South Australian River Murray Regional Wetlands Fish Assessment 2003–2012

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Contents

Summary

There have been approximately 47 freshwater, estuarine and diadromous fish species recorded in the South Australian River Murray catchment, including 16 species of conservation significance and eight alien species. At least two species are presumed extinct (Agassiz's glassfish, trout cod). The causes of decline are largely related to the effects of river regulation (e.g. altered flow regimes), and impacts from alien fish species are likely significant. As a consequence of drought, wetlands below Lock 1 were disconnected from the river channel and the Lower Lakes by 2006–2007, and habitats deteriorated (drying and salinisation). Wetlands were reconnected to the river channel when substantial increases in river flows commenced in 2010. The same circumstance applied to some off-channel sites above Lock 1 during the drought, but many remained connected to the river due to the hydraulic head upstream of the weirs.

The aim of this study was to combine data collected by South Australian Government agencies to assess regional shifts in fish communities from 2003–2012. The objectives of this study are to (1) determine how fish communities in wetlands of the South Australian River Murray have changed over time among geomorphic and river management (i.e. weir reach) regions, including analysis of early-drought, drought and post-drought periods, (2) identify threats to threatened species and determine if populations have reduced or increased since 2003, and (3) identify the extent of pest fish in the region and determine whether this has decreased or increased since 2003. This report also discusses how habitat conditions and fish communities might change over coming decades in the context of the Board's targets to improve and maintain water-dependant ecosystems. This study focuses only on the general patterns regarding shifts in regional wetlands fish communities without considering the details of micro-management activities. Specifically, sections of some wetlands underwent managed wetting and drying cycles during the drought, and carp exclusion screens were sometimes installed. Following the return of river flows in 2010, all structures were open and almost all carp exclusion screens were removed.

At least 28 native and five alien fish species were recorded from 2003–2012 in wetlands of the River Murray, South Australia. Freshwater ecological generalists (species with broad ecological requirements) were captured in all regions, including Australian smelt, bony herring, unspecked hardyhead, carp gudgeon complex, flathead gudgeon, golden perch, carp, goldfish, Gambusia and redfin. However, Murray rainbowfish was always absent from samples at the Lower Lakes. Freshwater ecological specialists (mostly threatened species) were mostly restricted to one of the four regions, including southern pygmy perch and Yarra pygmy perch (Lower Lakes), and southern purple-spotted gudgeon (below Lock 1). An exception, Murray hardyhead, was unrecorded only in the region between Overland Corner and Blanchetown. Estuarine and diadromous fishes (ecological specialists) were restricted to the two regions below Lock 1, namely congolli, common galaxias, smallmouth hardyhead and the gobies.

The findings demonstrate that fish communities in South Australian River Murray wetlands underwent substantial changes from 2003–2012. The shifts in fish communities appear to be a consequence of reduced river flows during drought. Drying and salinisation were key factors, and occurred naturally or through the managed closure of wetlands as flows diminished. Significantly, the shifts included major declines and extirpations of threatened species. Following the return of flows in 2010, there was a notable lack of recovery for most threatened species, except freshwater

catfish and congolli showed positive signs of renewed recruitment. Similarly, the commercially and recreationally important golden perch apparently benefitted from the increased flows. Critically, however, there were proliferations of carp, goldfish and redfin in wetlands, whereas the Gambusia population remained relatively constant throughout the study.

Over 2011–2012, a fish re-stocking program funded by the Murray–Darling Basin Authority, managed under the Department for Environment and Natural Resources’ Critical Fish Habitat project, aimed to assist population recovery for threatened wetland fish species, including Yarra pygmy perch, southern pygmy perch, Murray hardyhead and southern purple-spotted gudgeon. The population outcomes of the re-stocking efforts will not be determined until monitoring in the 2012–2013 breeding season. The current study demonstrates that freshwater catfish, congolli and golden perch show early signs of natural population recovery. This is particularly relevant to flow management in the lower River Murray as it relates to water quality and connectivity (for fish migration) between wetlands and the river and between the Lower Lakes and Coorong.

Introduction

There have been approximately 47 native freshwater, estuarine and diadromous fish species recorded in the South Australian River Murray catchment (Table 1). Several estuarine species have been omitted from the list because they rarely occur above the barrages (e.g. yellow-eye mullet *Aldrichetta fosteri*). The national *Environment Protection and Biodiversity Conservation Act 1999* lists three species as Vulnerable and three as Endangered. Using the International Union for the Conservation of Nature's criteria for assigning conservation status, and through extensive consultation with fish ecologists, the Action Plan for South Australian Freshwater Fishes lists five species as Critically Endangered, seven as Endangered, two as Vulnerable and two as Rare (Hammer et al. 2009). These conservation ratings correspond to listings in the Draft Threatened Species Schedules of the South Australian *National Parks and Wildlife Act 1972*. Two species are presumed extinct in the lower Murray (Agassiz's glassfish, trout cod: Hammer and Walker 2004), and other recent extinctions are likely (Yarra pygmy perch: Hammer et al. 2010; Wedderburn et al. 2012).

Regulation of the lower River Murray appears to have benefited some native ecological generalist fish species (broad environmental requirements), which often dominate fish communities in wetlands that are permanently inundated due to the hydraulic head associated with water impounded by the weirs (e.g. Australian smelt: Humphries and Lake 2000; bony herring: Puckridge and Walker 1990). Conversely, the reduction in flows since regulation, and the resultant limited exchange of water and biota between the river and its floodplain (Walker and Thoms 1993), may be responsible for the decline of some ecological generalists (narrow environmental requirements, e.g. southern pygmy perch: Tonkin et al. 2008). Other reasons include interactions with alien species and over-fishing (Cadwallader 1978; Gehrke et al. 1995), disruptions to migratory pathways (e.g. congolli: Zampatti et al. 2010) and increased salinisation of off-channel habitats (e.g. Yarra pygmy perch: Wedderburn et al. 2012). Many of these threats are predicted to increase under climate change forecasts (Pratchett et al. 2011).

As a consequence of drought and the associated habitat deterioration that occurred from 2003–2010, many ecological specialist wetland fish species declined or were extirpated (mostly threatened species: Hammer 2007b). This was apparent at the Lower Lakes (Murray hardyhead, Yarra pygmy perch, southern pygmy perch: Bice et al. 2010; Wedderburn and Hillyard 2010; Wedderburn et al. 2012), near Murray Bridge (purple-spotted gudgeon: Bice et al. 2011) and at refuges near Berri (Murray hardyhead: Bice et al. 2011). However, most ecological generalists apparently remained common throughout the drought (e.g. Australian smelt, bony herring: Conallin et al. 2011; Smith et al. 2009), even in wetlands below Lock 1 (Smith 2010).

A substantial increase in river flows in the second half of 2010 re-inundated wetlands and re-established their connectivity with the river channel. Given the sudden environmental changes to the lower River Murray caused by substantial high flows (often ~90,000 ML/day over summer 2010–2011) following drought, it is important to track the on-going changes in fish communities within wetlands by examining long-term data collected by the South Australian Murray–Darling Basin Natural Resources Management (SAMDBNRM) Board and the Department for Environment and Natural Resources (DENR). To date, the data has been used for adaptive management of the wetlands and summary reports for community groups and other Government agencies. However, the information has not been integrated to determine the broader regional trends of fish communities. It is important to know the regional status of fish communities in River Murray wetlands after the drought, especially with regard to the recovery of threatened fish populations. Further, because some alien fish species benefit from re-inundation of wetlands (e.g. carp: King et al. 2003), it is important to know the extent of their post-drought distributions and abundances, which will reflect their level of potential impacts on native fish communities.

The aim of this study was to combine the SAMDBNRM Board and the DENR data and assess regional shifts in wetland fish communities from 2003–2012. This study encompassed three main objectives:

(1) Determine how fish communities in wetlands of the South Australian River Murray have changed over time among geomorphic and river management (i.e. weir reach) regions, including analysis of early-drought, drought and post-drought periods.
(2) Identify threats to threatened species and determine if populations have reduced or increased since 2003.
(3) Identify the extent of pest fish in the region and determine whether this has decreased or increased since 2003.

This report also discusses how habitat conditions and fish communities might change over coming decades in the context of the SAMDBNRM Board's targets to improve and maintain water-dependant ecosystems. This study focuses only on the general patterns regarding shifts in regional wetlands fish communities without considering the details of micro-management activities. Specifically, sections of some wetlands underwent managed wetting and drying cycles during the drought, and carp exclusion screens were sometimes installed. Following the return of river flows in 2010, all structures were open and almost all carp exclusion screens were removed.

Table 1. Fishes recorded in the South Australian River Murray catchment and their conservation status.

Common name	**Taxonomic name**	*Conservation status*
Common galaxias	*Galaxias maculatus*	-
Murray galaxias	*Galaxias rostratus*	Extinct[1]
Climbing galaxias	*Galaxias brevipinnis*	Rare[1]
Mountain galaxias	*Galaxias olidus*	Vulnerable[1]
Australian smelt	*Retropinna semoni*	-
Bony herring	*Nematalosa erebi*	-
Murray rainbowfish	*Melanotaenia fluviatilis*	-
Smallmouth hardyhead	*Atherinosoma microstoma*	-
Murray hardyhead	*Craterocephalus fluviatilis*	Critically Endangered[1]; Endangered[2]
Unspecked hardyhead	*C. stercusmuscarum fulvus*	-
Southern pygmy perch	*Nannoperca australis*	Endangered[1]
Yarra pygmy perch	*Nannoperca obscura*	Critically Endangered[1]; Vulnerable[2]
Agassiz's glassfish	*Ambassis agassizii*	Critically Endangered[1]
River blackfish	*Gadopsis marmoratus*	Endangered[1]
Southern purple-spotted gudgeon	*Mogurnda adspersa*	Critically Endangered[1]
Murray–Darling carp gudgeon	*Hypseleotris* sp	-
Midgley's carp gudgeon	*Hypseleotris* sp	-
Western carp gudgeon	*Hypseleotris klunzingeri*	-
Hybrid carp gudgeon	*Hypseleotris* spp.	-
Flathead gudgeon	*Philypnodon grandiceps*	-
Dwarf flathead gudgeon	*Philypnodon macrostomus*	-
Lagoon Goby	*Tasmanogobius lasti*	-
Tamar River goby	*Afurcagobius tamarensis*	-
Blue spot goby	*Pseudogobius olorum*	-
Bridled goby	*Arenigobius bifrenatus*	-
Congolli	*Pseudaphritis urvillii*	Vulnerable[1]
Short-finned eel	*Anguilla australis*	Rare[1]
Murray cod	*Maccullochella peelii peelii*	Endangered[1]; Vulnerable[2]
Macquarie perch	*Macquaria australasica*	Extinct[1]; Endangered[2]
Estuary perch	*Macquaria colonorum*	Critically Endangered[1]
Golden perch	*Macquaria ambigua ambigua*	-
Trout cod	*Maccullochella macquariensis*	Extinct[1]; Endangered[2]
Silver perch	*Bidyanus bidyanus*	Endangered[1]; Vulnerable[2]
Spangled perch	*Leiopotherapon unicolor*	-
Freshwater catfish	*Tandanus tandanus*	Endangered[1]
River garfish	*Hyporhamphus regularis*	-
Sandy sprat	*Hyperlophus vittatus*	-
Pouched lamprey	*Geotris australis*	Endangered[1]
Shorthead lamprey	*Mordacia mordax*	Endangered[1]
Alien species		
Carp	*Cyprinus carpio*	-
Goldfish	*Carassius auratus*	-
Oriental weatherloach	*Misgurnus anguillicaudatus*	-
Tench	*Tinca tinca*	-
Gambusia	*Gambusia holbrooki*	-
Redfin	*Perca fluviatilis*	-
Brown trout	*Salmo trutta*	-
Rainbow trout	*Oncorhynchus mykiss*	-

[1]South Australia (Hammer et al. 2009)
[2]*Environment Protection and Biodiversity Conservation Act 1999*

Methods

Study regions

Fish sampling was conducted at wetlands associated with the River Murray in South Australia. In this study, 'wetland' is defined as a shallow, broad, off-channel waterbody that is often well-vegetated (e.g. swamp, lagoon, evaporation basin). The lower Murray was divided into four sections, primarily based on geomorphology and weir pool level considerations (Figure 1):

(1) Region 1: Riverland (Border – Overland Corner) is the Riverland where off-channel sites have been sampled by the DENR and the SAMDBNRM Board since 2003, including ephemeral and permanent wetlands, and wetland sections of salt evaporation basins.

(2) Region 2: Murray Gorge (Overland corner – Blanchetown) is the Gorge above Lock 1 and includes wetlands that have been sampled by the DENR and the SAMDBNRM Board since 2003.

(3) Region 3: Murray Gorge (Blanchetown – Wellington) is the Gorge below Lock 1, which was subject to more severe impacts of drought with regards to water level recession.

(4) Region 4: Lower Lakes are the fringing wetlands of Lake Alexandrina and Lake Albert, but excludes other off-channel waterbodies in the region (e.g. irrigation channels). Wetlands at the Lower Lakes were dry during the drought period, with the exception of Dunn Lagoon and Narrung Wetland which were sampled early in the drought period prior to drying.

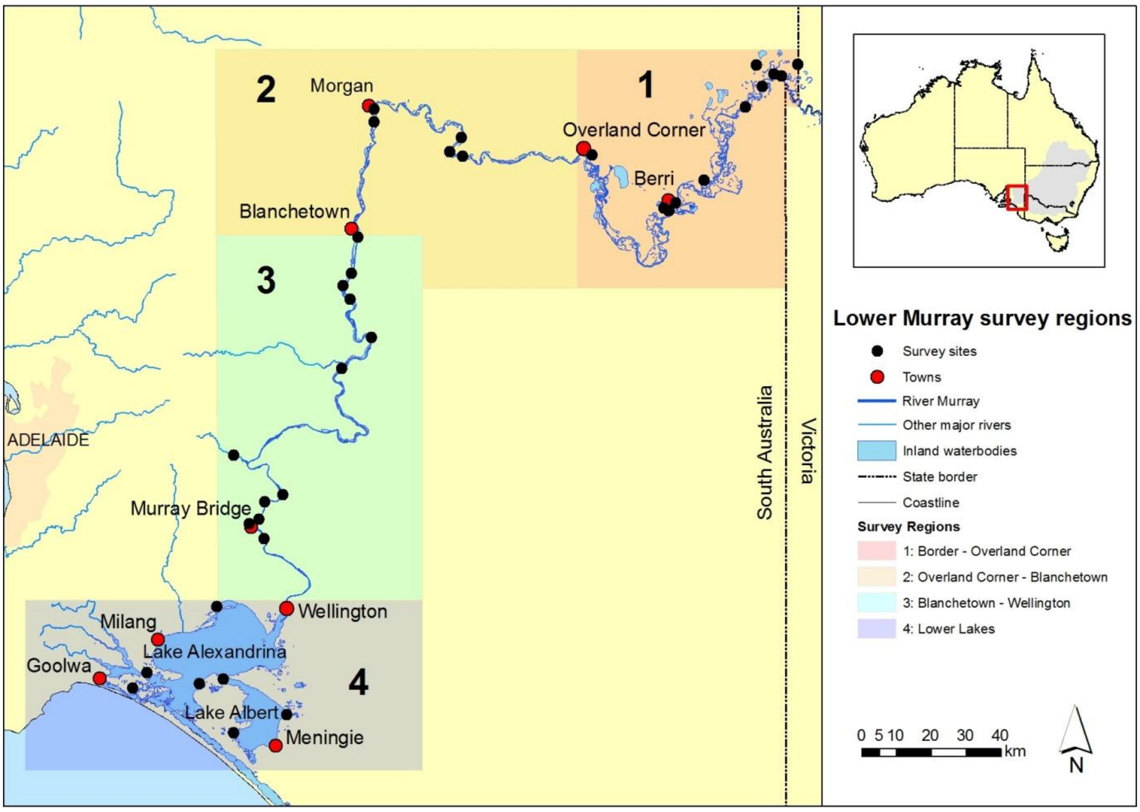

Figure 1. Fish sampling locations and regional divisions in the lower River Murray, South Australia.

Time periods

Three time periods were selected based on the effects of drought in wetlands, specifically when flow rates changed and connectivity of wetlands were altered (Figure 2):

(1) Early-drought period is from 2003–June 2006 (maximum monthly flow to SA = 2,798–15,100 ML/day).
(2) Drought period is from July 2006–June 2010 (maximum monthly flow to SA = 1,398–9,423 ML/day), when the consequences of drought started and ended having substantial effects on wetlands (disconnection, salinisation, water level recession).
(3) Post-drought period is from July 2010–January 2012, which commenced as substantial flows returned to the lower River Murray (e.g. max. 86,096 ML/day in February 2011).

This assessment examines changes in wetland fish communities at a regional level, so important aspects of individual wetland management strategies are omitted because they require more detailed analyses. Specifically, some sections of various wetlands throughout the Murray in South Australia were being managed for wetting and drying phases in the early-drought period, and carp exclusion screens were used in some cases. During the drought period, many of the wetlands above Lock 1 (regions 1 and 2) underwent prolonged, managed drying phases, with occasional refill events. Conversely, wetlands below Lock 1 (regions 3 and 4) underwent drying as a result of disconnection from the Murray because river water levels receded. All wetland structures were opened, and most carp screens were removed when high river flows commenced and river levels increased in the post-drought period.

