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Monitoring the ecological response of Commonwealth environmental water delivered in 2012-13 to the Murrumbidgee river system

Final Report

Monitoring the ecological response of Commonwealth environmental water delivered in 2012-13 to the Murrumbidgee river system.

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Executive summary

Two key Commonwealth environmental watering actions were undertaken in the Murrumbidgee River system in 2012-13. The first action provided in-channel fresh flows from October to December 2012, targeting native large bodied fish, focussed on creating suitable nesting sites and spawning conditions for the iconic Murray cod. The second watering action targeted the Western Lakes system west of the Lowbidgee floodplain with the aim of reinstating flows that would normally have entered the lakes during naturally occurring flood events but have been prevented from doing so by the Paika levee.

Monitoring activities to determine the success of Commonwealth environmental watering actions relative to the stated objectives were undertaken between August 2012 and June 2013. Overall, the expected outcomes of Commonwealth environmental watering actions were largely achieved.

With respect to native fish reproduction and larval and juvenile recruitment, the following outcomes were achieved: Overall, **the total abundance and biomass of native fish increased significantly after the delivery of Commonwealth environmental water**, due to recruitment by some small-bodied native species (carp gudgeon and Australian smelt) and immigration of large bodied fish, in particular Golden perch. Wetland fish communities were dominated by small-bodied native fish species, which outnumbered exotic fish species such as carp, goldfish and gambusia by more than 100 to one. There was no evidence of significant carp recruitment in the Murrumbidgee River main channel following the delivery of Commonwealth environmental water.

Twenty-seven Murray cod (*Maccullochella peelii*), six trout cod (*Macchullochella macquariensis*), five golden perch (*Macquaria ambigua*) and two silver perch (*Bidyanus bidyanus*) were implanted with acoustic tags to examine spawning related movement before, during and after delivery of the 2012-13 Commonwealth environmental fresh in the Murrumbidgee River. **Movement behaviours of tagged Murray cod were consistent with spawning related movements during Commonwealth environmental water delivery** (which also coincided with the known spawning season of this species). **Improved longitudinal connectivity provided by Commonwealth environmental water coincided with reach scale movements by**

tagged silver perch, throughout the mid-Murrumbidgee River. Larval fish communities were surveyed weekly in the Murrumbidgee River and Old Man Creek to assess fish spawning responses to Commonwealth environmental watering from September to December 2012. 519 cod larvae (*Maccullochella* spp.) were captured, with **a peak in abundance coinciding with the Commonwealth environmental water delivery period.** River blackfish (*Gadopsis marmoratus*), Australian smelt (*Retropinna semoni*) and carp gudgeon (*Hypseleotris* spp.) larvae were also collected during the sampling period in small numbers, as well as juvenile carp gudgeon and juvenile Australian smelt. Very few exotic fish larvae were collected.

With respect to the Commonwealth environmental watering objective ***"support habitat requirements of native fish in the Murrumbidgee River"*** peaks in nutrients, chlorophyll *a* (primary productivity) and microcrustacea (a critical food source for native fish) were recorded during the Commonwealth environmental water delivery period. Generalised linear regression modelling demonstrated that the abundance of drifting cod larvae was positively related to the density of microcrustacea (a critical food source for native fish) which indicates that the Commonwealth environmental watering action was successful in ***supporting habitat requirements of native fish in the Murrumbidgee River.*** In wetlands, microcrustacean densities in benthic and pelagic habitats were **above the critical threshold of 100/L to support larval fish feeding** in August, October, February and April and there was a positive relationship between the number of high flow days and the density of microcrustacea. The high densities of microcrustacea occurring during Commonwealth environmental watering actions were positively related to the abundance of the dominant small bodied native fish, carp gudgeon. These results demonstrate **that the Commonwealth environmental watering action was successful in achieving the goal of supporting habitat requirements of native fish (food supply).**

With respect to **biotic dispersal and the transport of sediments and nutrients**, the change in concentrations of nutrients (nitrogen and phosphorus) and carbon during the Commonwealth environmental watering action was monitored fortnightly in the mid-Murrumbidgee River (from October to December 2012) and every two months from August 2012 to February 2013 in the mid-Murrumbidgee wetlands, Lowbidgee wetlands and Western Lakes. There was evidence the Commonwealth environmental water release increased mobilisation of nutrient and carbon transport in the mid-Murrumbidgee River at some locations.

There was also an indication of enhanced biological activities and interaction at the wetland sites, as reflected in greater concentrations of total nutrients and carbon. The results presented show that the in-channel fresh flows contributed to biotic dispersal and the transport of sediments and nutrients within the Murrumbidgee River.

Throughout the monitoring period (September 2012-March 2013) the biomass of biofilms in the Murrumbidgee River was significantly higher than in the Goobarragandra River (which acted as a reference location). However, biofilm biomass in the Murrumbidgee River was lower during the Commonwealth environmental watering period compared to most other times during the study period. **This suggests that the Commonwealth environmental watering helped to reduce biofilm biomass in the Murrumbidgee River, bringing it closer to that in the reference river.**

Commonwealth environmental watering actions in the Murrumbidgee Catchment were also expected to contribute to ***the condition of native riparian, floodplain and wetland native vegetation***. Rates of vegetation recovery in floodplain wetlands can be slow, and, as a result, we drew on data collected at 11 wetlands (8 treatment plus 3 control sites) in the mid-Murrumbidgee wetlands over the past three years. Commonwealth environmental water was utilised in 2011-12 with the aim of promoting the recovery of aquatic vegetation communities. However, structural and management constraints prevented river levels from reaching a height that would allow reconnection in 2012-13, and, as a result, the majority of the mid-Murrumbidgee wetlands were dry by early February 2013. Drying of key wetlands that did not receive Commonwealth environmental water during 2012-13 had a negative impact on the ***health and extent of existing riparian, floodplain and wetland native vegetation communities,*** with an increase in the percentage cover of terrestrial exotic vegetation species in 2012-13 as the wetlands dried out.

The provision of Commonwealth environmental water to the Western Lakes was expected to contribute to the **survival and condition of waterbirds**, waterbird chicks and fledglings. In 2012–13, we undertook ground surveys for waterbirds in the mid-Murrumbidgee and Lowbidgee wetlands to assess waterbird responses in wetlands targeted for environmental watering and to complement long-term aerial waterbird surveys carried out each spring by the University of New South Wales. In the Western Lakes, which received Commonwealth environmental water, we recorded 48 waterbird species including two threatened species (NSW *TSC Act 1995*) and six species listed on one or more migratory bird agreements Australia has with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA). Colonial nesting waterbird breeding was limited at other wetlands in the Murrumbidgee river system that did not receive Commonwealth environmental water in 2012-13.

Commonwealth environmental water was also expected to contribute to reproduction of other vertebrates, including **frogs** and turtles, by providing improved access to suitable habitat. Three key responses were examined with respect to frog populations and communities in the mid-Murrumbidgee, Lowbidgee and Western Lakes regions between August 2012 and April 2013. The responses were: the presence of adult frogs, calling activity and tadpole abundance. Overall, we recorded six frog species, including the vulnerable southern bell frog (*Litoria raniformis*) (EPBC act 1999). Breeding activity differed significantly among wetland regions with areas receiving either Commonwealth environmental water (Western Lakes) or natural overbank inundation (Lowbidgee), supporting higher numbers of tadpoles than the mid-Murrumbidgee wetlands, which did not receive inflows.

We assessed the distribution, abundance and age structure of **freshwater turtles** in the mid-Murrumbidgee wetlands during August, October and December 2012. We recorded three freshwater turtle species across the five survey wetlands in the mid-Murrumbidgee: the Macquarie River turtle *Emydura macquarii macquarii*, broad-shelled turtle *Chelodina expansa* and eastern long-necked turtle *Chelodina longicollis.* Hatchlings of the Macquarie River turtle were detected in three of the five wetlands sampled in the mid-Murrumbidgee (Yarrada, Sunshower and McKennas lagoons), and hatchling Eastern long-necked turtles were detected breeding in McKennas lagoon.

The outcomes of this monitoring demonstrate the critical role that Commonwealth environmental watering actions play in maintaining the health and sustainability of wetland and river ecosystems in the Murrumbidgee. Monitoring activities through 2013-14 and beyond will allow environmental water managers to refine water management strategies to optimise the positive benefits of Commonwealth environmental water and other environmental water in future years.

Implications for future environmental watering in the Murrumbidgee river system

Two key Commonwealth environmental watering actions were undertaken in the Murrumbidgee river system in 2012-13, 1) in-channel fresh flows from October to December 2012, targeting native large bodied fish, and 2) watering action targeted the Western Lakes system west of the Lowbidgee floodplain.

With respect to in-channel fresh flows, the timing of environmental water delivery coincided with known breeding season of the target species (Murray cod) and triggered movement patterns that were consistent with known spawning behaviours. There were also clear changes in fish community composition before and after the environmental release associated with large scale movement of fish throughout the middle reaches of the Murrumbidgee River. The key assumption underpinning the Commonwealth environmental release was that a substantial rise in water level would increase the availability of nest locations for Murray cod leading to increased breeding activity and larval abundance. However we did not identify a clear, direct relationship between river height or discharge and larval abundance. While nest availability for Murray cod is important, differences in larval abundances between monitoring locations may indicate that other factors, such as adult abundance and channel morphology played a stronger role than discharge or river height. Given this, it may be possible to achieve similar spawning outcomes using smaller volumes of water provided that water levels are stable during the breeding period so that nests are not exposed.

The second watering action targeted the Western Lakes and other wetlands across the Lowbidgee floodplain. Overall the positive outcomes of Commonwealth environmental watering varied between different wetland areas, for example the Western Lakes provided important habitat for waterbirds and contained significantly higher diversity and abundance of waterbirds than other wetlands in Murrumbidgee which in comparison were drying down over 2012-13. River red gum spike rush wetlands adjacent to the Western Lakes were also important in supporting frog breeding and recruitment. In this respect Commonwealth environmental watering actions that support a diversity of wetland types and aquatic communities can help to maximise biodiversity outcomes across the region.

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1 Introduction

This report outlines the outcomes of Commonwealth environmental watering actions in the Murrumbidgee river system from June 2012 to July 2013. This report aims to be approachable and informative for all readers. To support readability, details of complex statistical analysis, modelling approaches and extended results have been presented in a series of linked appendices for each chapter for those readers seeking additional information.

1.1 Background on the Murrumbidgee River

The Murrumbidgee River and connected wetlands provide critical habitats for aquatic and semi-aquatic species including the endangered trout Cod (*Maccullochella macquariensis*), the vulnerable Murray Cod (*Maccullochella peelii*) and vulnerable southern bell frog (*Litoria raniformis*) (Environment Protection and Biodiversity Conservation Act, 1999 (EPBC Act)). The mid-Murrumbidgee Wetlands and Lowbidgee floodplain are listed as wetlands of national importance (Environment Australia 2001) and make up a large portion of the critically endangered "aquatic ecological community in the natural drainage system of the Murray River catchment" (NSW Fisheries Management Act, 1994). These wetlands provide critical nursery and breeding habitat for native fish, freshwater turtles, frogs and waterbirds, including those listed under the China–Australia Migratory Bird Agreement (CAMBA), Japan Australia Migratory Bird Agreement (JAMBA) and Republic of Korea Migratory Bird Agreement (ROKAMBA). In particular, the Lowbidgee floodplain provides critical rookery sites for colonial nesting waterbirds, with 37 waterbird species recorded breeding on the floodplain between 2008 and 2011 (Spencer and Wassens 2010, Spencer, Wassens *et al.* 2011).

In addition to its high conservation values, the Murrumbidgee River supplies major irrigation areas, including both Coleambally and Murrumbidgee Irrigation Areas, stock and domestic and urban water supply. Balancing environmental and consumptive uses to achieve long-term conservation and economic goals within the Murrumbidgee and connected wetlands is a key challenge for environmental water management.

Flows in the Murrumbidgee River system and connected wetlands are regulated by two major dams, the Blowering Dam on the Murrumbidgee's major tributary, the

Tumut River, and the Burrinjuck Dam on the Murrumbidgee River. The hydrology of the Murrumbidgee River has been heavily modified, causing significant reductions in the frequency of river flows capable of reconnecting the mid-Murrumbidgee wetlands (Frazier and Page 2006) and reductions and diversions of flows entering the Lowbidgee floodplain. This has contributed to an overall reduction in the frequency of reconnection events in wetlands close to the main river channel and the loss of permanent wetland nursery habitats. During the decade following 2000, the Murrumbidgee River experienced the lowest inflows ever recorded. This extended period of low flow resulted in the majority of wetlands along the main channel being disconnected for between five and ten years as well as critical spawning habitats, which are high in the main channel (for trout Cod and Murray cod), remaining free of water.

The 2012-13 intervention monitoring project was designed to describe the outcomes of environmental water releases in the Murrumbidgee catchment across four key regions (Figure 1):

- upper Murrumbidgee River below Burrinjuck dam,
- in-channel monitoring in the Murrumbidgee River between Gundagai and Boundary Bend (confluence with the Murray River),
- mid-Murrumbidgee wetlands between Narrandera and Carrathool, and
- Lowbidgee wetlands and Western Lakes from Maude in the east to areas north west of Balranald (hereafter referred to as the Western Lakes).

This report provides a detailed analysis of the outcomes of the 2012-13 monitoring project, with specific details on the environmental objectives of the watering activities, methodologies used to measure these key responses before, during and after the environmental watering action and key ecological outcomes related to the Commonwealth environmental watering objectives for 2012-13 in the Murrumbidgee.

1.2 Commonwealth water use options and flow dependent ecological objectives 2012-2013

Two key watering actions were undertaken in the Murrumbidgee catchment in 2012-13. The first action was an in-stream spring environmental flow (Option 1: Murrumbidgee River Channel Fish Pulse) that targeted native large bodied fish, in particular Murray cod within the main river channel. The key focus of this watering action was to promote spawning and maintain nest sites used by large bodied native fish and to provide conditions that would optimise the growth and survival of larval and juvenile fish (Table 1). The second watering action (Option 5) targeted the Western Lakes and was focused on reinstating flows that would normally have entered the lakes during naturally occurring flood events but were prevented from doing so by the Paika levee, which was constructed early last century. The key goals of this watering action were to improve tree condition in the Western Lakes and provide foraging habitats for wetland dependent fauna, particularly waterbirds (Table 1). In addition to the Western Lakes, this watering action also targeted river red gum wetlands in the North Redbank system with the goal of promoting aquatic vegetation growth and recruitment and providing breeding habitat for wetland dependant fauna (including frogs, fish and waterbirds).

Table 1 Commonwealth environmental watering objectives in the Murrumbidgee River and wetlands

Murrumbidgee River watering action (option 1)	**Wetland watering action (option 5)**
• Support breeding and recruitment of native fish. • Support habitat requirements of native fish (i.e. maximise opportunities for Murray cod and trout cod to locate nest sites and maintain inundation of nest sites long enough to complete spawning cycle) • Support ecosystem functions that relate to mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter). • Support ecosystem functions that relate to longitudinal connectivity (i.e. connectivity along a watercourse) and lateral connectivity (i.e. connectivity between the river channel, wetlands and floodplain) to maintain populations. • Support ecosystem functions that relate to creation and maintenance of bed, bank and riparian habitat.	• Support breeding and recruitment of native fish. • Maintain health of existing extent of riparian, floodplain and wetland native vegetation communities. • Provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities. • Support the habitat requirements of waterbirds. • Support breeding of colonial nesting waterbirds. • Support breeding and recruitment of other native aquatic species, including frogs, turtles, invertebrates. • Support habitat requirements of other native aquatic species, including frogs, turtles, invertebrates.

1.3 Monitoring locations

Monitoring activities have been established across the Murrumbidgee River system and connected wetlands. Monitoring activities focus on five key components of the system (see Figure 1) and described below.

Murrumbidgee River

Monitoring in the Murrumbidgee River main channel was focused on the river reach between Gundagai and Boundary Bend (where the Murrumbidgee River meets the Murray River). Fifteen main channel sites were selected along the Murrumbidgee main channel for fish community sampling before and after the environmental flow (Plate 1) (Figure 2). An additional two sites on Old Man Creek were used as comparison sites. Comparison sites on Old Man Creek were selected to be used as long term references to compare fish community responses to environmental water delivery. For example, in years of high flows (such as the 2012 spring flows), it can be expected that there would be little difference in the fish community as the magnitude of delivered flows affects Old Man Creek and the main channel similarly. However, in years of medium, low and no-flows, as well as after the construction of the Old Man Creek weir, the environmental conditions in Old Man Creek may be significantly different to those of the main channel. These comparison sites therefore provide information on the response of fish communities to different flow scenarios. Three main channel sites were sampled weekly, before, during and after the watering event, for fish larvae and drifting eggs as well as water quality, chlorophyll a and microinvertebrates.

Euroley Bridge on the Murrumbidgee River main

Narrandera on the Murrumbidgee River main

channel	channel
	
Berry Jerry Station on the Murrumbidgee River main channel	Bernofy Station on Old Man Creek

Plate 1 Larval fish monitoring sites in the Murrumbidgee River and Old Man Creek. Photos: M. Hill

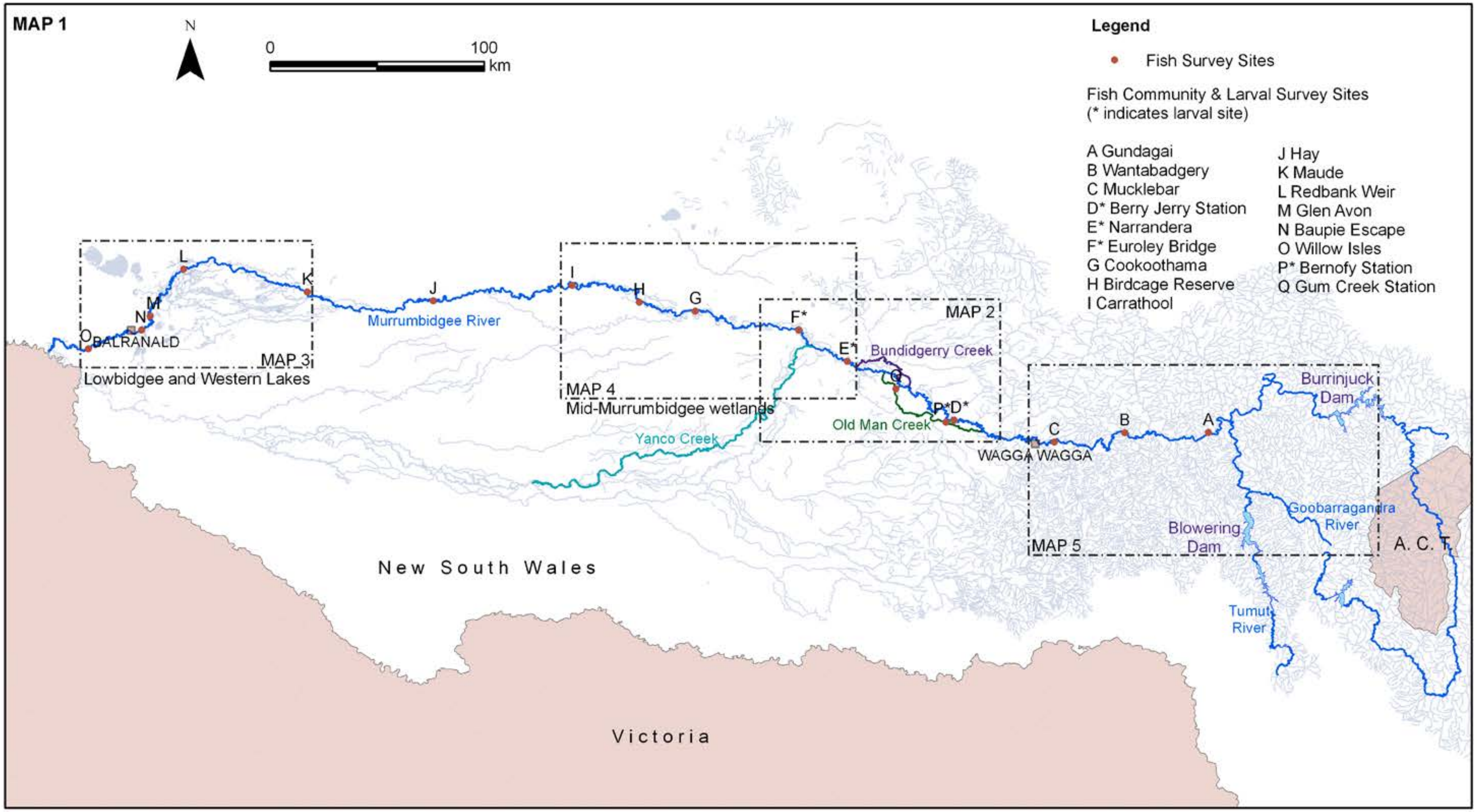


Figure 1 General survey region and location of monitoring sites.

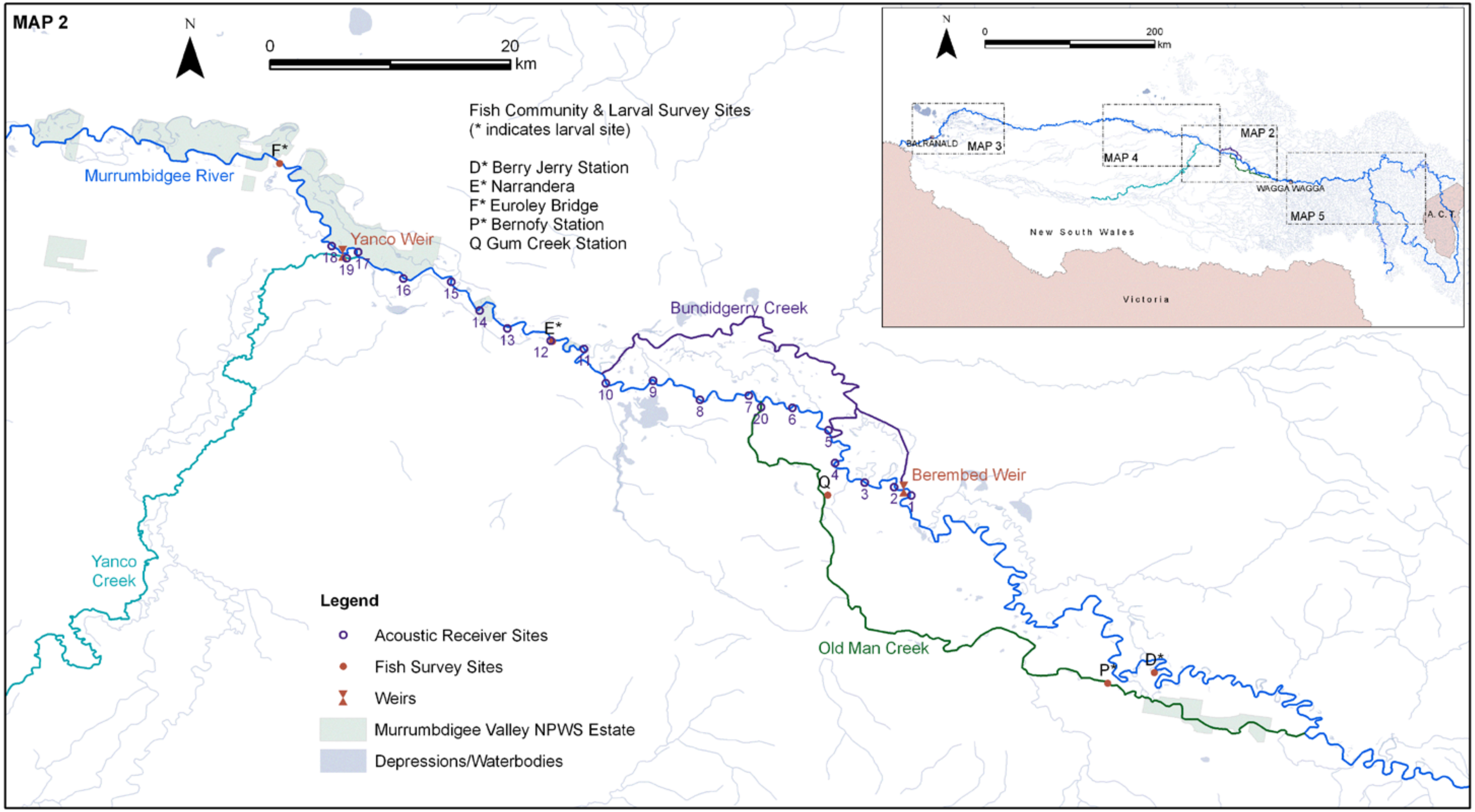


Figure 2 Distribution of larval and community fish monitoring sites and acoustic receiver sites in the mid-Murrumbidgee River and Old Man Creek.

