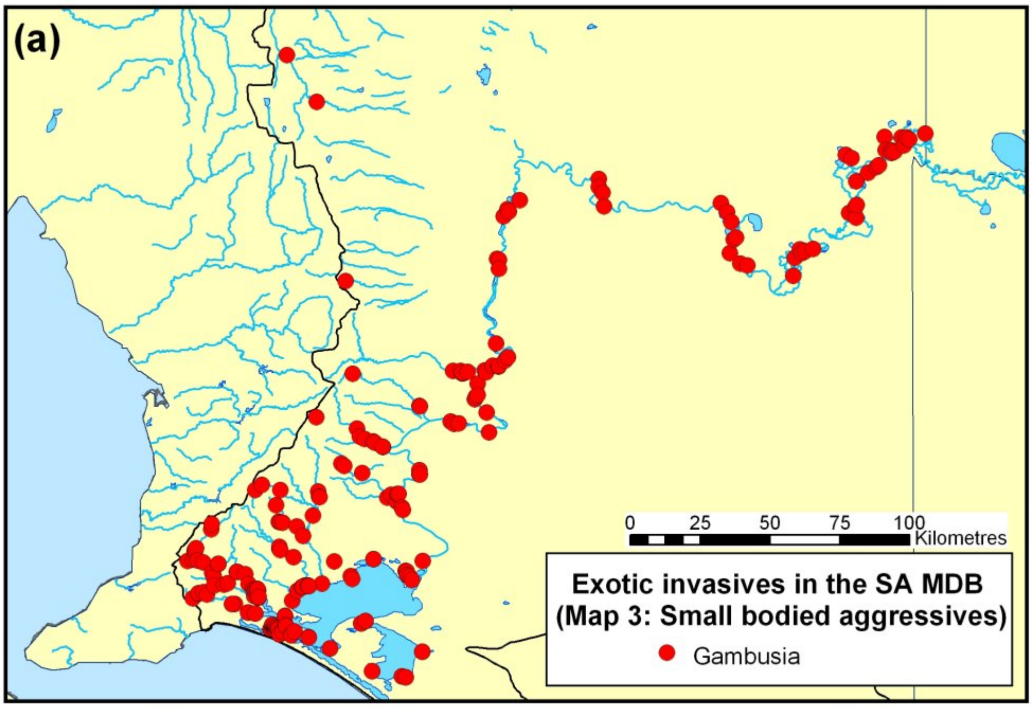


Figure 11. Map A shows the known current distribution of redfin perch, rainbow trout and brown trout within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.3.3 Eastern gambusia



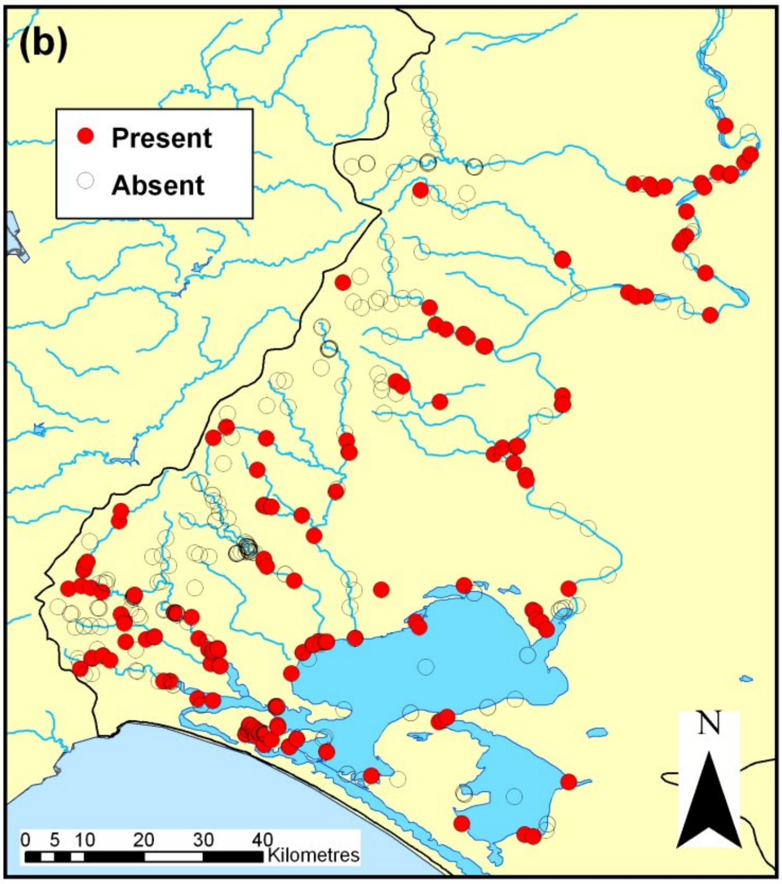


Figure 12. Map A shows the known current distribution of eastern gambusia within the entire South Australian Murray-Darling Basin. A smaller-scale distribution map for the Eastern Mount Lofty Ranges, the Lower Lakes and the lower Murray, for which there is more reliable survey data, is shown in Map B.

6.4 POSSIBLE INTERACTIONS BETWEEN EXOTIC AND THREATENED NATIVE FRESHWATER FISH

6.4.1 Dwarf flathead gudgeon

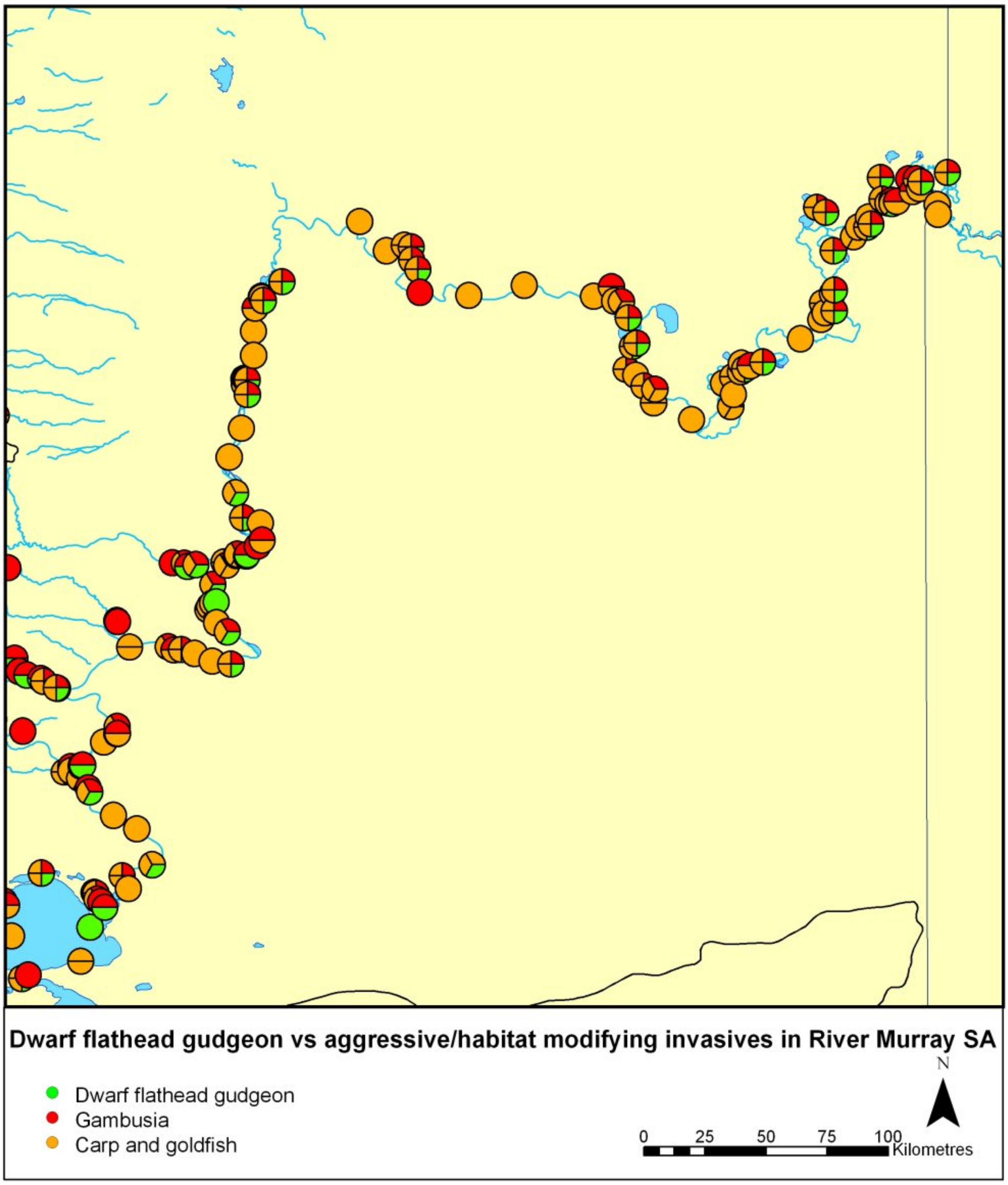


Figure 13. Map showing the current distribution and potential interactions between the native dwarf-flathead gudgeon and the exotic eastern gambusia, common carp and goldfish.

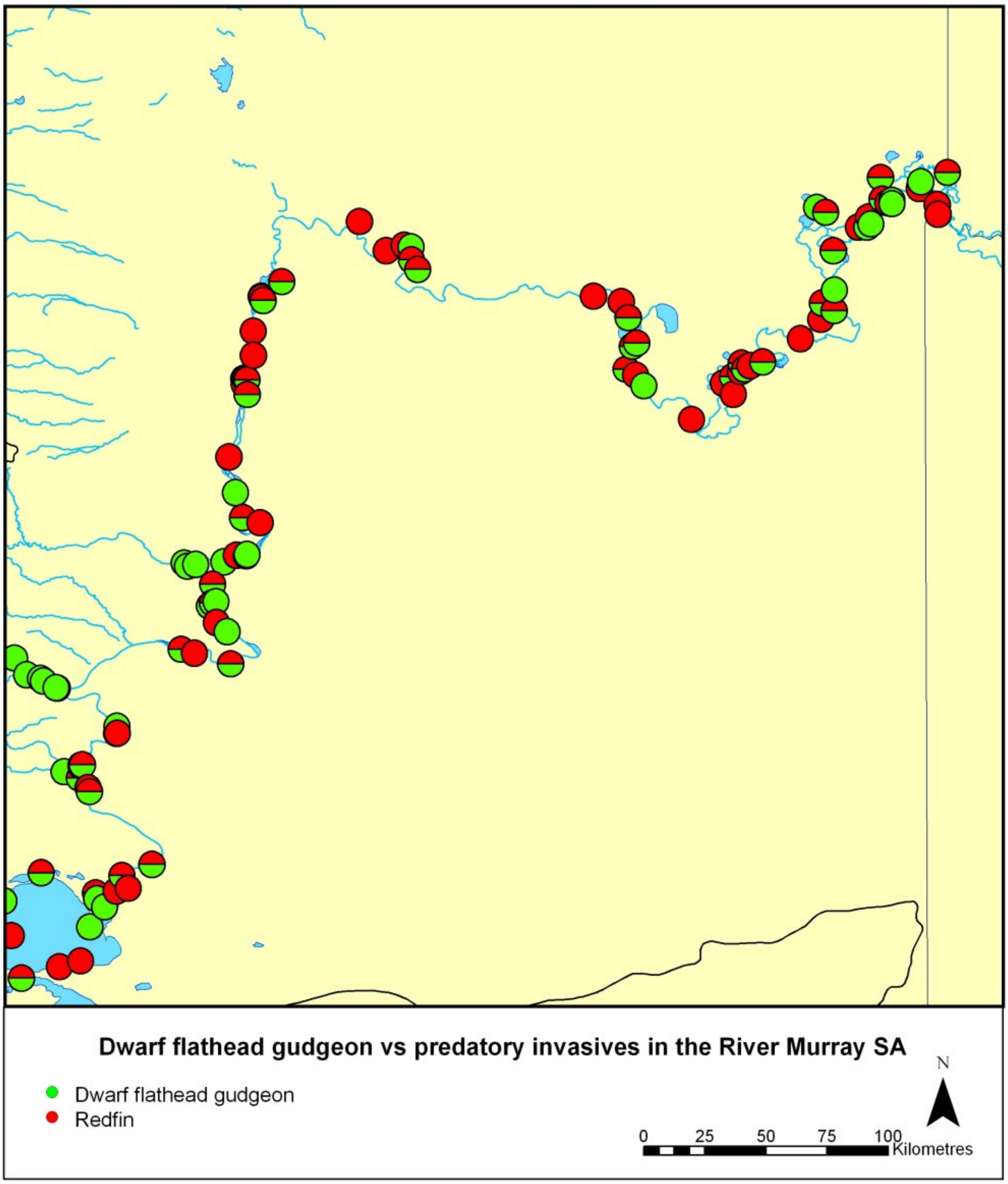


Figure 14. Map showing the current distribution and potential interactions between the native dwarf-flathead gudgeon and the exotic predator redfin perch.