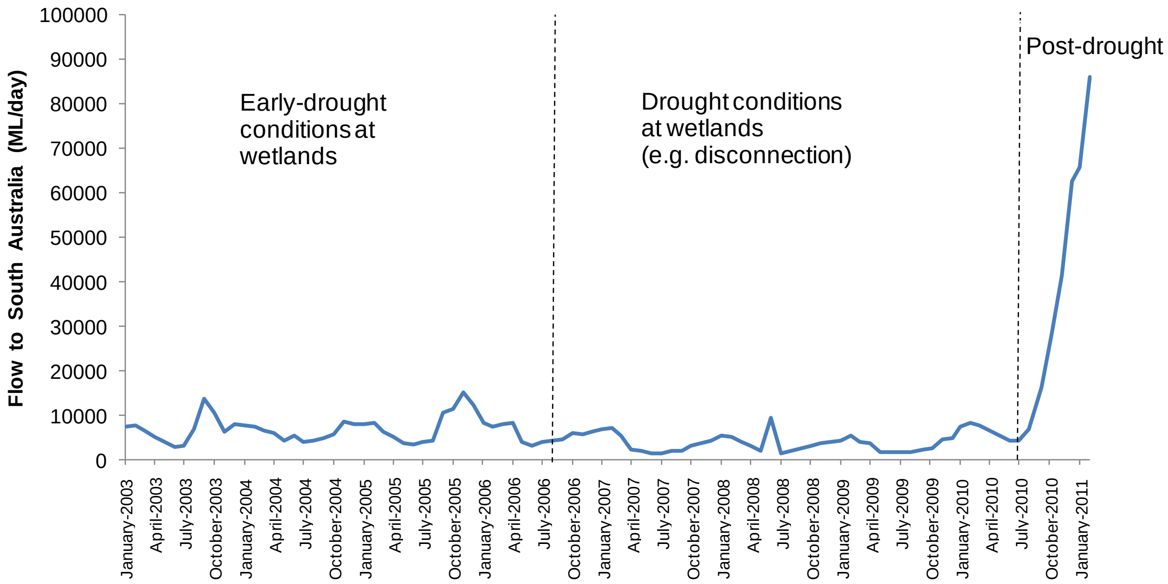

Figure 2. River Murray maximum monthly flow rates to South Australia from 2003–2011 (Department for Water, unpublished data).

Fish sampling

All data included in this report were collected using single-leader fyke nets (5-mm mesh). Nets were set from late afternoon through to the next morning to encompass day and night sampling (on most occasions) to adequately characterise wetland fish communities (see Baumgartner et al. 2008). The number of nets varied between sites and sampling occasions (1–4 nets), as did the duration of sets, and this information was recorded. All fish captured were identified to species and counted. An exception was the grouping of the carp gudgeon complex (*Hypseleotris* spp.), which require formal taxonomy. Total length was measured for the first 10–30 fish of each species captured in each fyke net. Fish were sampled intermittently at 35 wetlands from 2003–2012 (Table 2). Data for additional sites was supplied by Wedderburn et al. (2007), including for the early-drought period at five sites in the Lower Lakes that were lacking in Government data. Notably, most wetlands were dry downstream of Lock 1 at Blanchetown (i.e. regions 3 and 4) during the majority of the drought period.

Table 2. Wetlands and time period sampled.

Code	Wetland name	Early-drought	Drought	Post-drought
	Region 1 (Border – Overland Corner)			
LAK	Lake Littra	●	●	-
PIL	Pilby Lagoon	●	●	●
SLA	Slaney Billabong	●	●	●
WER	Werta Wert	●	●	●
MUR	Murtho Park	-	●	●
DIS	Disher Creek Evaporation Basin	-	●	●
BER	Berri Evaporation Basin	*	●	●
PIP	Pipeclay Billabong	●	●	●
LIT	Little Duck Lagoon	●	●	●
MAR	Martins Bend	-	-	●
CAU	Causeway Lagoon	●	●	●
OCS	Overland Corner	-	●	●
	Region 2 (Overland corner – Blanchetown)			
MOR	Morgan Conservation Park	●	●	●
NIG	Nigra	●	●	●
RAM	Ramco	●	●	●
HAR	Hart Lagoon	●	●	●
BRE	Brenda Park Lagoon	●	●	●
	Region 3 (Blanchetown – Wellington)			
WON	Wongulla	-	-	●
RED	Reedy Creek	-	●	●
SUG	Sugar Shack Lagoon	●	-	●
DEV	Devon Downs	-	●	●
PAI	Piawalla	●	●	●
RIV	Riverglades Wetland	●	-	●
ROC	Rocky Gully	-	-	●
JUR	Jury Swamp	-	-	●
SWA	Swanport	-	-	●
SWE	Sweeneys	-	●	●
NOO	Noonawirra	-	-	●
	Region 4 (Lower Lakes)			
TER	Teringie Wetland	●	-	●
NAR	Narrung Wetland	●	●	●
HIN	Hindmarsh Island	*	-	●
DUN	Dunn Lagoon	*	*	-
BOG	Boggy Lake	*	-	-
BEL	Belcanoe	*	-	-
WAL	Waltowa	*	-	-

● sampled by State Government agencies; * sampled by Wedderburn et al. (2007)

Data analyses

Ordination is a common approach in ecology to determine patterns in animal communities (e.g. Gehrke et al. 2002). To determine changes in wetland fish communities between 2003–2012 within each of the four study regions, standardised raw data (24 hour catch per unit effort [CPUE] in fyke nets) were analysed by Non-metric Multi-dimensional Scaling (NMS) ordination using the Relative Sørensen distance metric, in PC-ORD (ver. 4.36, McCune and Mefford 2002). Several species were removed from analyses (see McCune and Grace 2002), because they were recorded on less than three occasions (Yarra pygmy perch, southern pygmy perch, southern purple-spotted gudgeon, Murray cod, spangled perch, oriental weatherloach, yellow-eye mullet, jumping mullet, sandy sprat). Indicator Species Analysis (Dufrêne and Legendre 1997) was used to characterise the fish communities associated with the three time periods (see Figure 2) for each of the four study regions (see Figure 1). The indicator value (presented as a percentage of 'perfect indication') describes the faithfulness of occurrence of a species in a particular group (i.e. early-drought, drought, post-drought) – a perfect indicator species is always present in a group (i.e. wetlands in a region), and never occurs in other groups (McCune and Grace 2002).

Using the supplied values for total lengths of fish, length-frequency charts were prepared for threatened and alien species in each time period for the combined River Murray wetlands. The charts were used to determine life-history patterns related to breeding and recruitment. The charts were examined alongside distribution maps that were also prepared for the same species, to demonstrate changes in relative abundances over the three time periods. In this case, relative abundance is the average CPUE for each sampling event at each wetland (i.e. total CPUE/number of fyke nets set).

Results

Wetland fish community monitoring from 2003–2012 recorded five alien and 25 native fish species, and the carp gudgeon complex (Table 3). Additional information supplied by Wedderburn et al. (2007) included the two pygmy perch species recorded in December 2004 at the Lower Lakes, which were absent in sampling by Government agencies. The number of native fish species was highest in the two regions below Lock 1 (Figure 3). Freshwater ecological generalists were captured in all regions: Australian smelt, bony herring, unspecked hardyhead, carp gudgeon complex, flathead gudgeon, golden perch, carp, goldfish, Gambusia and redfin. However, Murray rainbowfish was always absent from samples at the Lower Lakes. Freshwater ecological specialists (mostly threatened species) were mostly restricted to one region, including southern pygmy perch, Yarra pygmy perch and southern purple-spotted gudgeon. An exception, Murray hardyhead, was recorded in regions 1, 3 and 4. Estuarine and diadromous fishes (ecological specialists) were restricted to regions 3 and 4 (i.e. below Lock 1 at Blanchetown), including smallmouth hardyhead and congolli.

Murray hardyhead (top) and smallmouth hardyhead (bottom) often cohabitated wetlands in regions 3 and 4 during the early-drought and drought periods.

Table 3. Fish species captured in each region during the 2003–2012 monitoring (● = recorded).

Common name	Region 1	Region 2	Region 3	Region 4
Native species				
Common galaxias	-	-	●	●
Australian smelt	●	●	●	●
Bony herring	●	●	●	●
Murray rainbowfish	●	●	●	-
Smallmouth hardyhead	-	-	●	●
Murray hardyhead*	●	-	●	●
Unspecked hardyhead	●	●	●	●
Southern pygmy perch*	-	-	-	●
Yarra pygmy perch*	-	-	-	●
Southern purple-spotted gudgeon*	-	-	●	-
Carp gudgeon complex	●	●	●	●
Flathead gudgeon	●	●	●	●
Dwarf flathead gudgeon	●	●	●	●
Lagoon Goby	-	-	-	●
Tamar River goby	-	-	-	●
Blue spot goby	-	-	-	●
Bridled goby	-	-	-	●
Congolli*	-	-	●	●
Murray cod*	-	-	-	●
Golden perch	●	●	●	●
Silver perch*	●	-	●	-
Spangled perch	-	-	●	-
Freshwater catfish*	●	●	●	-
Sandy sprat	-	-	-	●
Yellow-eye mullet	-	-	-	●
Jumping mullet	-	-	-	●
Alien species				
Carp	●	●	●	●
Goldfish	●	●	●	●
Oriental weatherloach	-	●	-	-
Gambusia	●	●	●	●
Redfin	●	●	●	●

1 = Border–Overland Corner; 2 = Overland Corner–Blanchetown; 3 = Blanchetown–Wellington; 4 = Lower Lakes
*species of conservation significance

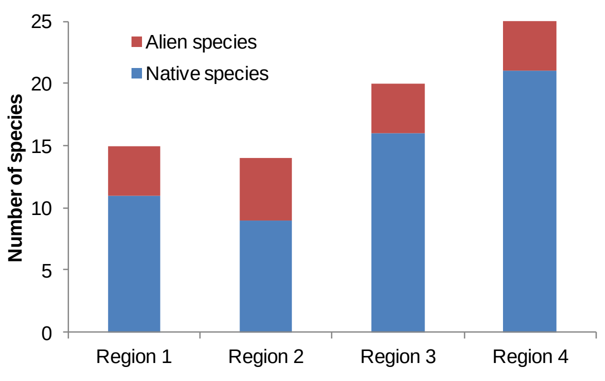

Figure 3. Total number of fish species captured in each region during the 2003–2012 monitoring.

Region 1 (State border – Overland Corner)

Ordination

The data yielded a two-dimensional ordination that failed to separate the three time periods (Figure 4). Multi-response Permutation Procedure (MRPP) confirmed that fish communities in the three time periods are similar (P = 0.736). Gambusia is the species most strongly associated with fish community structure on Axis 2 (correlation between Gambusia and axis score: r = –0.61). Murray hardyhead shows a similar trend on Axis 2 (r = –0.42) towards a group of sites (A), which includes Disher Creek (DIS), Berri Evaporation Basin (BER) and Causeway Lagoon (CAU). Several other species (e.g. carp gudgeon complex) show weaker associations on Axis 2 (r < 0.21) towards a larger group of sites (B) that is a mixture of early-drought, drought and post drought monitoring periods. There is a slightly stronger association on Axis 1 for carp (r = 0.38) and bony herring (r = –0.30) towards early-drought and drought samples from Pipeclay Lagoon (C).

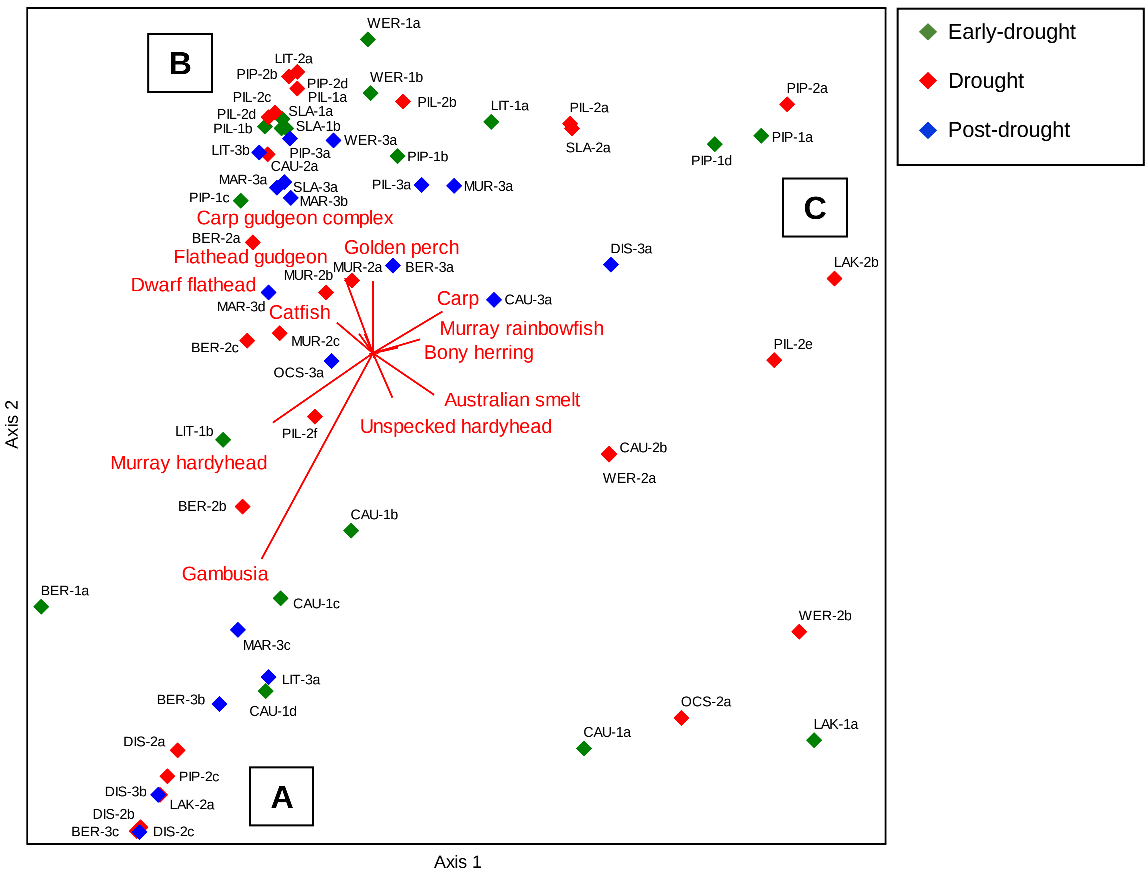

Figure 4. Ordination (stress 0.19) for Region 1 with correlations for fish species overlaid and time periods indicated.

Indicator species analysis

Indicator species values were calculated for three time periods related to drought (Table 4). Distinctive fish communities are identified for each time period. There were no significant indicator species in the early-drought period, when the fish community was represented mostly by the ecological generalists flathead gudgeon and unspecked hardyhead. There were no significant indicator species during the drought period, but Gambusia, carp gudgeon and carp were the most representative of the fish community. Golden perch (*P* = 0.002), Goldfish (*P* = 0.014) and freshwater catfish (*P* = 0.035) were significant indicator species of the wetland fish community in Region 1 during the post-drought period.

Table 4. Fish communities in Region 1 wetlands during the three time periods, as defined using indicator species analysis (percentage 'perfect indication').

Early-drought	**Drought**	**Post-drought**
Flathead gudgeon (50)	Gambusia (35)	Golden perch (42)*
Unspecked hardyhead (50)	Carp gudgeon complex (33)	Goldfish (33)*
Bony herring (24)	Carp (29)	Carp gudgeon complex (25)
Carp gudgeon complex (23)	Flathead gudgeon (16)	Gambusia (23)
Carp (20)	Dwarf flathead gudgeon (9)	Freshwater catfish (17)*
Dwarf flathead gudgeon (20)	Australian smelt (7)	Bony herring (12)
Australian smelt (13)	Goldfish (6)	Australian smelt (11)
Murray rainbowfish (13)	Murray hardyhead (6)	Carp (7)
Gambusia (11)	Bony herring (5)	Murray rainbowfish (6)
Redfin (5)	Murray rainbowfish (1)	Unspecked hardyhead (5)
Murray hardyhead (4)	Unspecked hardyhead (1)	Flathead gudgeon (4)
Goldfish (2)		Redfin (3)
Golden perch (1)		Dwarf flathead gudgeon (1)

*Significant indicator based on a Monte Carlo test of observed maximum indicator values

Fyke nets set in a wetland at Murtho Forest during the early-drought period, March 2004.

Region 2 (Overland Corner – Blanchetown)

Ordination

The data yielded a two-dimensional ordination, with no obvious separation of the three time periods (Figure 5). MRPP confirmed that wetland fish communities in the three time periods are similar (*P* = 0.246). Gambusia is the species most strongly associated with fish community structure on Axis 1 (*r* = 0.52), towards a group of sites (A) that are a mixture of the three time periods – predominantly Hart Lagoon (HAR) in the early-drought and drought periods. Unspecked hardyhead (*r* = –0.45), Australian smelt (*r* = –0.33), Murray rainbowfish (*r* = –0.33) and dwarf flathead gudgeon (*r* = –0.19) show an opposing trend on Axis 1 towards a small group of sites (B) sampled in the early-drought and drought periods. Goldfish (*r* = 0.27) and the carp gudgeon complex (*r* = 0.32) are associated with a group of sites on Axis 2 (C), which were predominately sampled in the post-drought period.