Wetlands of the mid and lower Murrumbidgee and Western lakes

The wetlands of the lowland sections of the Murrumbidgee catchment are an interconnected complex of water bodies that extend from Wagga Wagga in the east to areas west of Balranald (see Figure 1). In recent years, inflows to the Western Lakes and Lowbidgee have been managed through the use of regulators, canals and weirs that allow water to be moved onto the floodplain even during periods of low flow in the main river channel. In contrast, the majority of the mid-Murrumbidgee wetlands can only be filled when water levels in the main river channel reach a suitable height, typically referred to as their commence-to-fill (CTF) (expressed as ML/day), which is the volume of water that must be in the main river channel before it can begin to flow into a wetland. The need to supply water for irrigation during spring and summer, along with other capacity constraints make it difficult to maintain sufficient water volumes in the main river channel to reach wetlands in the mid-Murrumbidgee during the irrigation season. As a result, environmental releases targeting the mid-Murrumbidgee Wetlands are often run at times when peak irrigation demand is low, and there is a greater capacity for water to reach target wetlands. The interconnected nature of the mid and lower Murrumbidgee wetlands also means that moderate flows in the main river channel are likely to create inflows into river red gum wetlands in the Lowbidgee floodplain. From a management perspective, this means that while the Lowbidgee wetlands can be filled without inundating the mid-Murrumbidgee wetlands, the mid-Murrumbidgee cannot be filled without inundating sections of the Lowbidgee.

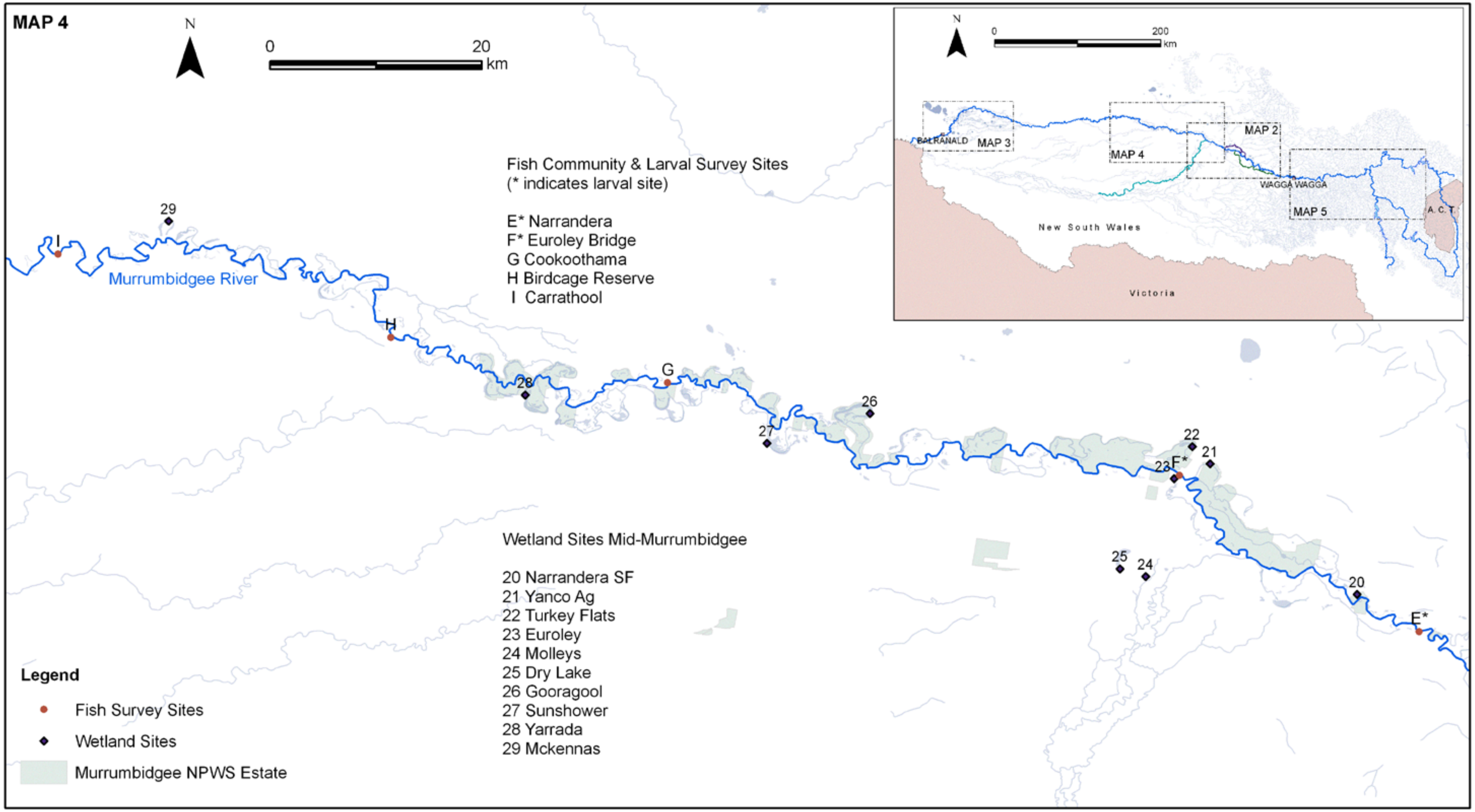


Figure 3 Location of fish community monitoring sites and wetland monitoring sites in the mid-Murrumbidgee River.

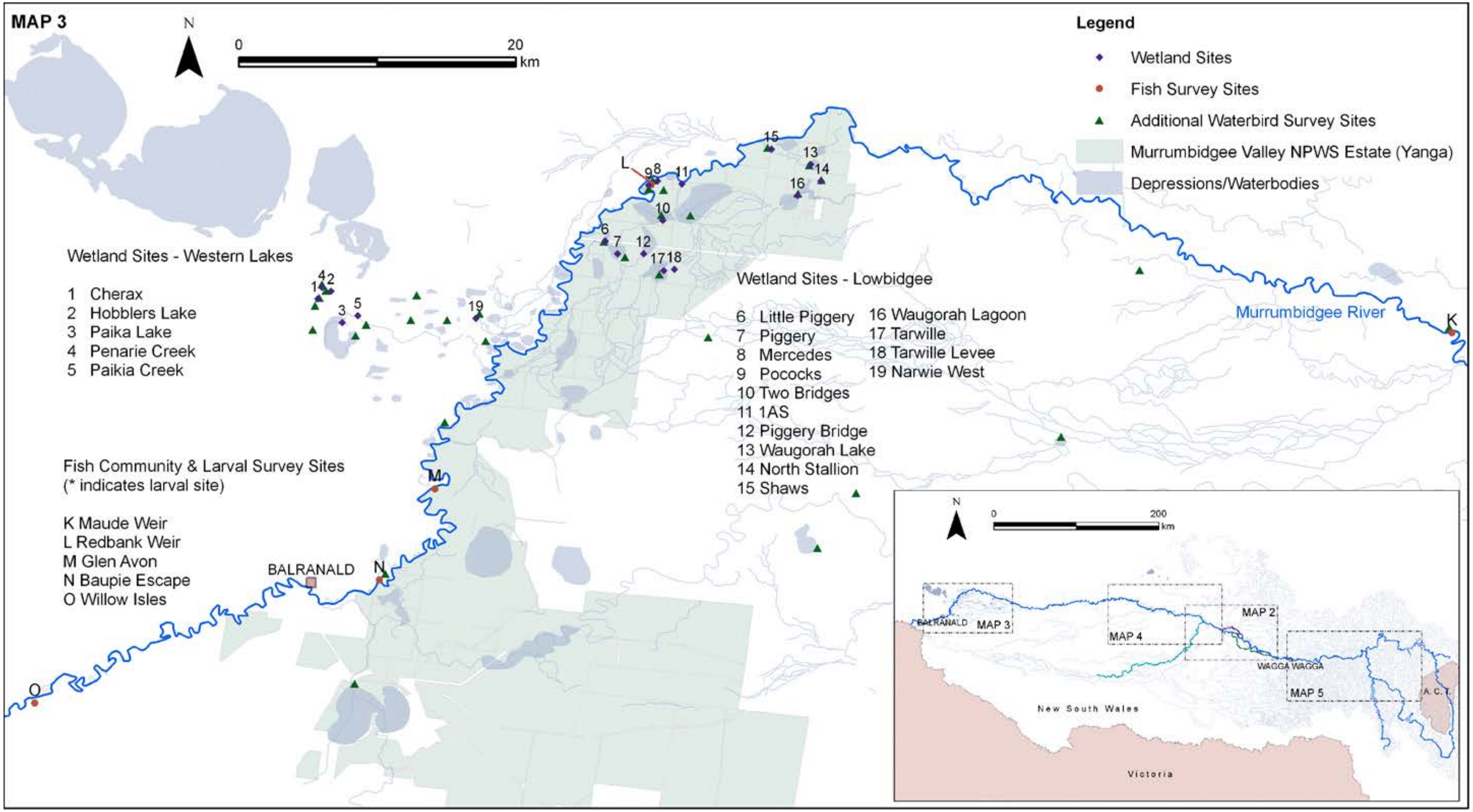


Figure 4 Location of fish community, frog, and waterbird monitoring sites in the Lowbidgee floodplain and lower Murrumbidgee River.

Mid-Murrumbidgee

The mid-Murrumbidgee wetlands are part of a complex of ox-bow lagoons that occur along the Murrumbidgee River between Wagga Wagga and Hay (Plate 2) (Figure 3). These wetlands connect to the Murrumbidgee River during periods of moderate to high in-channel flow. Prior to 2000, the majority of these wetlands regularly connected to the Murrumbidgee River, with wetlands sitting close to the river typically semi-permanent and only drying out completely in very dry conditions (Murray 2008). However, during the extended dry period between 2000 and 2009, the water levels in the Murrumbidgee River remained so low that many of the wetlands did not reconnect at any time during this decade. Due to regulation, this extended dry period was far longer than the average wetting and drying regimes normally experienced by wetlands in the Mid-Murrumbidgee. Following rewetting in 2010, the vegetation communities in these wetlands only slowly moved towards their prior state, most likely due to a diminished seed bank. Subsequent Commonwealth and state environmental watering actions in 2011 aided the recovery of these wetland communities (Wassens, Watts *et al.* 2012). Nevertheless, further watering actions are required before the wetlands are likely to return to their previous state.


Yarrada Lagoon


Gooragool Lagoon


McKennas Lagoon


Euroley Lagoon (control 1)

Plate 2 Wetlands of the Mid-Murrumbidgee.

Western Lakes

Wetlands targeted for environmental watering in 2012-13 are part of an extensive system of lakes to the west of the Murrumbidgee River (Figure 4). The Western Lakes are quaternary lake deposits (NSW National Parks and Wildlife Service 2003) forming shallow open wetlands. The wetlands are floodplain depressions surrounded by scattered black box woodland (with the exception of small areas of river red gum around Paika Lake). Prior to regulation, the vegetation in the area likely contained flood dependent species rather than true aquatic species, an artefact of the temporary nature of inundation (Kent, Earl *et al.* 2002). The Western Lakes were isolated from the Murrumbidgee River channel and floodplain due to the construction of the Paika levee built circa 1910 (pers. comm. Dianne Williams, Paika Station). This levee deprived the Western Lakes sites of riverine flooding for up to 100 years until 2011, when Paika Lake received NSW environmental water. Four waterbodies within the Western Lakes system (Paika, Cherax, Hobblers and Penarie Creek) (Plate 3) received environmental water in September 2012. Hobblers, Cherax and Penarie Creek were receiving water for the first time in over 80 years, while Paika Lake previously received environmental water in 2011as part of the NSW OEH environmental watering program. While there are limited data on the natural magnitude, duration and frequency of flooding at these sites, the extant vegetation community suggests that these wetlands filled during moderate to large flood events. The hydrology of these wetlands is currently being investigated to better understand natural inundation frequencies.

The Western Lakes watering action (Option 5) targeted four key sites. However, the movement of water to the lakes also created an opportunity to inundate Narwie West, a river red gum-spike rush wetland that is located within the North Redbank system of the Lowbidgee floodplain.


Paika Lake


Hobblers Lake


Cherax Swamp


Penarie Creek

Plate 3 Western Lakes October 2012.

Lowbidgee

The lower Murrumbidgee floodplain (Lowbidgee) is a flat, terminal delta. The Lowbidgee floodplain covers more than 347 000 hectares, although the areas of functional wetland were reduced over the past 50 years as a result of upstream diversion for irrigation, and the construction of levees and clearing of native vegetation (Kingsford and Thomas 2004) (see Figure 4). Despite significant hydrological alteration and land clearing the Lowbidgee floodplain remains one of Australia's most significant wetland complexes, with particular importance for breeding colonies of listed migratory species (Kingsford, Brandis *et al.* 2004, Kingsford and Thomas 2004). The Lowbidgee floodplain is also one of the few remaining natural wetland complexes to support the vulnerable Southern Bell frog (*Litoria raniformis*) (EPBC Act). For water management purposes, the Lowbidgee floodplain is divided into five main management regions (Murrumbidgee Catchment Management Authority 2009):

(1) the Nimmie-Caria,

(2) Fiddlers-Uara,

(3) Murrumbidgee corridor,

(4) Redbank (split into the South and North Redbank systems), and

(5) areas downstream of Balranald.

The Redbank system contains highly significant open spike rush wetlands, including Mercedes Swamp, Two Bridges Swamp and Piggery Lake (Plate 4). These wetlands support a very high diversity of aquatic vegetation species and are critically important for the southern bell frog, waterbirds and other wetland fauna (Spencer and Wassens 2010, Spencer, Wassens *et al.* 2011). The open structure of these wetlands is maintained by frequent watering and relatively long hydroperiods, which limits river red gum (*Eucalyptus camaldulensis*) recruitment within the main body of the wetlands.

The Redbank system is dominated by flood dependent river red gum forest. River red gum communities can be impacted by alteration of flooding regimes in three key ways:

(1) declining of tree condition due to reduced flooding and stranding (Wen, Ling *et al.* 2009),

(2) loss of open forest structure and crowding of understory species by river red gum saplings (Bren 1992), and

(3) declining tree condition due to increasing water permanence (Briggs and Thornton 1999).

Water managers within river red gum forests must therefore strive to maintain watering regimes that both promote tree health and encourage natural thinning of river red gum saplings, while ensuring appropriate drying periods between water events.

In general, the health of river red gums within the Murrumbidgee floodplain is improving due to an increase in the frequency and extent of natural and managed flows across the floodplain since 2009. However, small numbers of river red gum in wetlands close to the Redbank Weir show signs of water stress, due to a prolonged period of inundation caused by high water levels in the main river channel that resulted in overbanking and pooling of water against raised roadways and flow control infrastructure. In response to the declining tree condition, water managers opted to keep river heights below the inflow levels for the Lowbidgee wetlands during the environmental release (Option 1) in order to promote wetland draw down and improve the health of affected river red gums.


Mercedes Swamp


Two Bridges Swamp


Narwie West (north Redbank system)


Piggery Lake


Waugorah Lagoon

Plate 4 Key wetlands in the Murrumbidgee Corridor of the Lowbidgee floodplain. Note that Nawie West received Commonwealth environmental water as part of Option 5, while remaining wetlands filled during unmanaged high flows in the Murrumbidgee in August 2012.

2 Commonwealth environmental watering actions

Environmental Watering actions 2012-13

Murrumbidgee River

The watering action in the Mururmbidgee River channel (Option 1) commenced 10 October 2012 and was completed on 14 December 2012. The principle aim of the Commonwealth environmental watering action was to **"*support the breeding and growth of native fish communities in the mid and lower Murrumbidgee River*".** The total water estimate for this event was 223,956.8 ML, which was drawn from Commonwealth environmental water (150,000 ML), the living Murray (45,000 ML) and NSW environmental water allocation (28,956.8 ML). The flow was delivered to maintain a constant river level at approximately 1/3 of bank full or 6,000 ML/day at Darlington Point to promote spawning, larval dispersal and survival of large bodied native fish and microcrustacea production. It is noted that this level is well below minor flood levels.

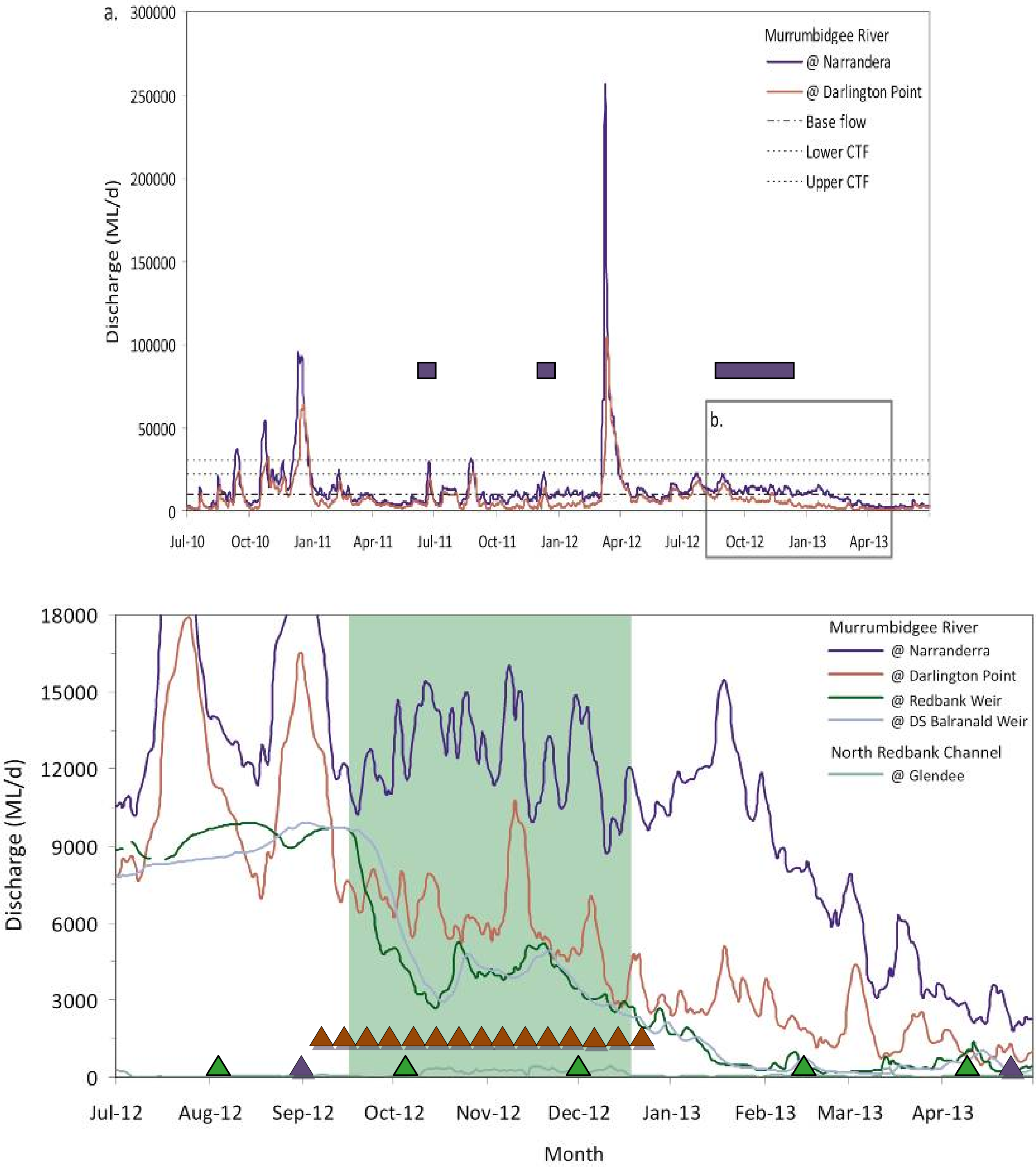


Figure 5 (a) Mean daily discharge in the Murrumbidgee River at Narrandera, and Darlington Point between 1 July 2010 to 30 June2013 with base flows (dash-dot line) and upper and lower commence to fill (CTF) levels. Horizontal bars show Commonwealth and NSW water actions in 2011-12 and 2012-13. (b) Mean daily discharge in the Murrumbidgee River at Narrandera, Darlington Point, Redbank Weir and DS of Balranald Weir gauges and on the North Redbank Channel at Glendee during survey period August 2012 to April 2013 and the timing of environmental water (Commonwealth and NSW OEH Adaptive Environmental Water). Sample dates are represented with green triangles for wetland monitoring of frogs and tadpoles, fish, vegetation, nutrients and water quality, with purple triangles for e-fish surveys (River), and with brick-colour triangles for larval fish and associated covariates.

Western lakes

The principle objective of the Western Lakes watering action (Option 5) was to "***re-establish and maintain the health and regeneration of native plant communities, and to provide habitat for native animals including waterbirds, fish and frogs***". Western Lakes watering commenced on 11 September 2012, the total water usage was 4979 ML of Commonwealth environmental water and 194 ML from the NSW environmental water allocation for a total usage of 5173 ML between 11 September and 17 December 2012. Flows were measured at the Glen Dee Gauge (see

Figure 5). The flows topped up Paika Lake, and filled Hobblers Lake, Cherax Lake, Penarie, Yarrawol and Paika Creeks, as well as 200 ha of River red gum spike rush wetland in the North redbank system at Narwie West. Following watering, the wetland systems were allowed to draw down over summer; Penarie and Paika Creek were dry by December 2012; Cherax had dried by April 2013; while Hobblers and Paika Lakes drew down signifincatly but retained water throughout the survey period (Plate 5).