6.4.2 Mountain galaxias

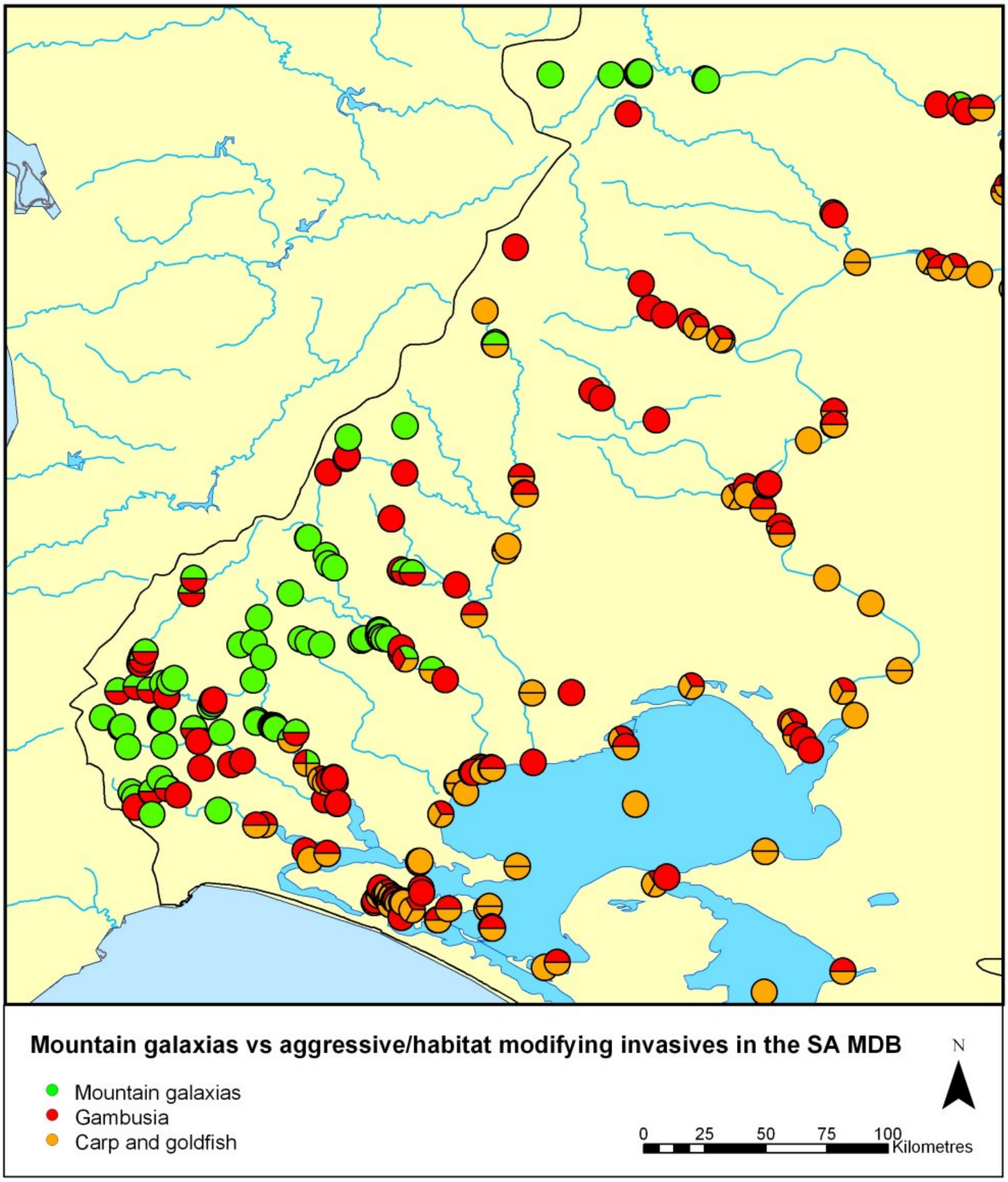


Figure 15. Map showing the current distribution and potential interactions between the native mountain galaxias and the exotic eastern gambusia, common carp and goldfish.

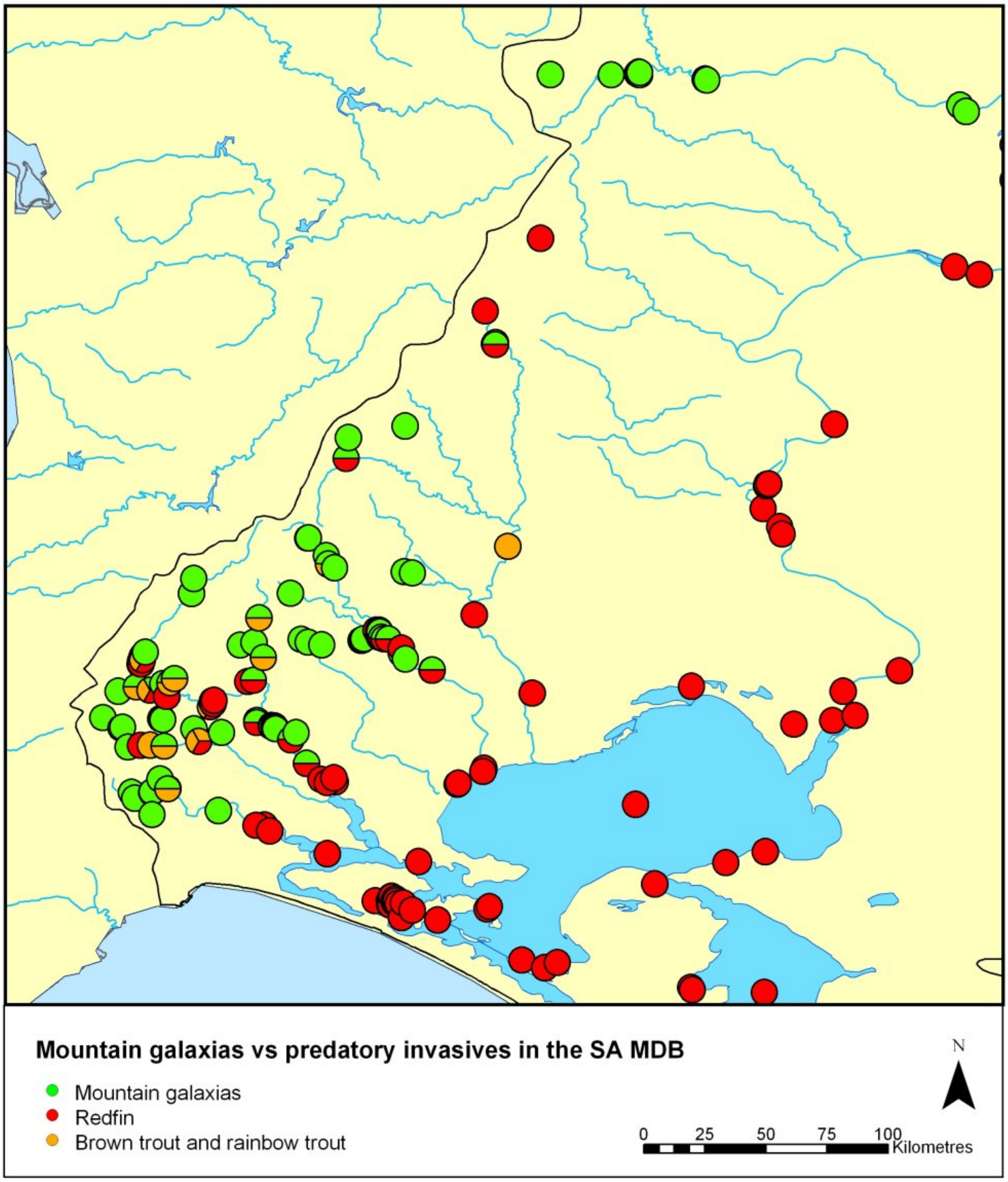


Figure 16. Map showing the current distribution and potential interactions between the native mountain galaxias and the exotic predators redfin perch, brown trout and rainbow trout.

6.4.3 Murray hardyhead

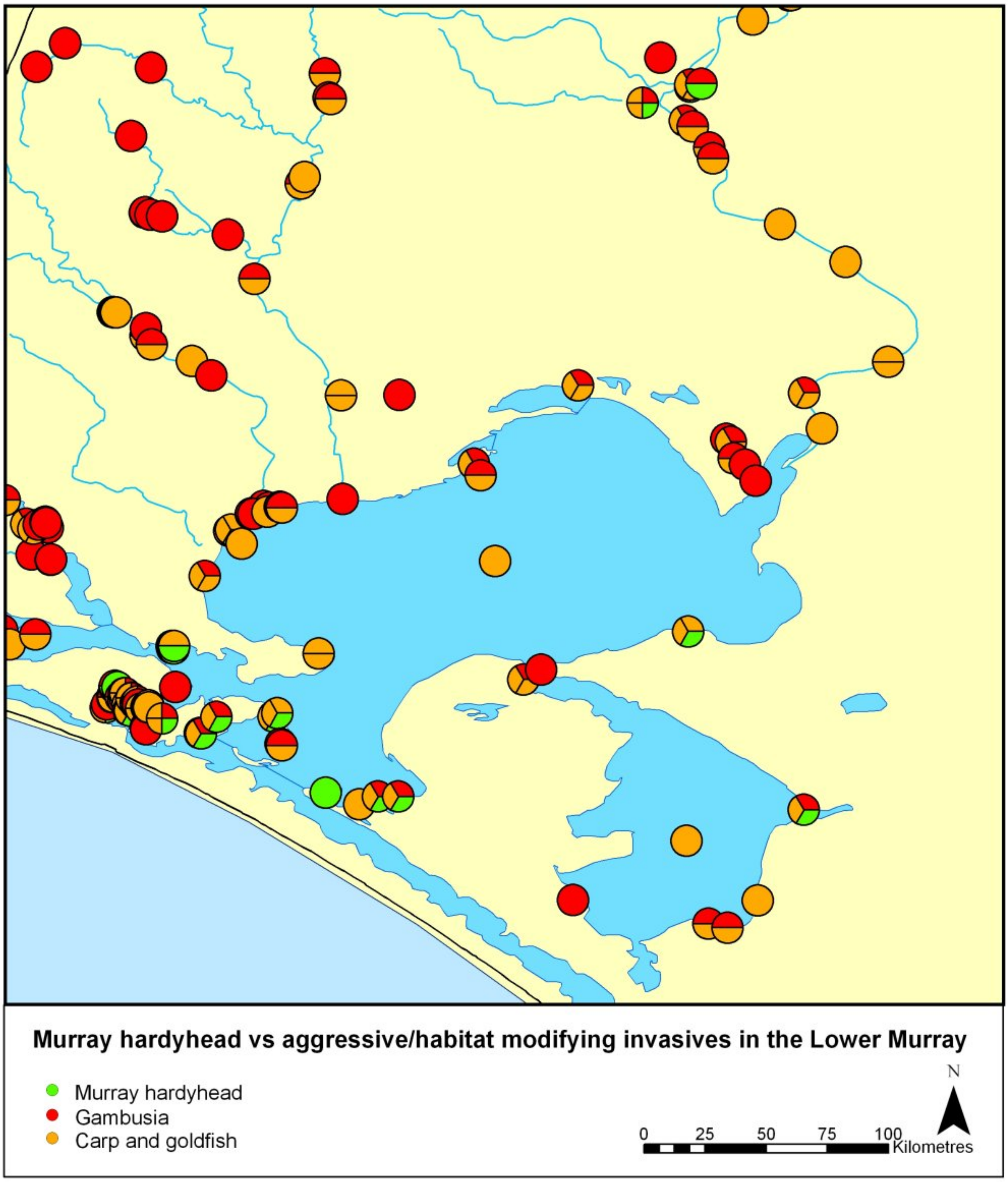


Figure 17. Map showing the current distribution and potential interactions between the native Murray hardyhead and the exotic eastern gambusia, common carp and goldfish.