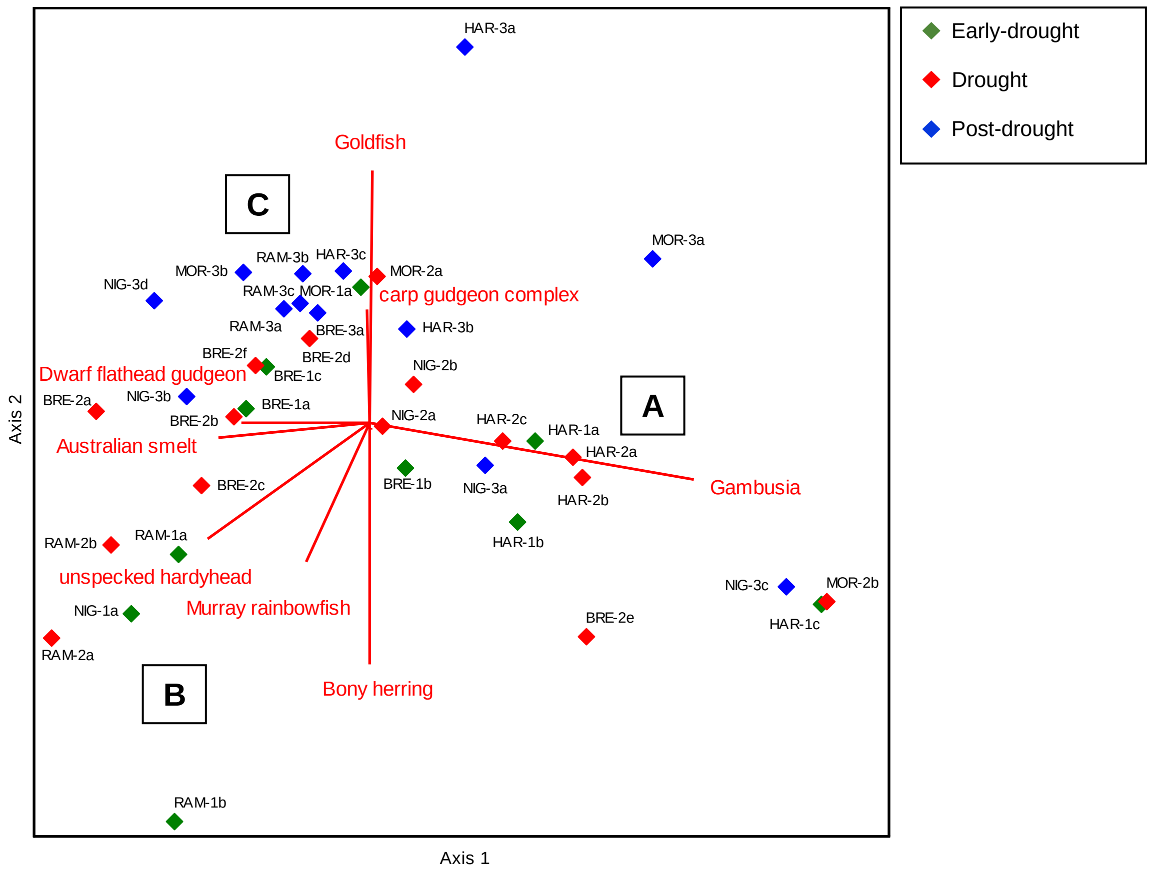

Figure 5. Ordination (stress 0.18) for Region 2 with correlations for fish species overlaid and time periods indicated.

Indicator species analysis

Indicator species values were calculated for three time periods related to drought (Table 5). Distinctive fish communities are identified for each time period in Region 2. There were no significant indicator species in the early-drought period, but the wetland fish community was represented mostly by the ecological generalists unspecked hardyhead, carp gudgeon complex, bony herring, Murray rainbowfish and Gambusia. Australian smelt was a significant indicator species in the fish community (P = 0.027) during the drought period. Goldfish (P = 0.002), carp (P = 0.012) and golden perch (P = 0.009) were significant indicator species in the post-drought period. Notably, freshwater catfish emerged as an indicator of the post-drought wetland fish community.

Table 5. Fish communities in Region 2 wetlands during the three time periods, as defined using indicator species analysis (percentage 'perfect indication').

Early-drought	**Drought**	**Post-drought**
Unspecked hardyhead (52)	Australian smelt (58)*	Goldfish (82)*
Carp gudgeon complex (31)	Flathead gudgeon (38)	Carp (57)*
Bony herring (30)	Dwarf flathead gudgeon (37)	Golden perch (43)*
Murray rainbowfish (28)	Gambusia (28)	Carp gudgeon complex (38)
Gambusia (25)	Carp gudgeon complex (28)	Flathead gudgeon (27)
Flathead gudgeon (19)	Unspecked hardyhead (24)	Gambusia (25)
Dwarf flathead gudgeon (7)	Bony herring (23)	Freshwater catfish (21)
Redfin (5)	Carp (5)	Redfin (16)
Australian smelt (3)	Goldfish (1)	Bony herring (12)
Carp (3)	Redfin (1)	Dwarf flathead gudgeon (10)
	Murray rainbowfish (1)	Unspecked hardyhead (6)
	Freshwater catfish (1)	Australian smelt (3)
		Murray rainbowfish (1)

*Significant indicator based on a Monte Carlo test of observed maximum indicator values

Brenda Park Lagoon in March 2005 following a managed watering event.

Region 3 (Blanchetown – Wellington)

Ordination

The data yielded a two-dimensional ordination that showed separation of fish communities in the three time periods (Figure 6). MRPP confirmed that fish communities in the three time periods are significantly different (P = 0.007). Carp is the species most strongly associated with fish community structure on Axis 1 (r = –0.51) and Axis 2 (r = 0.55), towards a group of sites (A) that were sampled in the post-drought period – an exception is the Reedy Creek wetland (REE) sampled during the drought period. Golden perch (r = 0.27) and goldfish (r = 0.09) show a similar but weaker association on Axis 2. Several species are associated with a group of sites (B) sampled in the early-drought and drought periods on Axis 1 and Axis 2: Gambusia (r = 0.66 and –0.02, respectively), carp gudgeon complex (r = 0.31 and –0.21), Murray rainbowfish (r = 0.35 and –0.24), flathead gudgeon (r = 0.09 and –0.55), unspecked hardyhead (r = 0.23 and –0.32), common galaxias (r = 0.11 and –0.24) and dwarf flathead gudgeon (r = 0.12 and –0.37).

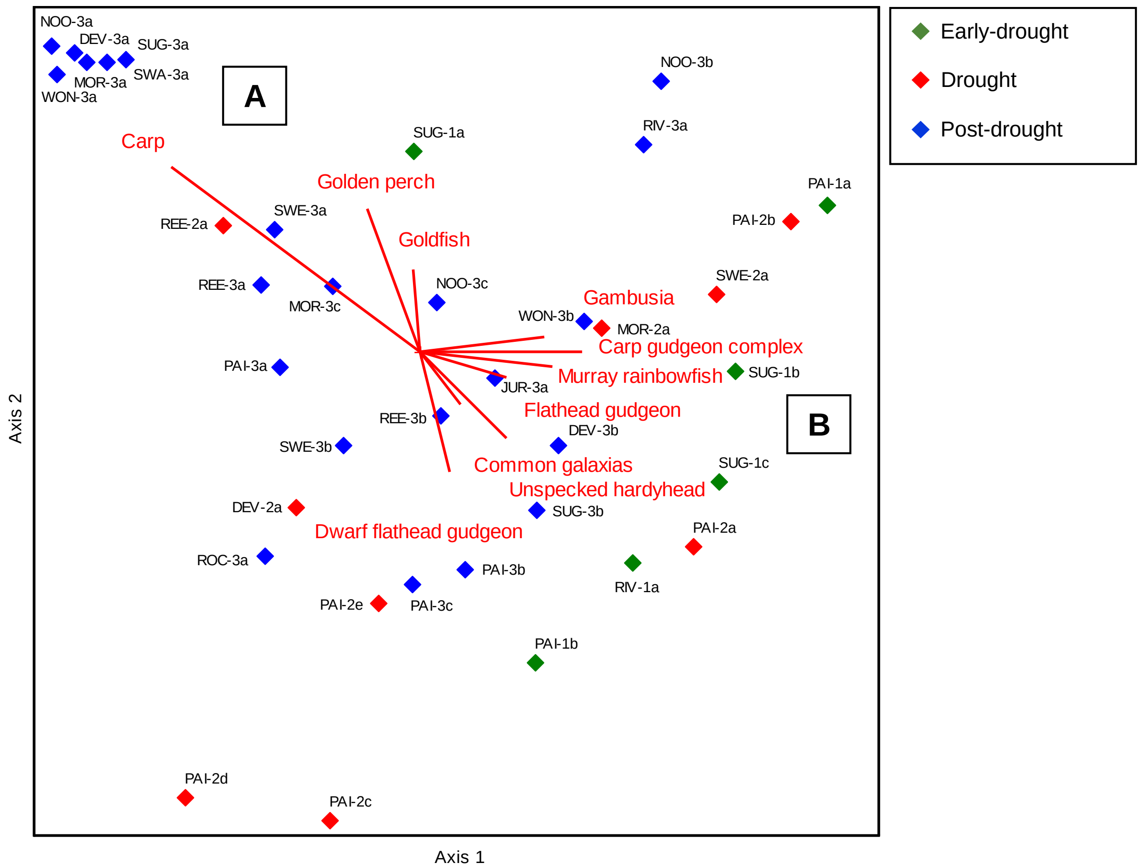

Figure 6. Ordination (stress 0.19) for Region 3 with correlations for fish species overlaid and time periods indicated.

Indicator species analysis

Indicator species values were calculated for the three time periods related to drought (Table 6). Distinctive fish communities are identified for each time period. There were three significant indicator species in the early-drought period, namely Gambusia (P = 0.015), bony herring (P = 0.001) and flathead gudgeon (P = 0.006). There were no significant indicator species during the drought period. Carp was the only significant indicator species (P = 0.001) in the post-drought period, but the emergence of freshwater catfish in the fish community is noteworthy. Notably, southern purple-spotted gudgeon is not represented in the analyses because it had to be removed due to the low sample sizes.

Table 6. Fish communities in Region 3 wetlands during the three time periods, as defined using indicator species analysis (percentage 'perfect indication').

Early-drought	**Drought**	**Post-drought**
Gambusia (91)*	Carp gudgeon complex (34)	Carp (97)*
Bony herring (85)*	Unspecked hardyhead (21)	Goldfish (39)
Flathead gudgeon (79)*	Flathead gudgeon (10)	Redfin (27)
Australian smelt (48)	Dwarf flathead gudgeon (10)	Freshwater catfish (27)
Murray rainbowfish (47)	Murray rainbowfish (9)	Unspecked hardyhead (21)
Carp gudgeon complex (37)	Common galaxias (8)	Golden perch (21)
Dwarf flathead gudgeon (34)	Goldfish (7)	Carp gudgeon complex (18)
Golden perch (22)	Australian smelt (6)	Australian smelt (16)
Unspecked hardyhead (21)	Gambusia (5)	Flathead gudgeon (6)
Redfin (9)	Bony herring (3)	Dwarf flathead gudgeon (6)
Goldfish (3)	Golden perch (1)	Murray rainbowfish (6)
Common galaxias (3)		Bony herring (5)
Carp (1)		Common galaxias (1)

*Significant indicator based on a Monte Carlo test of observed maximum indicator values

Devon Downs wetland during the early-drought period, February 2003.

Region 4 (Lower Lakes)

Ordination

The data yielded a two-dimensional ordination that shows distinct separation of two main groups of wetlands (A = early-drought; B = post-drought; most wetlands were dry during the drought period) (Figure 7). MRPP confirmed that fish communities are significantly different between time periods ($P < 0.001$). Smallmouth hardyhead is the species most strongly associated with fish community structure on Axis 2 ($r = –0.60$) towards an outlying group (C) of wetlands sampled post-drought at Narrung (NAR) and Hindmarsh Island (HIN). Notably, the group includes Dunn Lagoon (DUN) sampled during the drought, after it had salinised (see Wedderburn and Hillyard 2010). Unspecked hardyhead shows an opposing trend on Axis 2 ($r = 0.45$) and falls between the early-drought and post-drought groups of wetlands. Murray hardyhead is associated with wetlands monitored in the early-drought period (A), on Axis 1 ($r = 0.38$) and Axis 2 ($r = 0.36$). Gambusia is associated with the same group of sites on Axis 2 ($r = 0.54$). Conversely, on Axis 1, carp ($r = –0.68$), goldfish ($r = –0.44$) and congolli ($r = –0.26$) are associated with wetlands sampled in the post-drought period (B).

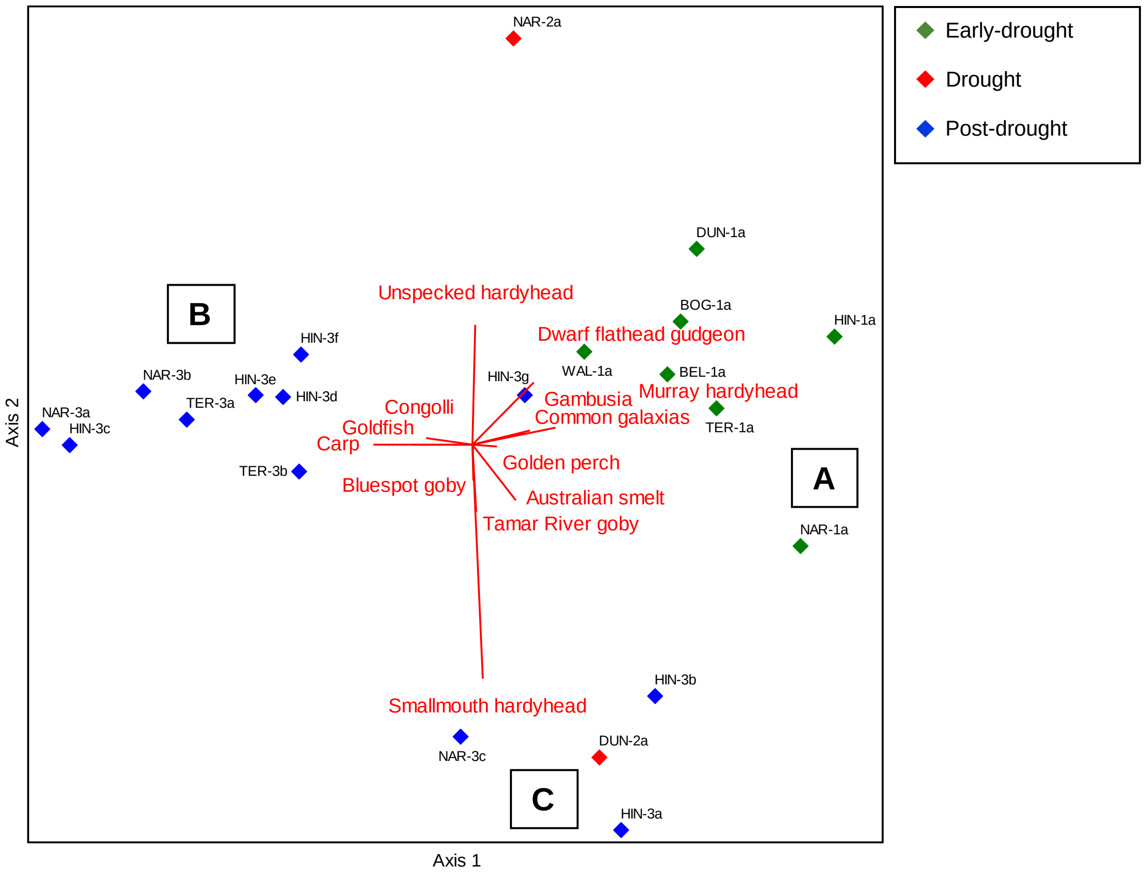

Figure 7. Ordination (stress 0.16) for Region 4 with correlations for fish species overlaid and time periods indicated.

Indicator species analysis

Only two wetlands were monitored during the drought, so the time period was excluded from indicator species analysis. Indicator species values were calculated for the two remaining time categories, and distinctive fish communities are identified (Table 7). There were five significant indicator species during the early-drought period, namely common galaxias (P = 0.001), Murray hardyhead (P = 0.004), Gambusia (P = 0.010), dwarf flathead gudgeon (P = 0.018) and unspecked hardyhead (P = 0.039). In the post-drought period, goldfish (P = 0.006) and congolli (P = 0.044) were significant indicator species, and carp, smallmouth hardyhead and flathead gudgeon were notable representatives of the fish community at the Lower Lakes.

Table 7. Fish communities in Region 4 wetlands during the two time periods, as defined using indicator species analysis (percentage 'perfect indication').

Early-drought	**Post-drought**
Common galaxias (92)*	Carp (83)
Murray hardyhead (71)*	Smallmouth hardyhead (82)
Gambusia (70)*	Goldfish (77)*
Dwarf flathead gudgeon (55)*	Flathead gudgeon (71)
Australian smelt (51)	Congolli (69)*
Bony herring (50)	Redfin (45)
Unspecked hardyhead (43)*	Blue-spot goby (37)
Blue-spot goby (36)	Tamar River goby (33)
Lagoon goby (34)	Bridled goby (33)
Redfin (33)	Bony herring (22)
Flathead gudgeon (29)	Carp gudgeon complex (20)
Golden perch (22)	Australian smelt (19)
Smallmouth hardyhead (11)	Lagoon goby (14)
Carp gudgeon complex (9)	Common galaxias (6)
Congolli (3)	Golden perch (4)
Goldfish (2)	Dwarf flathead gudgeon (1)

*Significant indicator based on a Monte Carlo test of observed maximum indicator values

Dunn Lagoon in 2003 was prime habitat for Murray hardyhead during the early-drought period.

Threatened fishes

Murray hardyhead

Critically Endangered

The distribution and abundance of Murray hardyhead declined in the lower River Murray during the drought, with no apparent post-drought recovery (Figure 8). Rocky Gully was not sampled during the drought in this study. Instead, Murray hardyhead was recorded at Rocky Gully during the drought period in the Drought Action Plan monitoring program: 760 fish in spring 2008, three fish in autumn 2009, no fish in spring 2009 and 103 fish in autumn 2010 (Bice et al. 2010), but the information is not represented in the distribution map. In the current study, Murray hardyhead was captured in moderate relative abundances in sites at the Lower Lakes in the early-drought and drought periods. During the post-drought period, only a single Murray hardyhead was recorded at the Lower Lakes (Hindmarsh Island).