Plate 5 Hobblers lake in October 2012 (right) and February 2013 (left)

Other wetlands

River red gum-Spike rush wetlands through the southern section of Yanga National Park received some inflows as a result of the normal operation of Redbank weir pools, which is adjacent to these wetlands in August 2012. This period of high water levels is indicated by the Redbank gauge in Figure 5 (Redbank gauge), while others retained water from previous years. All of the target wetlands retained water until December, after which they underwent a period of rapid drying with most sites almost dry in February and completely dry by April 2013 (Table 2).

The mid-Murrumbidgee wetlands were targeted with Commonwealth environmental water in 2011-12 (see Wassens et al. 2012 for details) and retained water through winter 2012 and into October 2012 (Plate 6). Without any additional inflows, the sites gradually dried down with the majority of sites dry in April 2013.

Table 2 Summary of the number of monitoring sites that contained water through the survey period.

	AUG-2012	OCT-2012	DEC-2012	FEB-2013	APR-2013
mid-Murrumbidgee	11	10	7	6	1
Lowbidgee	11	11	11	9	4
Western Lake	1	6	6	4	3


Plate 6 Mckennas Lagoon in the mid-Murrumbidgee October 2012 (right) and February 2013 (left).

3 Monitoring activities

The design of the monitoring strategy is based on the stated Commonwealth ecological flow objectives for the two target watering actions in the Murrumbidgee River, Western Lakes and other connected wetlands, and is shown previously in Table 1.

In relation to the Commonwealth environmental watering objectives, the monitoring program considered three key watering objectives related to ecosystem function (section 1), fish communities, movement and recruitment (section 2), wetland fauna and flora communities, breeding and recruitment (section 3) (Figure 6). For each of these broad objectives, we selected sets of indicators that could be measured in the field to provide a quantitative basis on which to assess the outcomes of Commonwealth watering actions.

The ecological response to environmental watering actions can occur over a range of timeframes; for example, water quality can change rapidly following environmental release, while the composition of species present in a wetland community can change more slowly. The monitoring program therefore included a range of parameters that were expected to respond rapidly to specific watering actions such as larval fish abundance and those that change more slowly such as fish community composition and age structure. This strategy allows us to track the improvements in wetland condition across successive years of environmental watering as well as quantify the short term responses to the specific Commonwealth watering action. We also aimed to select, where practicable, some indicators that could be applied within river and wetlands, these included water quality, nutrients and carbon and microcrustacea. As a number of other parameters (in addition to Commonwealth environmental water) can influence the outcomes of environmental watering actions, we also identified and measured important covariates (variables that have the potential to influence the outcomes of the response of interest).

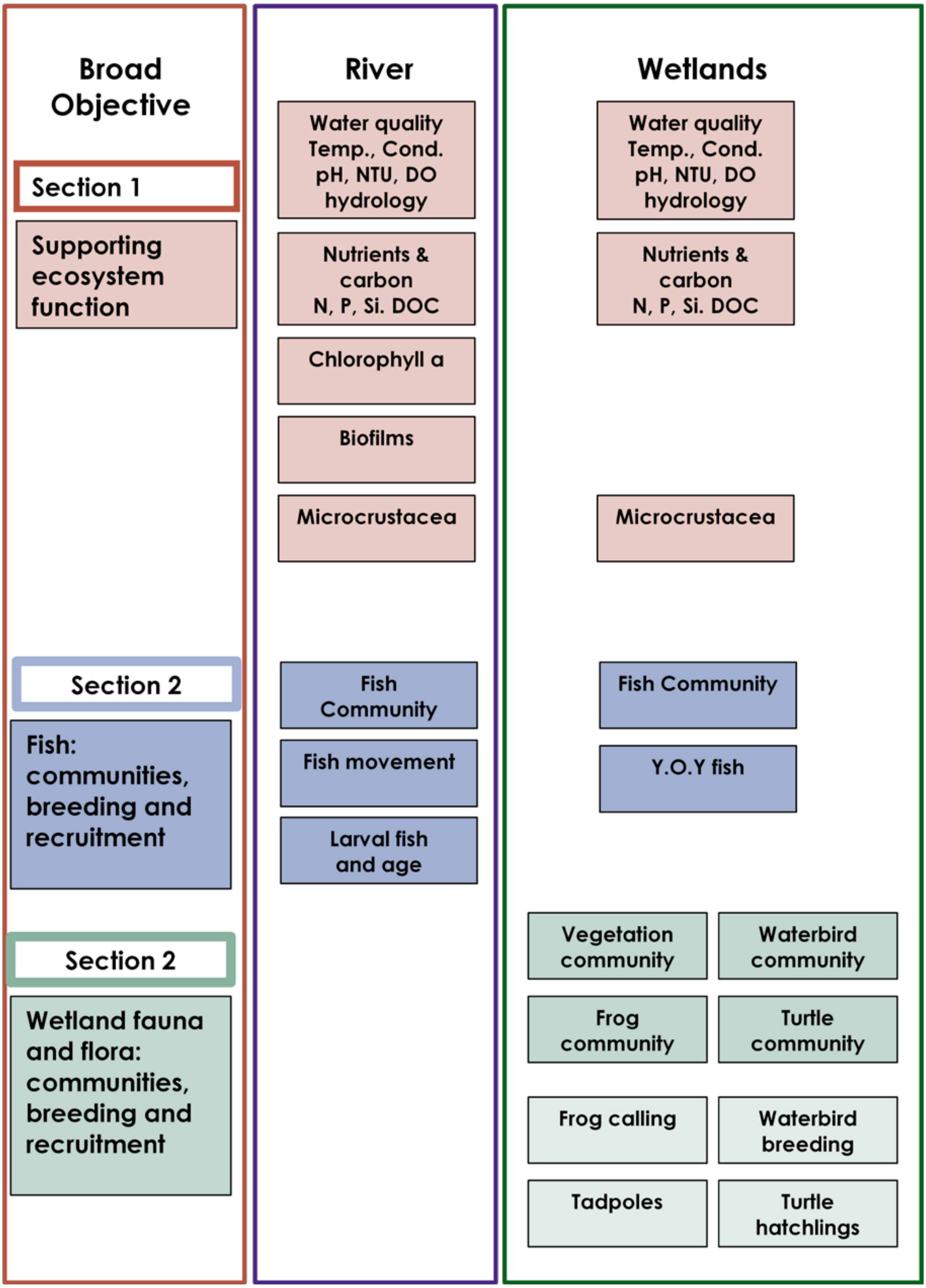


Figure 6 Conceptualisation of the monitoring framework used to assess the outcomes of Commonwealth environmental water in 2012-13.

Supporting ecosystem function – nutrients, carbon, primary productivity and secondary productivity

In this section, we provide an overview of the key outcomes for water quality, nutrient and carbon mobilisation, aquatic primary productivity (Chlorophyll a) and secondary productivity (microcrustacea) in rivers and wetlands. These parameters, while important in their own right, are critical covariates influencing the breeding and recruitment outcomes for fish, frogs and other wetland fauna following Commonwealth environmental watering actions. This section is designed to provide a general overview of these parameters, with data from these sections included as a covariate in later sections related to breeding outcomes for fish and frogs.

Water quality

Water quality parameters: temperature (°C), electrical conductivity (EC, µS/cm), turbidity (NTU), pH and dissolved oxygen (mg/L) where routinely measured in association with the larval fish monitoring (weekly between September and December 2012 during the Commonwealth environmental release in the Murrumbidgee River and every second month between August 2012 and April 2013 in wetlands). This section provides a general overview of water quality in the Murrumbidgee River and wetlands as water quality is a critical covariate contributing to the outcomes for a range of other ecological responses. These data are analysed further with respect to flow and other related parameters in section 9 (rivers) and section 13 (wetlands).

Key outcomes

- Dissolved oxygen concentrations remained above the critical threshold of 4mg/L through the monitoring period in rivers and wetlands.
- Water temperature in the Murrumbidgee River was above the threshold for Murray cod spawning (over 16°C) by early October 2012, and there is no evidence that the Commonwealth environmental release led to a decrease in water temperature.

4 Water quality

4.1 Introduction

The physiochemical properties of water are naturally variable over time, reflecting changes in air temperatures, discharge levels, inflows and wetting and drying patterns. In this section we provide a general summary of the key water physiochemical measurements (water temperature, conductivity, dissolved oxygen, pH and turbidity) in rivers and wetlands.

4.2 Methods

Water quality parameters, temperature (°C), electrical conductivity (EC, µS/cm), turbidity (NTU), pH and dissolved oxygen (mg/L), where routinely measured in association with larval fish monitoring (weekly between September and December 2012 during the Commonwealth environmental release in the Murrumbidgee River and every second month between August 2012 and April 2013 in wetlands).

In the Murrumbidgee River and Old Man Creek, water quality parameters were measured three times per week at each larval sampling site. A HORIBA U-52G water quality multi probe was used at 0.2 metres below the surface. In wetlands, the same water quality parameters were measured every second month (August, October, December, February and April) using a handheld YSI sonde unit.

Rivers

As expected, water temperature in the rivers increased during the monitoring period and was above the threshold for Murray cod spawning (over 16°C) by mid-October 2012 (Figure 7). There is no evidence that the Commonwealth environmental water release led to a change in water temperatures during the critical Murray cod spawning period. Dissolved oxygen levels were also well above the critical threshold of 4 mg/L through the duration of the monitoring period. Conductivity and turbidity were more variable over time, with turbidity undergoing a few spikes both in the Murrumbidgee River, which received Commonwealth environmental water, and in Old Man Creek (control). These spikes may be attributed to rainfall during the monitoring period. Turbidity levels during these spikes still remained below critical thresholds for lowland river systems (ANZECC water quality guidelines 2000).

Plate 7 Sun set over Paika Lake (Western Lakes). Despite the extended period that wetlands in this system had been dry, dissolved oxygen levels remained above the critical threshold of 4 mg/L throughout the monitoring period.

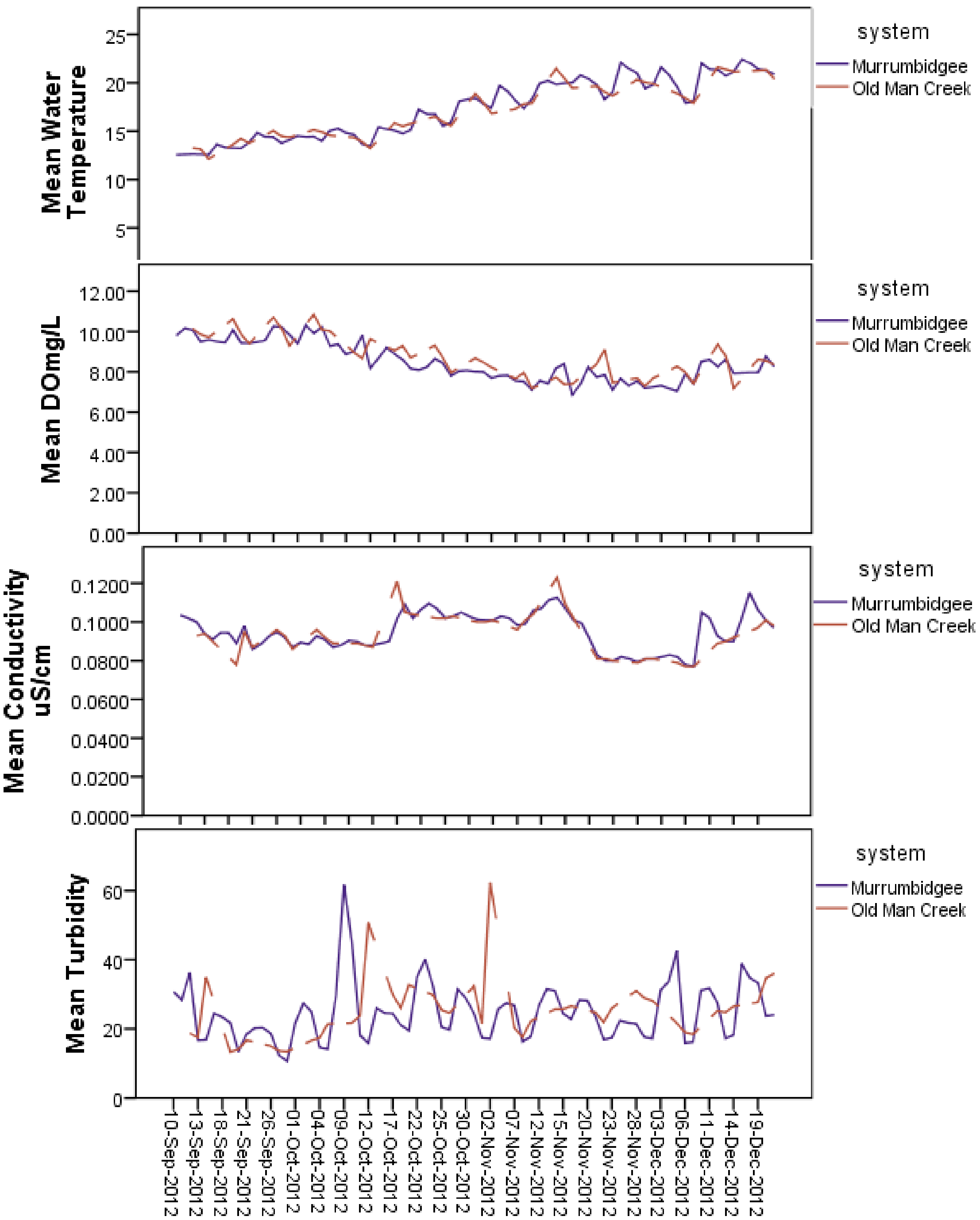


Figure 7 Change in key water quality parameters from 10 September to 19 December 2012 in the Murrumbidgee River and Old Man Creek.

Wetlands

Temperature did not differ significantly between regions (Generalised linear models: wald 18.04, $p<0.001$) and between survey occasions (wald 917.92, $p<0.001$). There was also a significant interaction between region and time (wald 62.37, $p<0.001$) indicating the temperature changed at different rates in different regions. As expected, water temperatures were high through summer in all regions. However, due to their depth, the Western lakes were on average cooler following Commonwealth environmental watering actions than wetlands in the mid and Lowbidgee. By February, when all wetlands were almost dry, water temperatures were similar between regions.

Dissolved oxygen concentrations remained above the critical threshold of 4 mg/L throughout the monitoring period at wetlands in the Western lakes that received Commonwealth environmental water in 2012-13. As expected, dissolved oxygen concentrations differed significantly between regions (wald 10.07, $p<0.001$) and over time (wald 135.15, $p<0.001$). A peak in dissolved oxygen concentrations in summer was probably caused by increases in wetland primary productivity. Conductivity levels changed predictably over time, increasing as wetlands dried between December and April in all regions. There were significant differences in conductivity levels between regions. In the Western Lakes, the very high conductivity levels were driven by one site reed bed that was included as part of the broader scale monitoring program but did not receive Commonwealth environmental water 2012-13.

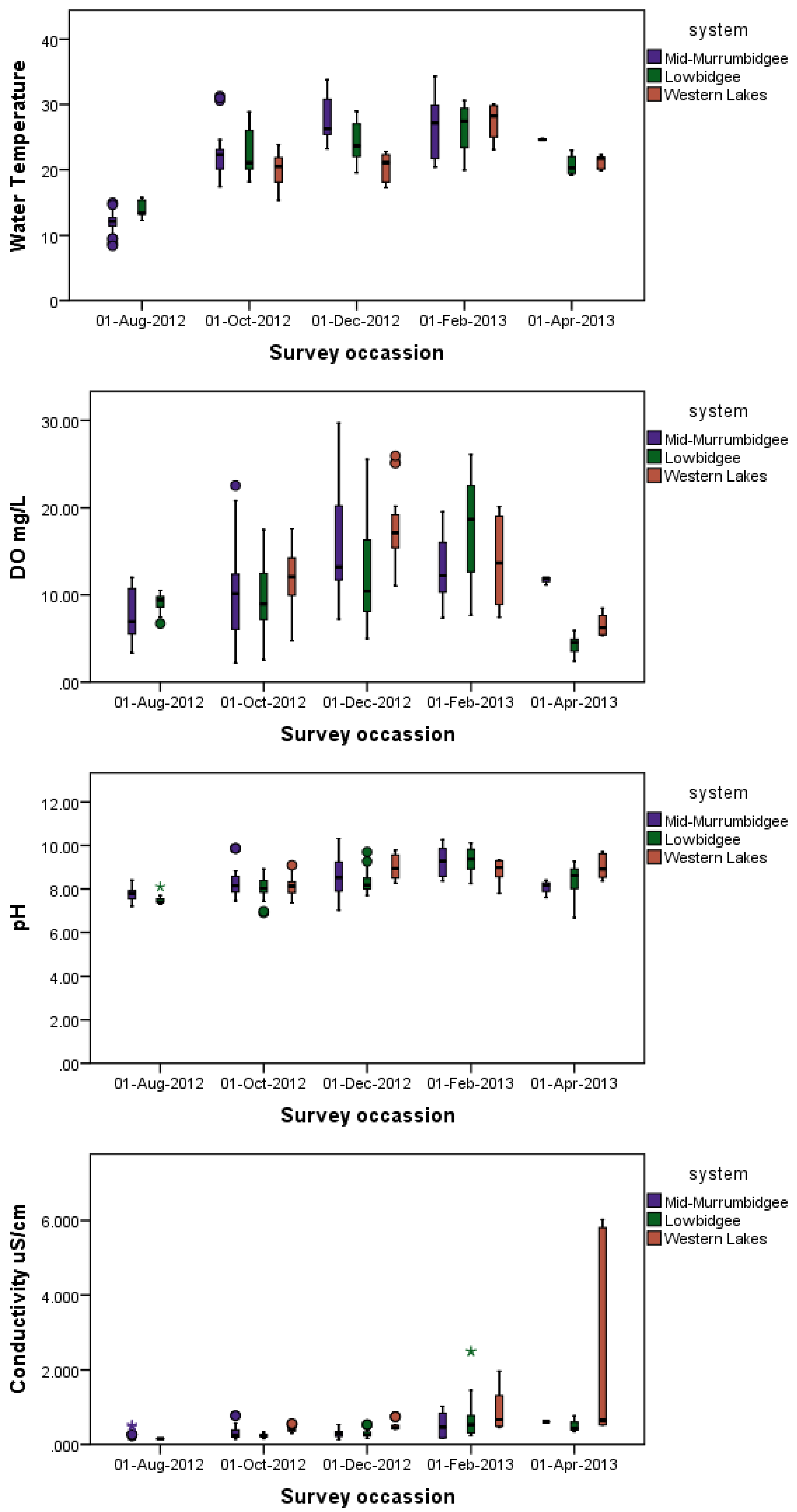


Figure 8 Mean (±SE) of water quality parameters in wetlands of the mid-Murrumbidgee, Lowbidgee and Western Lakes between August 2012 and April 2013.

Nutrients and carbon

The change in concentrations of nutrients (nitrogen and phosphorus) and carbon during the Commonwealth environmental watering action was monitored fortnightly in the mid-Murrumbidgee River (October to December) and every two months in wetlands from August 2012 to February 2013 in the mid-Murrumbidgee wetlands, Lowbidgee wetlands and Western Lakes.

The key objective of the Commonwealth environmental water release related to nutrients and carbon was to ***"Support ecosystem functions that relate to mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter)"*** and ***"support habitat requirements for native fish"***. This section provides a general overview of nutrients and carbon in the Murrumbidgee River and connected wetlands. As nutrients and carbon availability is a critical covariate contributing to the outcomes for larval fish, these data are analysed with respect to flow, water quality and other related parameters in section 9 of this report.

Key findings

- Using discharge rate at Narrandera as an indicator of the Commonwealth environmental watering action from October–December 2012, there was evidence the Commonwealth environmental water release increased nutrient and carbon transport in the mid-Murrumbidgee River.
- There was also an indication of enhanced biological activities and interaction at the wetland sites, evidenced by greater concentrations of total nutrients and carbon.
- The results presented show that the Commonwealth environmental watering action was successful in achieving its objectives related to mobilisation, transport and dispersal of nutrients and organic matter within the Murrumbidgee River.

5 Nutrients and carbon

5.1 Introduction

Nutrients and carbon (and their chemical forms) are a key factor driving primary productivity, for example the growth of photosynthetic algae and plants (Kobayashi, Ryder *et al.* 2009, Kobayashi, Ralph *et al.* 2013). This, in turn, feeds the complex food-web of microinvertebrates, which are consumed by larval fish and so on. In some instances, where floodplains have been dry for extended periods before re-wetting, large amounts of organic carbon can accumulate in floodplain wetlands as litter and coarse woody debris, with floods releasing substantial amounts of dissolved organic carbon (Robertson, Bunn *et al.* 1999). Under certain conditions, these very high organic matter inputs coupled with high water temperatures can lead to a rapid increase in microbial metabolism that decreases the concentration of dissolved oxygen (often referred to as blackwater events) (Howitt, Baldwin *et al.* 2007, Hladyz, Watkins *et al.* 2011). While excessive inputs of nutrients and carbon can sometimes contribute to declining water quality, extended dry periods and loss of in channel freshes can cause bioavailable nutrients to become limiting, reducing primary productivity and, in turn, food availability for aquatic species, even though concentrations of total nutrients are relatively high (Tilman, Kilham *et al.* , Reynolds and Irish , Kobayashi and Church 2003).

Concentrations of nutrients and carbon were monitored during the environmental watering action in 2012–2013 in order to determine if environmental flows supported wetland ecosystem functions that relate to mobilisation, transport and dispersal of nutrients and organic matter.

5.2 Methods

Total nitrogen (TN), total phosphorus (TP), dissolved inorganic nitrogen (DIN), dissolved reactive phosphorus (DRP), dissolved silica (DSi) and dissolved organic carbon (DOC) were measured by analysing water samples (n = 3 – 4 at each site) collected at a total of 21 sites from one channel and three wetland areas consisting of the mid-Murrumbidgee River channel (Old Man Creek, Berry Jerry, Euroley Bridge, McKennas and Narrandera), mid-Murrumbidgee wetlands (Berry Jerry, Euroley, Gooragool, McKennas, Narrandera, Sunshower and Yarrada), Lowbidgee (Little Piggery, Mercedes Swamp, Two Bridges Swamp and Wagourah Lagoon), and Western Lakes (Cherax, Hobblers, Paika Lake and Pencarie Creek) (**Figure 4**). The overall sampling period (23 August 2012 – 4 February 2013) covered the period of the environmental watering action (option 1) (10 October – 14 December 2012). In the present study, discharge (ML/day) at Narrandera was used as an indicator of the environmental watering action in the mid-Murrumbidgee region. Water samples were filtered in the field using a 0.45 μm plastic filter (Sarstedt) and were frozen until analysis. Nutrient and DOC analysis methods followed (Hosomi and Sudo , ASTM) and (Eaton, Clesceri *et al.*).

5.3 Results

Concentrations of nutrients and carbon differed between the Murrumbidgee River and wetland sites (Mid-Murrumbidgee, Lowbidgee and Western Lakes) (Figure 9, Table 3). In general, dissolved (or bioavailable) nutrients such as dissolved reactive phosphate (DRP), dissolved inorganic nitrogen (DIN) (GLM $F = 4.228$, $p < 0.01$) and dissolved inorganic silica (Si) ($F = 2.735$, $p < 0.05$), tended to be similar between the four regions or lower at the wetland sites. In contrast, total nitrogen (TN) (GLM $F = 8.157$, $p < 0.001$), total phosphorus (TP) (GLM $F = 12.022$, $p < 0.001$), and dissolved organic carbon (DOC) (GLM $F = 6.693$, $p < 0.001$) were higher and more variable (changed more over time) at the wetland sites than those at the river sites.