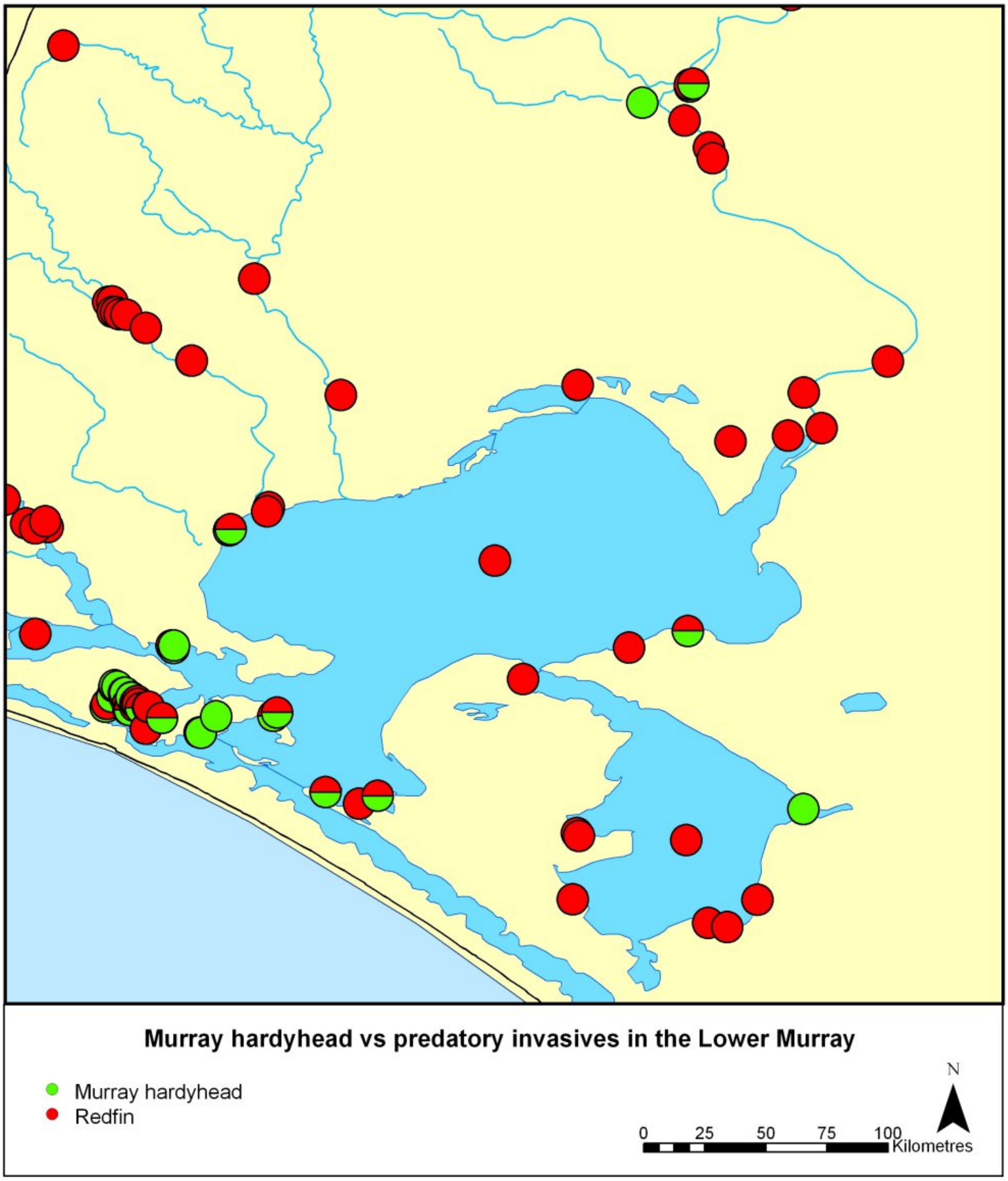


Figure 18. Map showing the current distribution and potential interactions between the native Murray hardyhead and the exotic predator redfin perch.

6.4.4 Murray rainbowfish

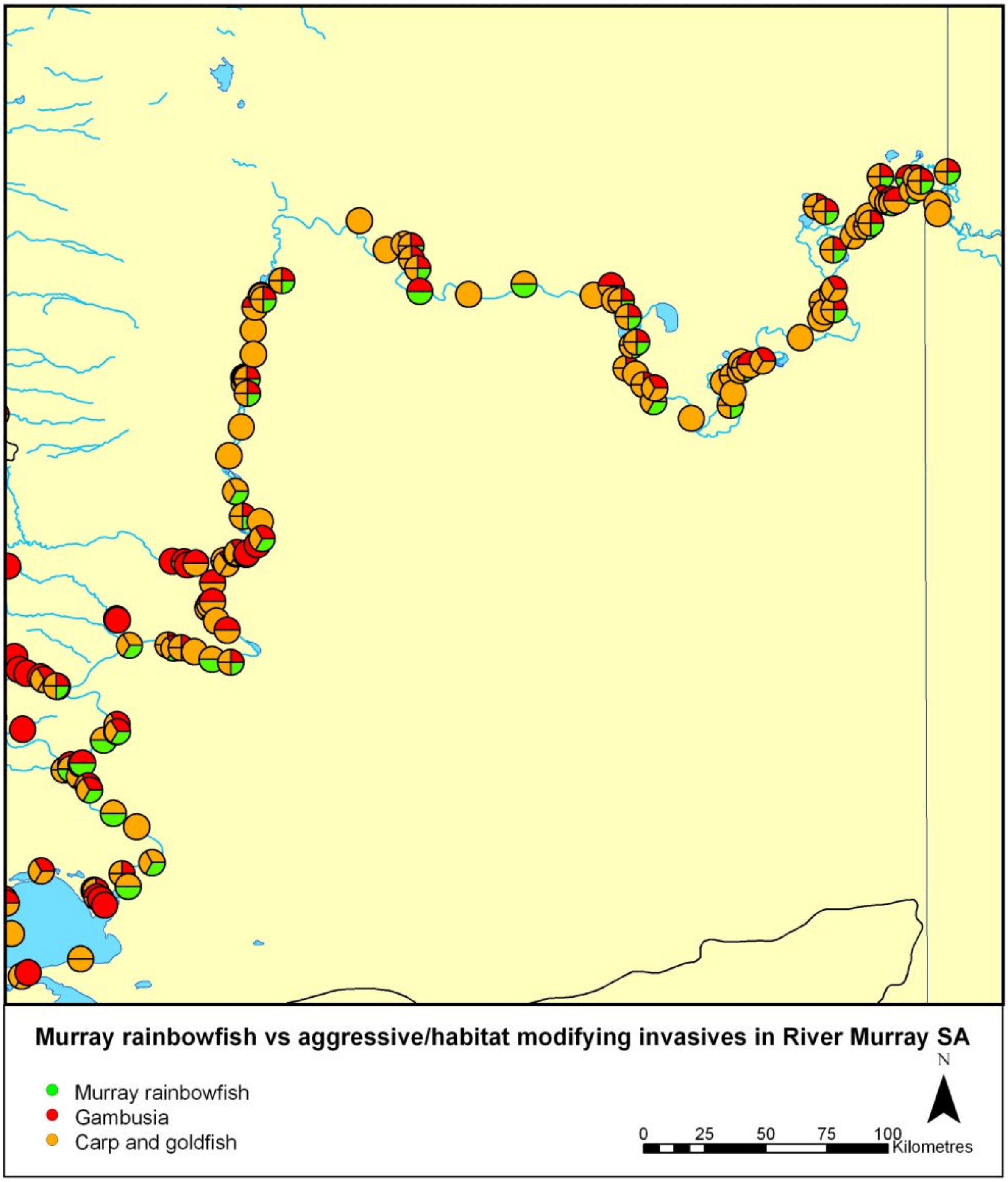


Figure 19. Map showing the current distribution and potential interactions between the native Murray rainbowfish and the exotic eastern gambusia, common carp and goldfish.

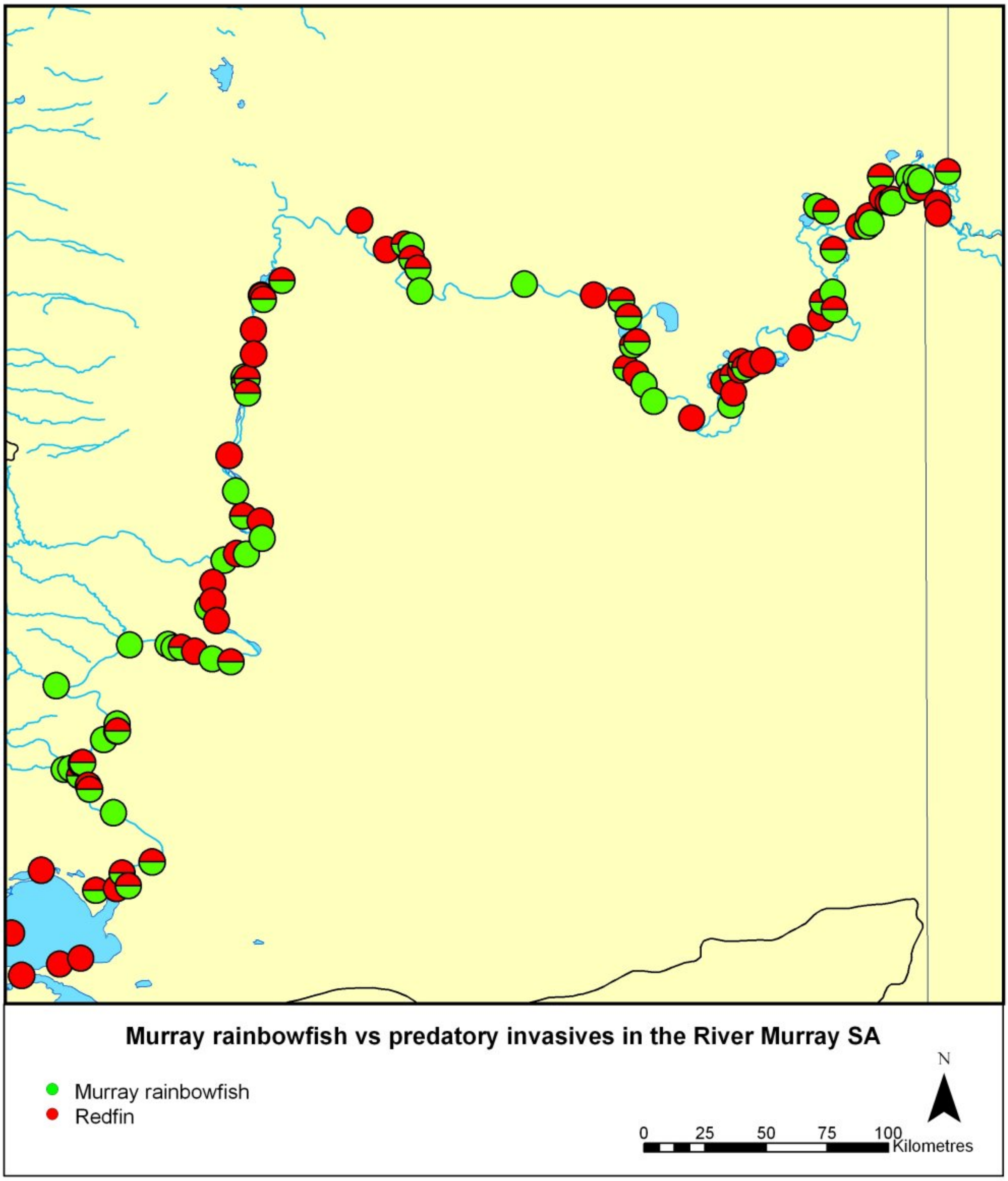


Figure 20. Map showing the current distribution and potential interactions between the native Murray rainbowfish and the exotic predator redfin perch.

6.4.5 River blackfish

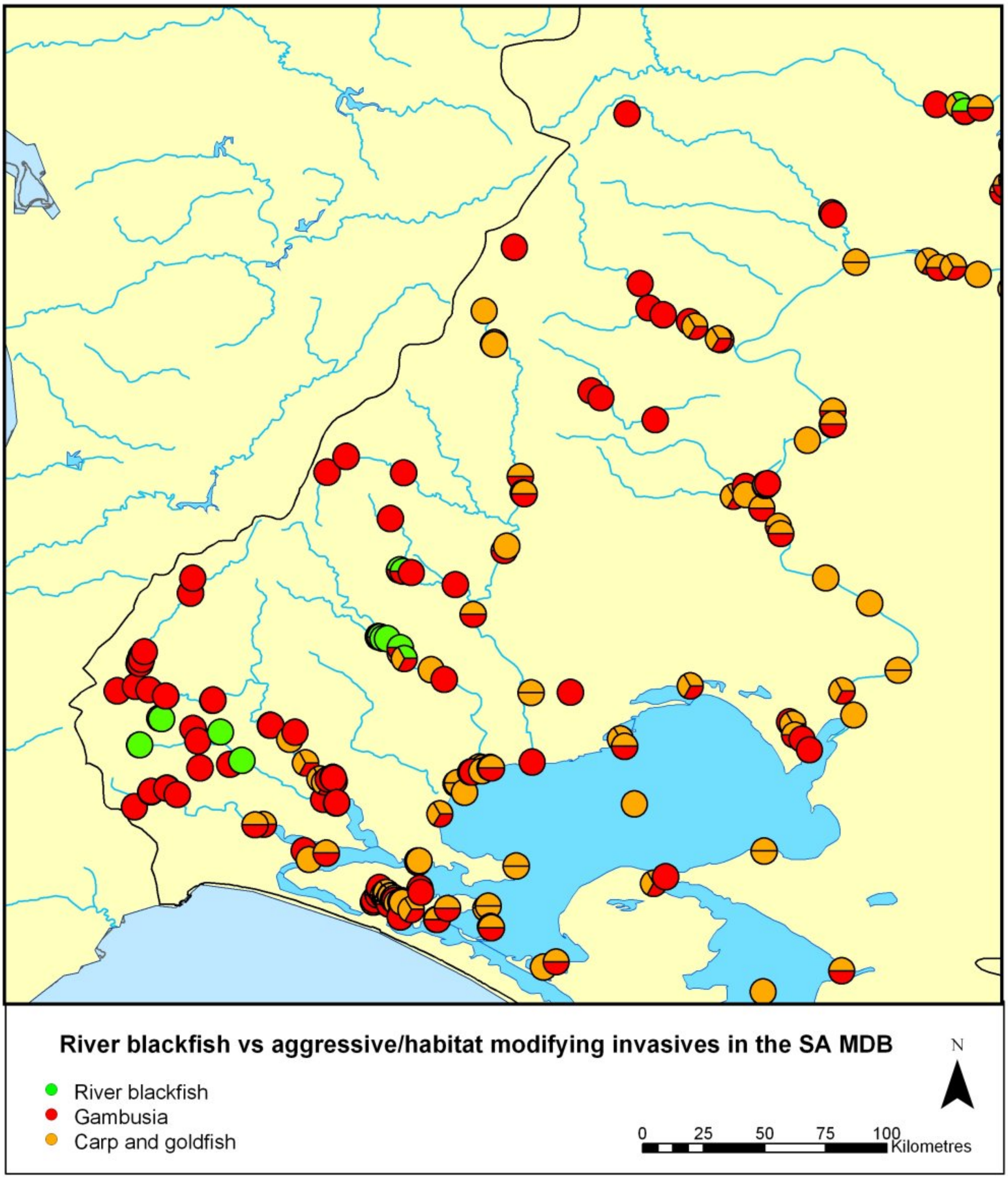


Figure 21. Map showing the current distribution and potential interactions between the native river blackfish and the exotic eastern gambusia, common carp and goldfish.