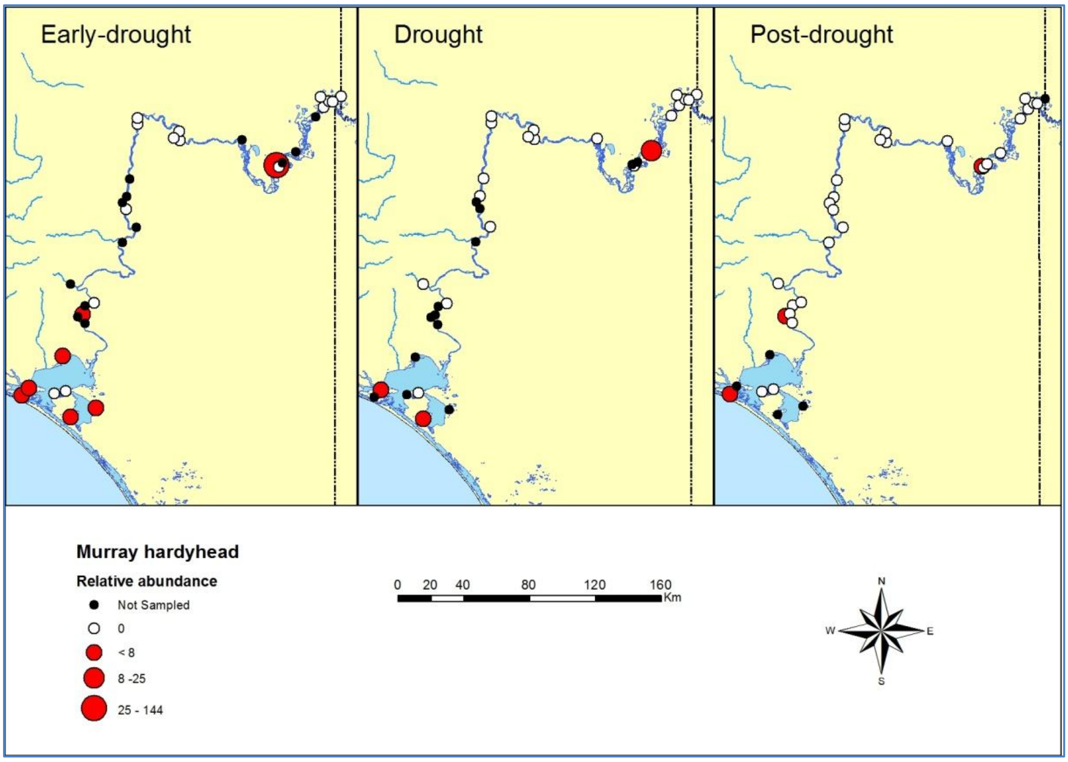

Figure 8. Distribution and relative abundance of Murray hardyhead during each time period.

The length-frequency is normally distributed for Murray hardyhead during the early-drought period, indicating a population that includes juvenile and adult fish (Figure 9). During the early-drought period, the length-frequency distribution represents Murray hardyhead recorded only in Riverglades Wetland (n = 46; av. length = 36 mm; September 2004). Length frequency data is not presented for the drought period, where relative abundance was supplied by Wedderburn et al. (2007). There were no records of the species in the current study at any wetland during the drought. However, another monitoring program showed that Murray hardyhead persisted in Rocky Gully and in wetland sections of salt evaporation basins near Berri during the drought period, with little or no evidence of recruitment (Bice et al. 2010). The length-frequency distribution for the post-drought period includes records only for Orange Island (n = 1; length = 52 mm; December 2010) and Rocky Gully (n = 38; average length = 53 mm; November 2011). During this period, the population consisted only of adult fish, indicating a lack of recruitment (females mature at >40 mm long: Lintermans 2007).

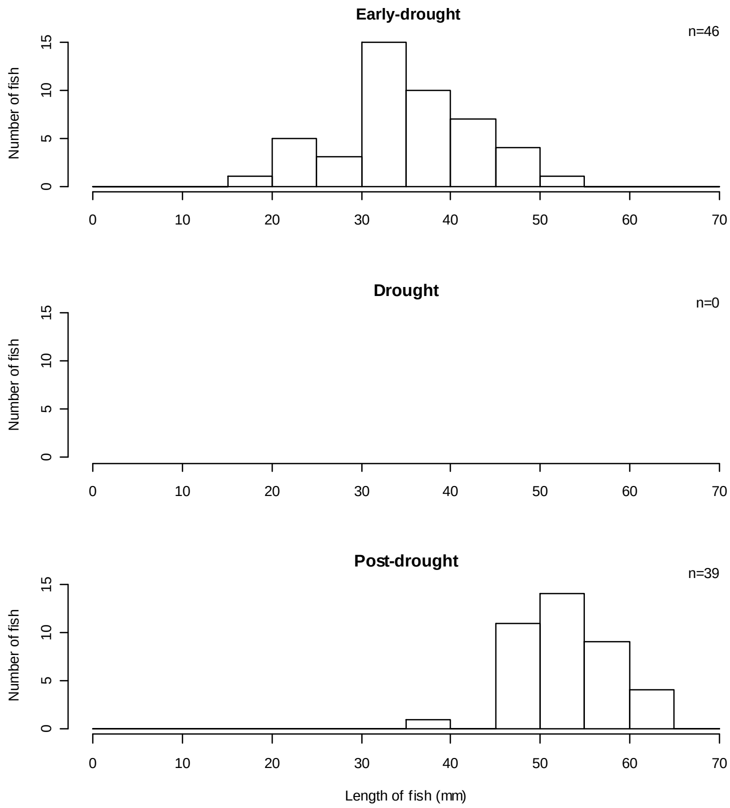

Figure 9. Length-frequency charts for Murray hardyhead in wetlands of the South Australian Murray during each time period.

Southern pygmy perch

Endangered

Southern pygmy perch was not recorded during monitoring by State Government agencies. In data supplied by Wedderburn et al. (2007), the species was recorded on Hindmarsh Island in January 2004 during the early-drought period (Figure 10). However, length-frequency data collected before the near extirpation of southern pygmy perch at the Lower Lakes is presented in reports from other monitoring programs (Bice et al. 2010; Wedderburn and Barnes 2009).

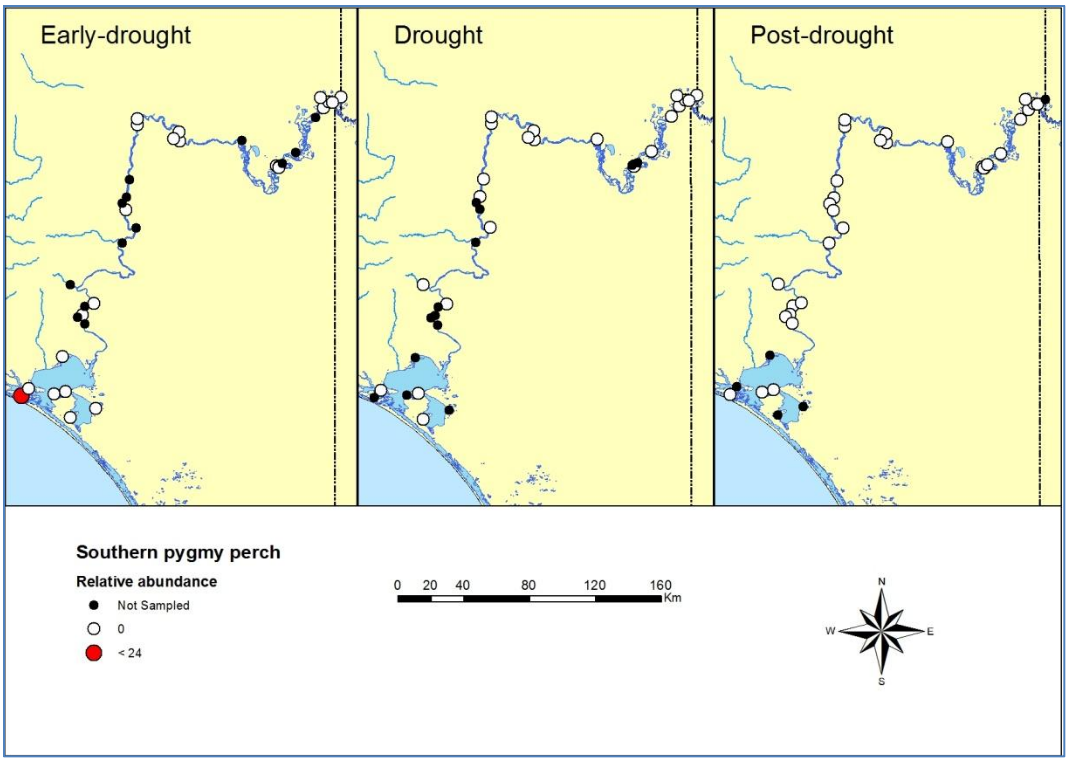

Figure 10. Distribution and relative abundance of southern pygmy perch in each time period.

Yarra pygmy perch

Critically Endangered

Yarra pygmy perch was not recorded in monitoring by the State Government agencies. In data supplied by Wedderburn et al. (2007), the species was recorded on Hindmarsh Island in January 2004 during the early-drought period (Figure 11). Data collected before its extirpation at the Lower Lakes in 2008 is presented in reports from other monitoring programs (Bice et al. 2008; Wedderburn and Hammer 2003).

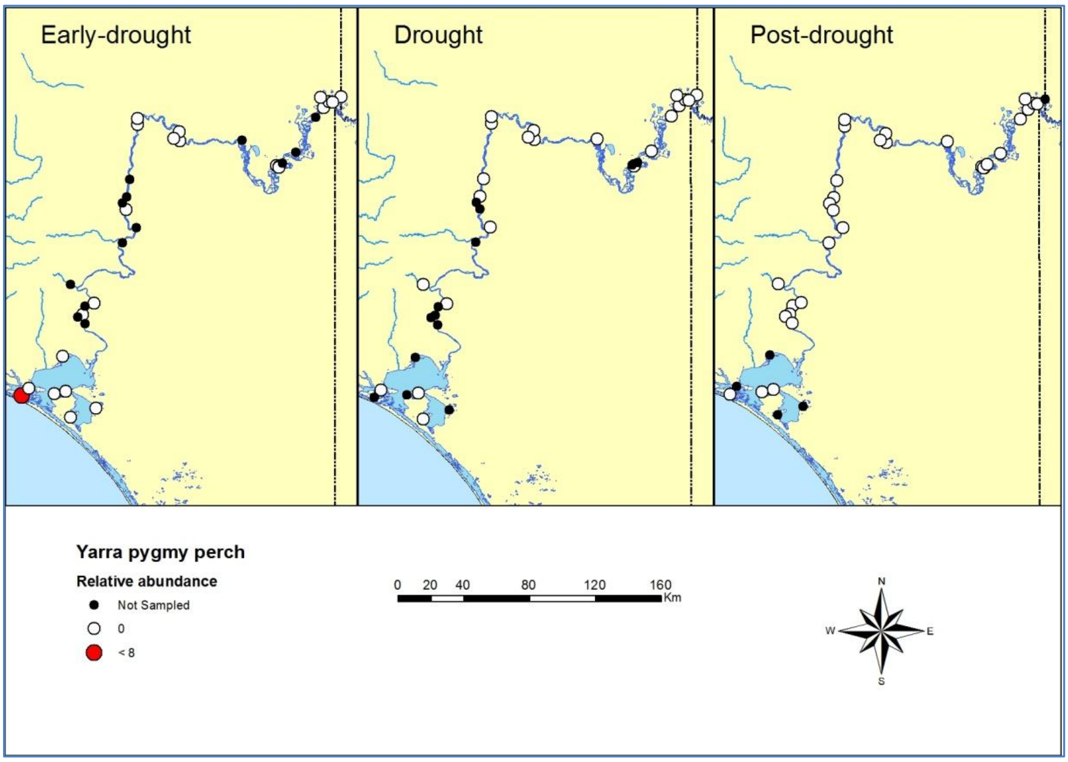

Figure 11. Distribution and relative abundance of Yarra pygmy perch in each time period.

Southern purple-spotted gudgeon

Critically Endangered

Southern purple-spotted gudgeon was present at a single location during all time periods (Figure 12). All fish recorded in the early-drought and drought periods were captured at Jury Swamp (Hammer 2007a), prior to the habitat drying in 2008. The presence of the species at Paiwalla during the post-drought period is the result of re-stocking from the captive maintenance program, which was funded by the MDBA and managed by the DENR, the SAMDBNRM Board and Aquasave. All southern purple-spotted gudgeon recorded during the post-drought period were re-captured at Paiwalla on the 5th of November 2011. The most recent evaluation of population status is presented in Bice et al. (2011).

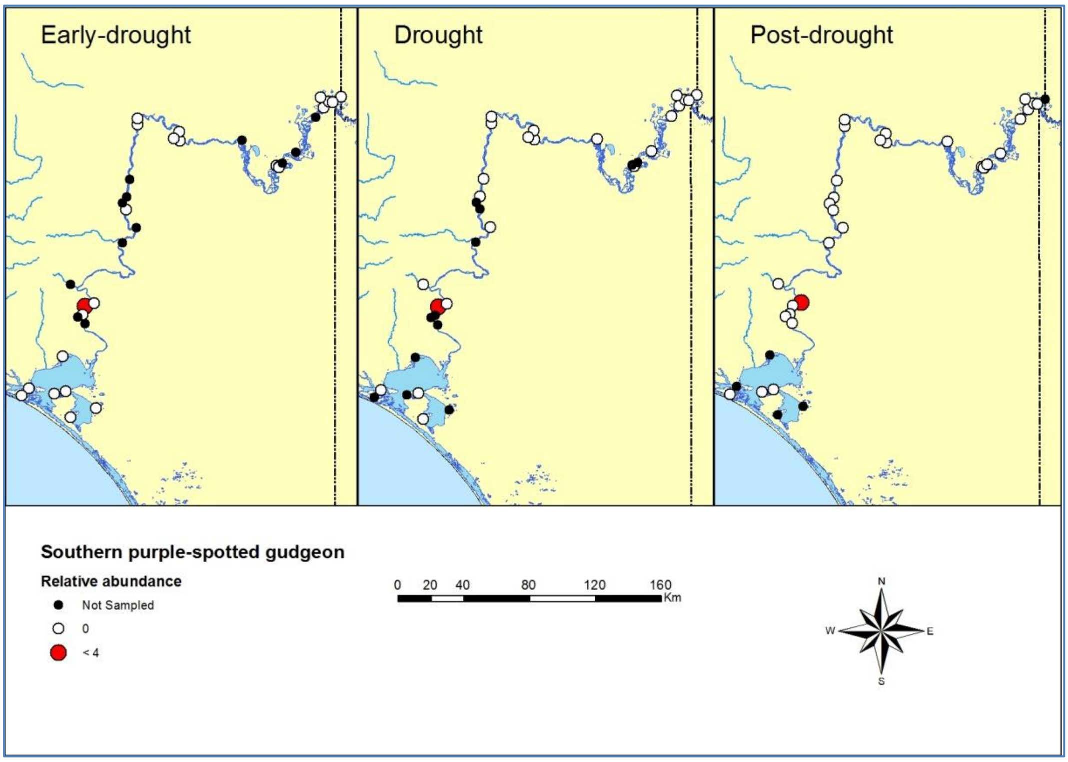

Figure 12. Distribution and relative abundance of southern purple-spotted gudgeon in each time period.

The length-frequency distributions for southern purple-spotted gudgeon (Jury Swamp) show a normal range of size classes in the early-drought and drought periods (Figure 13). Research also showed that the species was successfully recruiting in the wetland from 2005–2007 (Hammer 2007a). In the post-drought period (Paiwalla Wetland), the population consisted only of adult fish (>35 mm), which were re-captured from the re-stocking, with no apparent recruitment.

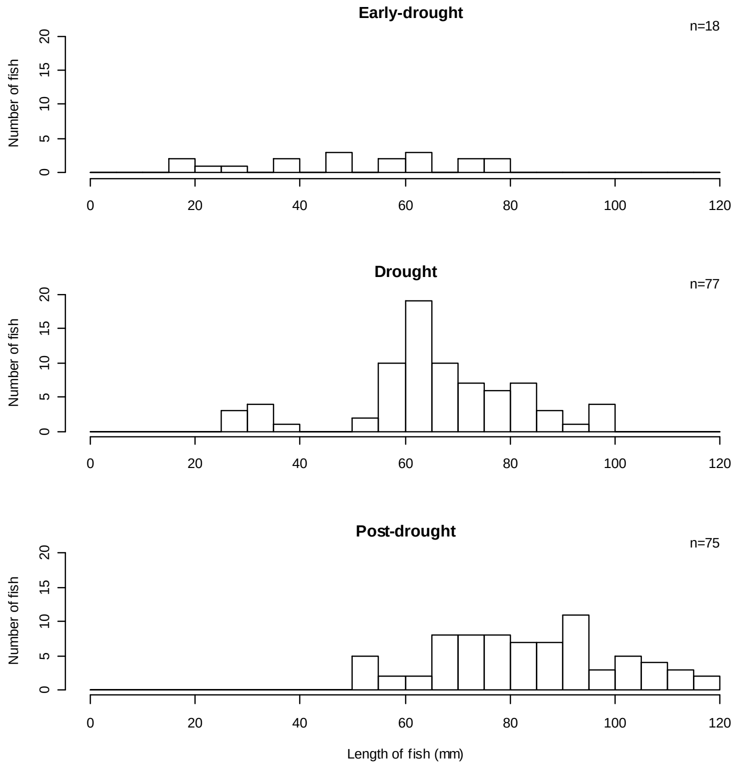

Figure 13. Length-frequency charts for southern purple-spotted gudgeon in wetlands of the South Australian Murray during each time period.