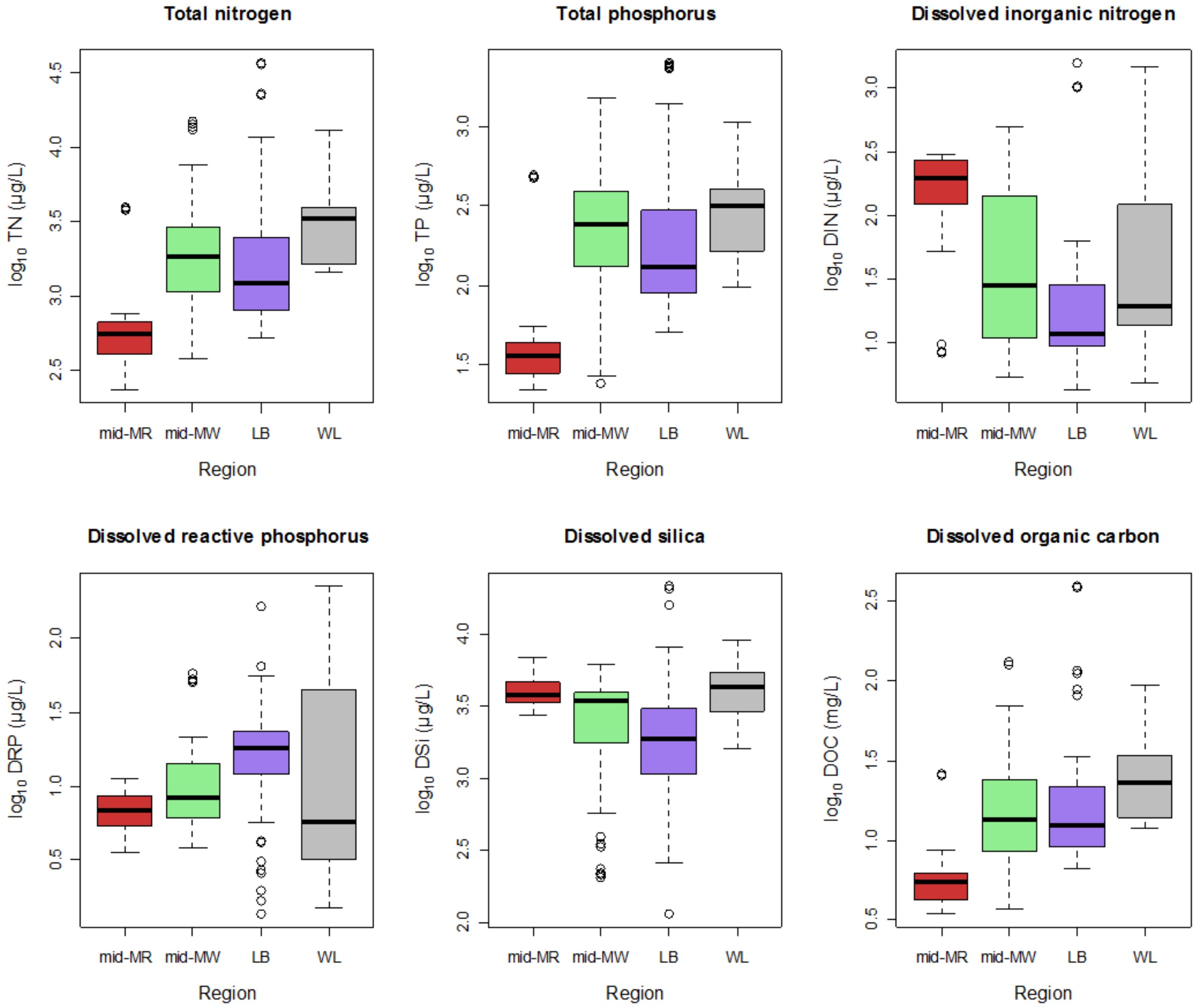


Figure 9 Boxplots of log_{10}-transformed concentrations of nutrients (TN: total nitrogen, TP: total phosphorus, DIN: dissolved inorganic nitrogen, DRP: dissolved reactive phosphorus, DSi: dissolved silica) and carbon (DOC: dissolved organic carbon). Sample size, n = 70 for mid-MR (mid-Murrumbidgee River channel), n = 57 – 60 for mid-MW (mid-Murrumbidgee wetlands), n = 64 for LB (Lowbidgee) and n = 41 for WL (Western Lakes).

Table 3 Summary statistics for nutrients and carbon in the mid-Murrumbidgee, Lowbidgee and Western Lakes between August 2012 and February 2013. Mean, median in parentheses, range in square brackets and sample size (n) are shown.

Area	Total ntrogen (TN, µg/L)	Total phosphorus (TP, µg/L)	Dissolved inorganic ntrogen (DIN, µg/L)	Dissolved reactive phosphorus (DRP, µg/L)	Dissolved silica (DSi, µg /L)	Dissolved organic carbon (DOC, mg/L)
Murrumbidgee River	707(554) [232-3904] n=70	62(36) [22-492] n=70	188(196) [8-302] n=70	7(7) [4-11] n=70	3986(3738) [2699-6819] n=70	7(6) [4-26] n=70
mid-Murrumbidgee wetlands	3288(1822) [380-14780] n=57	356(243) [24-1533] n=57	105(28) [5-500] n=60	13(8) [4-58] n=60	3073(3408) [206-6162] n=60	24(14) [4-130] n=60
Lowbidgee wetlands	4474(1228) [512-36980] n=64	425(132) [51-2546] n=64	75(12) [4-1578] n=64	22(18) [1-164] n=64	2993(1860) [115-21490] n=64	40(13) [7-390] n=64
Western Lakes	4247(3259) [1416-12880] n=41	384(319) [98-1070] n=41	199(20) [5-1465] n=41	37(6) [2-224] n=41	4348(4311) [1586-9010] n=41	32(23) [12-94] n=41

Mobilisation of Nutrients

Time-series responses of nutrients and carbon differed between channel and wetlands in the mid-Murrumbidgee. In three channel sites (e.g. Euroley Bridge, Berry Jerry and Old Man Creek), the concentrations of dissolved organic carbon were higher at the beginning of the Commonwealth environmental watering action period and declined towards the end (Figure 10).

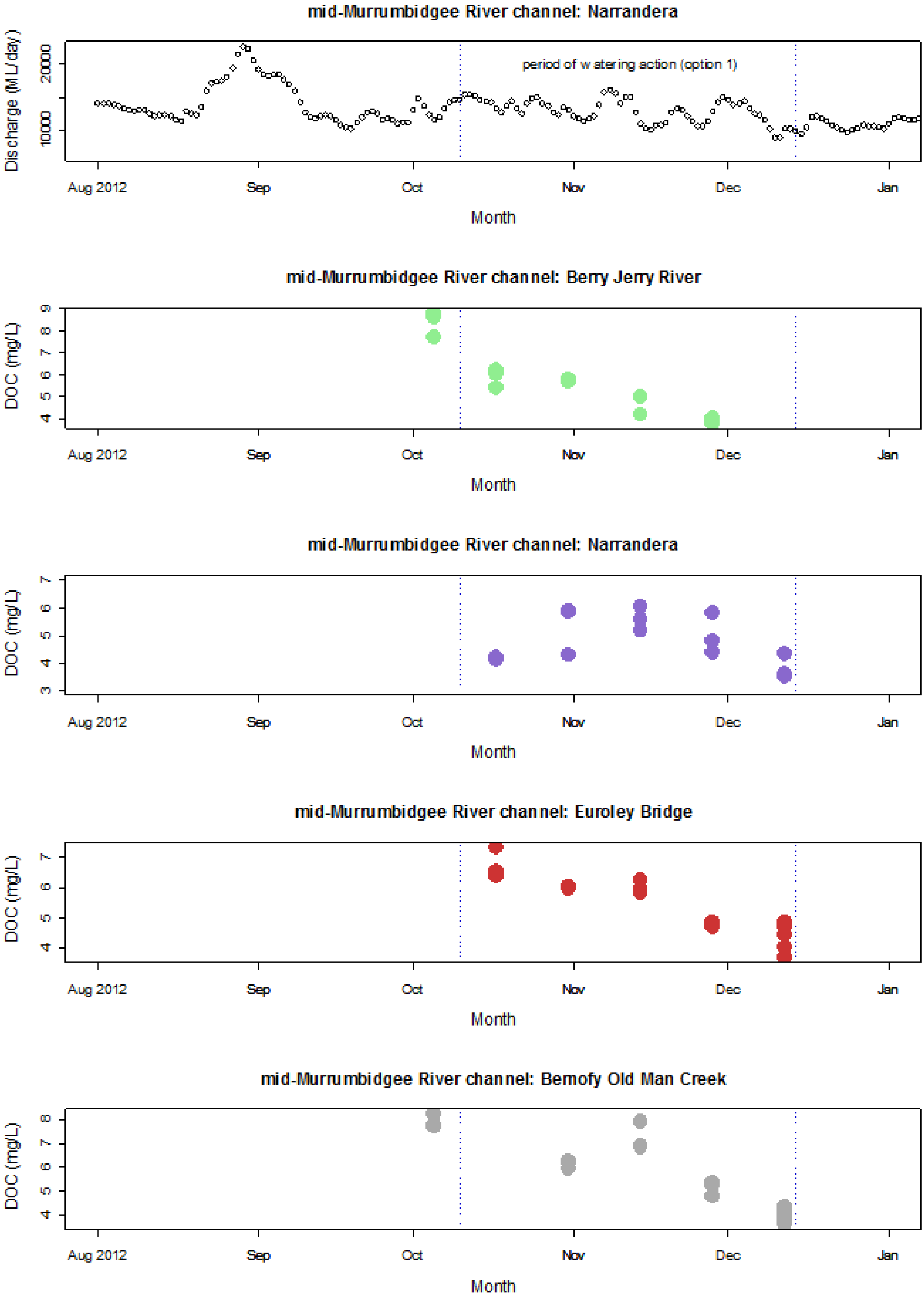


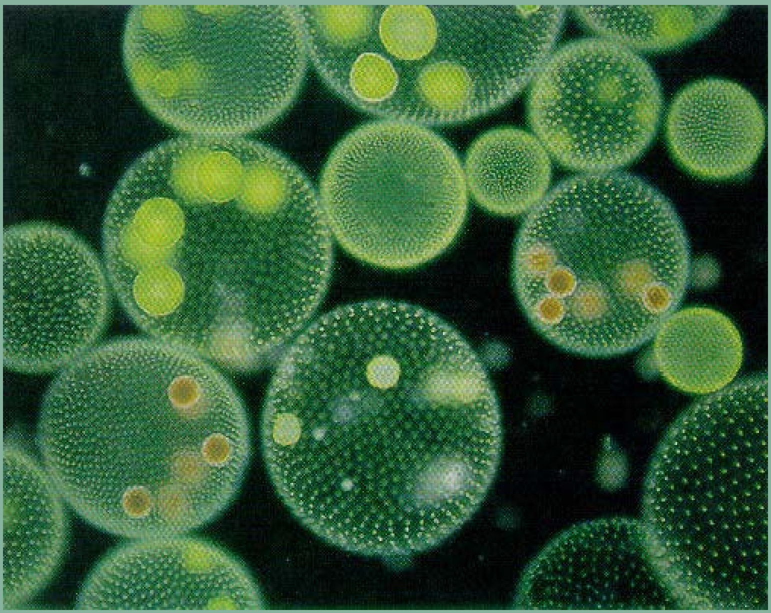
Figure 10 Time-series plots of river channel discharge and concentrations of dissolved organic carbon (DOC) in the mid-Murrumbidgee River channel and Old Man Creek. Dotted line indicates Commonwealth environmental watering period.

5.4 Discussion

There is evidence that nutrients and carbon were mobilised and transported downstream in the mid-Murrumbidgee River channel during the environmental watering period. In addition to enhancing the river channel ecology, environmental flows feeding into areas of dry/semi-dry floodplains and wetlands can trigger aquatic processes at the water-sediment interface and within the water-column (Baldwin and Mitchell , Kobayashi and Church , Knowles, Iles *et al.* 2012). The concentrations of total nutrients (TN and TP) and carbon (DOC) at the wetland sites were much greater than those in the river channel site. However, the concentrations of dissolved inorganic (or bioavailable) nutrients, especially dissolved inorganic nitrogen (DIN), were much lower at the wetland sites than those at the channel sites. These results likely reflect the enhanced biological activities (e.g. extensive use of bioavailable nutrients by algae) and interactions (e.g. retention of particulate nutrients in the form of microinvertebrate growth), coupled with release of nutrients and carbon from inundated soils and sediments at the wetland sites (Kobayashi, Iles *et al.* 2011, Knowles, Iles *et al.* 2012, Baldwin, Rees *et al.* 2013). These aspects can be tested experimentally *in situ*.

The present monitoring results summarise the response of nutrients and carbon during the environmental watering action in 2012–2013. There was an indication of increased nutrient and carbon transport in the mid-Murrumbidgee River channel during the environmental watering action. There was also an indication of enhanced biological activities and interaction at the wetland sites, coupled with release of nutrients and carbon from inundated soils and sediments. We conclude that environmental flows supported wetland ecosystem functions that relate to mobilisation, transport and dispersal of nutrients and organic matter.

Primary productivity-Chlorophyll *a*



Phytoplankton and biofilms (algae and diatoms) are key components of aquatic ecosystems. Photosynthetic algae play similar roles in aquatic systems as they do on land, providing food for aquatic animals and contributing dissolved oxygen while fixing carbon. The balance between primary production (algae and diatom growth) and the breakdown of organic matter (carbon release) are critical parameters for understanding the functioning of river and wetland ecosystems. The change in concentrations of chlorophyll a during the Commonwealth environmental watering action were monitored fortnightly in the mid-Murrumbidgee River and Old Man Creek (October to December). The key objective of the Commonwealth environmental water release related to primary production was to "***Support ecosystem functions that relate to mobilisation, transport and dispersal of biotic and abiotic material (e.g. sediment, nutrients and organic matter).***" This section provides a general overview of primary productivity in the Murrumbidgee River. As Chlorophyll a is a critical covariate contributing to the outcomes for larval fish, these data are analysed with respect to flow, water quality and other related parameters in section 9 of this report.

Key findings

- Using discharge rate at Narrandera, there was evidence the Commonwealth environmental water release from October – December 2012 increased primary production at the target reaches downstream of Narrandera.
- The results show that the Commonwealth environmental release was successful in achieving its objectives related to mobilisation, transport and dispersal of nutrients and organic matter within a stretch of the Murrumbidgee River.

6 Primary productivity

6.1 Introduction

As we have seen from the previous section, during periods of high flow, nutrients (dissolved inorganic, dissolved organic and particulate N and P) and dissolved organic carbon (DOC) can be mobilised and redistributed through aquatic systems. This mobilisation of nutrients, combined with increasing water temperatures and daylight hours promotes the growth of phytoplankton communities leading to changes in primary productivity, which in turn influence the abundance of microcrustacea and food availability for fish. Chlorophyll *a* is the most dominant photosynthetic pigment in plants and is frequently utilised as an indicator of phytoplankton primary productivity (algae) and algal biomass (Wetzel and Likens 2000). Monitoring Chlorophyll *a* within river sites provides an indication of the level of primary productivity before, during and after the delivery of Commonwealth environmental water and in this monitoring program is measured in conjunction with water quality, nutrients, microcrustacea and larval fish. The complex interaction between these components of the food web and the relative contribution that primary productivity makes in supporting larval fish is considered in section 9.

6.2 Methods

Sampling for Chlorophyll a was paired with sampling of larval fish, nutrients and microcrustaceans in three sites within the Murrumbidgee River and one control site in Old Man Creek. Three replicate water samples were collected from each site by submerging a one litre Schott bottle under the surface of the water (bottle triple rinsed before being submerged approximately 200 mm deep). A 250 mL sub-sample of water was measured and filtered through a 0.45 µm Whatman filter paper using a Nalgene vacuum pump plastic filter housing. Once water was filtered, filter papers were folded twice and stored in a sterile 15 mL centrifuge tube, and kept below -18°C until processing. All filter paper samples were kept out of UV light by wrapping in aluminium foil before being stored. In the lab, Chlorophyll *a* was extracted from filter papers using an ethanol buffer technique (heated in a water bath) and filter papers were discarded. Chlorophyll *a* concentration was measured using a spectrophotometer at both 650 and 750 nm wavelengths (Eaton, Clesceri *et al.*

2005) which were converted into a concentration in micrograms per litre (µg/L) according to (Ritchie 2006).

6.3 Results

Chlorophyll concentrations in the Murrumbidgee River showed a small increase in September 2012 following the release of Commonwealth environmental water and a larger peak in late November (Figure 11). This response was not consistent as chlorophyll a concentrations did not pulse at one of the Murrumbidgee River sites, Berry Jerry. The control site in Old Man Creek, which did not receive environmental water, experienced a small and lagged increase in September and a small peak in mid-November.

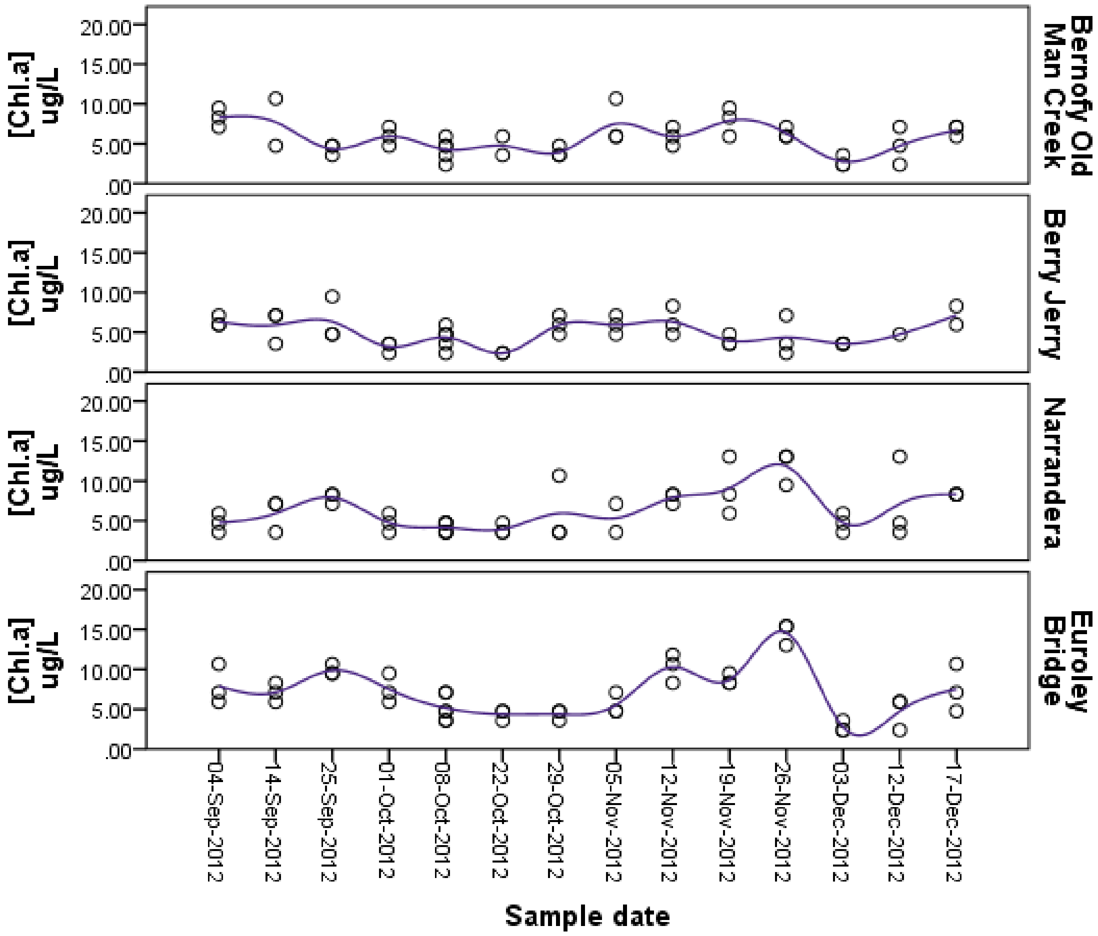


Figure 11 Chlorophyll concentrations over time in the Murrumbidgee River at Berry Jerry, Euroley Bridge and Narrandera and in Old Man Creek.

6.4 Discussion

Overall, the chlorophyll monitoring detected two pulses in chlorophyll a concentrations within the Murrumbidgee River in 2012. The pulses follow the release of Commonwealth environmental water, although the largest peak also coincided with warmer temperatures and increased available light, which both act to increase chlorophyll production. However, given that chlorophyll a concentrations showed a reduced peak at the control site which did not experience higher flows, it appears that the environmental watering boosted primary productivity. This peak coincided with a pulse in microcrustaceans and larval fish.

Biofilms

Biofilms are important components of freshwater foodwebs. However, a reduced variability of discharge can sometimes cause the biomass of biofilms to increase to nuisance levels (over 100 mg/m^2). Pulsing flows and increasing variability in flow (towards that under modelled unregulated conditions) is a way to reduce biofilm biomass and improve river health. Monitoring of biofilms was undertaken in the Murrumbidgee River downstream of Burrinjuck Dam, in the Tumut River downstream of Blowering Dam, and in the Goobarragandra River, an unregulated tributary of the Tumut River (use as a reference river). Sampling was undertaken monthly from September 2012 to March 2013. Some sites in the Murrumbidgee River and Tumut River could not be sampled on several occasions due to high river conditions preventing sampling from being undertaken safely. The key objective of the Commonwealth environmental watering actions in 2012-13 that relate to biofilms was to ***"Support ecosystem functions that relate to creation and maintenance of bed, bank and riparian habitat"***.

Key outcomes

- Throughout the monitoring period the biomass of biofilms in the Murrumbidgee River was significantly higher than in the Goobarragandra River (reference). However **biofilm biomass in the Murrumbidgee River was lower during the Commonwealth environmental watering period compared to most other times during the study period**. This suggests that the environmental watering helped to reduce biofilm biomass in the Murrumbidgee River, bringing it closer to that in the reference river.

7 Biofilms

7.1 Introduction

Biofilms are a combination of bacteria, algae and fungi that grow on submerged surfaces (e.g. wood, sediment, rock) in aquatic systems. They are a major instream source of carbon in river systems and provide food and habitat for a range of organisms. Biofilms are excellent indicators of ecological responses to environmental watering because they respond to flow changes in a time frame (e.g. days to weeks) that is appropriate for flow management (Burns and Ryder 2001). Previous studies (Ryder 2004, Watts, Ryder *et al.* 2009, Watts, Ryder *et al.* 2010, Watts, Nye *et al.* 2005, Watts, Ryder *et al.* 2008) have shown that regulated flow regimes with low variability in discharge can result in reduced productivity, lower diversity, and high biomass of biofilms (that often becomes a nuisance to the general public or landholders) than a regime that has a more variable discharge.