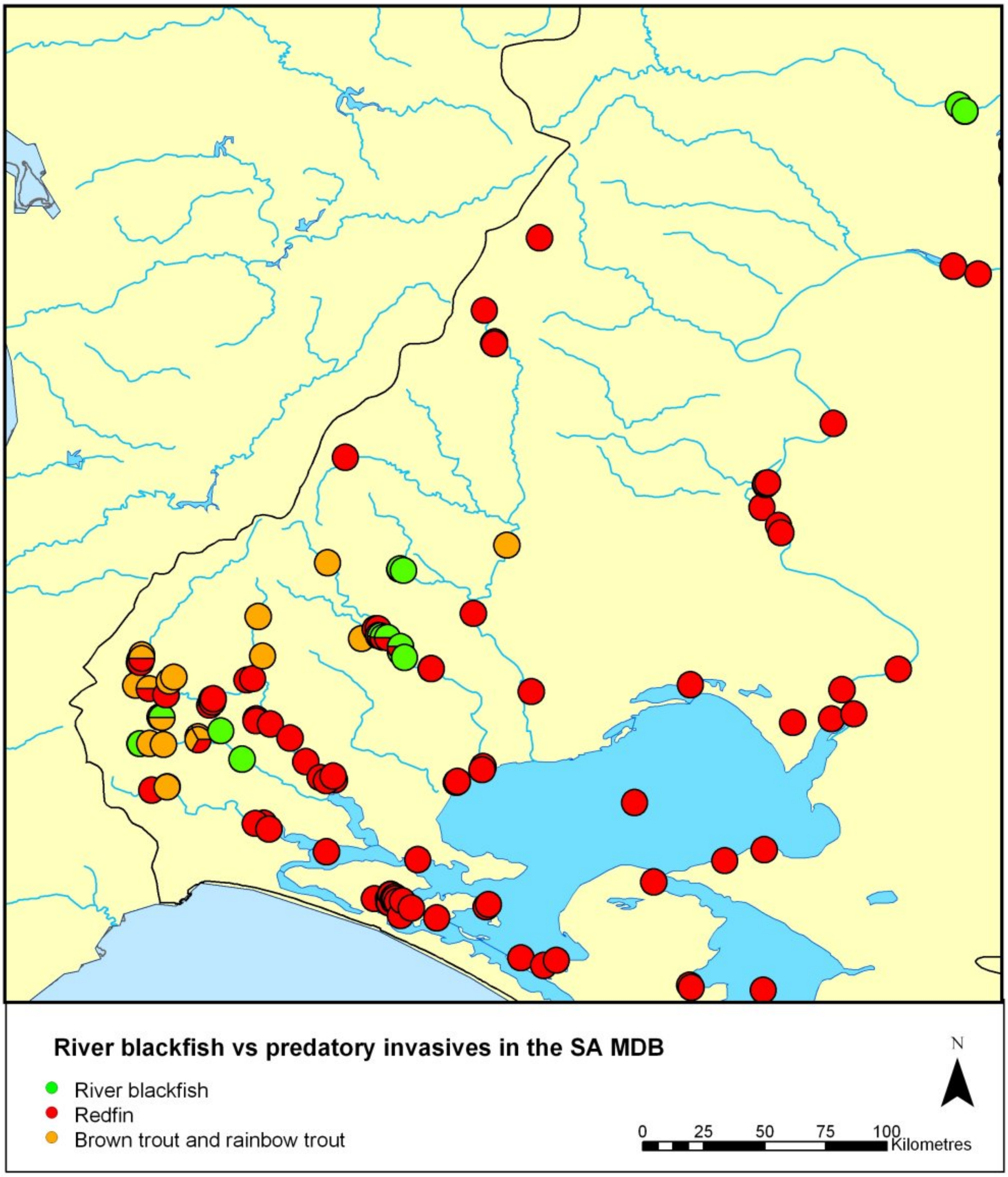


Figure 22. Map showing the current distribution and potential interactions between the native river blackfish and the exotic predators redfin perch, brown trout and rainbow trout.

6.4.6 Southern pygmy perch

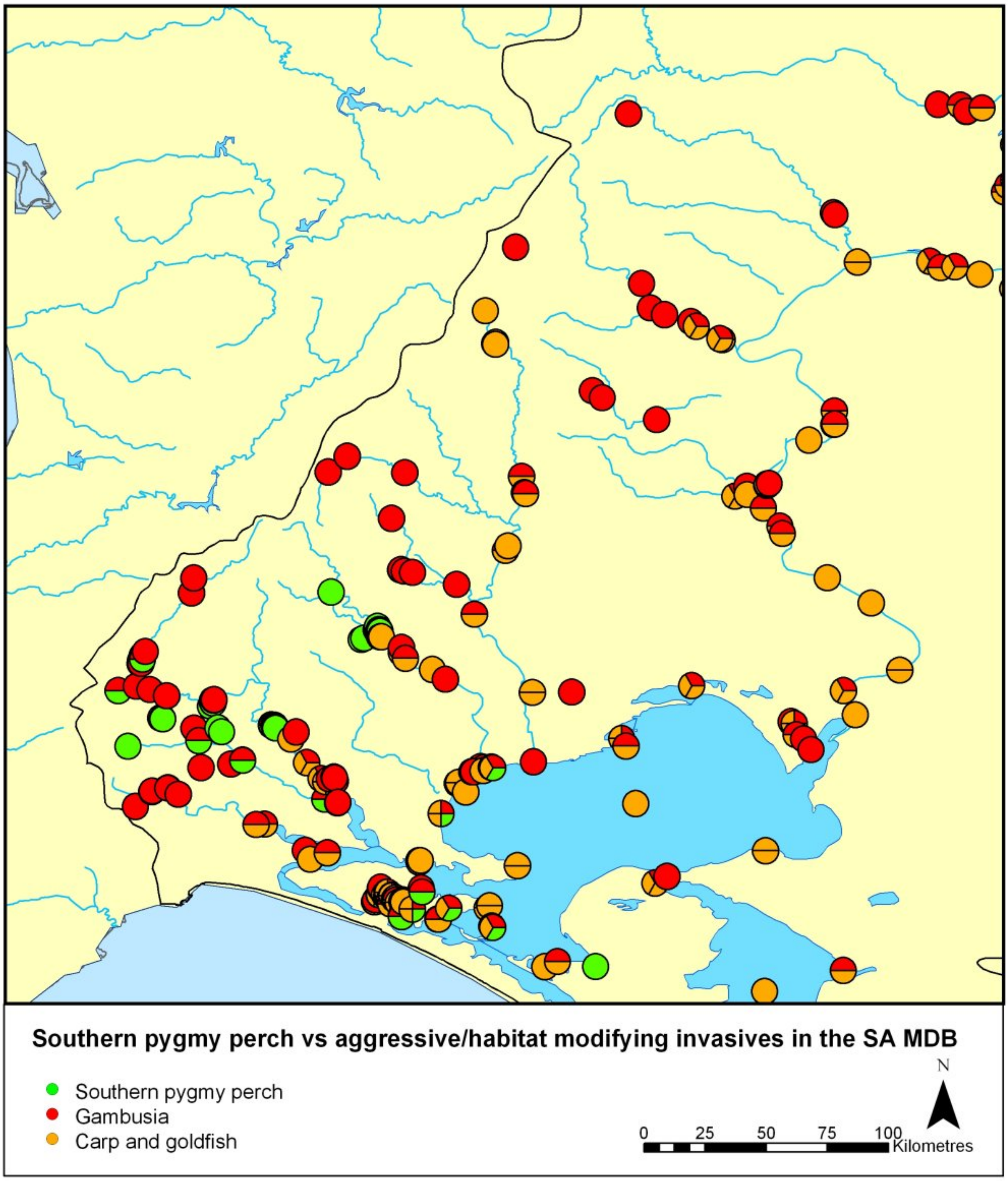


Figure 23. Map showing the current distribution and potential interactions between the native southern pygmy perch and the exotic eastern gambusia, common carp and goldfish.

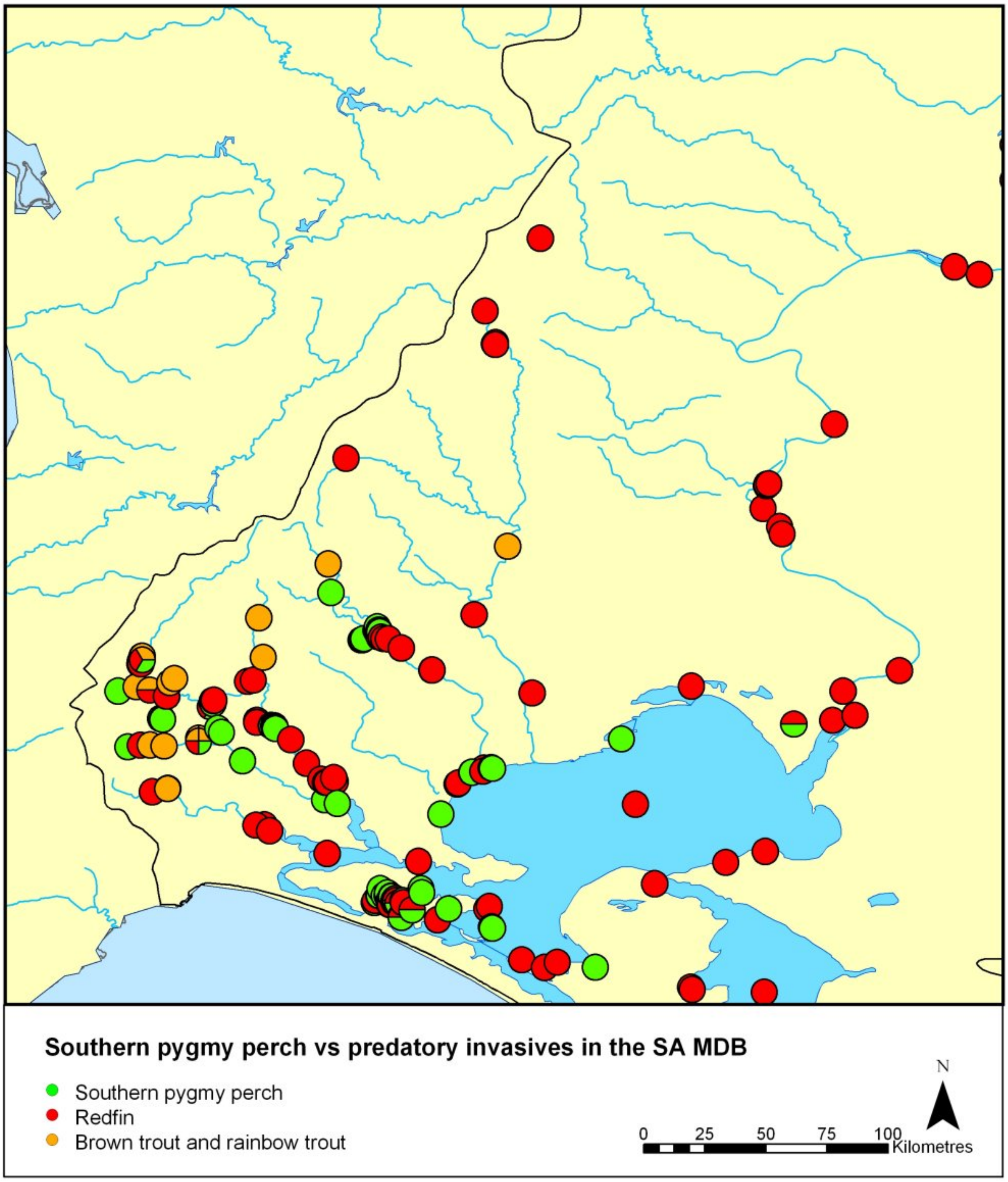


Figure 24. Map showing the current distribution and potential interactions between the native southern pygmy perch and the exotic predators redfin perch, brown trout and rainbow trout.