Congolli

Vulnerable

In the early-drought period, congolli was recorded on a single occasion during State Government monitoring. Combined with additional data supplied by Wedderburn et al. (2007), it is apparent that congolli was present in low to moderate relative abundances in wetlands below Lock 1 prior to the drought (Figure 14). The species was absent in samples during the drought period, and similar results were obtained in concurrent research (Bice et al. 2010; Wedderburn and Hillyard 2010). During the post-drought period, congolli was captured in moderate relative abundances in wetlands fringing the Lower Lakes.

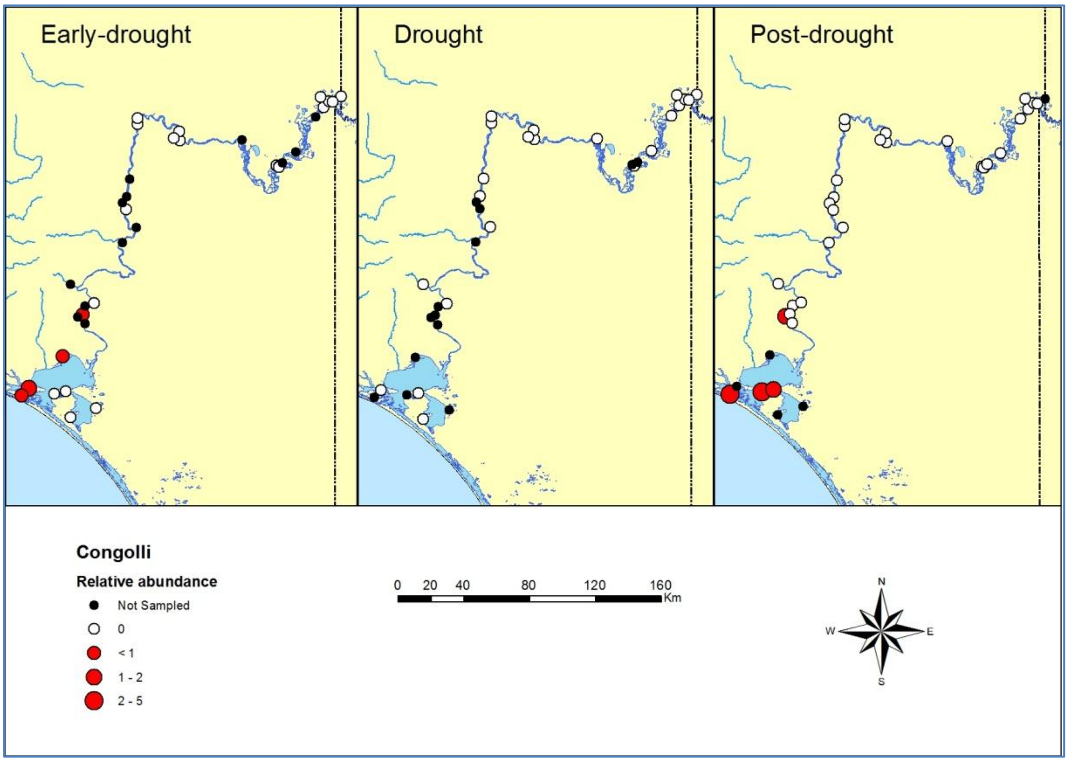

Figure 14. Distribution and relative abundance of congolli in each time period.

A single adult congolli was measured in the early-drought period, and the species was undetected during the drought (Figure 15). During the post-drought period, 276 young-of-the-year, juvenile and early-adult fish were measured, and the length-frequency distribution indicates substantial breeding and recruitment levels from 2010–2012. This is a reflection of the reconnection between the Lower Lakes and Coorong (at the barrages) following the return of flows, which allowed female congolli to enter the estuary and breed with resident male fish (see Zampatti et al. 2011).

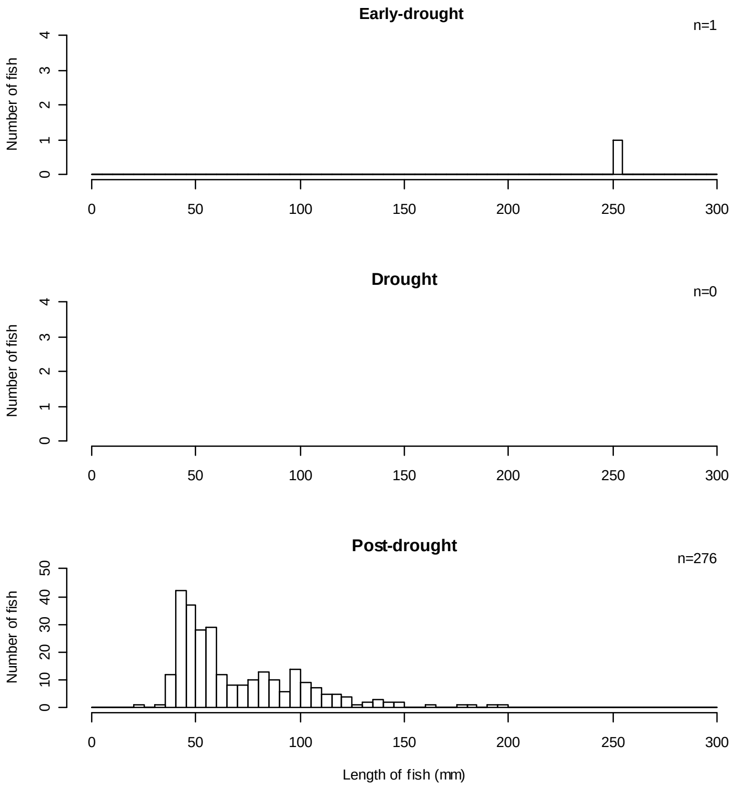

Figure 15. Length-frequency charts for congolli in wetlands of the South Australian Murray during each time period (y-axis scales vary).

Juvenile congolli captured at the Lower Lakes during the post-drought period (February 2011).

Silver perch

Endangered

Silver perch was absent from wetland monitoring data in the early-drought period, and only a few individuals were recorded during each of the subsequent time periods: on the 18th of November 2009 at Paiwalla (215 mm long), on the 17th of November 2011 at Murtho Park (185 mm long), and on the 24th of June 2011 at Disher Creek (200 mm long) (Figure 16). Although silver perch spawns in flooded backwater between November and April, it mostly inhabits main channels (Clunie and Koehn 2001c). This partly explains the small numbers of fish captured in 2003–2012 wetland monitoring. Sampling methods (fyke nets set at the shoreline) also failed to target silver perch, which has a preference for deeper, open water (Clunie and Koehn 2001c).

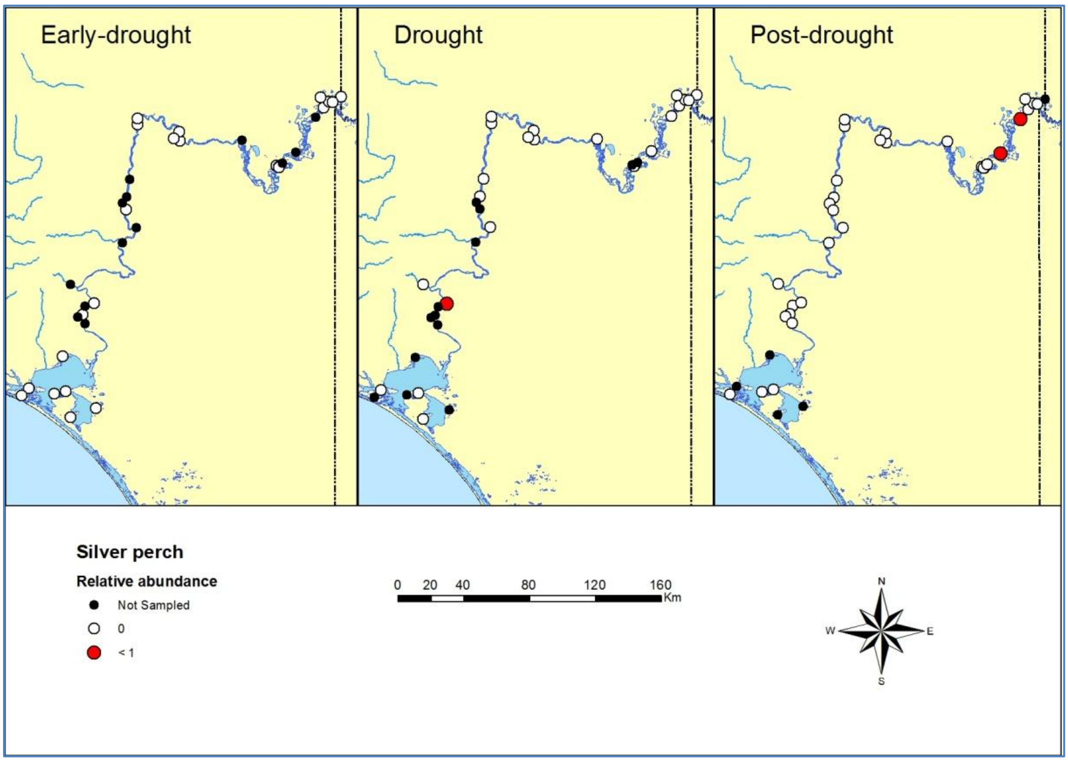

Figure 16. Distribution and relative abundance of silver perch in each time period.

Freshwater catfish

Endangered

Freshwater catfish was not recorded during early-drought monitoring in wetlands, but one fish was captured during the drought period. The distribution and relative abundance of freshwater catfish in South Australian River Murray wetlands increased substantially in the post-drought period (Figure 17). During the post-drought period, the distribution of freshwater catfish apparently expanded to include Region 3 (Blanchetown–Wellington), where its relative abundance was highest. However, the expansion in range might not entirely relate to increased river flows, because carp exclusion screens were removed from some wetlands as water levels increased in the post-drought period.

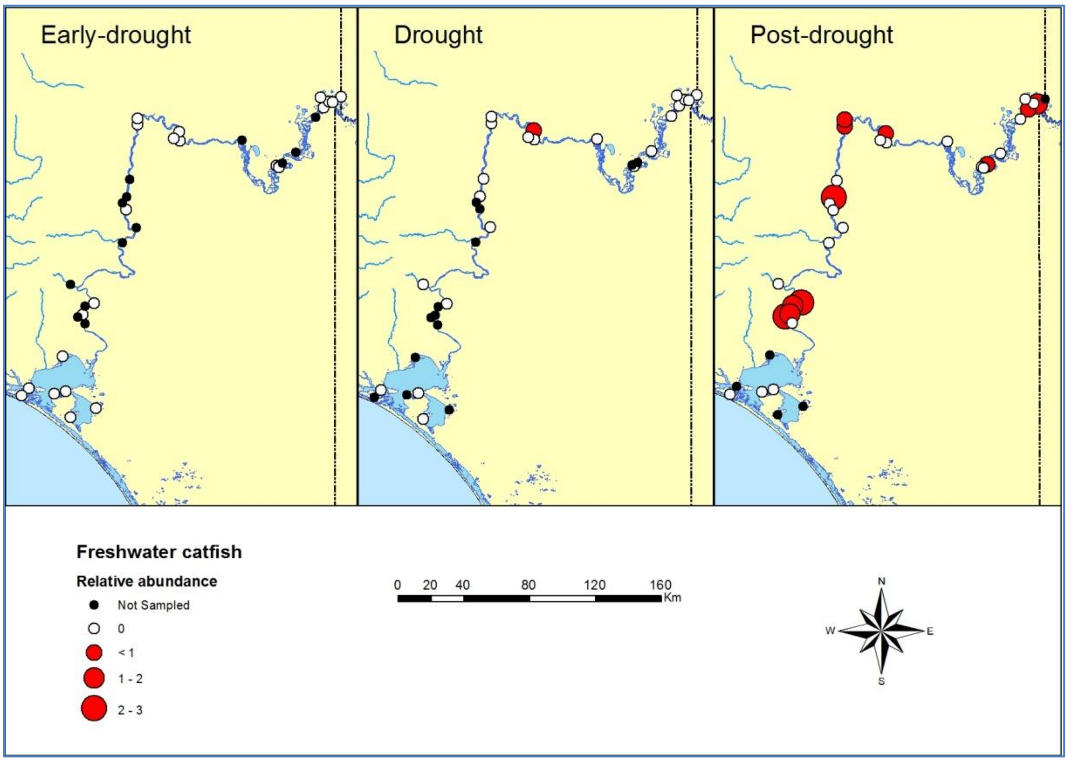

Figure 17. Distribution and relative abundance of freshwater catfish in each time period.

Freshwater catfish was not recorded in the early-drought period, but a single early adult fish was measured during the drought period (Figure 18). The length-frequency distribution of freshwater catchfish captured in the post-drought period represents all size classes, but the majority of the population were young-of-the-year or juvenile fish (<130 mm long). The absence of early life stages obviously suggest recruitment was low for freswater catfish during the early-drought and drought periods (i.e. fish small enough to move through carp exclusion screens). However, it is impossible to determine from the 2003–2012 monitoring data whether the lack of recruitment was flow-related or because adult freshwater catfish were excluded from spawning in the few remaining wetlands. The latter scenario is plausible given that sampling by SARDI Aquatic Sciences shows the species was relatively abundant in the Chowilla floodplain during the drought period (Sandra Leigh, unpublished data).

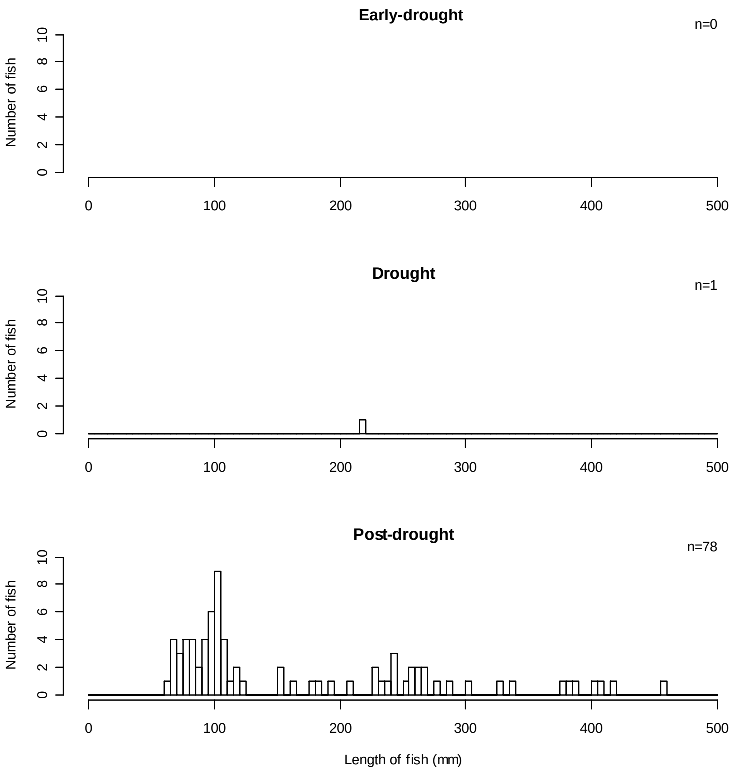

Figure 18. Length-frequency charts for freshwater catfish in South Australian Murray wetlands during each time period.

Juvenile freshwater catfish captured at North Purnong wetland during the post-drought period (January 2012).

Golden perch

There is no conservation rating for golden perch, but the species is presented here because of its high recreational and commercial value.

Golden perch had a patchy distribution in South Australian River Murray wetlands, and was captured in low relative abundances in the early-drought and drought periods (Figure 19). During the post-drought period, there was a substantial increase in its distribution and relative abundance in wetlands.

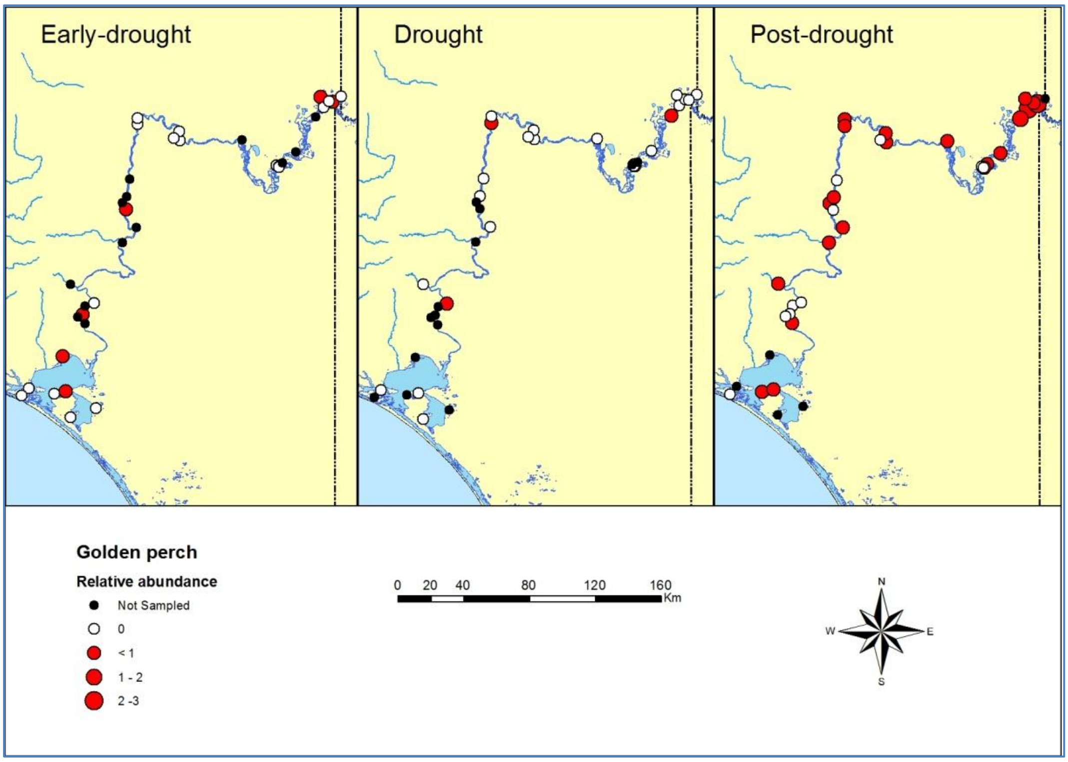

Figure 19. Distribution and relative abundance of golden perch in each time period.