Disturbance by flood events is one of the most important regulators of spatial and temporal variability in benthic communities of streams (Davis and Barmuta 1989), with shifts in benthic algal community structure and function being well documented (Peterson and Stevenson 1992, Uehlinger, BÜhrer *et al.* 1996, Biggs, Smith *et al.* 1999). The effects of water velocity on biofilm biomass and productivity has been investigated in flumes (e.g. Horner, Welch et al. 1990), experimental streams (e.g. Biggs, Smith et al. 1999) and by survey in natural streams (Uehlinger, Kawecka *et al.* 2003). Research in the Mitta Mitta River has demonstrated that the release of pulsed flow events can scour and reset biofilms (Sutherland, Ryder *et al.* 2002, Watts, Nye *et al.* 2005: Watts, 2009 #3179, Watts, Ryder *et al.* 2008). This had a positive effect on the instream ecosystem by reducing the biomass of biofilm and enabling early successional algae (e.g. diatoms) to become established, thereby facilitating a shift in the biofilm community towards that of a reference stream (Watts, Ryder *et al.* 2009, Watts, Nye *et al.* 2005). The benefits of resetting biofilms through the delivery of in-channel environmental flows include the following:

- Promotion of early successional algal taxa (e.g. diatoms) and higher biofilm diversity. A high diversity of biofilms usually indicates good ecosystem health.

- Provision of nutrients and particulate organic matter in the water column, thus providing an important food resource for downstream communities.
- A reduction in the nuisance of a high algal biomass of biofilm growing on the beds of rivers to levels unacceptable to the general public or landholders. Quinn (1991) recommended that "the seasonal maximum cover of stream or river bed by periphyton as filamentous growths or mats (greater than about 3 mm thick) should not exceed 40% and/or biomass should not exceed 100 mg chlorophyll-*a* /m^2.

Based on previous studies, it was predicted that biomass of biofilms on cobbles will decrease following the environmental watering due to scouring of biofilms from increased flow velocity. In addition, increased flow variability from in-channel environmental watering will ensure biofilm biomass in these systems remains below nuisance levels.

7.2 Methods

Daily discharge data were obtained from NSW Government water information website (NSW Office of Water, 2012) for gauging stations in the Murrumbidgee River downstream of Burrinjuck Dam at Gundagai (410004), and the Goobarragandra River at Lacmalac (410057), which is an unregulated tributary of the Tumut River. In 2012-13 environmental watering occurred from 10 October to 14 December 2012 resulted in a maximum discharge of 16,775 Ml/day at Gundagai on 16/10/2012.

Monitoring of in-stream parameters was undertaken in three reaches of the Murrumbidgee River downstream of Burrinjuck Dam and four reaches of the Tumut River downstream of Blowering Dam (refer Figure 1). One reach in the Goobarragandra River, an unregulated tributary of the Tumut River, was sampled as a reference. Each of the river reaches selected for the study included a cobble bench (Plate 8). Sampling was undertaken monthly at Gundagai and two sites in the Goobarragandra River. Sampling at two other sites in the Murrumbidgee (near Bookham and Jugiong) and sites in the Tumut River could only be sampled on one or two occasions due to high river conditions preventing sampling from being undertaken safely.

Plate 8 Murrumbidgee River at Gundagai (left) and Goobarragandra River near Tumut (right) showing presence of cobble benches at each site.

An area in the channel at each site that would remain permanently inundated throughout the study period was selected for sampling biofilms. On each sampling, occasion five cobbles (ranging between 0.1 and 0.2 m diameter) were collected from this area within each reach, placed in labelled sealed plastic bags and stored in the dark in an esky for transport back to the laboratory. A Horiba water quality monitor was placed just below the water surface at each site on each sampling date to obtain spot measures of the temperature (ºC), specific conductivity (mS/cm), dissolved oxygen (%), pH, and turbidity (NTU) of the water.

The biofilm was scrubbed from each cobble into 100 mL of distilled water and a subsample was filtered through a GC-50 0.5 µm filter for chlorophyll-a assessment. Samples were placed in 8 mL of 90% methanol containing 150 mg magnesium hydroxide carbonate, extracted for 18 hours at 4°C, transferred to a 70°C water bath and heat treated for two minutes. Samples were centrifuged at 4500 rpm for three minutes and optical densities at 750 and 666 nm were measured pre- and post-acidification using a UV/Visible Spectrophotometer. Chlorophyll *a* concentration was determined following Ritchie (2006). For assessment of total and organic biomass, a subsample was filtered through a GC-50 0.5 µm filter paper, the filter paper dried at 80°C for 24 hours, weighed, combusted for four hours at 500°C and reweighed. The colonisable rock surface area (CRSA) of each cobble was calculated using the method of Doeg & Lake (1981). CRSA measurements were used to standardise biofilm dry weight (total biomass) and ash free dry weight (organic biomass) to g/m^2 and chlorophyll *a* (algal biomass) to mg/m^2. Percent organic matter was calculated as the proportion of AFDW to DW and converted to a percentage to standardise across sites and dates.

A one-factor ANOVA was undertaken to test if algal biomass and organic biomass was significantly different across the sample dates in the Murrumbidgee River. When significant differences were indicated, *post hoc* pairwise comparisons were undertaken. All univariate analyses were conducted using the software package SPSS Statistics v20.

7.3 Results

The total, organic and algal biomass of biofilms in the Murrumbidgee River was significantly higher than levels observed at the reference sites in the Goobarragandra River (Plate 9). This was due to a high level of sediment entrained within the biofilm as well as higher organic biomass of biofilms in the Murrumbidgee River compared to the Goobarragandra River.

Plate 9 High biomass of biofilm on cobbles collected from the Murrumbidgee River on 26/2/2013.

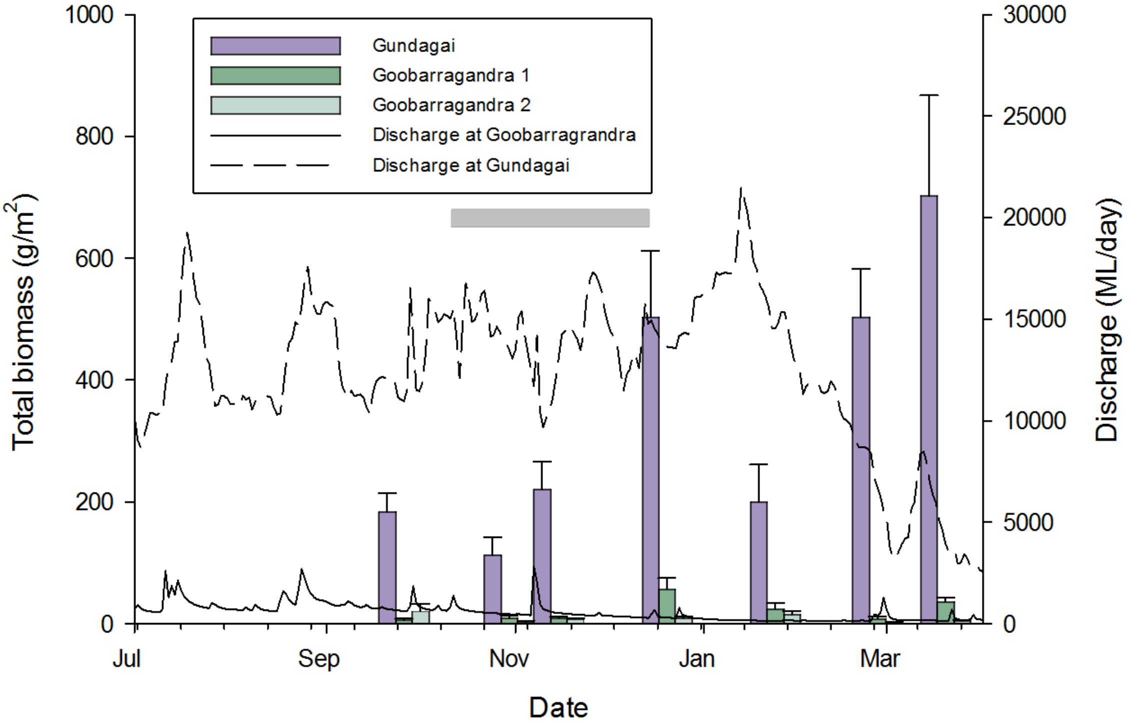


Figure 12 Mean (±SE) of total biofilm biomass (g/m²) on cobbles from sites in the Murrumbidgee River at Gundagai and the Goobarragandra River (reference) between September 2012 and April 2013. The horizontal grey bar indicates duration of the environmental watering in the Murrumbidgee River.

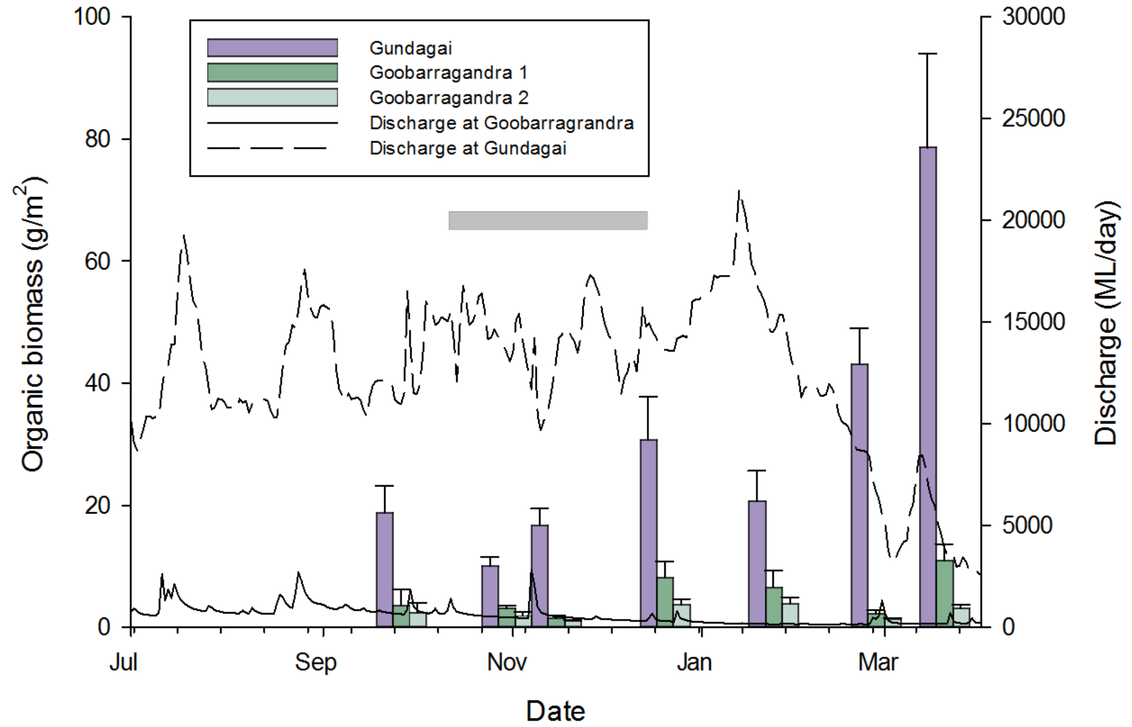


Figure 13 Mean (±SE) of organic biofilm biomass (g/m²) in the Murrumbidgee River at Gundagai and the Goobarragandra River (reference) between September 2012 and April 2013. The horizontal grey bar indicates duration of the environmental watering in the Murrumbidgee River.

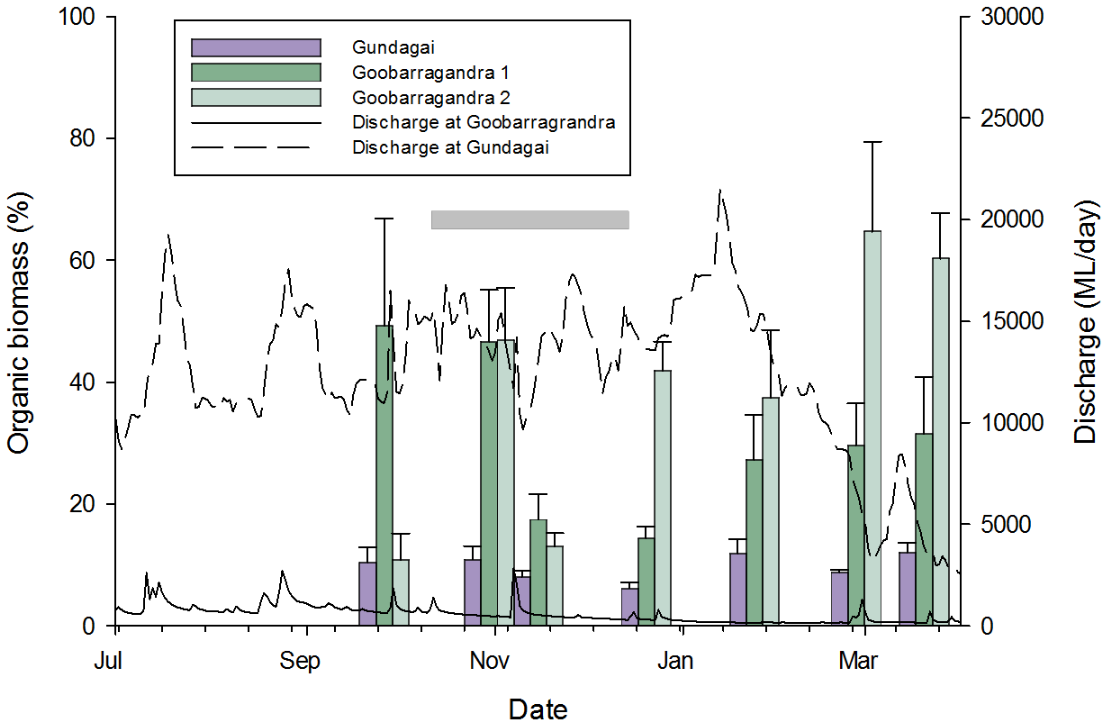


Figure 14 Mean (±SE) of percent organic biofilm biomass in the Murrumbidgee River at Gundagai and the Goobarragandra River (reference) between September 2012 and April 2013. The horizontal grey bar indicates duration of the environmental watering in the Murrumbidgee River.

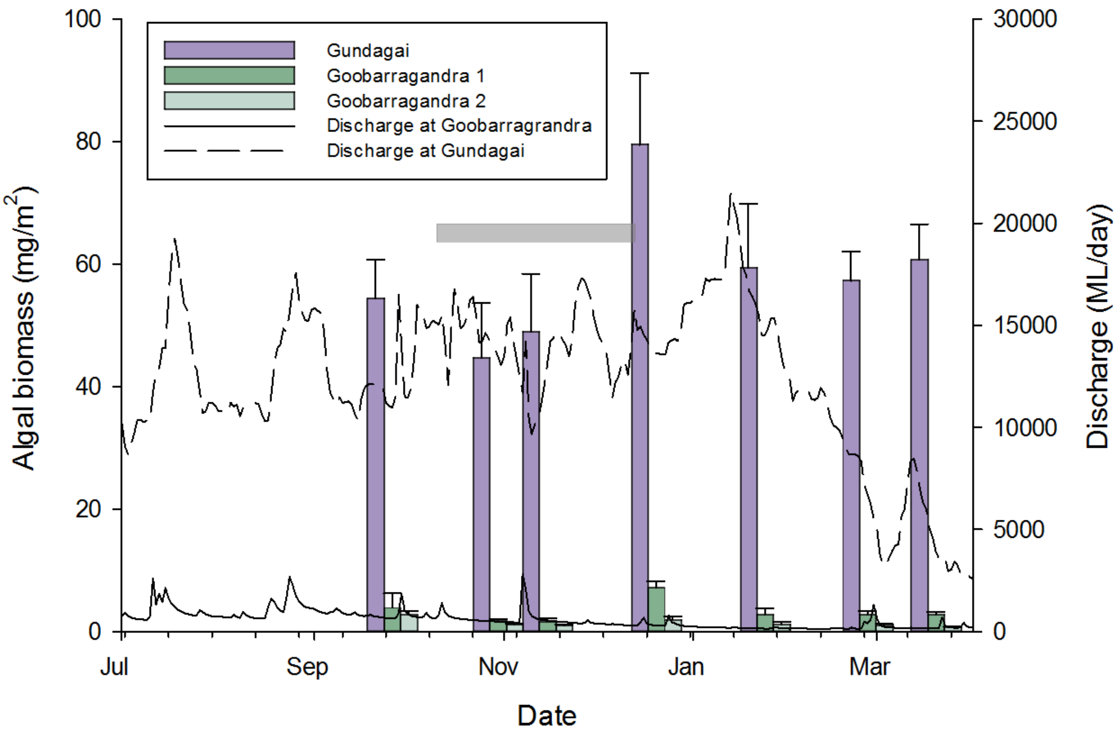


Figure 15 Mean (±SE) of algal biofilm biomass (mg/m^2) in the Murrumbidgee River at Gundagai and the Goobarragandra River (reference) between September 2012 and April 2013. The horizontal grey bar indicates duration of the environmental watering in the Murrumbidgee River.

The total biomass and organic biomass at Gundagai in the Murrumbidgee River was significantly lower during the environmental watering period compared to most other times during the study period, with the exception being immediately after a regulated flow pulse on 12 January 2013 after the completion of the Commonwealth environmental release (Figure 12 AND Figure 13). The percent organic biomass was consistently higher in the Murrumbidgee River than in the Goobarragandra River (Figure 14). This is consistent with the hypothesis that the environmental watering would either prevent the build up of sediment in the biofilm or flush some of the sediment from the biofilm, resulting in a greater percent of organic biomass. The algal biomass of biofilms (measured as Chlorophyll a) in the Murrumbidgee River ranged from approximately 45 to 80 mg/m^2, which is nearing the level regarded to be nuisance levels (100 mg/m^2; Quinn 1991) (Figure 15).

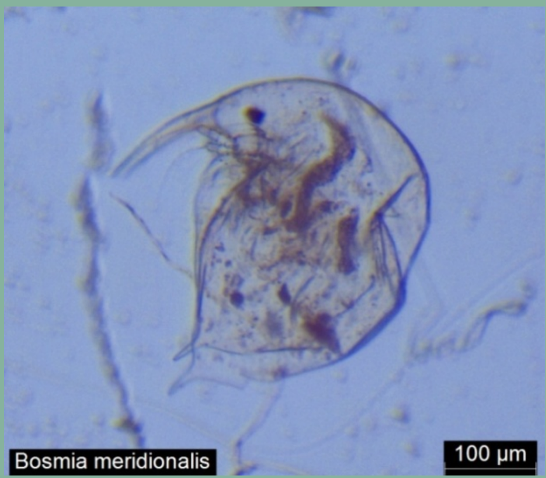
7.4 Discussion

Significant reductions in the total and organic biomass of biofilms in the Murrumbidgee during Commonwealth environmental water delivery may have been due to the environmental watering reducing the accumulation of sediment and detritus in the biofilm and/or assisting with the scouring of these components leading to improvements in the condition of the biofilm.

These results are consistent with the hypothesis that biomass of biofilms on cobbles will decrease following the environmental watering due to scouring from increased flow velocity, and that in-channel environmental watering will help biofilm biomass remain below nuisance levels. These findings are consistent with studies of biofilm responses to variable flow releases from Dartmouth Dam to the Mitta Mitta River, where it was demonstrated that pulsed flows can scour and reset biofilms, reducing biomass and facilitating a shifting in the biofilm community towards that of a reference stream (Watts, Nye et al. 2005; Watts, Ryder et al. 2008; Watts, Zander et al. 2011).

These results suggest that the environmental watering helped to reduce total and organic biofilm biomass in the Murrumbidgee River, shifting them closer to that in the reference river. Commonwealth environmental water releases, in combination with unregulated flows and improved management of regulated flows, can contribute to pulsed water releases in the Murrumbidgee system to help support ecosystem functions relating to creation and maintenance of bed, bank and riparian habitat, and help avoid biofilms reaching nuisance levels.

Microinvertebrates



Microinvertebrates play a key role in floodplain river food webs, as prey to a wide range of fauna including fish (King 2004) and as important consumers of algae, bacteria and biofilms. Microinvertebrates also respond strongly to water regime, particularly the history of flooding and drying in floodplain wetlands (Jenkins and Boulton 2003, Jenkins and Boulton). They are also good indicators of ecological connectivity in floodplain river systems (Jenkins and Boulton , Jenkins, Iles *et al.* 2013). Based on these characteristics, we monitored microinvertebrates in the Murrumbidgee River to complement larval fish monitoring and in wetlands from the mid-Murrumbidgee, Lowbidgee and Western Lakes from spring 2012 to autumn 2013. The key objectives of the Commonwealth environmental watering actions in 2012-13 that relate to microinvertebrates were to ***"support habitat requirements of native fish"*** and ***"Support breeding and recruitment of other native aquatic species, including frogs, turtles, invertebrates"***. Our monitoring focussed on the microcrustacean taxa that comprise a larger size class within the microinvertebrate community, and include copepods, cladocerans and ostracods that provide food for fish larvae. This section presents results of the wetland microinvertebrates while the results on the interaction between larval fish and microinvertebrates in the Murrumbidgee River (Option 1) are presented in Section 9.

Key outcomes

- Numbers of microcrustacean taxa in benthic and pelagic habitats in wetlands from the Lowbidgee, mid-Murrumbidgee and Western Lakes were highest in August 2012 and April 2013, with a trough in the spring and summer months, coinciding with fish spawning activity.
- Microcrustacean densities in benthic and pelagic habitats were **above the critical threshold of 100/L to support larval fish feeding** in August, October, February and April.
- The length of microcrustaceans did not show a consistent pattern in the three groups of wetlands across time, but larger specimens were observed in the Western Lakes than the Lowbidgee and mid-Murrumbidgee, possibly reflecting reduced rates of predation by fish in the latter two regions.

8 Microinvertebrates

8.1 Introduction

Native fish diversity and fish recruitment are strongly influenced by the availability of suitable food resources, particularly microinvertebrates that are eaten by adults of some species of freshwater fish as well as providing critical prey for larval fish of all species. Due to this strong link between larval fish and microinvertebrates, a limited supply of microinvertebrates is a key factor that can cause failed recruitment and high initial mortality of larval fish (Balcombe and Humphries 2006). Blooms of microinvertebrates are associated with better condition in some fish species (Pothoven, Nalepa *et al.* 2001), particularly those utilising wetlands (Beesley, Price *et al.* 2011), where densities of microinvertebrates are higher than in nearby river channels (Jenkins, Iles *et al.* 2013). Microinvertebrates pulse after floods (Jenkins and Boulton 2003, Jenkins and Boulton 2007) and this higher food availability is associated with improved body condition in fish species after floods compared to periods of low flow (Balcombe, Lobegeiger *et al.* 2012).

Microinvertebrate communities are very diverse, and density of the major microcrustacean groups, a sub group of the microinvertebrates, (for example copepods, cladocerans and ostracods) can differ significantly between wetlands and the river channel (Jenkins, Iles *et al.* 2013) and also between the benthic and pelagic zones within these habitats (King 2004).

The resilience of microinvertebrate communities is influenced by flow, particularly the length of the dry period between inundation events in wetlands. Microinvertebrates produce dormant propagules (eggs) as a means of surviving dry or unfavourable conditions and their eggbanks decline in productivity and diversity as dry duration extends (Jenkins and Boulton 2007). Assessing microinvertebrate communities in river and wetland habitats, indicates the health of the system and whether there is an adequate supply of prey to support wetland food webs.