6.4.7 Unspecked hardyhead

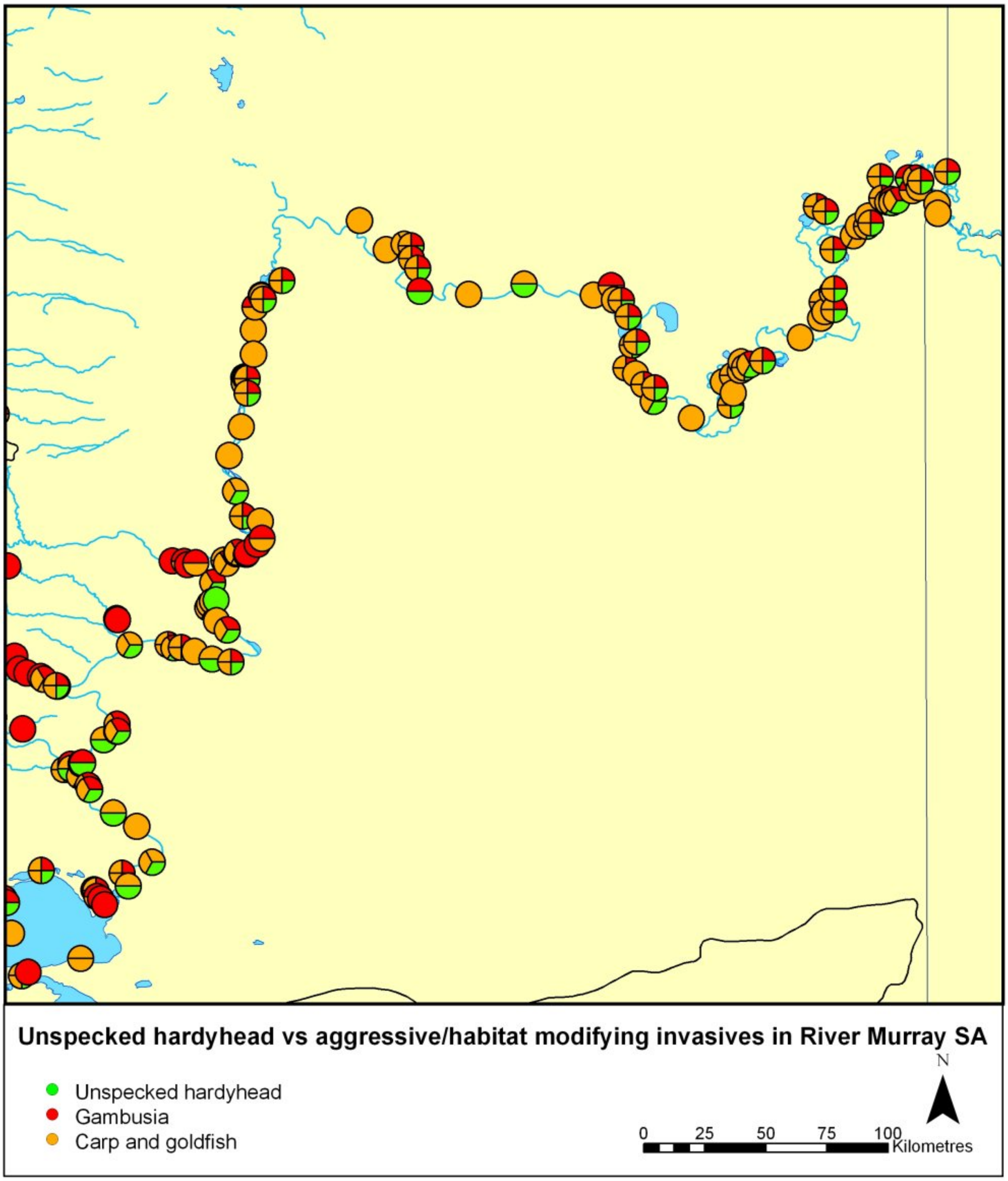


Figure 25. Map showing the current distribution and potential interactions between the native unspecked hardyhead and the exotic eastern gambusia, common carp and goldfish.

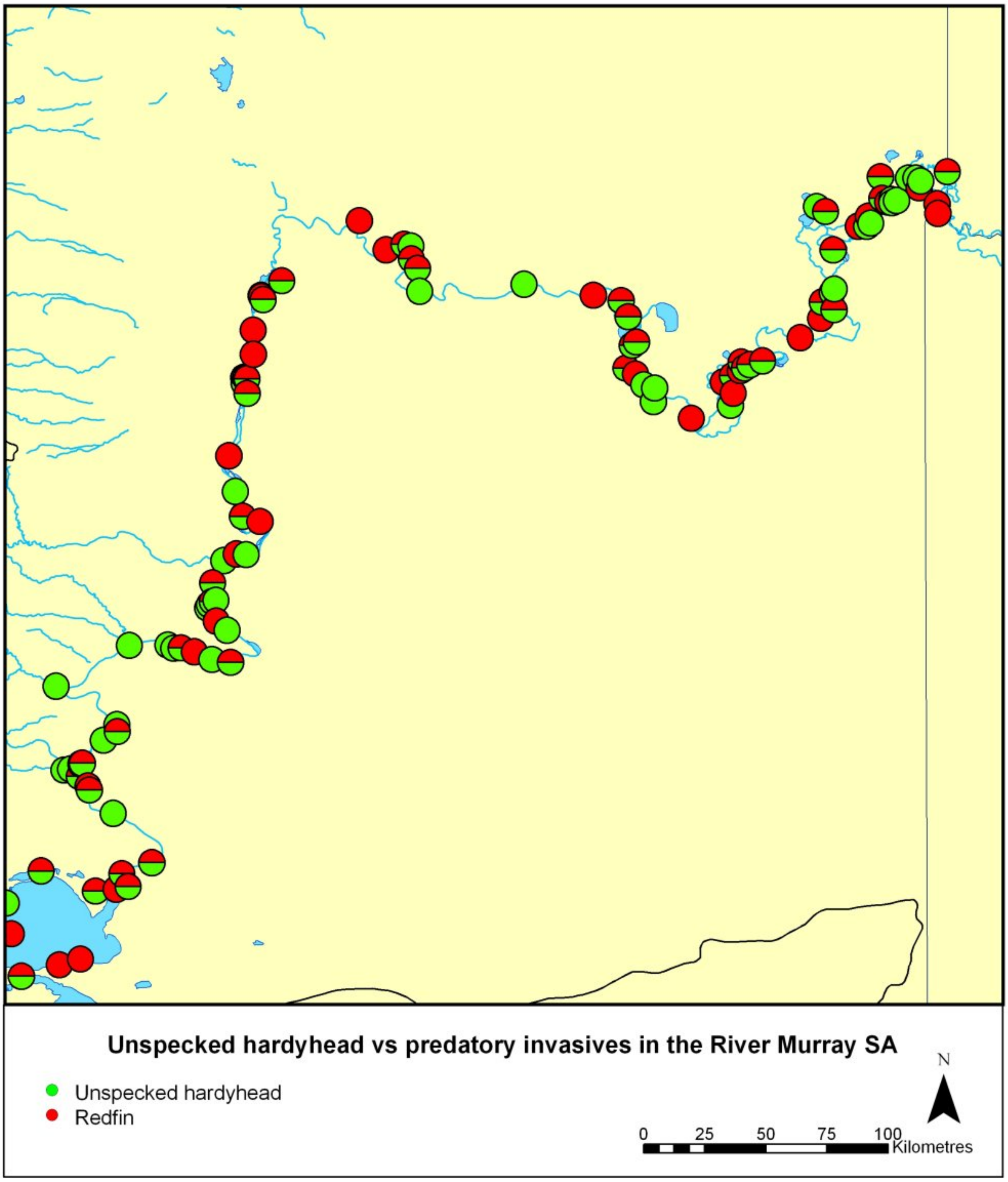


Figure 26. Map showing the current distribution and potential interactions between the native unspecked hardyhead and the exotic predator redfin perch.

6.4.8 Yarra pygmy perch

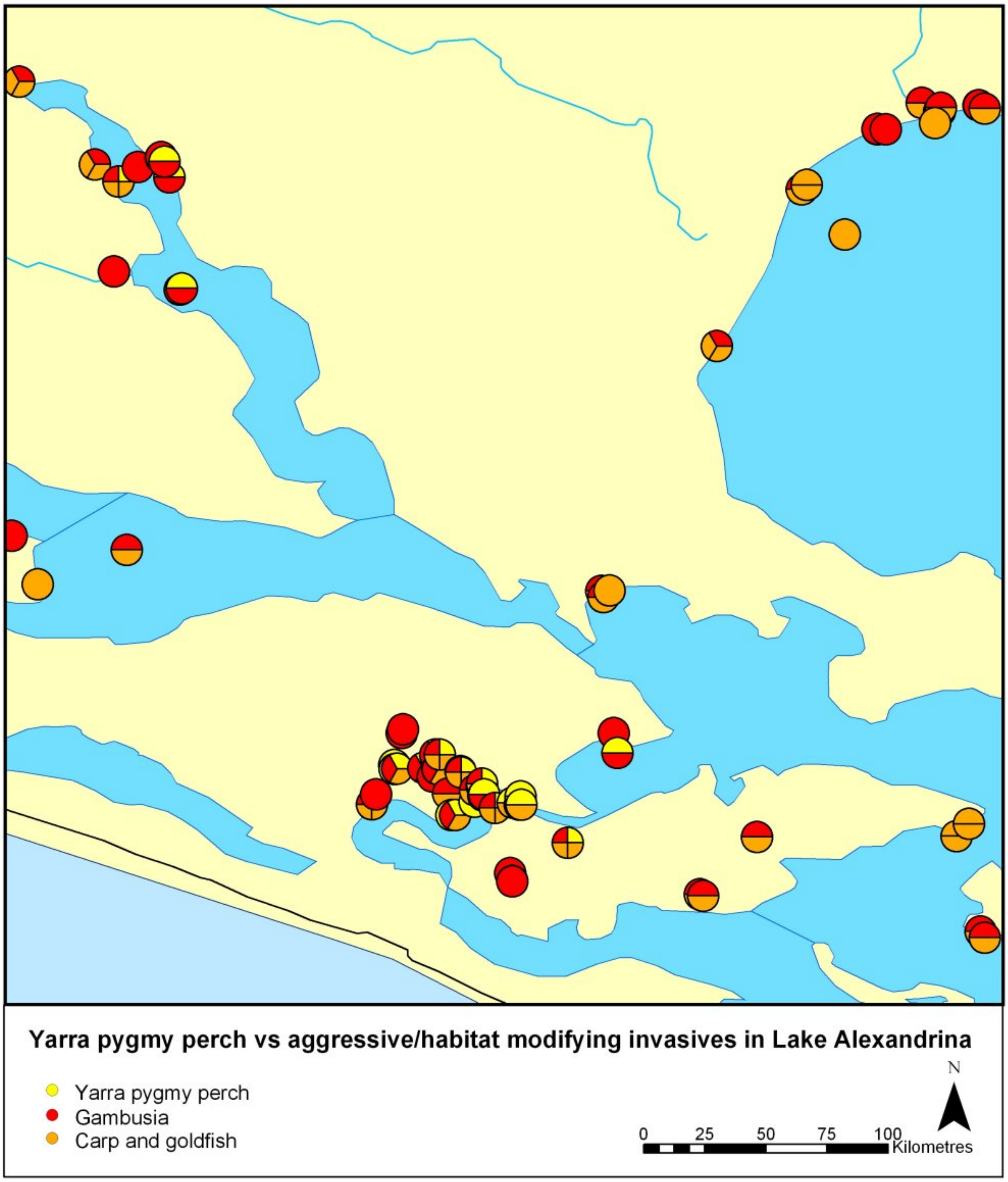


Figure 27. Map showing the current distribution and potential interactions between the native Yarra pygmy perch and the exotic eastern gambusia, common carp and goldfish.