The length-frequency distributions for the early-drought and drought periods are limited, because only a small number of golden perch were measured (Figure 20). The bi-modal length-frequency distribution for the post-drought period displays a population that includes two apparent cohorts: 95-180 mm and 215-330 mm long.

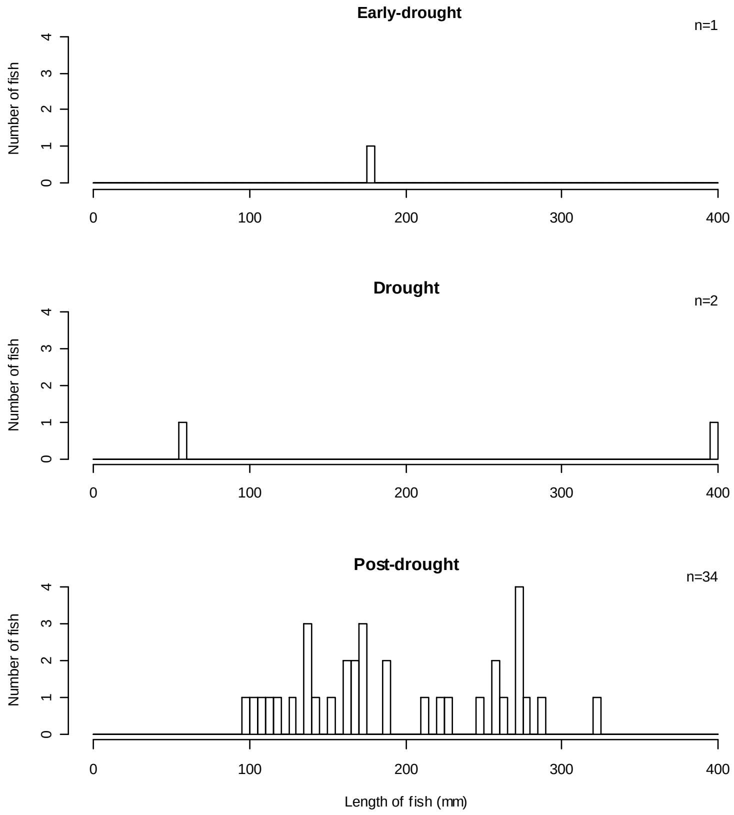

Figure 20. Length-frequency charts for golden perch in South Australian Murray wetlands during each time period.

Juvenile golden perch captured at the Lower Lakes during the post-drought period (November 2011).

Alien fishes

Carp

Carp was relatively abundant in South Australian River Murray wetlands during the early-drought and drought periods (Figure 21). However, the distribution and abundance of carp at the Lower Lakes was considerably reduced during the drought period. Its distribution and relative abundance increased substantially in the post-drought period throughout River Murray wetlands, including at the Lower Lakes. The initial increase in carp numbers following the return of substantial river flows was predominantly because of extremely high numbers of young-of-the-year fish (e.g. Wedderburn and Barnes 2011).

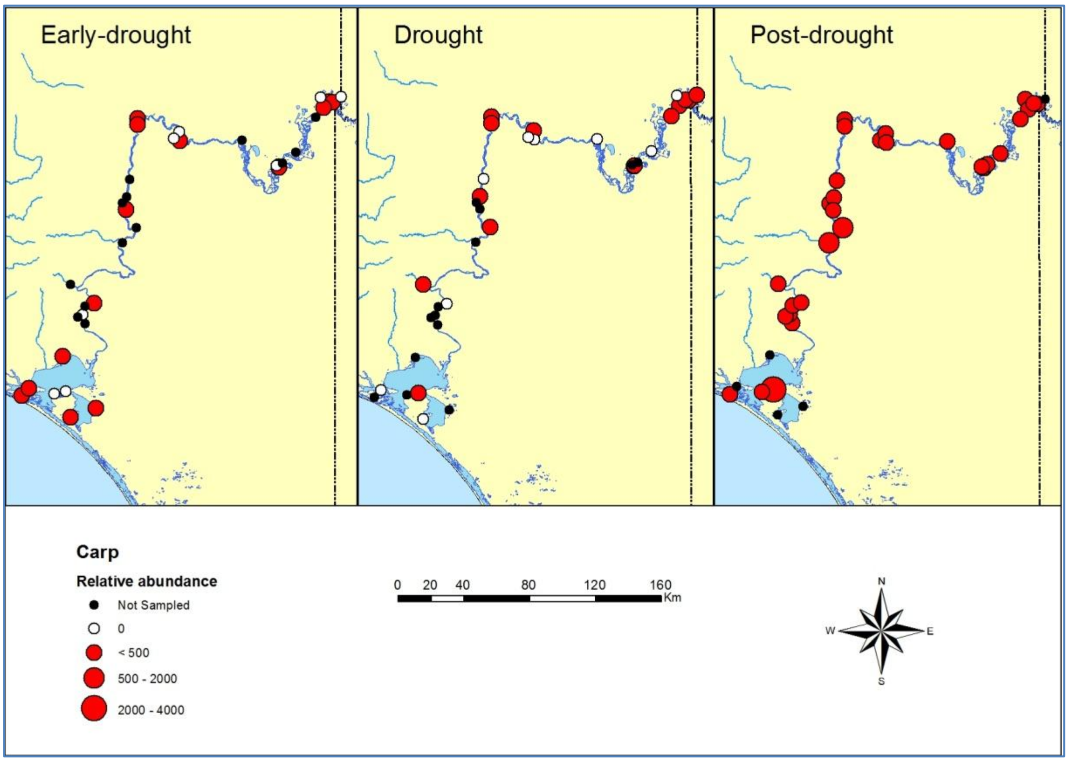

Figure 21. Distribution and relative abundance of carp in each time period.

The length frequency distribution for carp shows a variety of size classes in the early-drought period, but young-of-the-year and juveniles predominated (Figure 22). In the drought period, a similar range of sizes were present, but the proportion of young-of-the-year fish was lower. Following the drought, the population was heavily weighted towards young-of-the-year fish, indicating a substantial breeding event. This represents a population response that is typical for carp in newly inundated habitats (e.g. Bice and Zampatti 2011; King et al. 2003).

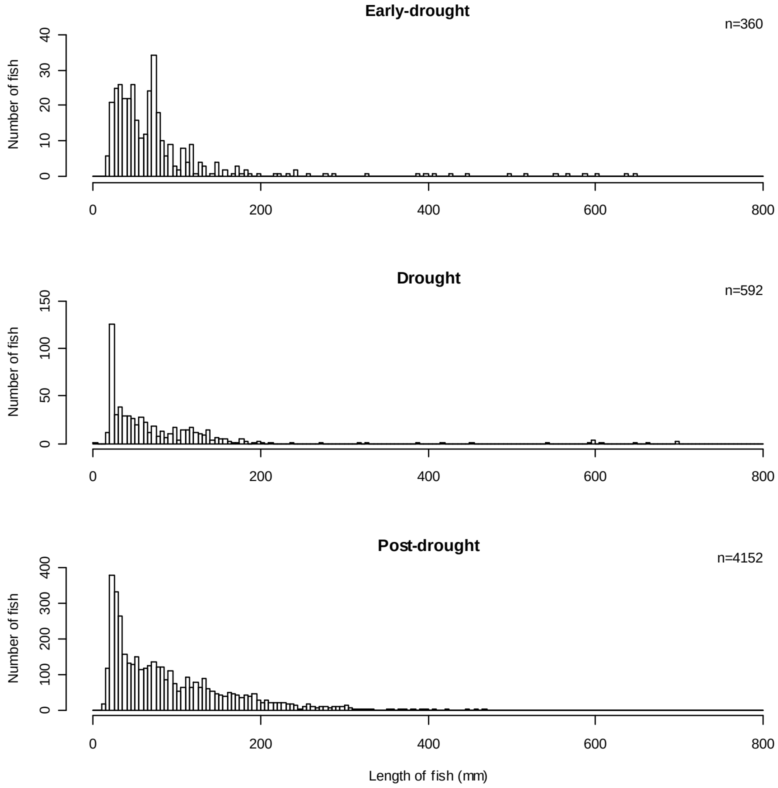

Figure 22. Length-frequency charts for carp in South Australian Murray wetlands during each time period (y-axis scales vary).

Goldfish

Goldfish had a patchy distribution in South Australian Murray wetlands during the early-drought and drought periods, and was recorded in low relative abundances at several locations (Figure 23). During the post-drought period, the species had a widespread distribution throughout wetlands of the lower River Murray and often occurred in moderate to high relative abundance.

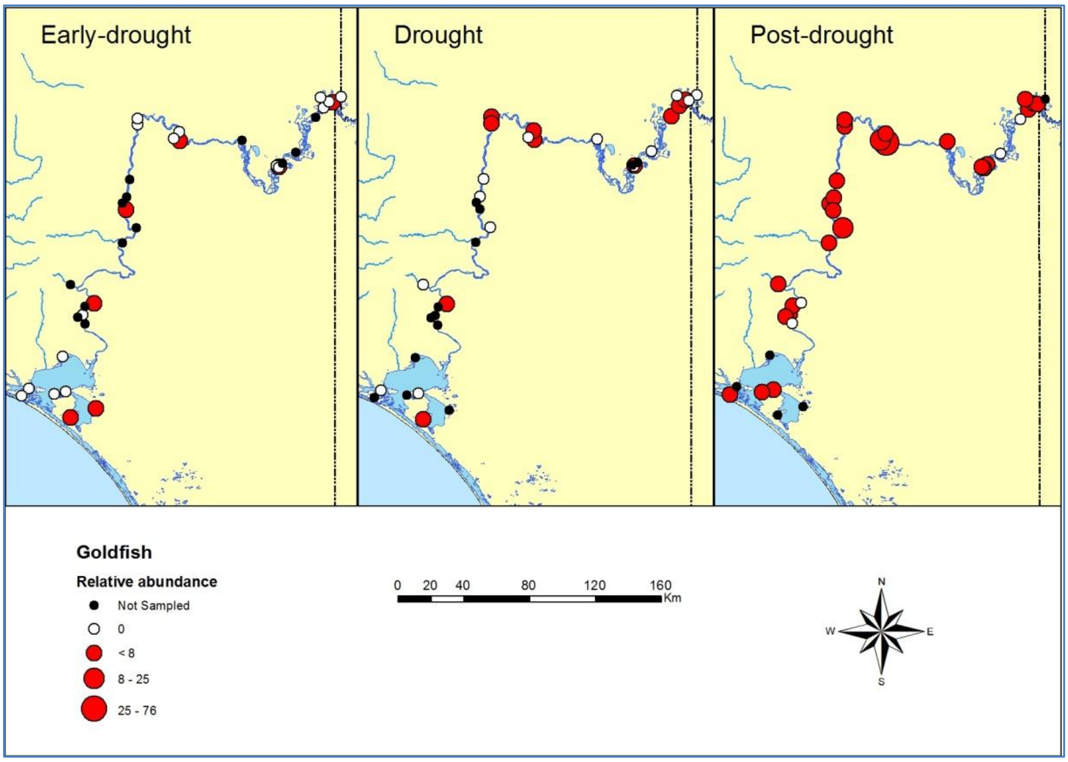

Figure 23. Distribution and relative abundance of goldfish in each time period.

The length-frequency distributions for goldfish display a juvenile–adult cohort (50–180 mm) during the early-drought period, which increased to include a full range of size classes (30–300 mm) during the drought period (Figure 24). During the post-drought period, the goldfish population in South Australian River Murray wetlands was highly weighted towards young-of-the-year fish, which represents a substantial recent breeding event.

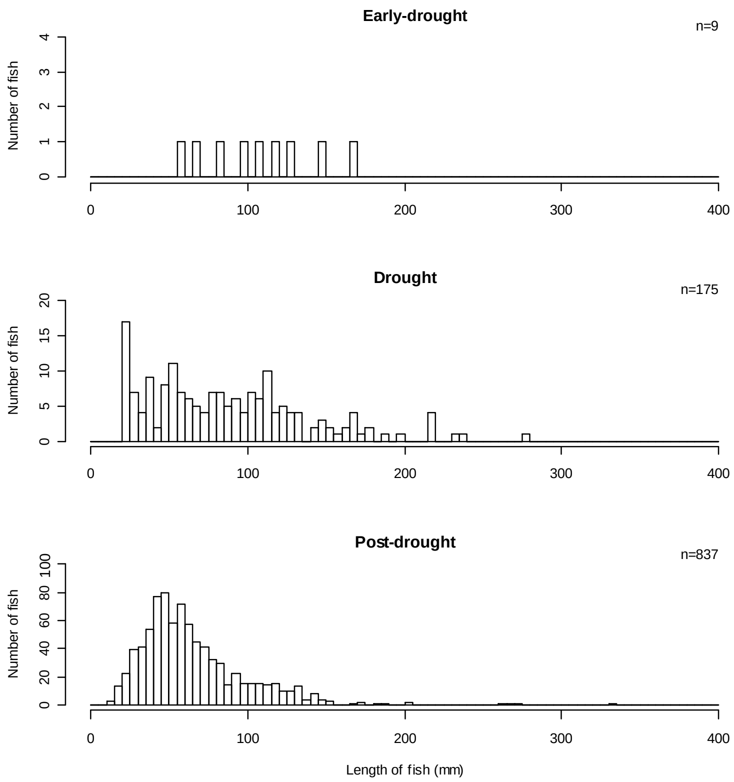

Figure 24. Length-frequency charts for goldfish in South Australian Murray wetlands during each time period (y-axis scales vary).

Redfin

Prior to the drought, redfin was recorded only downstream of Overland Corner in this study, with the highest relative abundances being in wetlands at the Lower Lakes (Figure 25). During the drought period, the species was recorded only at Brenda Park Lagoon and Hindmarsh Island. Following the return of river flows in 2010, the distribution of redfin increased to include wetlands along the entire South Australian River Murray, where it was captured in moderate to high relative abundances. Notably, the species was captured in very high relative abundance at Hindmarsh Island in the early-drought period.

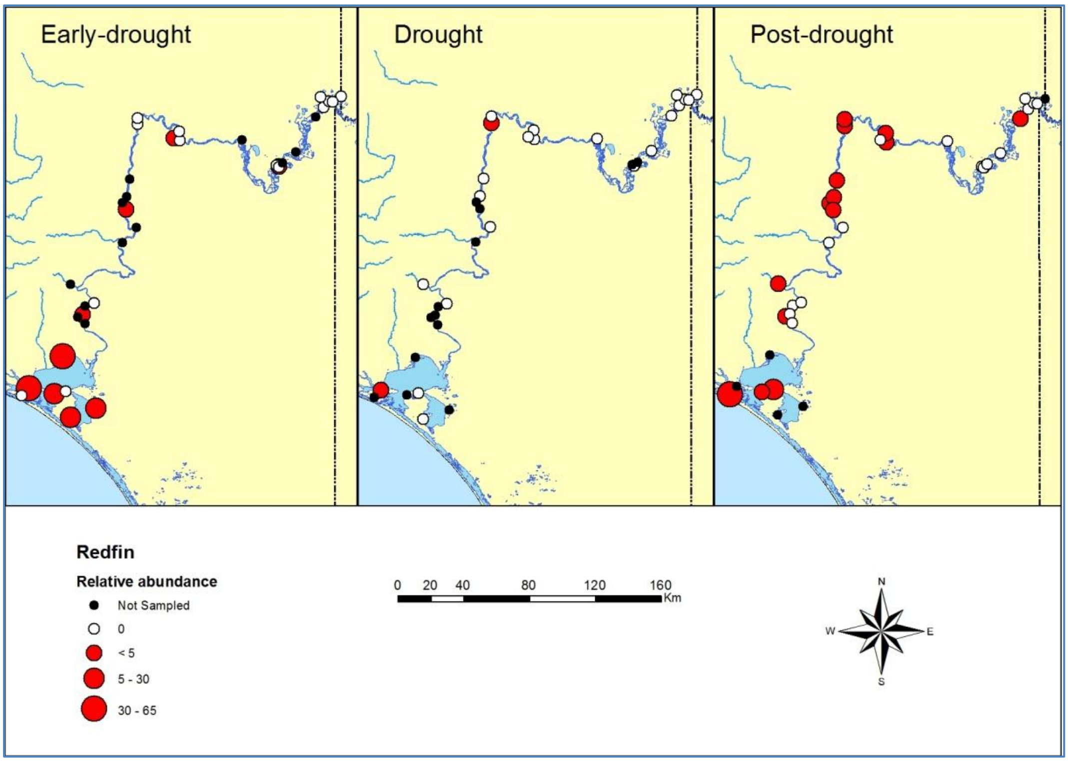

Figure 25. Distribution and relative abundance of redfin in each time period.

Prior to the drought, the redfin population in South Australian River Murray wetlands consisted of three size classes: young-of-the-year (<100 mm), juvenile (~150 mm) and adult (~250 mm) fish (Figure 26). Monitoring showed that the species declined substantially under drought conditions to a small number of wetlands, where the population consisted only of juvenile fish (100-150 mm). During the post-drought period, young-of-the-year (<80 mm) made up the majority of the relatively abundant population.