8.2 Methods

Microinvertebrate samples were collected from up to 15 wetlands in the mid-Murrumbidgee, lower Murrumbidgee and Western Lakes over five surveys from

August 2012 to April 2013. Two composite samples (pelagic and benthic) were collected at each wetland in association with fish and tadpole monitoring. Benthic samples were collected with a corer (50 mm diameter x 120 mm long, 250 mL volume). Five cores were collected from haphazard locations within each site with replicates spaced at least 20 m apart. The corer was pushed into the sediment to a depth of 10 mm, the top was then sealed with a plastic cap and the sediment and overlaying water extracted with the aid of a hardened rubber trowel. The contents of the corer were emptied into a wide mouth jar and allowed to settle for one hour. Once settled, the supernatant was poured through a 63 µm sieve to retain microcrustaceans. The retained sample was washed into a sample jar and stored in ethanol (80% w/v).

To assess the pelagic microcrustacean community, a composite sample consisting of 10 x 10 litre buckets was collected at each site. Each bucket was poured through a plankton net (63 µm mesh). Retained samples were stored in ethanol (80% w/v) until time of enumeration. Pelagic microinvertebrate samples were also collected paired with the larval fish sampling, from three sites on the Murrumbidgee River and one site on Old Man Creek. This sampling was undertaken from 10 September to 21 December 2012.

In the laboratory, benthic microcrustacean samples were poured into a bogorov tray (Goathead Industries) and enumerated with the aid of a dissecting microscope (Leica M125) at a magnification of 32x to 80x. Rose Bengal stain was used to highlight individuals in samples with excessive sediment present. Pelagic samples were made up to 200 mL volume and three 1 mL subsamples were examined. Specimens were identified with relevant guides to species where possible (Williams 1980, Shiel 1995, Smirnov and Timms 1995).

8.3 Results

A total of 16,058 microcrustaceans from 18 taxa were recorded during the wetland study and four from the larval fish sites in the Murrumbidgee River and Old Man Creek. In wetlands, the dominant taxa were cladocerans (water fleas) (*Bosmina meridionalis* (659), chydorids (1596), *Daphnia* sp. (927), *Moina micrura (1326), Ceriodaphnia* sp. *(144))*, Copepods (copepod nauplii (4,901), cyclopoid copepods

(4,131), calanoid copepods (1,444)), and an array of ostracods. Numerically, almost twice as many copepods (10,517) were captured during the study compared to cladocerans (5089), with ostracods an order of magnitude lower (452). Fewer individuals were captured at larval fish sites in the Murrumbidgee River and Old Man Creek, with 98 individuals across the sampling period from four taxonomic groups: calanoid copepods, *Daphnia lumholtzi*, *Macrothrix spinosa* and copepod nauplii.

Taxonomic richness

The taxonomic richness (number of taxa) was highest in the frequently inundated sites; the Lowbidgee had 16 taxa as did the mid-Murrumbidgee, which received Commonwealth environmental water in 2011-12. The Western Lakes, which received Commonwealth environmental water in 2012-13 but had been dry for several decades previously, supported nine taxa. The numbers of microcrustacean taxa were also significantly different across time (Term 1, Table 4), with higher numbers coinciding with Commonwealth environmental watering actions, and natural overbank flows in August and October declining by December 2012 (Pair-wise $p \approx 0.006$ and 0.016) as the wetlands began to dry. Following this decline period, there was an increase in numbers of taxa with more taxa recorded in April 2013 than December 2012 and February 2013 (Pair-wise $p \approx 0.017$ and 0.047) (Figure 16). Although not significantly different to benthic taxa, the timing of peaks and troughs in pelagic taxa as wetlands dried in February 2013 lagged behind the fall in numbers in benthic habitats before also increasing in April (possibly due to concentration effects as the wetlands dried).

The findings for numbers of cladoceran taxa were similar to the overall taxon richness patterns, with significant differences across time (Term 1, Table 4) and no differences among regions, between habitats, nor any interactions. It is clear from the graphs that the number of cladoceran taxa underpinned the variation in the overall taxon richness (Figure 16).

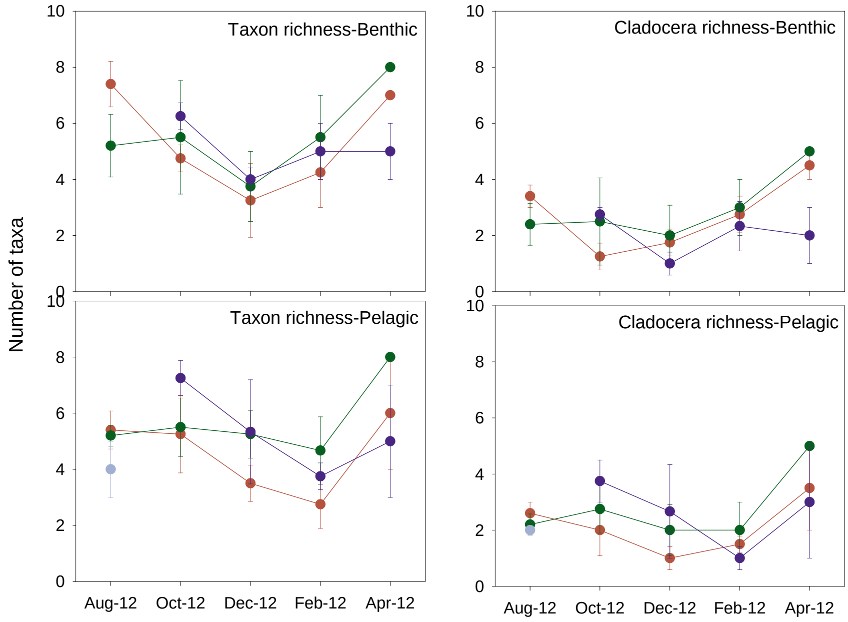


Figure 16 Taxon richness of microcrustaceans (left) and cladocerans (right) sampled in benthic and pelagic habitats across the four Murrumbidgee regions [Lowbidgee (red), Mid-Murrumbidgee (green), Western Lakes (purple) and Murrumbidgee River (blue)]. Values are means with standard error bars. Note that the Western Lakes were not sampled until October following inflows in September 2012 and the Murrumbidgee River was only sampled in August 2012.

Table 4 Permanova results for overall taxon richness, cladoceran taxon richness, microcrustacean community composition and cladocera community composition.

Term	Taxon Richness		Cladocera richness		Community composition		Cladocera community	
	F	p	F	p	F	F	F	p
1. Time	3.59	0.008	2.49	0.039	3.12	0.001	4.50	0.001
2. Region	1.01	0.404	0.75	0.575	3.03	0.001	3.85	0.001
3. Microhabitat	0.21	0.782	0.45	0.533	16.36	0.001	4.54	0.001
4. Time x region	1.33	0.196	1.45	0.193	1.76	0.001	2.12	0.001
5. Time x microhabitat	0.86	0.509	1.25	0.301	2.02	0.001	0.87	0.66
6. region x microhabitat	0.61	0.572	0.67	0.518	0.94	0.565	1.21	0.27
7. Time x region x microhabitat	0.20	0.998	0.23	0.99	1.04	0.39	0.50	1.00

Community composition

Overall, the microcrustacea communities were relatively homogeneous across regions with two widespread and highly abundant taxa dominating communities (copepod nauplii and cyclopoid copepods) in all regions and over time. The dominance of these two taxa overwhelmed the response of other taxonomic groups in the statistical analysis (Figure 17) and although there were significant differences, the community changes were minor, making it difficult to identify the effects of Commonwealth environmental watering actions. When the effect of these two dominant taxa were removed, and focusing on the cladocerans we identified significant differences in community composition between the three wetland regions; the mid-Murrumbidgee, Lowbidgee and Western Lakes (Pair-wise p<0.005-0.001). The simper analysis revealed the Lowbidgee community was dominated by chydorids (54%) and *Moina micrura* (20%), whereas the mid-Murrumbidgee was dominated by *Moina micrura* (42%), *Bosmina meriodionalis* (30%) and *Daphnia* sp. (22%). In contrast, *Daphnia* sp. dominated the Western Lakes (59%), with chydorids (24%) (Figure 17). Three cladoceran taxa dominated both the benthic and pelagic communities, but in varying compositions (Figure 17). However, *Macrothrix spinosa* was also present in benthic communities, whereas *Bosmina meriodionalis* characterised pelagic communities.

The change in overall community composition reflected that of taxa richness, with similar communities in August to October, followed by an abrupt change in community composition, coinciding with a decline in taxa richness in December 2012 when *Moina micrura,* a species that can tolerate declining water quality became more common (10%). By February 2013, *M. micrura* was more dominant (22%), while the contribution of copepod nauplii were reduced (from approximately 40% to 15%) and by April 2013 copepod nauplii contributed less than 5% to the community composition, which was dominated by cyclopoid copepods (60%) and included ostracods (8%) (Pair-wise p ≈ 0.034 to 0.001).

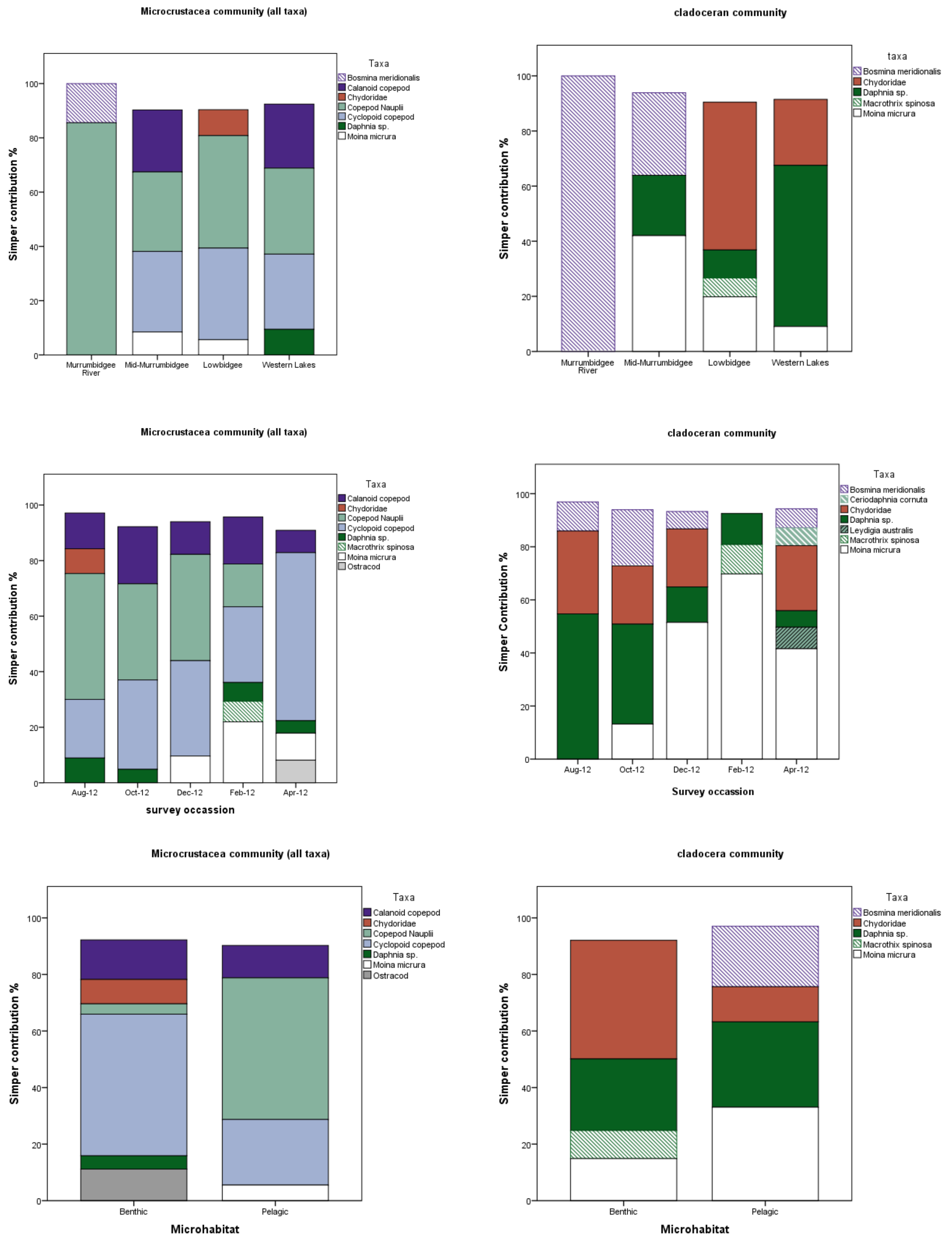


Figure 17 Simper contributions to overall community composition between regions (upper), over time (middle) and between microhabitats (bottom) for all microcrustacea taxa (left) and the cladocera component of the microcrustacea taxa (right).

Density

Densities of both benthic and pelagic microcrustaceans followed a similar trend to taxon richness (Term 1, Table 8), being significantly higher in August and October than December 2012 (Pair-wise p ≈ 0.018 and 0.009) when the lowest densities were found (Figure 18). There was a small non-significant increase in February and April 2013. Densities of benthic microcrustaceans in all the sampled wetlands were above the larval fish threshold of 100 individuals per litre until December 2012, while pelagic densities were above this threshold until April 2013.

Total densities of microcrustaceans were significantly different among the regions sampled (Term 3, Table 5), although this difference was due to higher densities in both the Lowbidgee and mid-Murrumbidgee compared to the Murrumbidgee River (Pair-wise p ≈ 0.033 and 0.01). The densities of microcrustaceans in benthic and pelagic habitats did not differ significantly overall (Term 3, Table 5); however, there was a significant interaction between habitat and time (Term 5, Table 5) as indicated by the different trends in densities in benthic and pelagic habitats across time (Figure 3). Benthic densities were highest in August 2012, whereas, pelagic densities were highest in February 2013, and were slightly higher overall than benthic densities (Figure 3).

The trends in total density are largely explained by those for copepod density (Figure 18, Terms 1, 2, 4 and 5, Table 5). In contrast, both cladoceran and ostracod densities although significantly different across time (Term 1, Table 5), showed little variation compared to copepods (Figure 18). Cladocerans contributed to a peak in overall density in the Lowbidgee in August 2012 (benthic) and in February 2012 (pelagic).

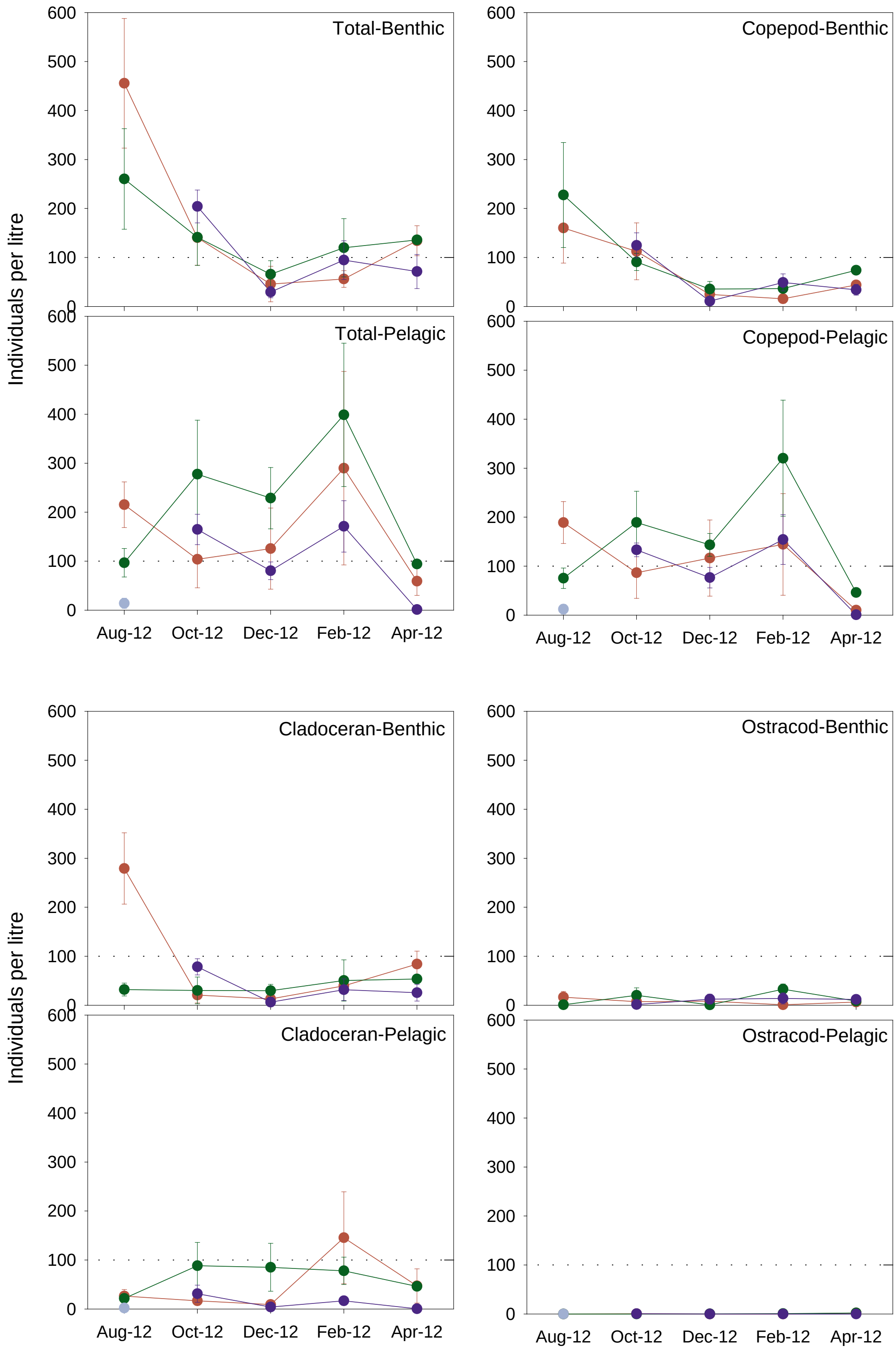


Figure 18 Density of all microcrustaceans, copepods, Cladoceran and ostracods sampled in benthic and pelagic habitats across the four Murrumbidgee regions [Lowbidgee (red), Mid-Murrumbidgee (green), Western Lakes (purple) and Murrumbidgee River (blue)]. Values are means and standard errors. Note that the Western Lakes were not sampled till October following inflows in September 2012 and the Murrumbidgee River was only sampled in August 2012.

Table 5 Permanova results for densities of total microcrustaceans, copepods, cladocerans and ostracods.

Term	Total Density		Copepod density		Cladocera density		Ostracod density	
	F	p	F	p	F	p	F	p
1. Time	2.00	0.034	3.10	0.009	1.80	0.062	4.28	0.003
2. Region	2.35	0.025	3.82	0.014	0.84	0.530	0.59	0.670
3. Microhabitat	0.71	0.532	1.93	0.14	1.15	0.299	31.74	0.001
4. Time x region	1.68	0.045	2.54	0.014	1.31	0.202	2.93	0.006
5. Time x microhabitat	2.82	0.004	3.25	0.005	0.76	0.651	0.61	0.694
6. region x microhabitat	1.11	0.355	0.89	0.445	1.17	0.326	2.34	0.107
7. Time x region x microhabitat	0.88	0.605	1.36	0.196	0.52	0.949	1.59	0.122

Size

The lengths of microcrustaceans differed significantly across time (Term 1 Table 6), although any significant differences appear trivial graphically (Figure 19). Differences in lengths of microcrustaceans among the three wetland regions were greater than changes across time. The longest individuals were recorded in the Western Lakes while the shortest individuals tended to be from the Lowbidgee wetlands (Pair-wise $p<0.001$). Lengths in the mid-Murrumbidgee were between those in the Lowbidgee and Western Lakes (Pair-wise $p \approx 0.025$ and 0.001). Microcrustaceans were significantly larger in benthic than pelagic habitats (Term 3, Table 6), but these differences were not large.

Table 6 Permanova results for lengths of total microcrustaceans, copepods, cladocerans and ostracods.

Term	**Length all microcrustaceans**		**Copepod length**		**Cladocera length**		**Ostracod length**	
	F	p	F	p	F	p	F	p
1. Time	3.93	0.004	5.29	0.002	2.64	0.013	2.53	0.035
2. Region	10.89	0.001	10.07	0.001	9.58	0.001	3.45	0.039
3. Microhabitat	4.63	0.037	16.26	0.001	0.73	0.45	0.70	0.472
4. Time x region	2.58	0.014	1.64	0.125	3.88	0.001	1.02	0.428
5. Time x microhabitat	1.52	0.177	0.70	0.62	1.18	0.309	1.80	0.154
6. region x microhabitat	0.98	0.366	3.15	0.034	0.71	0.569	3.17	0.052
7. Time x region x microhabitat	0.64	0.752	1.08	0.398	0.74	0.701	No test	

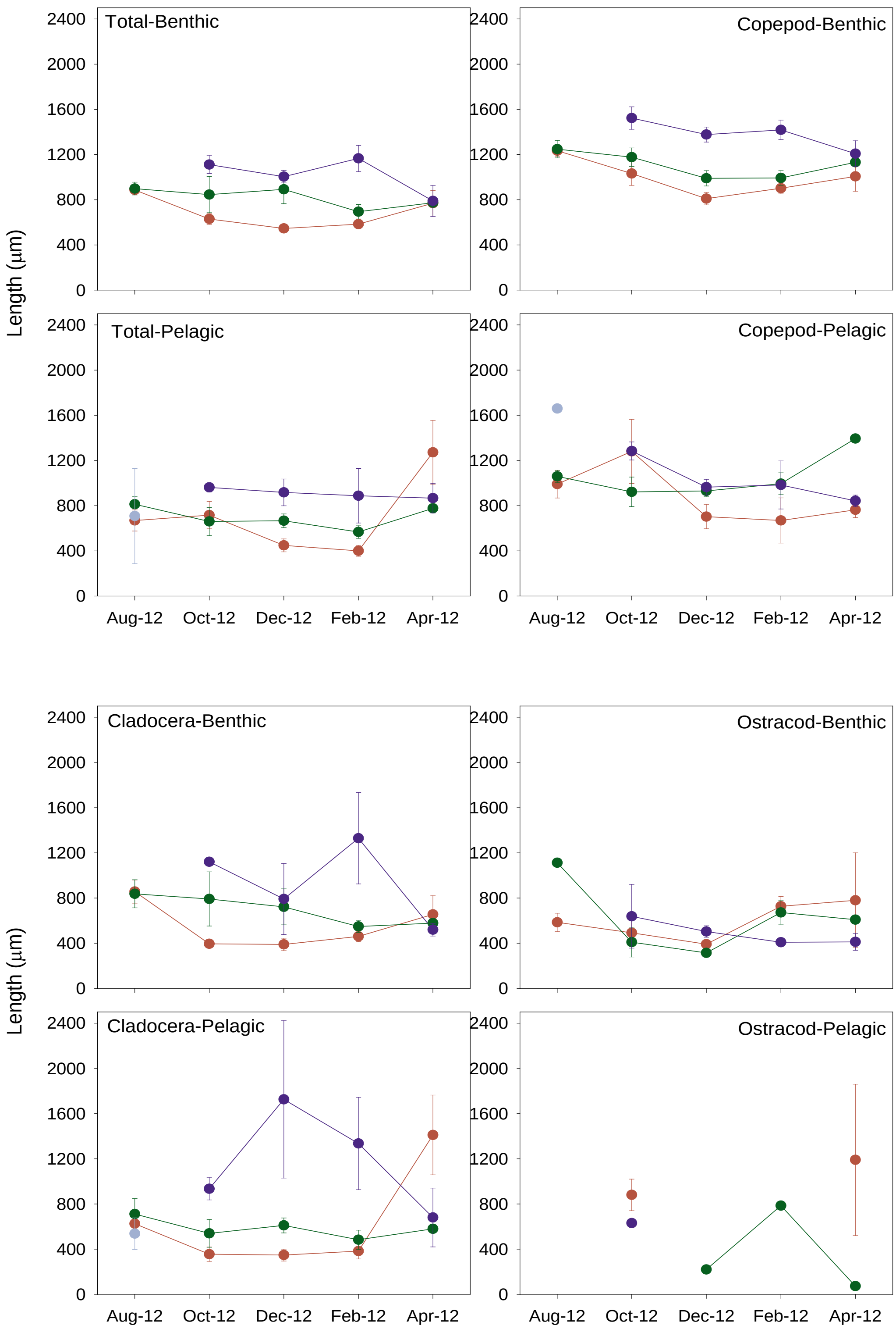


Figure 19 Mean length of all microcrustaceans sampled in benthic and pelagic habitats across the four Murrumbidgee regions [Lowbidgee (red), Mid-Murrumbidgee (green), Western Lakes (purple) and Murrumbidgee River (blue)]. Values are means and standard errors. Note that the Western Lakes were not sampled until October following inflows in September 2012, and the Murrumbidgee River was only sampled in August 2012.