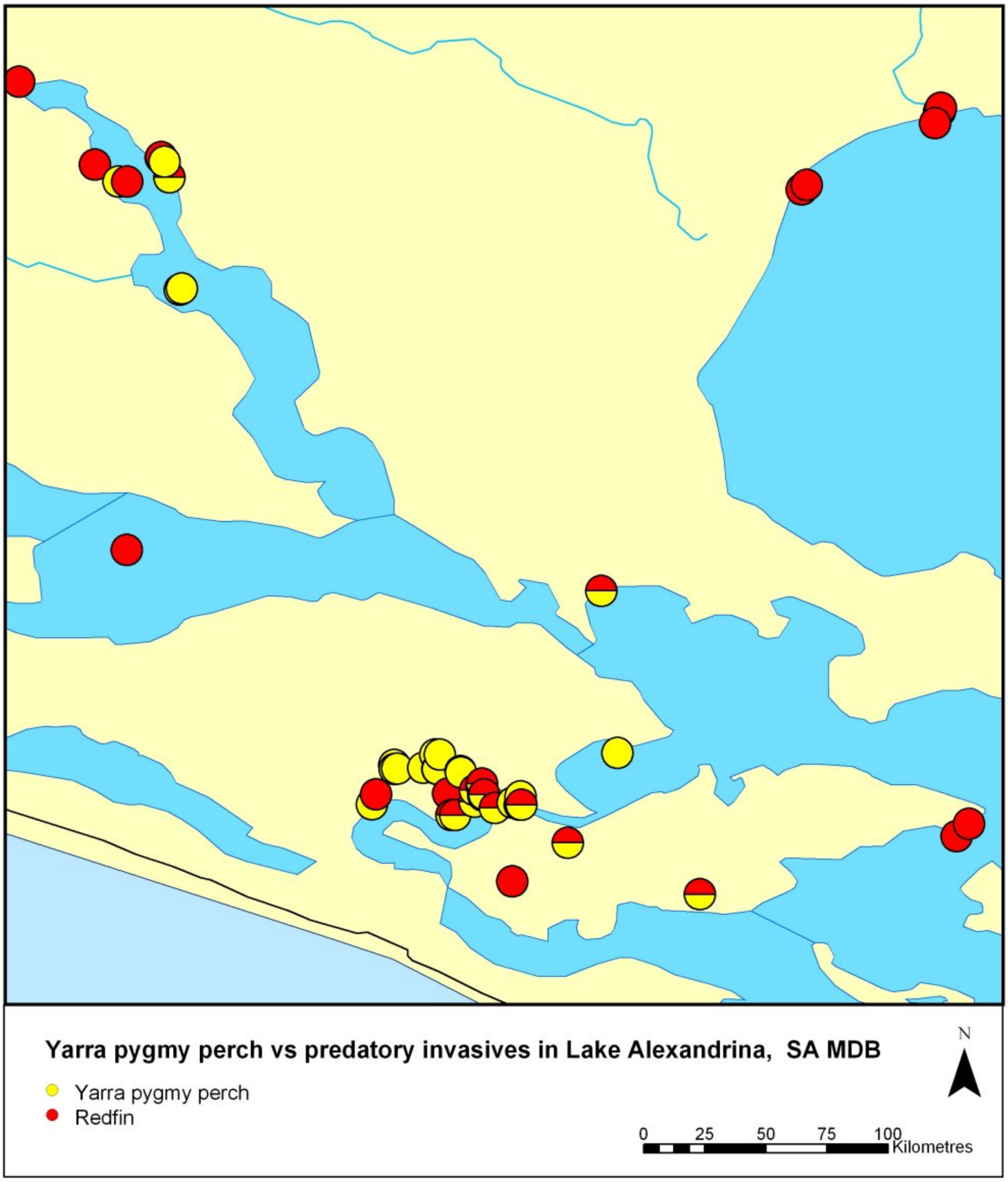


Figure 28. Map showing the current distribution and potential interactions between the native Yarra pygmy perch and the exotic predator redfin perch.

6.4.9 Common galaxias (non-threatened but with a restricted range in SA MDB)

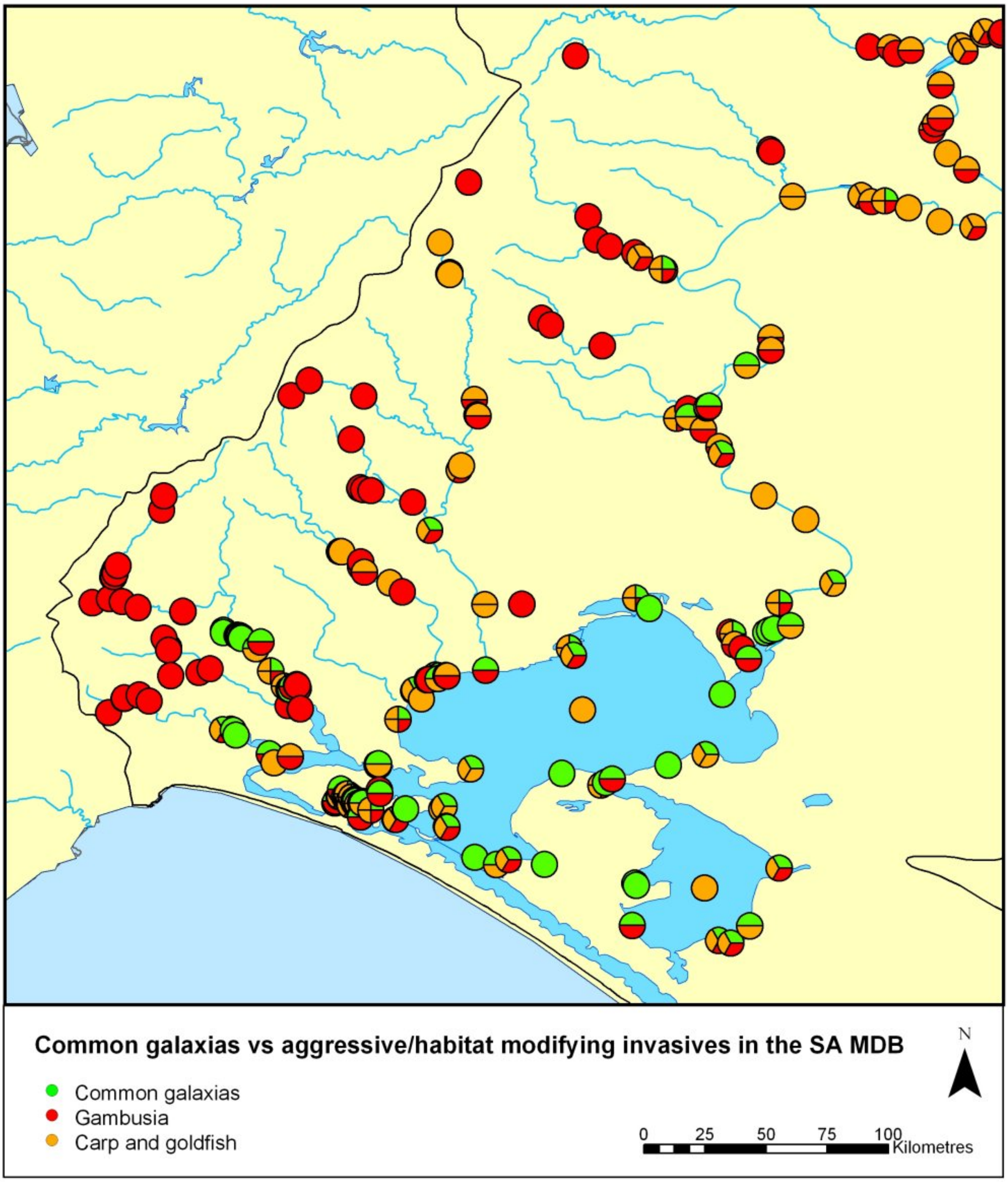


Figure 29. Map showing the current distribution and potential interactions between the native common galaxias and the exotic eastern gambusia, common carp and goldfish.

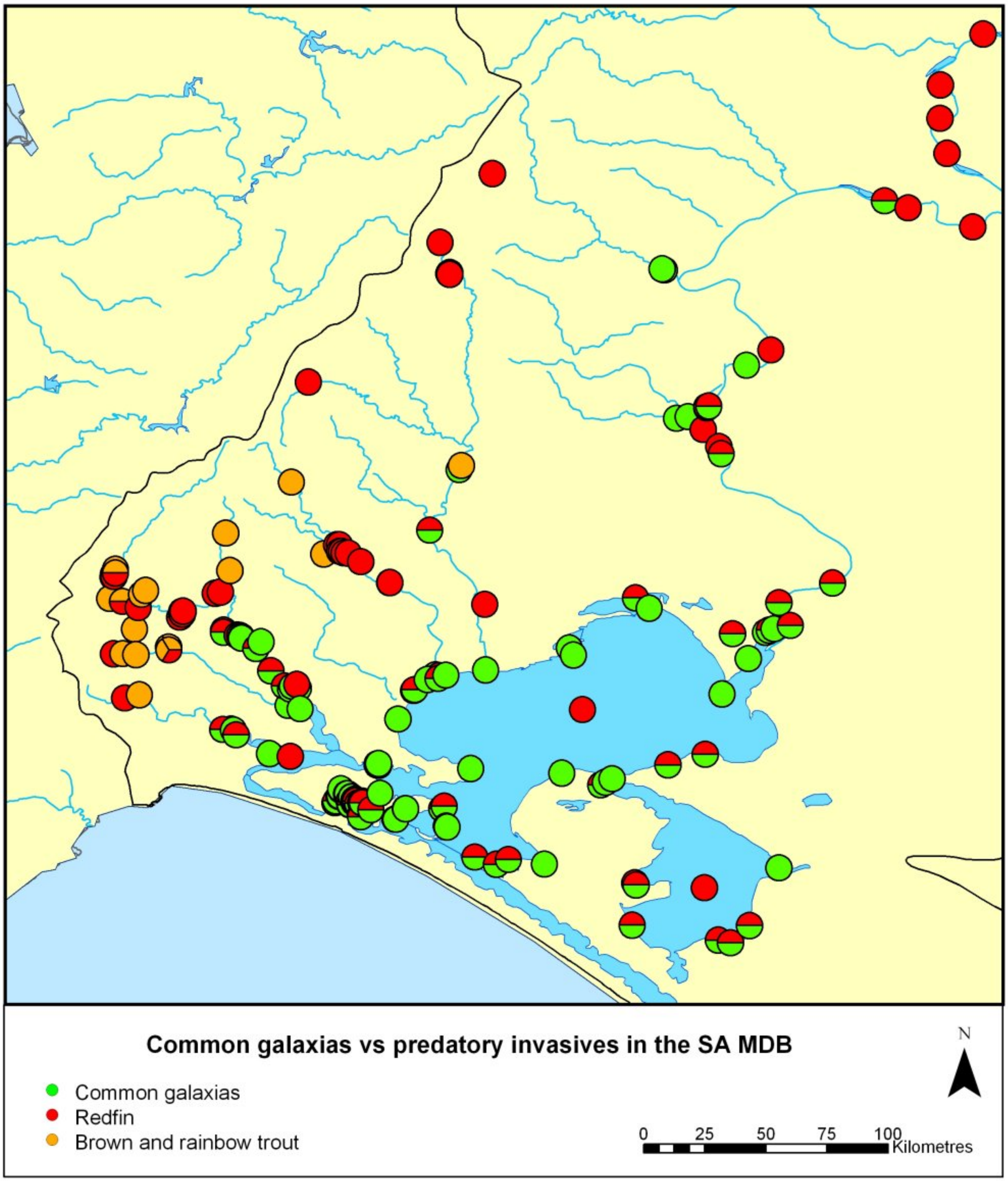


Figure 30. Map showing the current distribution and potential interactions between the native common galaxias and the exotic predators redfin perch, brown trout and rainbow trout.

7. INTRODUCED EXOTIC FISH AND THEIR ENVIRONMENTAL IMPACTS

In general, field surveys, field and laboratory observations and gut content analyses all suggest significant environmental degradation caused by exotic fish. However, for three main reasons, it is difficult to assign accurate levels of impact to any exotic species from field- or larger-scale mesocosm experiments. First, exotic fish have been established in most parts of the Murray-Darling Basin for several decades and information on the condition of river and wetland environments before their introduction is virtually non-existent (Robertson *et al.*, 1997). Thus, true "before and after" comparisons are unworkable. Second, the establishment of exotic fish in Australia has been preceded, and assisted, by co-occurring anthropogenic influences. Accordingly, it is virtually impossible to discriminate the short-term effects of exotic fish from the long-term, cumulative effects of human disturbance (Smith, 2005). These stem from river regulation and water abstraction, catchment clearance and destruction of riparian vegetation, overgrazing, bank erosion, siltation, 'river improvement' schemes, pesticide use and overfishing (Cadwallader, 1978; Walker, 1983); in essence, exotic fish thrive in degraded environments supporting plant and animal communities with little resistance to invasive species. Third, manipulative experiments to date have sometimes been criticised for using inappropriate experimental protocols, which has led to low statistical power and interaction of main effects (for example, see Smith 2005). Despite the points above, analyses of the biology and population dynamics of exotic fish leave little doubt that their impacts are significant, and worth quantifying and attempting to ameliorate via quality research and management. Accordingly, several research priorities are listed in Section 9.

Below, we provide a brief overview of the environmental impacts of exotic invasive fish in the South Australian Murray-Darling Basin; this does not cover the impacts of translocated Australian native species (see Hammer & Walker (2004) for a complete list, and Arthington (1989) for a comprehensive review). Taxa with similar environmental impacts (due to possessing similar ecological/foraging behaviours) have been grouped together under four main banners (Sections 8.1 - 8.4): large bodied predators, potential habitat modifiers, a small-bodied aggressive predator, and an imminent invader. Note that some level of competition for resources is implied across categories.