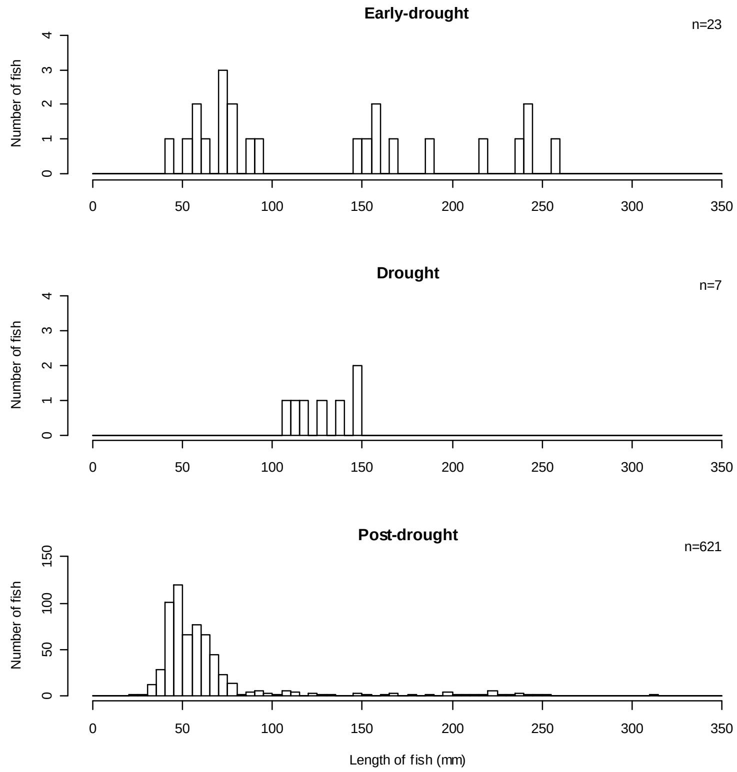

Figure 26. Length-frequency charts for redfin in South Australian Murray wetlands during each time period (y-axis scales vary).

Gambusia

Gambusia was widespread in wetlands of the South Australian River Murray during all three time periods, but its relative abundance was sometimes higher during the drought period (Figure 27). Its distribution included most wetlands sampled in the post-drought period, where it occurred in moderate abundances.

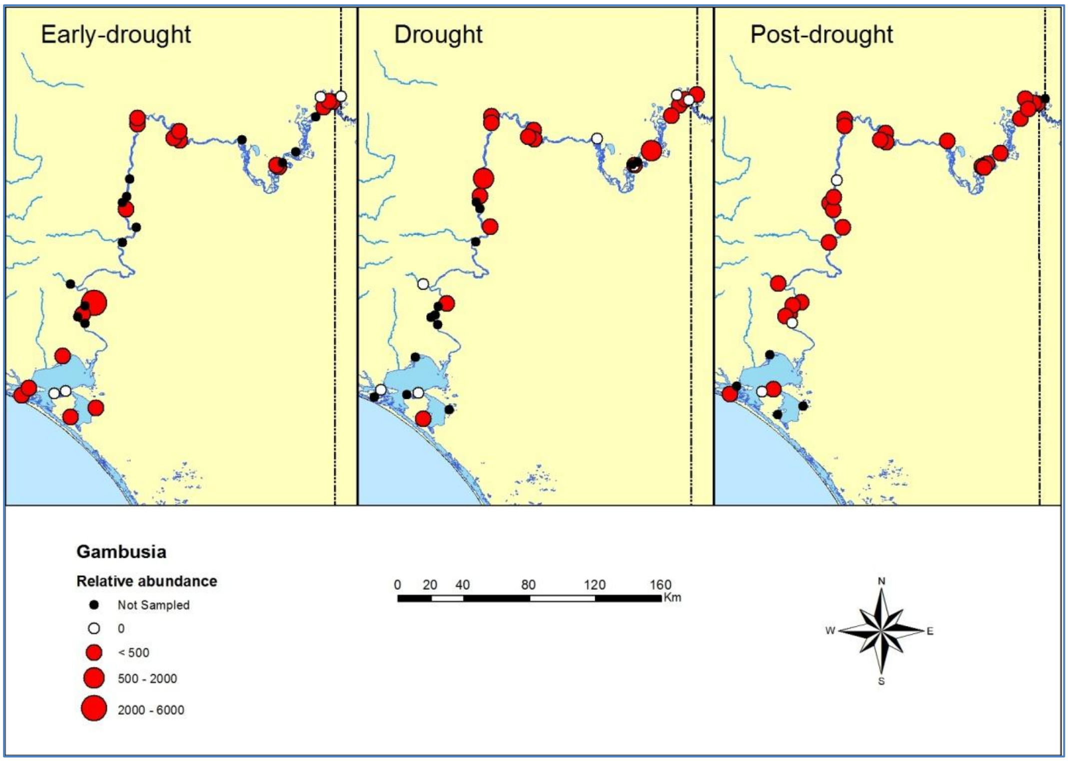

Figure 27. Distribution and relative abundance of Gambusia in each time period.

The length-frequency distributions for Gambusia indicate that the population always included a full range of size classes during each time period (Figure 28), indicating that the species was able to successfully recruit under all conditions.

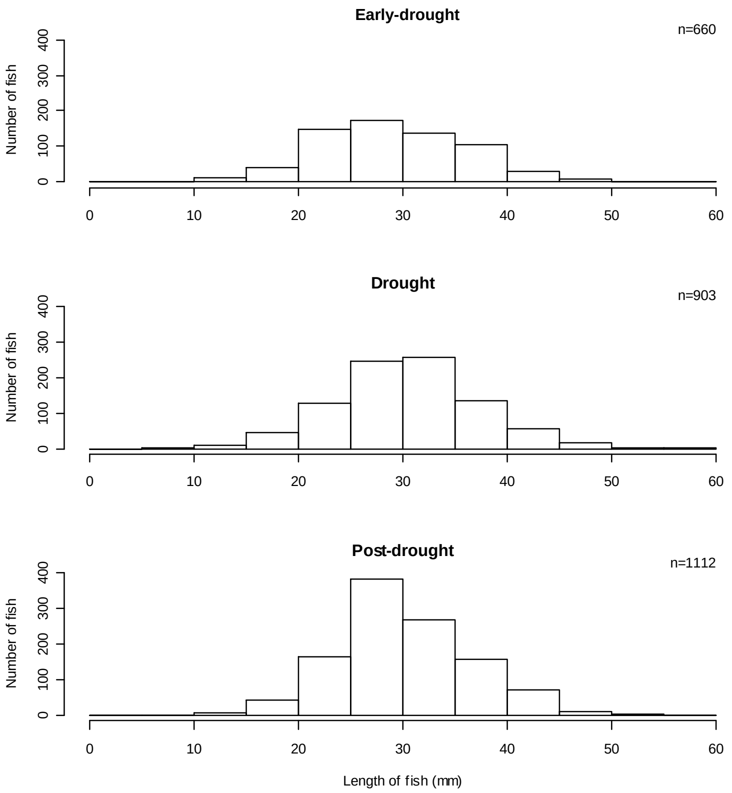

Figure 28. Length-frequency charts for Gambusia in South Australian Murray wetlands during each time period.

Oriental weatherloach

Oriental weatherloach was recorded in South Australian River Murray wetlands only during the post-drought period (Figure 29). Three fish were captured during the post-drought period: two fish on the 9th of March 2011 in Hart Lagoon (100 mm and 120 mm long), and one fish on the 10th of March 2011 in Ramco Lagoon (120 mm long). All three fish are likely to be sexually mature (i.e. mature from 100 mm: Lintermans 2007), so have the potential establish self-sustaining populations over the 2012–2013 season.

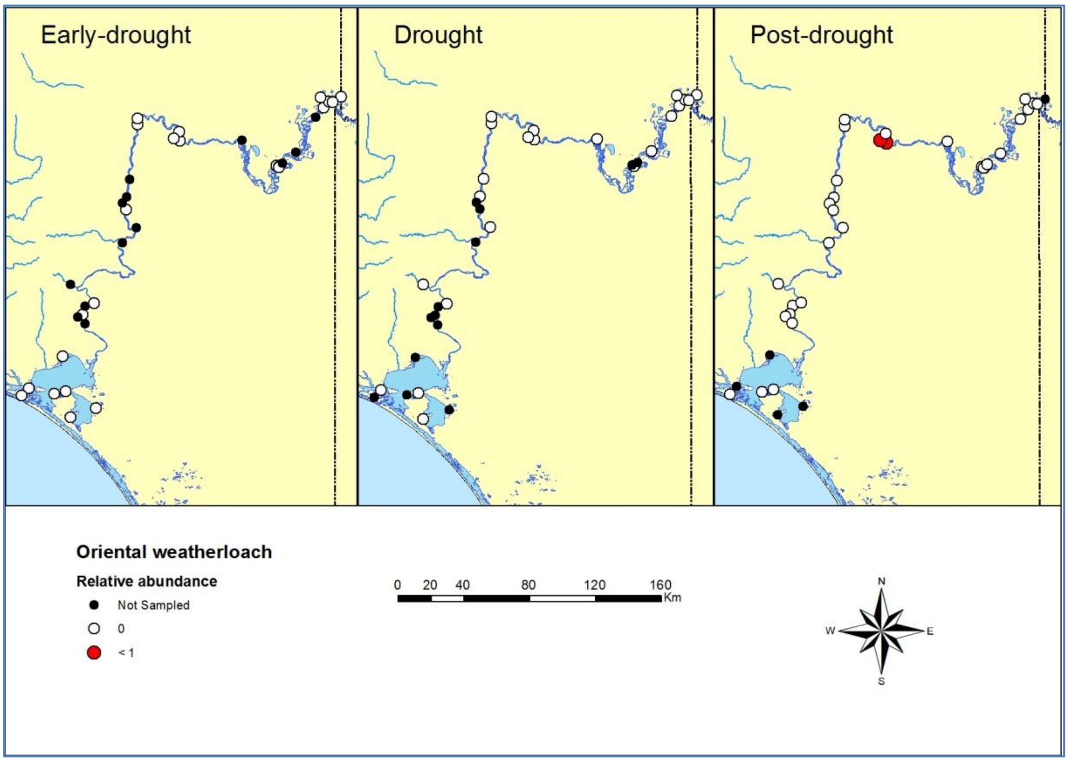

Figure 29. Distribution and relative abundance of oriental weatherloach in each time period.

Discussion

Objective 1: Shifts in regional wetland fish communities

Wetland fish monitoring by the South Australian Murray–Darling Basin Natural Resources Management (SAMDBNRM) Board and the Department for Environment and Heritage (DENR) recorded 23 of the approximately 39 native fish species previously documented for the South Australian section of the River Murray, including six species of conservation significance (see Table 3). Additional data supplied by Wedderburn et al. (2007) added the two threatened pygmy perch species to this study. Notably, this study provides little information for silver perch and Murray cod, because only a few individuals were captured. This is possibly related to their preference for channel habitats, or partly due to sampling methods that failed to target the species (fyke nets were set in littoral habitats of wetlands). Monitoring also recorded five alien fish species, which included the first documentation of oriental weatherloach in South Australia.

Native freshwater ecological generalists (e.g. Australian smelt, bony herring) commonly remained widely distributed and relatively abundant in South Australian River Murray wetlands from 2003–2012, but a few species showed signs of regional decline during the drought (e.g. unspecked hardyhead in wetlands of the Lower Lakes; Murray rainbowfish downstream of Lock 1). The distribution and relative abundance of all freshwater ecological specialists (mostly threatened species) declined in all regions throughout the study, and numerous extirpations were apparent during the drought. Significantly, natural post-drought population recovery is lacking for several threatened freshwater fish species (Murray hardyhead, Yarra pygmy perch, southern pygmy perch, and southern purple-spotted gudgeon). An exception, freshwater catfish apparently benefitted from the return of flows in 2010, with widespread recruitment. A comparable pattern was evident for golden perch. Similarly, the diadromous congolli apparently benefitted from the reconnection between the Lower Lakes and Coorong from 2010–2012 (via constructed fish ways, and opening of the Goolwa Barrage lock), which led to substantial recruitment events (see Wedderburn et al. 2011; Ye et al. 2011). In a regional context, greater shifts in wetland fish communities occurred below Lock 1 from 2006–2010, where the effects of drought and over-abstraction of water were more influential (e.g. water level recession and salinisation in the Lower Lakes: Aldridge et al. 2011).

In Region 1 (border – Overland Corner) during the pre drought period, wetland fish communities predominantly comprised common ecological generalist species (flathead gudgeon, unspecked hardyhead, bony herring, and carp gudgeon complex). Similar fish communities were recorded at wetlands in other monitoring programs in the region (Smith et al. 2007). Fish communities shifted during drought conditions to being dominated by alien carp and Gambusia, and a native ecological generalist (carp gudgeon complex). Importantly, when flows returned to the region in the post-drought period the large-bodied native freshwater catfish and golden perch were significant indicator species within the wetland fish communities, after having been recorded in low numbers during the drought. Notably, the threatened Murray hardyhead and the alien Gambusia often cohabited during all time periods.

In Region 2 (Overland Corner – Blanchetown), wetland fish communities were largely represented by ecological generalists prior to the extreme effects of drought (unspecked hardyhead, carp gudgeon complex, bony herring, Murray rainbowfish and Gambusia). Most persisted through the drought period, when Australian smelt was the only significant indicator species of wetland fish communities in the region. Following the return of flows to the lower River Murray in 2010, golden perch, carp and goldfish were significant indicator species, and freshwater catfish was prominent. Wetland populations of these species mostly consisted of young-of-the-year and juvenile fish.

In Region 3 (Blanchetown–Wellington), the wetland fish communities shifted from Gambusia, bony herring and flathead gudgeon to predominantly carp. Similarly, Conallin et al. (2011) found the same generalist wetland fish species were abundant in the region during spring 2006. Notably, however, freshwater catfish was largely absent in wetlands during the drought, but was recorded in the region during the post-drought period. Similarly, its absence in most wetlands during the drought was noted in another monitoring program (Smith 2010). Significantly, Region 3 is the only area where southern purple-spotted gudgeon was recorded, but its sole remaining habitat was dry from 2007–2010 (see Hammer 2007a). Indeed, all wetlands below Lock 1 underwent drying and salinisation during the drought due to the lowering river levels, but the associated shifts in fish communities in the latter stages was only documented in two known studies. Smith (2010) sampled fish in or adjacent to seven wetlands in November 2008, which was repeated in April 2009 if water remained. Native fishes represented 97% of the catches, which included mostly common freshwater species (e.g. flathead gudgeon) and low numbers of catfish and silver perch. Bice et al. (2010) sampled fish in or adjacent to two wetlands below Lock 1 that were inhabited by southern purple-spotted gudgeon or Murray hardyhead, and showed that both populations had declined substantially by the end of the drought.

In Region 4 (Lower Lakes), shifts in wetland fish communities between 2003–2009 resulting from the effects of drought and over-allocation of water are documented, showing a substantial decline in the proportion of ecological specialists (mostly threatened species) and an emerging dominance of estuarine and generalist freshwater species (Wedderburn et al. 2012). The current study only compares early-drought and post-drought periods in wetlands of the Lower Lakes (most were dry during the drought), but highlights distinct differences in fish communities. Prior to the effects of drought, the threatened Murray hardyhead and the alien Gambusia were significant indicators of wetland fish communities, and Yarra pygmy perch and southern pygmy perch were often recorded. Following the return of river flows after drought, and the re-establishment of lake levels (connectivity and freshening of wetlands), congolli and goldfish were the major representatives of wetland fish communities at the Lower Lakes. Yarra pygmy perch and southern pygmy perch were abundant at some wetlands prior to the drought (Hammer et al. 2002; Wedderburn and Hammer 2003). However, they were not recorded in the current study, which further highlights their severe decline in distribution and abundance, or extirpation.

Objective 2: Threatened fish species

Murray hardyhead

Murray hardyhead is Critically Endangered in South Australia (Hammer et al. 2009), and was recently elevated from Vulnerable to Endangered nationally under the *Environment Protection and Biodiversity Conservation Act 1999*. During the early-drought and drought periods, Murray hardyhead was captured in moderate relative abundances at Disher Creek and Berri Evaporation Basin (Region 1) during the current study and in other sampling (Bice et al. 2010; Wedderburn et al. 2007). Monitoring showed that Murray hardyhead gradually declined at Berri Evaporation Basin throughout the drought, until it was undetected in autumn 2011 (Bice et al. 2011). In the current study, low relative abundances of mature fish were recorded (6–8 fish) during the post-drought period. Due to substantial river flows in the post-drought period, both basins were connected to the river during 2010, 2011 and 2012 and were extensively flooded. The population decline is possibly related to the inlets becoming opened to the river channel. For example, reconnection with the river channel might have reduced salinity so that it was unsuitable for Murray hardyhead, allowed dispersal or increased predation (e.g. by redfin).

The Murray hardyhead population downstream of Blanchetown is distinct from the population in Region 1, and warrants extra conservation measures because of its unique genetic structure (Adams et al. 2011). The decline of Murray hardyhead in regions 1 and 2 during the drought was likely related to drying and salinisation of habitats (e.g. drought refuges at the Lower Lakes: Wedderburn et al. 2010). During the post-drought period, only a single Murray hardyhead was recorded at the Lower Lakes (Hindmarsh Island) in the current study. The recent decline and extirpations of Murray hardyhead in the South Australian River Murray has also been noted in other sampling programs (Drought Action Plan: Bice et al. 2011; The Living Murray: Wedderburn and Barnes 2011). The future viability of Murray hardyhead in South Australia likely rests with its natural ability to recover from the effects of drought. To assist population recovery, approximately 3,500 Murray hardyhead were released into the Lower Lakes in March 2012 under the DENR's Critical Fish Habitat project (Bice et al. 2012).