The overfall trends in total length and length of copepods alone were similar (Figure 19). Cladocerans and ostracods were more variable over time, particularly in the Western Lakes where large *Daphnia* sp. had the greatest influence on the pattern of variability (Figure 18 and Figure 19). In terms of length, copepods and cladocerans contained individuals of a similar size range, although some of the *Daphnia* sp. from the Western Lakes was among the largest individuals observed in this study.

8.4 Discussion

Monitoring of microcrustaceans over time demonstrated strong responses in density, diversity and composition (the relative abundance of various taxa) to the delivery of Commonwealth environmental water. Higher numbers of microcrustacean taxa coincided with Commonwealth environmental watering actions, and natural overbank flows in August and October declining by December 2012 as the wetlands began to dry.

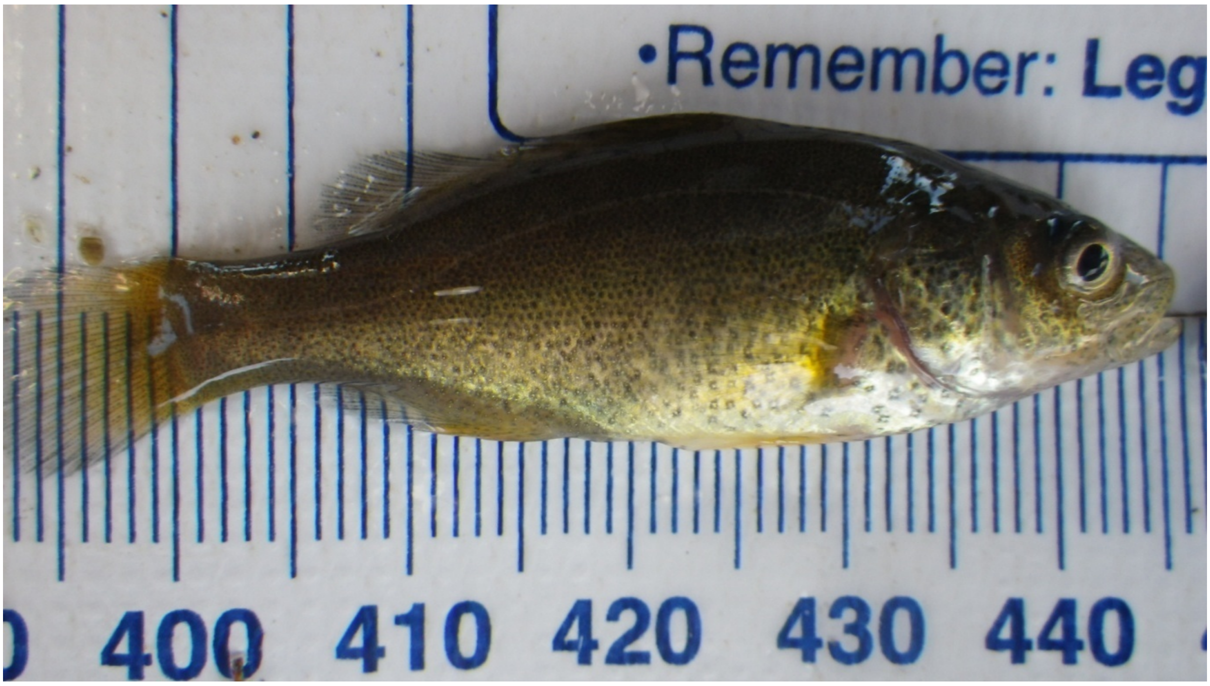
The higher taxonomic richness in the frequently inundated wetlands from the Lowbidgee and mid-Murrumbidgee shows the benefits of Commonwealth environmental water in 2011-12 as well as 2012-13 in the Lowbidgee. Inundation of the Western Lakes with Commonwealth environmental water in 2012-13 provided a timely opportunity for this system that had been dry for several decades to replenish its egg bank (Jenkins and Boulton 2007). Although it supported seven fewer taxa than the frequently flooded wetlands, it contained some of the largest microcrustaceans, the *Daphnia* sp. that had a strong positive relationship with carp gudgeons (see section 16) and are likely to have underpinned the food web for the significant waterbird breeding event on the western lakes (see section13).

Overall, wetlands across the three regions had similar densities and numbers of microcrustacea taxa, but the composition (the relative abundance of various taxa) varied between regions. The unique communities in wetlands in the three regions reflects differences in flow, vegetation communities and water quality which are considered in section 16. The Lowbidgee community was dominated by chydorids, *Moina micrura* and *Macrothrix spinosa*, whereas the mid-Murrumbidgee was dominated by *Moina micrura*, *Bosmina meriodionalis* and *Daphnia* sp. In contrast, *Daphnia* sp. dominated the Western Lakes, with chydorids.

All of the wetlands in this study were drying from December to April, and the onset of this drying phase led to a crash in microcrustacea densities and a shift in community composition towards more tolerant taxa such as *Moina micrura*, which increased in abundance and compensated for the decline in more sensitive species.

Based on this study, all the regions contained sufficient densities (>100/L) of microcrustaceans on many sampling occasions to support larval fish recruitment (King 2004), particularly in pelagic habitats. Pelagic habitats were dominated by copepod nauplii and adults, which are main prey items identified for larval and juvenile fish (King 2005). However, chydorids and macrothricids are also main prey items (King 2005) and they are more common in benthic habitats. The dominant cladoceran within the Lowbidgee, the chydorids are consumed by larval Australian smelt, rainbowfish and Murray cod as well as carp and gambusia (King 2005). Macrothricid cladocerans, also found in the Lowbidgee, are a preferred prey item for Murray cod (King 2005). However, both *Moina micrura* and *Bosmina meriodionalis* the two dominant cladoceran taxa in the mid-Murrumbidgee wetlands were only consumed by preflexion Australian smelt in King's (2005) study of larval fish diet in six species. *Daphnia* sp., the dominant taxa in the Western Lakes were eaten by juvenile/adult carp gudgeons, supporting the link found in this study, and also by carp and gambusia (King, Crook *et al.* 2005).

Fish: Communities, movement, breeding and recruitment



In the following section we outline fish responses to Commonwealth environmental water in the Murrumbidgee River and connected wetlands. The specific objectives that are assessed in this section are: **"Support breeding and recruitment of native fish and Support habitat requirements of native fish".** The success of the Commonwealth environmental watering actions in achieving these objectives is measures via three key indicators:

- Communities - Assessment of pre and post flow fish community composition and size structure in the Murrumbidgee River and wetlands of the mid-Murrumbidgee, Lowbidgee and Western lakes.
- Movement - Spawning movements of large bodied native fish in response to the Commonwealth environmental flow in the Murrumbidgee River.
- Spawning - Changes in larval fish abundance and daily ages during the Commonwealth environmental flow in the Murrumbidgee River.

Fish communities

Fish communities can change in response to the delivery of environmental flows, due to recruitment, immigration and emigration. Fish communities of the Murrumbidgee River and wetlands were monitored between August 2012 and April 2013. The key focus areas were the Murrumbidgee River and the Western Lakes, both of which received Commonwealth environmental water between September and December 2012. The Lowbidgee and mid-Murrumbidgee wetlands did not receive Commonwealth environmental water but were included as part of the monitoring program, in order to provide continuity during the transition to the Long Term Intervention Monitoring Program (LTIM) commencing in 2014. The key objectives of the Commonwealth environmental watering action assessed in this section are to "***support the breeding and recruitment of native fish"***.

Key outcomes

- Overall **the total abundance and biomass of native fish increased significantly after the delivery of Commonwealth environmental water**, due to recruitment by some small-bodied native species (carp gudgeon and Australian smelt) and immigration of large bodied fish, particularly Golden perch.
- Wetland fish communities were dominated by small-bodied native fish species, which outnumbered exotic fish species such as carp, goldfish and gambusia by more than 100 to one.
- There was no evidence of significant carp recruitment in the Murrumbidgee River main channel following the delivery of Commonwealth environmental water. There was some evidence of low levels of carp spawning in the wetlands in October 2012 but subsequent surveys over 2012-13 indicated low recruitment rates of carp with total carp numbers decreasing in all wetland regions.

9 Fish communities

Fish communities of the Murrumbidgee Catchment are severely degraded, with only eight of the 21 native species that would have historically occurred in the region recorded since 1975 (Gilligan 2005). Historically, small-bodied floodplain species such as the Murray hardyhead (*Craterocephalus fluviatilis*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and olive perchlet (*Ambassis* agassizii) utilised wetland habitats of the Murrumbidgee (Anderson 1915), however these species are now considered locally extinct (Gilligan 2005). Previous surveys conducted by the project team in the Murrumbidgee have shown that native small-bodied fish species dominate wetland fish communities and use wetland habitats as nursery grounds for spawning and recruitment (Wassens, Watts *et al.* 2012).

Commonwealth environmental water was delivered to the Murrumbidgee Catchment in 2012-13 to provide ecological benefits to two areas: the Murrumbidgee River downstream of Darlington Point and the Western Lakes north of Balranald (Figure 3 and Figure 4).

Commonwealth environmental water was delivered to the Murrumbidgee River with the aim of promoting the movement and spawning of large-bodied native fish species, specifically Murray cod (*Maccullochella peelii*). Fish community surveys were carried out in the Murrumbidgee River before (September 2012) and after (May/June 2013) the release of Commonwealth environmental water to determine the current status of fish communities and determine specific locations where Murray cod occurred in large numbers. These locations were then targeted for movement and spawning monitoring (see section 10 and 11). Surveys of wetland regions focused on the Western Lakes, the Redbank system in the Lowbidgee floodplain (which received a natural overbank flow in August 2012) and the mid-Murrumbidgee wetlands (which received Commonwealth environmental water in 2011-12, but not in 2012-13) (Figure 5). Both the Lowbidgee and mid-Murrumbidgee wetlands were drying during 2012-13, with the majority of monitoring sites dry by February 2013.

9.1 Methods

Main channel sampling

Murrumbidgee River fish communities were sampled on two occasions, once before the delivery of Commonwealth environmental water (September 2012) and once after delivery (May/June 2013). Boat electrofishing following the Sustainable Rivers Audit Protocol (MDBC 2004) was conducted at 15 reaches (sites) in the Murrumbidgee River between Gundagai and Willow Isles (downstream of Balranald) as well as two reference sites on Old Man Creek (see Figure 2) (which did not receive environmental flows). Electrofishing involved 12 replicate electrofishing shots, that lasted 90 seconds each (Smith-Root Model 7.5KVa electrofishing units), at each site in all available habitat types (Plate 10). In addition to this, ten unbaited bait traps were deployed at each site to capture small-bodied fish species. Bait traps were set in edge habitats for a minimum of two hours at each site. At the conclusion of sampling, all fish were identified, measured (first 50 individuals of each species to the nearest millimetre - total length) and counted (for shots/traps that had more than 50 individuals of each species).

Plate 10 (a) Boat electrofishing surveys and (b) wetland fish community surveys using fyke nets.

Wetland community sampling

Fish communities were also surveyed in wetlands in the mid-Murrumbidgee (five sites), Lowbidgee (five sites) and Western Lakes (four sites; Table 7). Surveys were conducted every two months between August 2012 and April 2013 (total of five sampling trips; Table 7). Not all wetlands were surveyed on all sampling trips, as the timing of inundation and drying rates varied among the wetlands. A combination of large fyke nets, small fyke nets, bait traps and sweep netting were used to sample all micro-habitat types within the wetlands. Five bait traps (dimensions 25 x 10 cm, 5 mm mesh) were set overnight at each site. Traps were baited and positioned under or near fringing vegetation to target small cryptic fish. Four small (2 x 2 m wings, 2 mm mesh) fyke nets were left overnight at sites in the Western Lakes and Lowbidgee wetlands. A combination of two small fyke nets and two large fyke nets (2 x 10 m wings, 12 mm mesh) were set in the mid Murrumbidgee wetlands where water depths allowed. All fish collected were identified to species, and the first 50 individuals of each species captured in each net were measured to the nearest millimetre. Alien fish species were euthanased and native species were returned to the waterbody.

Natural flow attenuation downstream of Darlington Point may lead to natural changes in fish community structure in these regions compared to regions further upstream, regardless of the successful delivery of environmental water. To address this, river fish community sampling sites were divided into four regions, three in the Murrumbidgee River (upper, middle and lower Murrumbidgee River) and one in Old Man Creek. Wetlands were also split into three distinct regions: the mid-Murrumbidgee wetlands, Lowbidgee wetlands and the Western Lakes (Table 7). Fish community data from river and wetland sampling were pooled to determine species richness in each region. Relative abundance from small fyke nets was standardised to catch per unit effort (number of fish per fyke net hour) for statistical analyses.

Table 7 Fish community surveys were completed in four river regions (16 river sites) and three wetland regions (14 wetland sites) (see Figure 1 for site locations). All river sites were sampled before (September 2012) and after (May/June 2013) the delivery of Commonwealth environmental water. Surveys of inundated wetland sites were completed (W = wet and surveyed, NS= wet and not surveyed, D = wetland dry) from August 2012 – April 2013.

River Region	River sites	Wetland regions	Wetland sites	Aug	Oct	Dec	Feb	Apr
Upper	Gundagai							
	Wantabadgery							
Middle	Mucklebar	Mid-Murrumbidgee	Euroley Wetland	W	W	W	D	D
	Berry Jerry Station		Goorogool Lagoon	W	W	D	D	D
	Narrandera		McKennas Lagoon	W	W	W	D	D
	Euroley Bridge		Yarrada Lagoon	W	W	W	W	W
	Cookoothama		Sunshower Lagoon	W	W	W	D	D
	Birdcage Reserve							
	Carrathool Hay							
Lower	Maude	Lowbidgee	Piggery Swamp	W	W	NS	D	D
			Little Piggery	W	W	NS	D	D
	Redbank Weir		Mercedes Wetland	W	W	NS	D	W
			Wagourah Lagoon	W	W	NS	W	W
	Glen Avon		Two Bridges Swamp	W	W	NS	D	D
		Western Lakes	Paika Lake	NS	W	NS	W	W
	Baupie Escape		Cherax Swamp	D	W	NS	W	D
			Hobblers Wetland	D	W	NS	W	W
	Willow Isles		Penarie Creek	D	W		D	D
Old Man Creek	Bernofy							
	Gum Creek Station							

9.2 Results

A total of 97,077 fish were collected during surveys of the Murrumbidgee Catchment in 2012-13. Most fish were caught in the Western Lakes (44,547 fish), compared to the Lowbidgee wetlands (33,817 fish), mid-Murrumbidgee wetlands (15,594 fish) and Murrumbidgee River (3,119 fish). Overall, ten native species, one native species complex (carp gudgeon species complex; *Hypseleotris* spp.) (Plate 11) and six exotic species were captured (Figure 20). Murray cod (*Maccullochella peelii),* river blackfish (*Gadopsis marmoratus*), and trout cod (*Maccullochella macquariensis*) (Plate 12) were only collected from river sites while flat-headed gudgeon (*Philypnodon grandiceps*) and oriental weatherloach (*Misgurnus anguillicaudatus*) were only collected from wetland sites. Native fish abundance increased substantially in the Murrumbidgee River following the delivery of Commonwealth environmental water. Carp gudgeons dominated fish communities in the wetland sites on all survey occasions (Figure 23).

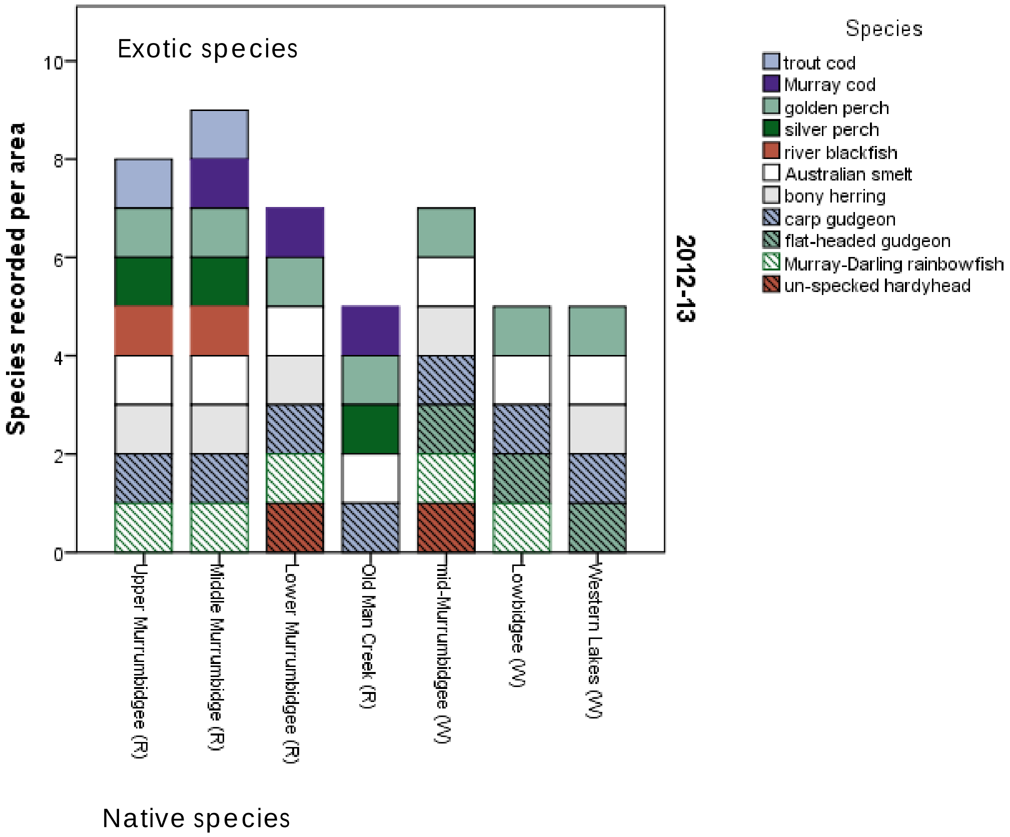


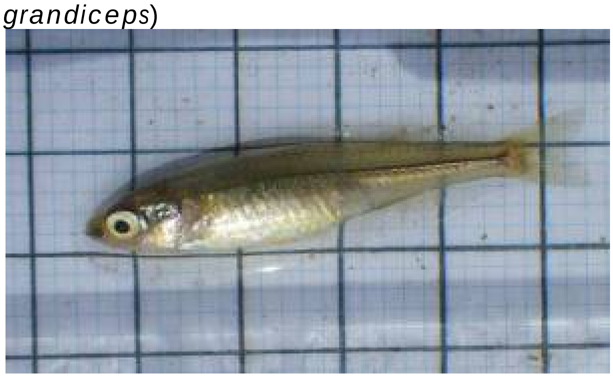
Figure 20 Species richness (number of species recorded) at each river (R) and wetland (W) fish community survey sites for native (top) and exotic (bottom) fish species.

Australian smelt (*Retropinna semoni*)

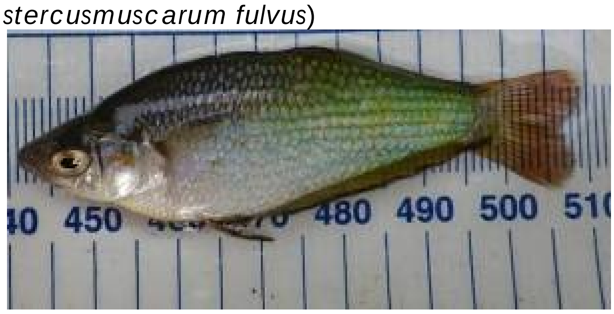
golden perch *(Macquaria ambigua)*

flat-headed gudgeon (*Philypnodon grandiceps*)


carp gudgeon (*Hypseleotris* spp.)


un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*)


bony herring (*Nematalosa erebi*)



Murray-Darling rainbowfish (*Melanotaenia fluviatilis*)

Plate 11 Native fish species recorded during the 2012-13 surveys of wetlands in the mid and Lower Murrumbidgee.

Murray cod (*Maccullochella peelii)*Photo: J. Hutchison

golden perch (*Macquaria ambigua*) Photo: M. Hill

river blackfish (*Gadopsis marmoratus*) Photo: J. McPherson

trout cod (*Maccullochella macquariensis*) Photo: R. Rehwinkel

Plate 12 Key fish species surveyed 'before' Commonwealth environmental watering in the Murrumbidgee River.

Main channel fish community composition

In the Murrumbidgee River, the composition of fish communities changed significantly after the delivery of Commonwealth environmental water (ANOSIM: Global R = 0.408, $p < 0.001$). Pairwise tests used to determine if fish communities differed among the river regions before and after the delivery of Commonwealth environmental water indicated that there were no significant differences among the upper Murrumbidgee River, middle Murrumbidgee River or Old Man Creek. Fish communities of the lower Murrumbidgee River differed significantly from the mid- and upper-Murrumbidgee river regions (upper R = 0.4, $p = 0.04$; middle R = 0.426, $p = 0.02$), due to larger numbers of Australian smelt, bony herring and carp in the lower region.