7.1 REDFIN PERCH, BROWN TROUT AND RAINBOW TROUT

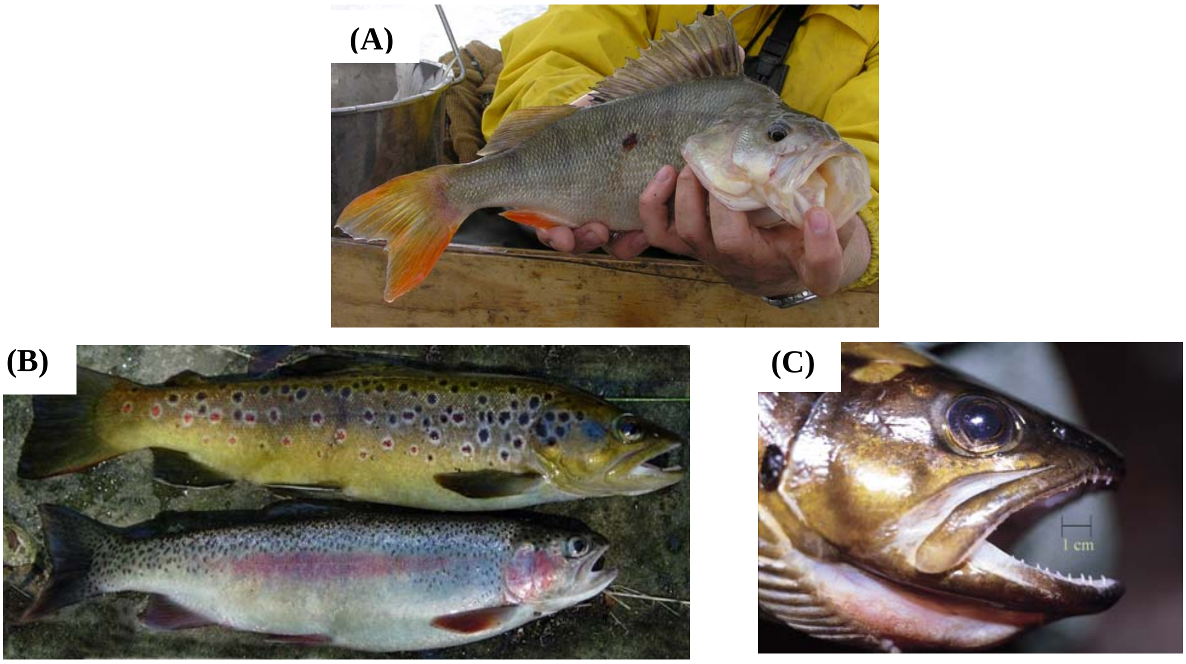


Figure 31. Photographs of (A) redfin perch and (B) brown trout (top) and rainbow trout (bottom). The jaws of the predatory brown trout are highlighted in (C).

Redfin perch are widely distributed in the SA MDB. They occur in upland, slopes and lowland waterbodies (Fig. 11), and prefer areas with aquatic vegetation, rocky outcrops and woody debris, although high water temperatures, high salinities and fast flowing water seem to restrict their distribution interstate (Clunie *et al.*, 2002; Morgan *et al.*, 2004; ISSG, 2005). A similar trend is obvious in the Eastern Mount Lofty Ranges (Hammer, 2004).

Redfin perch are piscivorous by nature but they also prey on macro-invertebrates such as shrimps, yabbies, molluscs and crayfish. Consequently, through direct predation, redfin perch are implicated in the decline and fragmentation of native fish communities. Redfin perch also have the potential to affect native fish through the introduction of pathogens such as the Epizootic Haematopoietic Necrosis Virus (EHNV), which is pathogenic for silver perch, mountain galaxias, Macquarie perch, Murray cod and possibly other native fish (Clunie *et al.*, 2002). Indeed, the *pattern* of redfin perch presence (which may reflect a variety of ecological *processes* from predation, to disease or environment/habitat conditions) may now represent the greatest factor influencing the distribution of small-bodied threatened fishes in the SA MDB (i.e. dwarf-flathead gudgeons, mountain galaxias, Murray hardyhead, Murray rainbowfish, river blackfish, southern pygmy perch, Yarra pygmy perch and common galaxias).

This situation in SA is comparable to that in south-eastern Western Australia, where Morgan *et al*. (2004) state "*the continued illegal translocation of P. fluviatilis is, after habitat degradation, perhaps the greatest threat to endemic fishes and decapods in many south-western Australian aquatic ecosystems*". However, whilst there is significant range overlap between threatened native fishes and redfin perch at the macro-habitat scale (i.e., within river regions), there is lesser range overlap at the micro-habitat scale (i.e., within a wetland or river section, see Figs. 14, 16, 18, 20, 22, 24, 28, and 30). This suggests that the availability of suitable refuge habitat, and the maintenance and rehabilitation of those habitats, is critical for maintaining threatened native fish populations.

On an optimistic note, observations as part of baseline studies and longer-term monitoring in the Angas River Catchment (Eastern Mount Lofty Ranges: Hammer 2004) suggest that native fish can return to pools following redfin perch (and trout) removal, provided that source populations remain. Such observations must be quantified by scientific research, considering local food webs and trophic ecosystem processes. For example, on the Ovens River (Victoria), preferential predation by redfin perch on gambusia appeared to provide competitive benefits to native fish such as carp gudgeons (Stoffels and Humphries 2003; McNeil 2004).

Brown trout and rainbow trout are both coldwater species (optimum, c. 4-19^{o}C). They are active predators, which typically occur in shallow, well-oxygenated waters. They prefer streambeds of gravel, cobbles and pebbles but are also found in deeper holes, lakes and estuaries with large amounts of overhanging riparian vegetation and in-stream woody debris (Clunie *et al.*, 2002). Warm water temperatures generally limit the distribution of self-maintaining trout populations, as they need low water temperatures to breed (Morgan *et al.*, 2004). Juveniles of brown trout and rainbow trout feed on terrestrial aquatic insects that fall onto the water's surface and a diverse array of aquatic micro- and macro-invertebrates. Larger trout also feed on other fish species, mice, frogs, worms, crustaceans and molluscs (Morgan *et al.*, 2004). Food selection varies according to seasons and local variations in abundances and tends to be opportunistic during concentrated conditions in small seasonal waterways (Hammer, 2005, in press).

As a consequence of active predation and competition for food and habitat, brown trout and rainbow trout are implicated in the decline, fragmentation and in some cases, the entire replacement of native fish (particularly galaxiids, Closs and Lake 1996) and macro-invertebrate communities (at meso-habitat or river reach scales; Clunie *et al*. 2002; ISSG 2005). At minimum, small-bodied native fish such as mountain galaxias, river blackfish, southern pygmy perch and Yarra pygmy perch are often pushed into shallow marginal habitats, to the point where there is little range overlap between them and trout (at the micro-habitat scale, see Figs 16, 22, 24 and 28; Clunie *et al.*, 2002; Hammer & Walker 2004; Hammer, 2005, in press).

While trout were detected within a small section of the area under investigation, there are two important aspects with respect to their distribution: (a) trout have been, and are likely to continue to be stocked (legally and illegally) into all suitable permanent waters within the EMLR (Fulton, 2004; Hammer *et al.*, 2005), and (b) the current distributional range of trout overlaps with significant ecological assets in the EMLR, including some of the more pristine habitat and longer-term refuges (i.e. permanent pools). At these locations, site- or microhabitat separation of native species and exotic predators has been noted (Hammer, 2004).

7.2 EASTERN GAMBUSIA

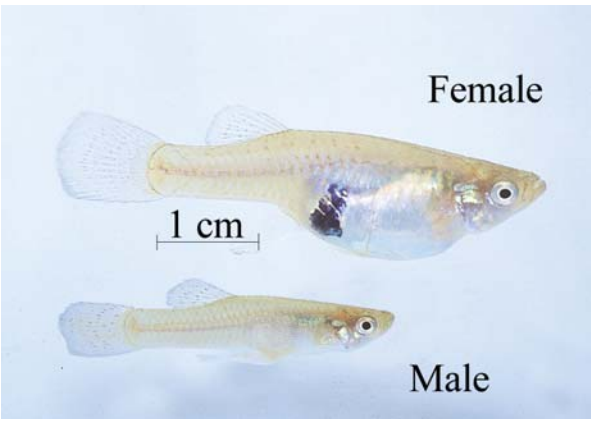


Figure 32. Photographs of female and male eastern gambusia.

The name eastern gambusia is derived from the Cuban word ‘gambusino’ which means “nothing” or “something worthless” (Clunie *et al.*, 2002). The eastern gambusia, *Gambusia holbrooki*, is the only *Gambusia* species present in Australia (McDowall, 1996) and is widely distributed within the SA MDB (Fig. 12). They occur in all SA MDB regions and coexist at some locations with virtually all of SA’s native freshwater fish species. Eastern gambusia are most abundant in lentic, warm, shallow, well-vegetated littoral habitats. Naturally variable flows, high river discharges and cool water temperatures appear to be their only barrier to dispersal and establishment (Fig. 12; Hammer, 2001; Hammer, 2004; McNeil 2004).

As opportunistic, generalist predators, they feed on terrestrial insects that land on the water’s surface and aquatic invertebrates including rotifers, cladocerans, ostracods, copepods, mayflies, dragonflies, molluscs and beetles (Clunie *et al.*, 2002). Despite their voracious predation on aquatic invertebrates, it is now accepted that eastern gambusia are no more effective at controlling mosquitoes (for which they were introduced) than native fish (Lloyd, 1987). Indeed, by removing zooplankton predators, they may actually encourage the proliferation of mosquitos and algal blooms, thereby decreasing water clarity and quality (Ling, 2004). Eastern gambusia also display aggressive behaviour (such as fin-nipping) toward other small fish, and prey on the eggs and larvae of larger native fish and amphibians (Morgan *et al.*, 2004). Indeed, 35 species worldwide are suspected to have declined in abundance or range as a result of direct interactions with eastern gambusia (ISSG 2005). It is unsurprising then that eastern gambusia has been given such titles as “fish destroyer”, “damnbusia” and “plague minnow” (Ling, 2004). The name “damnfloosies” is also appropriate, given the abundance of pregnant females (D. McNeil, Pers. Comm.), but “plague minnow” is most accurate.

In habitats without cover, small native fishes and the larvae of amphibians are particularly prone to predation and aggressive interactions (NSW National Parks and Wildlife Service, 2003; Morgan *et al.*, 2004). Through competition for food and habitat eastern gambusia has, and will continue to exert pressure on Australia’s native fish fauna including members of the genera *Mogurnda, Ambassis, Melanotaenia, Craterocephalus, Nannoperca* and *Retropinna* (Lloyd, 1987; Clunie *et al.*, 2002). Conversely, when given a choice of prey, native and exotic fish predators avoid eastern gambusia (MacKenzie *et al.*, 2001).

Whilst a long co-existence between eastern gambusia and other native fish species may imply that competition and predation is minimal (Ling 2004), the abundance of eastern gambusia and the continuing decline in the range and abundance of small-bodied threatened native species cannot be ignored. The restoration of riparian and littoral habitat, via fencing and revegetation may provide suitable refuge habitat or increased structural diversity to allow co-habitation with native aquatic fauna. Re-instating natural components of flow regimes may also help to depress eastern gambusia abundance by discouraging their establishment and providing more suitable conditions for native fishes - thus affording greater resilience or resistance against negative interactions.

7.3 COMMON CARP, GOLDFISH AND TENCH

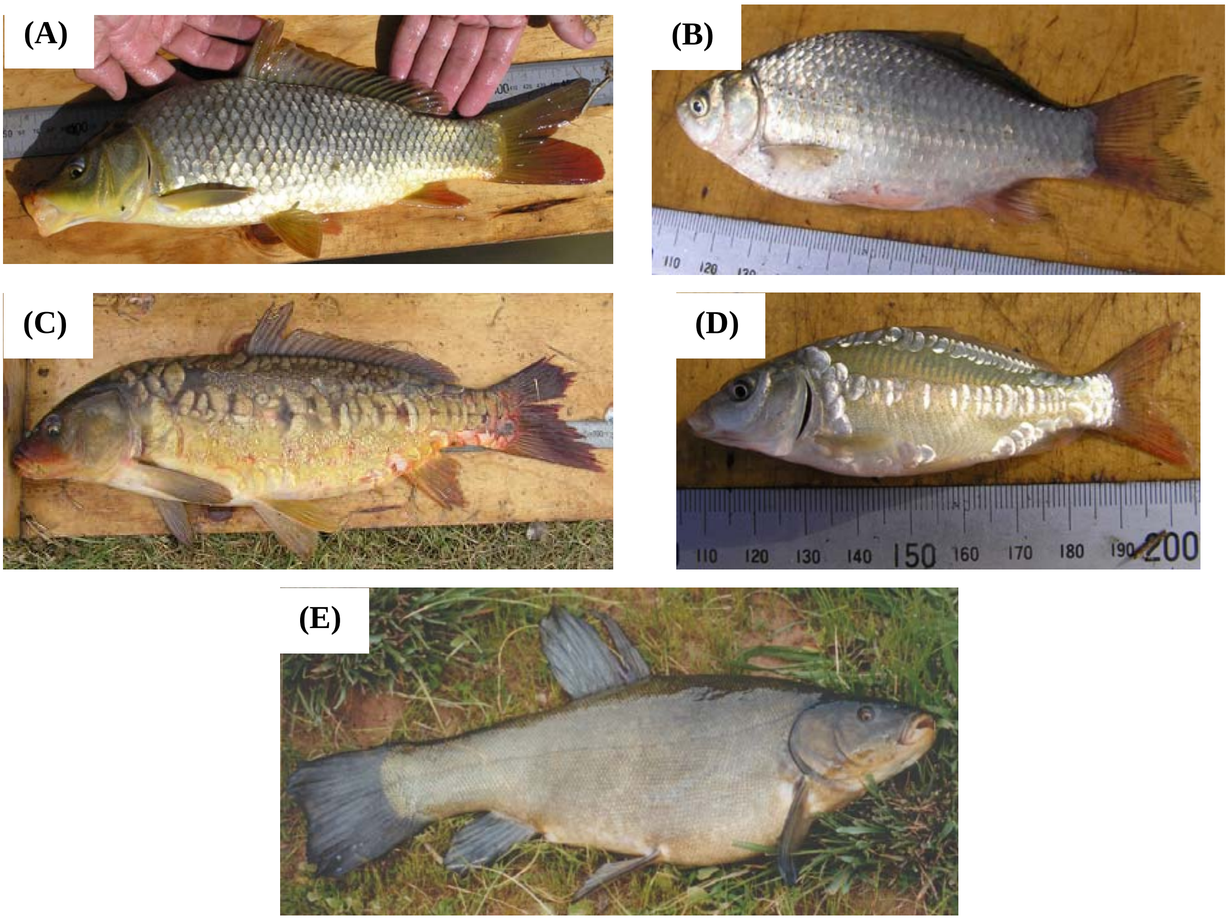


Figure 33. Photographs of (A) common carp, (B) goldfish and (C-D) scaled varieties of common carp; ‘mirror’ carp and ‘line’ carp. A large tench is shown in (E).