Southern pygmy perch

Southern pygmy perch is Endangered in South Australia (Hammer et al. 2009). The species was commonly found in fringing swamps and tributary streams of the lower River Murray (e.g. near Renmark in the 1970s: Llewellyn 1974) and Lake Alexandrina (e.g. Nettlebeck 1926). However, substantial declines were documented in the tributaries and fringing wetlands of Lake Alexandrina during the time of the current study (Bice et al. 2008; Hammer 2005; Wedderburn and Barnes 2009). That the current study failed to record southern pygmy perch is further indication the population underwent a severe regional population decline since 2003, and that any level of natural post-drought recovery up to 2012 is unlikely. Therefore, the best chance of population recovery is by re-stocking through the Critical Fish Habitat Project. Over the 2011–2012 season, thousands of southern pygmy perch were released at several wetlands fringing Lake Alexandrina (Bice et al. 2012). Although recapture rates are low (Bice et al. 2012; Wedderburn and Barnes 2012), that some individuals have survived provides a positive sign for its population recovery.

Yarra pygmy perch

Yarra pygmy perch is Critically Endangered in South Australia (Hammer et al. 2009). There are no historical documents describing the species in the MDB, but South Australian Museum specimens dating back to 1915 indicate its extended presence in the lower River Murray and Lake Alexandrina (Hammer et al. 2009). The species was recently rediscovered in wetlands fringing Lake Alexandrina (Hammer et al. 2002), but its subsequent extirpation is apparent (Wedderburn et al. 2012).

Yarra pygmy perch was not detected in the current study, although the species was recorded on Hindmarsh Island in the early-drought period in other studies. For example, Bice et al. (2008) show that low relative abundances of only adult fish (>45 mm TL) remained in wetlands on Hindmarsh Island during spring 2007. Yarra pygmy perch was last recorded in the MDB at the

Lower Lakes in February 2008 during collection for the captive breeding program (Hammer 2008a). The species has not been recorded since, despite extensive sampling. This represent a significant loss to biodiversity in the MDB, given that this genetic lineage represented an Ecologically Significant Unit (Hammer et al. 2010). However, there is an opportunity for population recovery through the Critical Fish Habitat project, where several thousand Yarra pygmy perch were released at Hindmarsh Island over the 2011–2012 season (Bice et al. 2012).

Southern purple-spotted gudgeon

Southern purple-spotted gudgeon is Critically Endangered in South Australia (Hammer et al. 2009). It was common in numerous regions of the MDB, but its rapid decline in the latter half of the 1900s is partly attributed to interactions with alien species (e.g. Gambusia and redfin: Larson and Hoese 1996) and changes to habitat associated with river regulation (see review in Hammer et al. 2009). Until recently, the last verified record was a specimen collected in 1973 near Blanchetown (Glover 1987), and in the 1980s the species was considered Endangered in South Australia (Lloyd and Walker 1986). Unfortunately the South Australian population was excluded from a recent genetic study, which showed MDB populations are characterised by lineages with highly localised endemism (Faulk et al. 2008). The species was rediscovered in Jury Swamp in 2004, and subsequent genetic testing confirmed that it was an endemic isolate (Hammer 2008b).

The southern purple-spotted gudgeon population was successfully recruiting at Jury Swamp from 2004–2007, but by May 2007 the effects of drought placed the population at serious threat (Hammer 2007a). Consequently, a rescue and captive maintenance program began, which resulted in the release of several hundred southern purple spotted gudgeon to Paiwalla from 2009–2010. The population was monitored in the current study, and the data demonstrates that the released fish were persisting until the 5th of November 2011, but recruitment was lacking (see figures 11 and 12). In March 2012, a further 400 southern purple-spotted gudgeon were released at the Finniss River arm of Lake Alexandrina (Bice et al. 2012). Hammer (2007a) provides important information regarding former habitat (rocky, aquatic vegetation – *Vallisneria*, *Ceratophyllum*, *Typha*) and hydrology (water level fluctuations, flushing) in Jury Swamp that will greatly assist planning for population recovery. Further information is presented in Hammer et al. (2009), which stresses that re-stocking programs should continue to expand the population's range in South Australia.

Congolli

Congolli is Vulnerable in South Australia (Hammer et al. 2009). During the recent drought, its migratory pathways were inhibited by barrages at low water levels, so recruitment was extremely low (Zampatti et al. 2010). Just months before substantial flows returned to the lower River Murray after drought, the lock was opened in July–August 2010 to facilitate the movement of congolli that were congregated above the Goolwa Barrage (Zampatti et al. 2011). The return of river flows in late 2010 carried abundant food resources (e.g. zooplankton: Shiel and Aldridge 2011) to the Lower Lakes and Coorong that, combined with water level increases allowing passage through fish ways, likely enhanced reproduction and early-life survivorship of congolli. Consequently, the species exhibited successful recruitment over the 2010–2011 breeding season (Wedderburn et al. 2011; Ye et al. 2011).

Research by Zampatti et al. (2011) suggests congolli in the lower River Murray exhibits limited movement from October–April, and this corresponds with populations in Victorian rivers (Crook et al. 2010). Therefore, connectivity and fish way functioning is important between May–July for optimal reproduction and recruitment. Following a successful breeding event, some of the newly recruited congolli migrated upstream to inhabit wetlands below Lock 1 (e.g. Lake Carlet: Aldridge et al. 2012), while others remain in the estuary and Lower Lakes (Zampatti et al. 2011). The significance of off-channel sites between Blanchetown and Wellington (Region 3) in the life-cycle of congolli is unknown and warrants further study (see Crook et al. 2010). Possibly, this occupation relates to the highly productive nature of wetlands that provide richer feeding areas for female fish (i.e. more food = larger body size = greater reproductive fitness: Jonsson and Jonsson 1993).

Silver perch

Silver perch was considered one of the most abundant fishes in the River Murray (Scott 1962), but substantial declines over recent decades, largely because of disruptions to migratory pathways (Lintermans 2007), means it is Endangered in South Australia (Hammer et al. 2009). The species has also been nominated for listing under the *Environment Protection and Biodiversity Conservation Act 1999*. Silver perch was largely absent in wetlands during this study, with only three adult fish captured. The species usually occupies the channel habitat (Lintermans 2007), so its population status is not assessed in wetland studies.

The apparent importance of high flows in the life cycle of sliver perch suggests its life cycle is largely impacted by river regulation and drought (see Gehrke and Harris 2000). Indeed, silver perch appears to be particularly sensitive to flow regulation and other catchment disturbances (Gehrke and Harris 2001). For example, tagged silver perch moved an average of 41 km after the 1975 flood, with one fish moving 570 km upstream in 17 months (Reynolds 1983). Also, silver perch spawning activity is increased following floodplain inundation (King et al. 2009), but this pattern was not observed during the post-drought period in the current study. Other threats to silver perch include barriers to migration, diseases and predation by redfin, but all topics require further research. A Recovery Plan has been prepared for silver perch (Clunie and Koehn 2001b), and detailed information regarding the biology and threats to silver perch is presented in an accompanying Resource Document prepared for the MDBA (Clunie and Koehn 2001c).

Freshwater catfish

Freshwater catfish was not recorded in early-drought monitoring, but one fish was captured during the drought period. Its distribution and relative abundance in South Australian River Murray wetlands increased substantially in the post-drought period. The length-frequency distribution of freshwater catfish captured in the post-drought period represents all size classes, but the majority of the population are young-of-the-year or juvenile fish (<130 mm long). These results indicate one or more breeding events occurred within individual regions when substantial river flows returned.

There is conjecture regarding the causes of substantial increases in freshwater catfish numbers during the post-drought period. Possibly, there was longitudinal movement of the species from upstream with the incoming flows (e.g. oriental weatherloach and spangled perch were recorded outside of their normal distribution range during this time). However, this contradicts a study undertaken during the 1975 flood in the lower River Murray, which showed that tagged freshwater catfish were re-captured within 14 km of their release site, suggesting that migration is absent even during high flow events (Reynolds 1983). Alternatively, high flows entering South

Australia encouraged lateral movement of freshwater catfish, which might have been assisted by the removal of carp screens at some wetlands. For example, flooding of dryland floodplain rivers raises the abundance of some fish species (higher numbers of juveniles), suggesting that flooding and access to a greater variety of habitats through lateral and longitudinal connectivity supports increased productivity in fish communities (Puckridge et al. 2000; Zeug and Winemiller 2007). Obviously, the response of freshwater catfish to changes in flow regime and the corresponding changes in habitat require further study.

Detailed information regarding the biology and threats to freshwater catfish is presented in a Resource Document (Clunie and Koehn 2001a) and a Recovery Plan (Clunie and Koehn 2000) prepared for the MDBA. In summary, threats include river regulation, introduced species, reduced water quality, diseases, overfishing, and breeding and genetic issues. Further, there are interactions between threats that make it difficult to determine the causes of regional declines (Clunie and Koehn 2001a).

Golden perch

Golden perch had a patchy distribution in South Australian River Murray wetlands, and was captured in low relative abundances in the early-drought and drought periods. During the post-drought period, there was a substantial increase in its distribution and relative abundance throughout Murray wetlands. Under normal river pool levels, opportunities to access off-channel habitats might have been less frequent due to the presence of barriers such as flow control structures, carp screens and other deterrents occurring within wetland inlet channels. For example, the lateral passage of fish in the River Murray can be dependent on connecting channels that facilitate movement between riverine and off-channel habitats (Jones and Stuart 2008). A study undertaken during the 1975 flood found the upstream migration of golden perch in the lower River Murray appears to follow a rise in water level at the onset of major flooding, where some adults move over 1000 km (Reynolds 1983).

Objective 3: Alien fish species

Carp

Carp was widespread in wetlands of the South Australian River Murray throughout the study period. In the post-drought period, it was a significant indicator species of wetland fish communities in the Overland Corner–Blanchetown (Region 2) and Blanchetown–Wellington (Region 3) reaches, and had a high but non-significant indicator value at the Lower Lakes (Region 4). In the river reach from the border–Overland Corner (Region 1), carp was widespread in wetlands during all time periods, which suggests the drought had less effect on the population in this upstream section. The carp population in wetlands of the South Australian River Murray was always dominated by young-of-the-year fish, but this finding might partly be influenced by the sampling method: small fyke nets, sometimes with 5 cm grids at the entrance, were mostly set in water <1 m deep. However, substantial river flows in the post-drought period apparently triggered a massive breeding event, which is indicated by the extremely high numbers of young fish measured. Carp exclusion screens preventing mature carp from entering the few remaining wetlands that persisted during the drought were removed from some wetlands following the return of substantial river flows in the post-drought period (Rebecca Turner, pers. comm.). This likely increased access to suitable spawning habitat for carp, thereby contributing to the sudden increase in numbers.

The massive breeding event observed for carp in the post-drought period was expected, given that water level rises promote its larval abundance and recruitment in floodplain wetlands of the MDB (e.g. Bice and Zampatti 2011; King et al. 2003; Stuart and Jones 2006). The species is further advantaged in wetlands of the lower River Murray because it can spawn multiple times over a season (Smith and Walker 2004). As a result of this event, it is likely that large adult carp will again dominate wetland fish communities in the lower River Murray over coming years. The effects on wetland habitat, such as the destruction of aquatic plants and reductions in water quality (Roberts et al. 1995), are likely to peak during the next decade. To reduce its spawning and recruitment potential, mature carp could be excluded from some wetlands using carp exclusion screens, however, up to 65% of large-bodied native fishes (e.g. golden perch) are prevented from entering the wetland (Hillyard et al. 2010).

Goldfish

Prior to the effects of drought on wetlands (early-drought period), goldfish was irregularly captured at a few wetlands in all regions of the South Australian River Murray. There is little evidence to suggest that its distribution and abundance declined under severe drought conditions. Following the drought, the distribution and abundance of goldfish increased substantially through a massive breeding and recruitment event that was associated with increased river flows and the subsequent reconnection and freshening of wetlands. Further, after the drought, goldfish was a significant species in wetland fish communities in three of the four regions. The high numbers now present in the lower River Murray pose a serious threat to native fishes, because goldfish compete for similar food resources and are often heavily infested with parasites (Hammer et al. 2009; Lintermans 2007). However, goldfish is more prone to infections in fresh water (salinity <1.0 g/L: Altinok and Grizzle 2001), so the population might decline naturally in wetlands of the lower River Murray if salinity remains low as a consequence of substantial river flows.

Gambusia

The Gambusia population remained relatively constant throughout the study period, but above Lock 1 it was mostly associated with sites in the drought and post-drought periods. Further, although it was a significant indicator species at the Lower Lakes prior to drought conditions, the species was less predominant following the 2010 increase in river flows. However, sampling equipment used in this study (fyke nets with ≥5 mm mesh) generally do not capture fish <10 mm long, so early life stages of Gambusia were likely undetected. Details of the impacts of Gambusia are presented elsewhere (Rowe et al. 2008), but they include predation on native fishes and amphibians, and competition for food resources with native fishes.

Redfin

The current study showed that redfin was apparently disadvantaged under drought condition, when distribution and relative abundance declined. However, soon after substantial flows returned in 2010, redfin underwent considerable recruitment, and was recorded in most wetlands in all regions. Redfin is a substantial threat to native fishes (see review by Rowe et al. 2008). Threats include competition for food resources with large-bodied native fishes (e.g. Murray cod, golden perch: Cadwallader and Backhouse 1983), and predation on small-bodied fishes (e.g. Pen and Potter 1992). However, the impacts on native fishes resulting from competition and predation by redfin in the lower River Murray are largely unknown, and warrant investigation. Redfin is also the major host of the Epizootic Haematopoietic Necrosis Virus, which can be transferred to native fish (e.g. silver perch: Lintermans 2007).

It is important to monitor and establish if breeding in the post-drought period leads to substantial recruitment in the redfin population. A large population size of adult redfin would have dire consequences for native fishes over coming years, including limiting the recovery of threatened fish populations. Further, high abundances of adult redfin will diminish the efforts of threatened fish species re-stocked through the Critical Fish Habitat project.

Oriental weatherloach

Prior to February 2011, Oriental weatherloach was not recorded in the River Murray in South Australia (Lenon and Suitor in prep.). In the current study, oriental weatherloach was recorded in wetlands during the post-drought period, but only within Region 2. The species is native to East Asia and has established in several countries. Oriental weatherloach matures at approximately 100 mm long, and is a multiple spawner that can lay between 4,000 and 8,000 eggs per spawning event (Lintermans 2007). It feeds by taking mouthfuls of sediment and filtering out food items, with barbells around the mouth assisting with sensing any potential prey items (Keller and Lake 2007).

Currently in South Australia, the species has been recorded from up to five different locations, occurring within at least two regions defined in the current study (Lenon and Suitor in prep.). Therefore, its distribution and abundance within South Australia still appears limited. The potential impacts of Oriental weatherloach on native fish is unclear, but controlled experiments suggest that completion for food resources is likely (macroinvertebrates: Keller and Lake 2007). However, the species has occupied areas of the MDB for two decades, but there have been no lasting impacts reported – possibly because research is lacking (see Koster et al. 2002). SARDI Aquatic Sciences are currently undertaking a risk assessment for Oriental weatherloach in the lower River Murray (Fredberg and Thwaites in prep.).

Conclusions

This study shows that fish communities in South Australian River Murray wetlands underwent substantial changes from 2003–2012 that were related to the effects of reduced river flows during drought, which included major declines and extirpations of threatened species. Following the return of flows in 2010, there was a notable lack of recovery for most threatened species, except freshwater catfish and congolli showed positive signs of renewed recruitment. Similarly, the commercially and recreationally important golden perch apparently benefitted from the increased flows. Critically, however, there were also proliferations of carp, goldfish and redfin, while the Gambusia population remained relatively constant throughout the monitoring program.

In the Murray–Darling Basin, the greatest threat to freshwater fishes in coming decades is the reductions in surface water availability and riverine flow predicted under climate change forecasts (Pratchett et al. 2011). Although interstate ecologists believe that fish communities in the South Australian River Murray are highly degraded and future climate change effects to flow will probably result in little impact (Balcombe et al. 2011), there are numerous threatened fish species that should be excluded from this assertion. First, re-stocking through the Critical Fish Habitat project might assist population recovery for threatened wetland fish species, including Yarra pygmy perch, southern pygmy perch, Murray hardyhead and southern purple-spotted gudgeon

(Bice et al. 2012). However, the population outcomes of the re-stocking efforts will not be determined until monitoring in the 2012–2013 breeding season. Second, the current study demonstrates that freshwater catfish, congolli and golden perch show early signs of natural population recovery. This is particularly relevant to flow management in the South Australian River Murray as it relates to water quality and connectivity (for fish migration) between wetlands and the river and between the Lower Lakes and Coorong. However, threats from alien fish species that benefitted from the return of substantial river flows are a concern. Most importantly, the redfin population should be monitored to determine if high abundances of adults occur in the near future so that action can be taken to address the level of impact the species might have on threatened small-bodied fishes. Similarly warranting attention is the emerging threat associated with the high recruitment levels of carp and goldfish. For example, management interventions should aim to reduce access to some wetlands (e.g. using optimised carp exclusion screens: Hillyard et al. 2011), which are ideal spawning habitat for carp. Obviously, this type of intervention will benefit native small-bodied fish populations in the wetlands.

Fish re-stocking on Mundoo Island by SARDI Aquatic Sciences and Aquasave in March 2012 through the MDBA's captive maintenance program managed under the DENR's Critical Fish Habitat project.

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