In Australia, common carp typify a successful exotic invader. In SA, they are widely distributed (Fig. 10), large-bodied, and during spring/summer are a conspicuous component of many off-stream wetlands, lakes and billabongs. Species attributes include fast growth, early maturation, longevity, high reproductive potential, broad physiological and environmental tolerances, opportunistic omnivorous diet and few predators (Smith, 2005). The major affiliation of carp is with lowland, regulated, degraded habitats that reflect sustained human impact (Cadwallader, 1978). Where semi-natural flow patterns and diverse plant and animal communities are maintained, however, carp are absent or present in only minor numbers (Hume *et al.*, 1983; Gehrke *et al.*, 1995).

Many of the assertions regarding the effects of carp on the environment primarily relate to the benthic feeding of carp, whereby mouthfuls of bottom sediment are sucked into the mouth and separated from food in the pharyngeal slits (Sibbing *et al*., 1986); food items are retained, finer particles are expelled behind the opercula and large particles are forcibly egested (Lammens & Hoogenboezem, 1991). In this way, carp are claimed to increase turbidity, disturb and re-distribute benthic seeds and invertebrates, undermine aquatic plants, prevent the establishment of seedlings and compete with small native fishes for food and space. Indirectly, they are also implicated in the development of toxic algal blooms and in reducing the growth of algal biofilms and aquatic plants (Clunie *et al.*, 2002). Further, carp are claimed to decrease the value of natural waterways for recreational fishers and therefore negatively affect the tourism industry (MacKenzie *et al.*, 2001). Whilst many of these effects are still speculative and based on uncritical extrapolations from observations of captive fish, the mere presence of carp and their sheer biomass in many of Australia's lowland rivers (Gehrke *et al.*, 1995; Gehrke & Harris, 2000) must contribute to river degradation. Effects are likely to be greatest in small, shallow (drying) lakes or wetlands with high densities of carp and limited food resources (Fletcher *et al.*, 1985). In these instances the effects that carp are accused are probably realistic. There is no evidence, however, to suggest that carp:

1. Uproot vegetation that they spawn over.
2. Undermine emergent, robust plants (i.e., *Juncus*, *Typha*, *Phragmites* spp.), or species that form dense masses and thick growth (*Myriophyllum*, *Ludwigia* spp.). Only submerged, shallow-rooted aquatics with soft-leaves are vulnerable (i.e., *Potamogeton* spp., Charophytes and *Vallisneria*).
3. Undermine river-banks or contribute to bank slumping.
4. Reduce plant growth via sustained shading caused by temporary increases in turbidity

Goldfish and tench are closely related to carp (all members of the family Cyprinidae), and goldfish have similar behavioural, foraging, spawning and habitat preferences. Goldfish also occupy a similar range to carp in SA (Fig. 10) and as such, are implicated in causing similar ecological impacts (Morgan *et al.*, 2005). In addition, goldfish can carry the bacteria *Aeromonas salmonicida*, which causes bleeding ulcers on their skin (Clunie *et al.*, 2002) and is known to devastate salmonids such as brown trout and rainbow trout. The potential for on-going release of unwanted aquarium stock also presents a continual potential source of pathogens and parasites to naïve (no acquired immunity) native fishes (Lintermans, 2004).

Tench has a limited distribution throughout Australia (and SA, Fig. 10), having generally declined since the introduction of carp, and in any case are thought to have caused limited environmental impact (Clunie *et al.*, 2002). Juveniles feed on zooplankton and small insects and crustaceans, while adults are essentially carnivorous (rather than omnivorous like carp and goldfish) feeding on molluscs, insect larvae, small crustaceans and occasionally plant material (Clunie *et al.*, 2002). Thus, there may be local issues relating tench to habitat degradation and competition for food and habitat (ISSG, 2005). Interestingly, tench co-occur in low numbers in the Angas River Catchment with reasonable numbers of the endangered river blackfish, suggesting impacts to this species under current environmental conditions are minimal.

7.4 ORIENTAL WEATHERLOACH – AN IMMINENT EXOTIC INVADER

Figure 34. Picture of an oriental weatherloach sampled February 2004 from a wetland at Gunbower State Forest which is ~400 river km from the SA border.

The name oriental weatherloach derives from the belief, so far unsubstantiated, that the fish becomes restless during changes in air pressure (ISSG, 2005). Whilst oriental weatherloach (*Misgurnus anguillicaudatus*) are not yet in South Australia, they are widespread globally and have established self-maintaining populations in NSW, Vic, the ACT and Qld. They occur in many lowland habitats (main channel, anabranches and wetlands), and are capable of moving over land to colonise new water bodies. They are a relatively small species (max. length = 20 cm in Australia) and have a flexible omnivorous diet (insect larvae, crustaceans, detritus and algae), broad physiological and environmental tolerances, high reproductive potential and can respire and survive temporarily out of water where they burrow into the sediments to aestivate and/or avoid predation (ISSG, 2005; Amonline, 2006). Due to their species attributes and competitive ability, the establishment of self-sustaining populations of weatherloach in most habitats of the South Australian Murray-Darling Basin is virtually unavoidable once they are physically introduced (Clunie *et al.*, 2002; McNeil 2004). In that regard, downstream dispersal/transport of young is a major vector for invasive species colonising new riverine habitats (Koehn *et al.*, 2003). Indeed, Koehn *et al.* (2003) declare "*oriental weatherloach probably provide the clearest example of rapid downstream colonisation by an invasive species in the MDB. Since 1985, they have spread downstream from the Ovens River near Wangaratta, apparently aided by floods, and now inhabit the Murray River as far downstream as Swan Hill*"; Swan Hill is <400km from the SA border.

The ecological impacts of weatherloach remain unsubstantiated but speculative impacts include competition with native fishes for food (and space), shelter and spawning sites, disturbance or predation of eggs and larvae, alteration of habitat through stirring up sediments and uprooting plants (Koster *et al.*, 2002). Past experience demands the precautionary approach to managing pest fish incursions (ABG, 2005), and in SA, *a-priori* research should begin to determine the potential range, likely impacts and options for management for oriental weatherloach, especially in sensitive areas where threatened fish occur. Section 6.2 identifies the Eastern Mount Lofty Ranges and Lower Lakes as a priority in this regard.

8. RESEARCH PRIORITIES

8.1 THREATENED NATIVE SPECIES

1. Intensive mapping and ecological studies (habitat and environmental flows) to: (a) identify critical meso- and micro-habitats and important environmental conditions, particularly those in close proximity to threats such as large-bodied predators and aggressive species, (b) compare data to historic sampling points and analyse with respect to species ecology at remaining habitat to identify *optimal* habitat conditions, and (c) identify negative interactions between exotic fish which threaten the viability of important populations of native fishes.

2. Use the findings of 9.1.1. to: (a) enhance local habitat as a proactive means to prevent further range contractions, (b) restore areas connected to threatened species habitat, to aid in natural re-colonisation by local genotypes, and (c) assist in holistic catchment wide management. Note that some of this work is already underway for the threatened southern pygmy perch (Hammer, 2002b) and Eastern Mount Lofty Ranges habitat (MREFTP, 2003; RWCMB environmental flows program), and all three points above cover minimising interactions with exotic fishes (see 9.2).

8.2 EXOTIC INVASIVE SPECIES

1. By reviewing existing data and undertaking ecological studies, identify the physical, chemical and flow conditions at locations (various spatial scales) where key exotic fishes are present. Compare this with locations where they are absent, and use the information to predict the final distribution of each species within the SA MDB. Subsequently, identify (a) critical rivers, reaches and/or refuge areas for threatened native species, where the spread of exotic invasive species must be prevented/controlled, and (b) management goals centred on environmental manipulation/restoration to reduce the occupied range of exotics (and in doing so, ensure the protection of native species: see 9.1.2). Possible innovative control methods should also be scoped and implemented if negative interactions are deemed to be a threat to the future viability of important populations of native fish and/or significant ecological assets.

2. Critically evaluate the effect of young-of-the-year (YOY, juvenile) exotic fish on our native fish populations and trophic ecosystem processes. Juvenile carp, gambusia, redfin perch and trout are significant planktivores, aggressors and small predators, respectively, and given their extreme abundance in comparison with adult fishes, are likely to represent the greatest ecological threat. Threatened native fish species such as Murray rainbowfish, Murray hardyheads and dwarf-flathead gudgeons, which continue to decline in range and abundance, are seemingly most at risk.

3. As part of an integrated strategy to prevent further range contractions, fragmentation of populations and declines in native fish abundance, the development of a redfin perch control strategy should be seen as a high priority. Given a more expansive range elsewhere in the state (e.g. Hammer, 2002a; Hammer, 2005, in press) it should also be a priority for other NRM regions. In the meantime, manipulative field experiments, which follow accepted scientific protocols, must be instigated to quantify the impact of redfin perch on native fish communities, and the responses of native fish and aquatic ecosystems following redfin perch removal (initial circumstantial evidence for the Eastern Mount Lofty Ranges suggests this could be possible at least in the short-term). Key research questions include: how quickly do changes occur? Can native fish recolonise habitats that they were previously excluded from? What effect do redfin perch have on local food webs, and what effect does this have on trophic ecosystem processes? Is it necessary to also remove gambusia to maximise the recovery of native fish?

4. Wetland carp separation cages (CSC's; akin to carp separation cages as used in river fishways, see Staurt *et al*. 2003) represent a unique opportunity for harvesting significant quantities of carp (and minimising their environmental impacts) as they bottleneck through wetland inlets for spawning. However, wetland CSC's are untested within wetlands and given the disparate conditions between wetland inlets and river fishways, preliminary data is needed to ensure their success and optimise their use. Testing and evaluation of wetland CSC's should be targeted at carp recruitment 'hot spots' such as the southern lagoon at Walker Flat.

5. In regards to carp, there are several additional research priorities for SA which align with the national priorities (under the National Strategy for Carp Control) and those of the newly developed Invasive Animals Cooperative Research Centre. They include, a) identifying carp recruitment ‘hot spots’, b) identifying chemical or biological attractants, b) evaluating carp movement/migration patterns and correlating these with environmental cues, and c) investigating innovative physical and chemical control measures.

6. The wide range and general abundance of eastern gambusia in the SA MDB places a high priority on investigating control options, or ways of mitigating impacts from this species. In that regard, providing natural flow and habitat conditions would be the desired option (see recommendation 9.2.1).

7. While trout occupied only a small section of the area under investigation, there was critical overlap with key threatened native species, pristine habitat and areas otherwise free of exotic fish. At these sites, there is evidence suggesting negative interactions between these exotic predators and native fish, particularly galaxiids. Stocking and control should thus be critically examined within a scientific framework of native species conservation. With specific reference to stocking in the study region and elsewhere in the State, investigate the population dynamics and environmental factors for new introductions of salmonids i.e. are all introductions successful? Can ‘best practice’ stocking policies (with regard for sizes and densities) be developed? What are the quantifiable ecological impacts of stocking salmonid fry, even if they do not result in self-sustaining populations?

8. Past experience demands the precautionary approach to managing pest fish incursions, and in SA *a-priori* research should begin to determine the potential geographic range, likely impacts and options for managing oriental weatherloach; it is not a question of *if* but *when* they will arrive in SA. In SA, the introduction of weatherloach represents a unique opportunity to undertake robust research using a BACI (Before-After Control-Impact) type-approach for the experimental design.

9. In line with points above (and with the recommendations of the Native Fish Strategy, the Australian Society for Fish Biology and the Invasive Animal CRC), an overriding management objective should be the development of rapid response plans to pest fish incursions, for likely invaders and for locations/river systems that are still free from a majority of exotic species (i.e. Cooper Creek/Lake Eyre Basin, much of South-East South Australia and indeed particular catchment sections of the Eastern Mount Lofty Ranges). As soon as there is a report of a new population a standard plan should be implemented to maximise chances, and significantly reduce the long-term costs, of successful control.

9. ACKNOWLEDGEMENTS

Thanks to Qifeng Ye, David Creeper and Adrian Harvey for initial project discussions and early planning. Dale McNeil, Qifeng Ye and John Carragher also provided constructive comments on an earlier version of this manuscript. PIRSA Rural Solutions and SARDI Aquatic Sciences funded this work.

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