The biomass of fish communities in the Murrumbidgee River also changed significantly after the delivery of Commonwealth environmental water (ANOSIM: Global R: 0.229; $p < 0.001$). Total biomass for each species was substantially higher after environmental watering, with the total biomass of Murray cod, trout cod, golden perch, bony herring and carp doubling between pre-watering and after-watering periods (Figure 21). There were no significant differences among river regions based on fish biomass, suggesting that each region was able to support a similar sized fish community, at least when overall fish biomass was considered. Carp increased in abundance and biomass after the delivery of Commonwealth environmental water, but this could not be attributed to recruitment, with no significant increases in abundance of juvenile carp indicated by the analysis of length-frequency distributions (Figure 24). The survey results suggested that the size structure of Australian smelt changed significantly after the delivery of environmental water (KS = 2.116; $p<0.001$). Observed increases in the number of Australian smelt within the Murrumbidgee River after the delivery of environmental water were attributed to the recruitment of juvenile smelt, with a shift in the distribution of length frequencies to smaller-sized individuals after watering (see Figure 24).

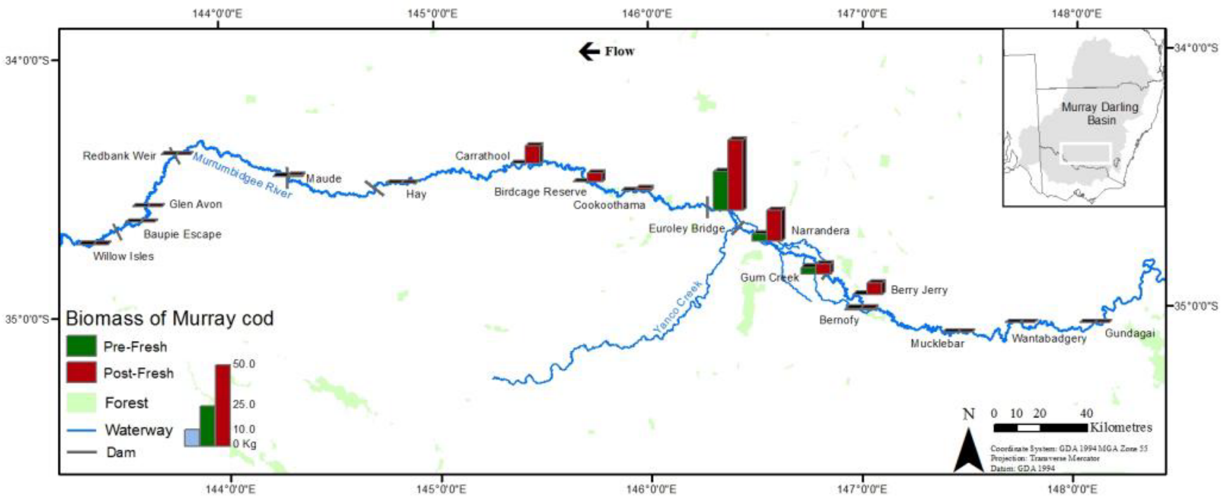


Figure 21. Distribution of Murray cod in the Murrumbidgee River system pre- and post- 2012 Commonwealth environmental water delivery. Note the control site Bernofy on Old Man Creek.

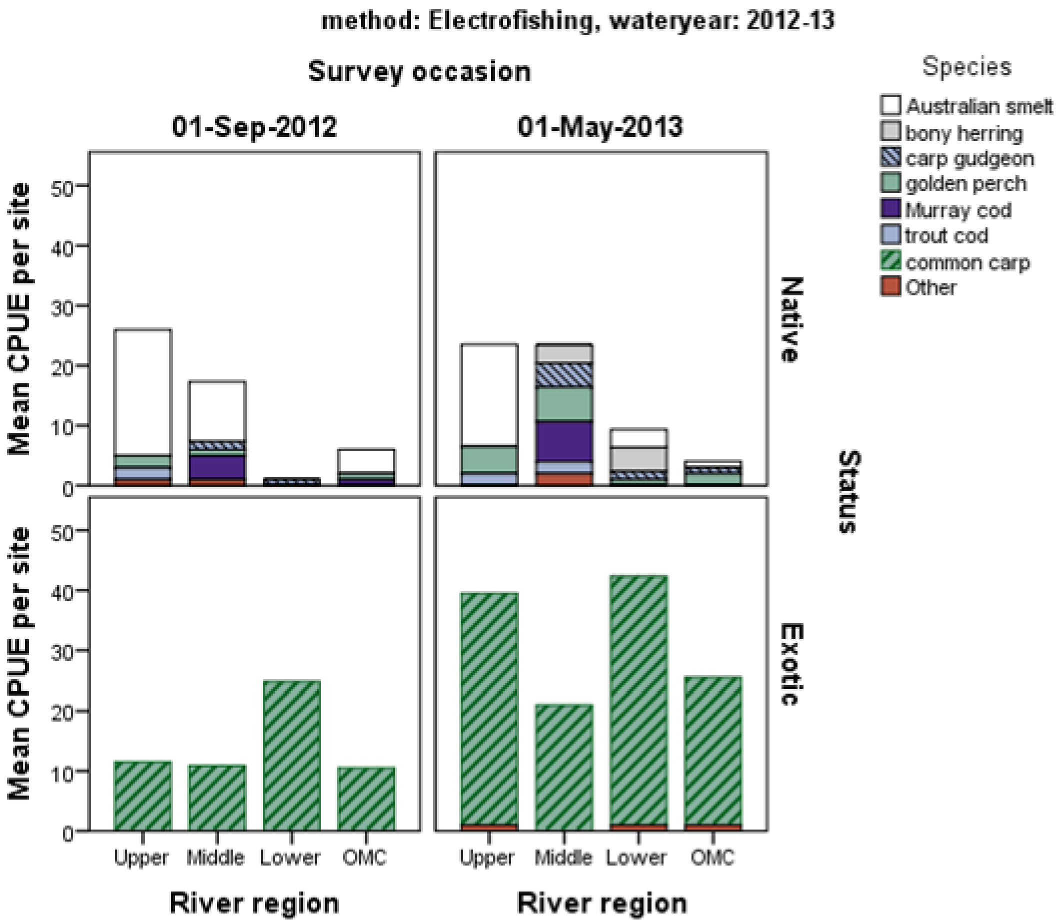


Figure 22 Number of fish captured in the Murrumbidgee River (upper, middle and lower) and Old Man Creek (OMC) before (September 2012) and after (*May/June 2013) Commonwealth environmental water delivery.

Wetland fish community composition

Wetland fish community structure also changed significantly over time (ANOSIM: Global R = 0.194, p = 0.012) (Figure 23). Pairwise tests identified that these changes were due to differences in wetland fish communities between October and December 2012 (R = 0.24, p = 0.029), and October 2012 and February 2013 (R = 0.303, p = 0.024) sampling occasions. Differences in the catch between the October and December surveys were a result of the higher proportion of carp and gambusia in the Lowbidgee in the October surveys, and the dominance of carp gudgeon in the mid-Murrumbidgee wetlands in the December surveys. In addition, there was a substantial increase in the relative abundance of all fish species in wetlands sampled between October 2012 and February 2013, particularly in the Western Lakes and

Lowbidgee regions where more than 200 fish were caught per fyke net hour. These increases were driven by very high catches of carp gudgeon.

Wetland fish communities differed among the wetland regions (ANOSIM: Global R = 0.26, p = 0.017), with differences between the Lowbidgee wetlands and both the mid-Murrumbidgee wetlands (R = 0.271, p = 0.029) and the Western Lakes region (R = 0.343, p = 0.036). The Mid-Murrumbidgee wetlands and Western Lakes were overall characterised by a large proportion of small bodied native fish with a dominance of carp gudgeon.

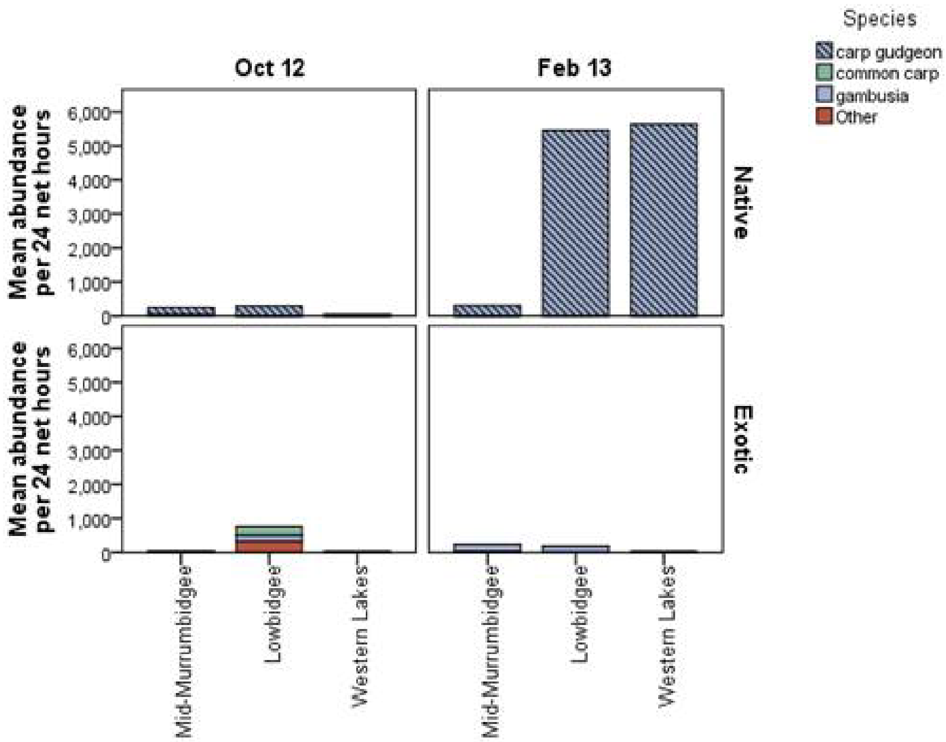


Figure 23 The mid-Murrumbidgee wetlands, Lowbidgee wetlands and Western Lakes in spring (October 2012) and summer (February 2013) (catch per unit effort; fish per 24 fyke net hours).

Fish sizes and recruitment

Length frequency distribution analysis was used to detect recruitment in wetland fish species in the form of an increase of smaller sized fish cohorts. The length frequency distribution of carp gudgeon changed significantly from October 2012 to February 2013 across all wetland regions (Mid KS = 8.281, $p < 0.001$; Low KS = 10.248, $p < 0.001$, Western Lakes KS = 9.856, $P < 0.001$). A new carp gudgeon cohort is evident in each wetland region in the February surveys, indicating that spawning is likely to have occurred within wetlands between December 2012 and February 2013, the known spawning season for this species.

Carp and goldfish were combined for the length frequency analysis due to difficulty in identifying very small individuals of these species in the field. The length frequency distribution of carp/goldfish changed significantly among sampling occasions, with a new cohort evident in October in the mid-Murrumbidgee wetlands ($KS = 2.393$, $p < 0.001$; Figure 25). Wetlands in this region were disconnected at this time and did not receive inflows in 2012-13. Therefore, spawning by this species was by individuals that remained within the wetlands since it was last filled in autumn 2012 and was not in response to the delivery of Commonwealth environmental water in spring 2012. In the Western Lakes, water was delivered in September 2012, and while there were some carp less than 20 mm in October 2012, by February and April 2013 total carp numbers had substantially decreased (no carp were captured at all) while the surveys indicated a substantial increase in carp gudgeon numbers.

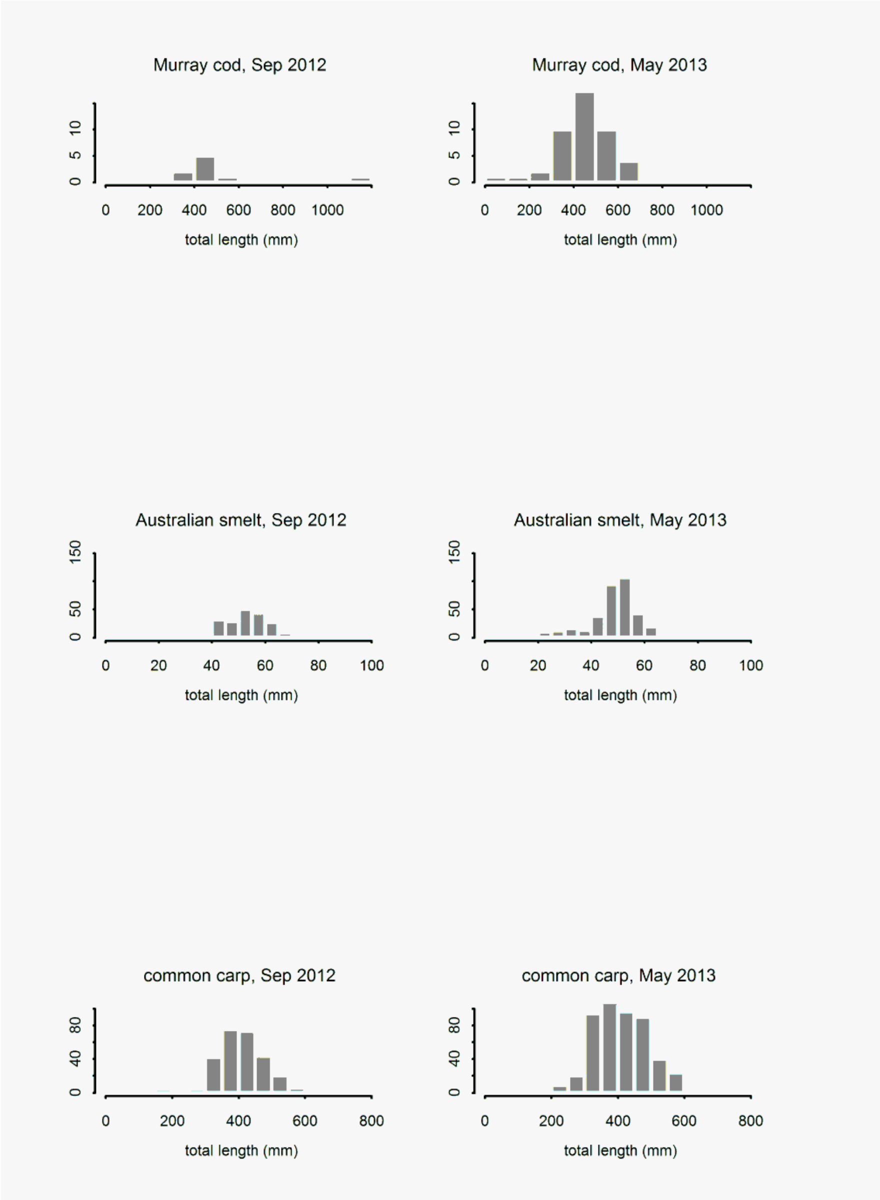


Figure 24 Relative length frequency distribution of Murray cod (top) Australian smelt (middle) and common carp (bottom) in the Murrumbidgee River before and after Commonwealth environmental watering (September 2012 (before) and May 2013 (after) Commonwealth environmental release. Note the differences in y axis scales across charts.

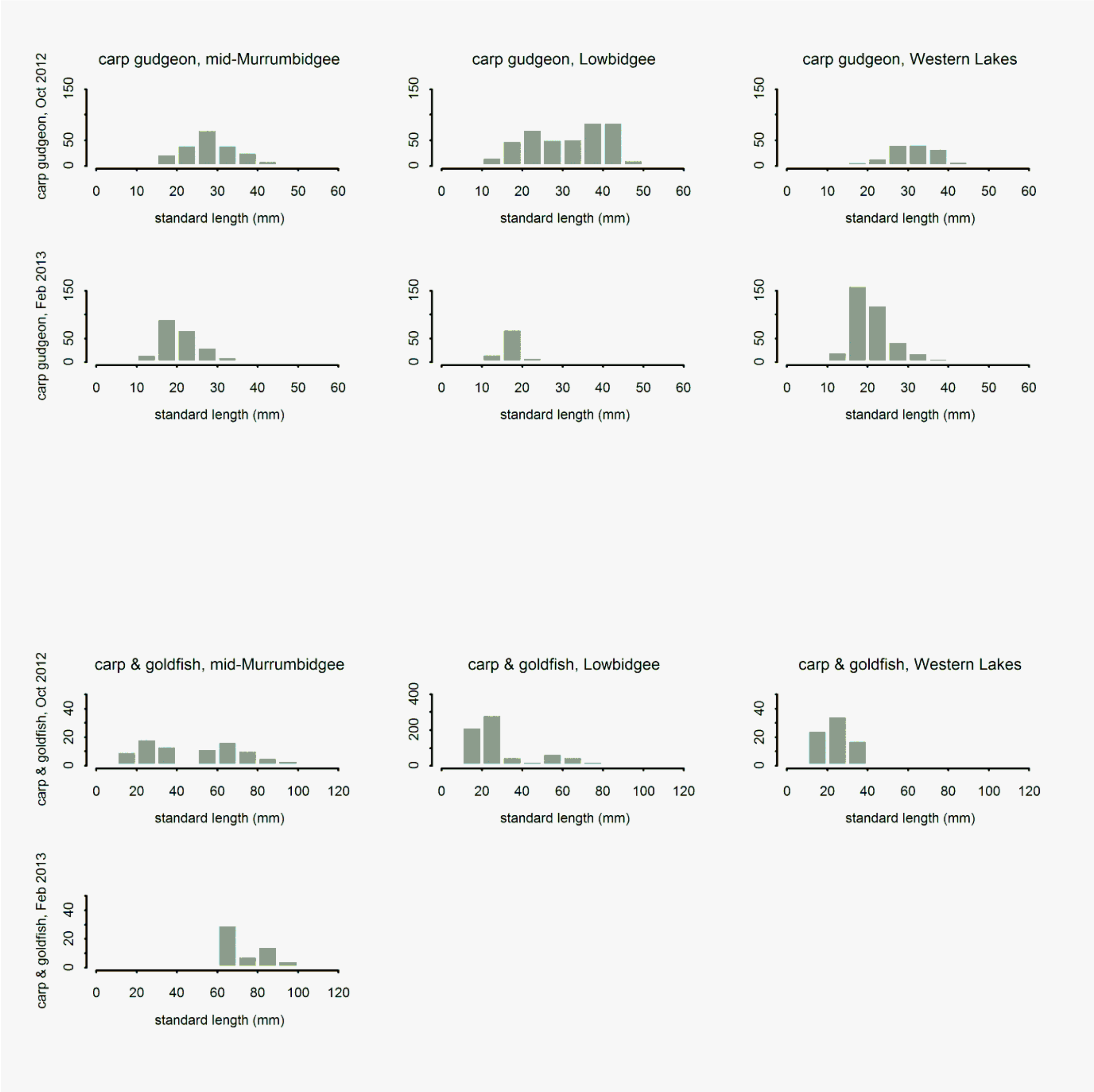


Figure 25 Size distribution of carp gudgeons (top) and Common carp and goldfish (bottom) in October 2012 and February 2013 in the mid-Murrumbidgee wetlands, Lowbidgee wetlands and Western Lakes. Note the differences in y axis scales across charts.

9.3 Discussion

Wetland fish communities were dominated by small-bodied native fish species, which outnumbered exotic fish species such as carp, goldfish and gambusia by more than 100 to one.

There was no evidence of significant carp recruitment in the Murrumbidgee River main channel following the delivery of Commonwealth environmental water. There was some evidence of low levels of carp spawning in the wetlands in October 2012 but subsequent surveys over 2012-13 indicated low recruitment rates of carp with total carp numbers decreasing in all wetland regions.

The composition of fish communities in the Murrumbidgee River and associated wetlands has changed markedly over the past 50 years with many wetland species, such as the Murray hardyhead and southern purple spotted gudgeon, which were once abundant in the Murrumbidgee (Anderson 1915), now locally extinct. Overall, the total abundance and biomass of native fish increased significantly after the delivery of Commonwealth environmental water, both within the Murrumbidgee River and the Western Lakes. This change in abundance and biomass was driven by a combination of recruitment by small-bodied native species (carp gudgeon and Australian smelt) and immigration of large bodied fish, in particular golden perch.

While fish communities are expected to change seasonally in response to changes to the availability of habitat, recruitment of small bodied native fish was significantly higher in wetlands receiving Commonwealth environmental water (Western Lakes) than either the mid-Murrumbidgee or Lowbidgee, which dried rapidly over the water year. In the Murrumbidgee River, observed differences in fish communities were due to increased abundances of native species following the delivery of environmental water, particularly Australian smelt and bony herring.

Commonwealth environmental flows delivered in 2012 were targeted to increase the availability of spawning habitat for Murray cod and encourage recruitment by this iconic species. Murray cod were most abundant in the middle region of the Murrumbidgee River, between Wagga Wagga and Hay, and were therefore targeted for specific fish movement and spawning and recruitment monitoring (refer to following sections). Total biomass increased for most fish species after the environmental water was delivered, with some species (e.g. Australian smelt) producing new cohorts of larvae and juveniles, leading to increased biomass, while other species (e.g. golden perch) re-distributed throughout the river in response to improved connectivity created by the environmental flow.

Although the total abundance and total biomass of carp increased in the Murrumbidgee River after the delivery of Commonwealth environmental water, this was not attributed to spawning of carp within the river channel, and there was no evidence of young of year fish or larval carp (see following sections). This interpretation is further supported by a similar increase in carp biomass in the control site, Old Man Creek, where no environmental flows were received. This outcome demonstrates that flows delivered in 2012 were not conducive to carp recruitment within the Murrumbidgee River, as had been shown in long-term analysis of common carp populations (Forsyth, Koehn *et al.* 2013). There were, however, a very small number of young-of-year carp in wetlands, and it should be noted that the mid-Murrumbidgee and Lowbidgee did not receive Commonwealth environmental water in 2012-13. At all wetland sites, common carp abundance decreased over summer, while native carp gudgeon numbers increased significantly. The Western Lakes are fitted with carp screens to preclude the establishment of large carp, and this appears to have been successful in limiting carp recruitment within the system.

In 2012-13, Commonwealth environmental water increased connectivity, habitat and food availability for native fish species in the Murrumbidgee River and the Western Lakes. Increases in abundance and biomass of native species in the Murrumbidgee River and the absence of carp recruitment indicated a successful flow delivery in terms of allowing native species to re-distribute within the system whilst also providing suitable environmental conditions for spawning by small-bodied natives. Although the mid-Murrumbidgee and Lowbidgee wetlands remained disconnected throughout the watering year, changes in their fish communities could be attributed to recruitment and/or death of fish within populations established through managed and natural reconnection flow events in 2011-12 (Wassens, Watts *et al.* 2012). High abundances of native fish in the survey wetlands demonstrated that these habitats support a native fish population during their drying phase. Prior to river regulation, many of these wetlands would remain wet throughout the year, with multiple reconnections to the river sustaining these populations and allowing movement of recruits between the wetland and river. Differences in the diversity and abundance of fish species among the wetland regions are likely to be heavily influenced not only by the wetland type but also by environmental water management, which is crucial for maintaining the values of wetland habitats for native fish communities.

Fish movement

Murray cod ready for release after being surgically implanted with an acoustic tag

Freshwater fish are highly mobile and move in association with flow changes in order to spawn, disperse and feed (Lucas, Mercer *et al.* 1998). Twenty-seven Murray cod (*Maccullochella peelii*), six trout cod (*Macchullochella macquariensis*), five golden perch (*Macquaria ambigua*) and two silver perch (*Bidyanus bidyanus*) were surgically implanted with acoustic tags in September 2012 and March 2013 to examine spawning related movement before, during and after delivery of the 2012-13 Commonwealth environmental watering in the Murrumbidgee River. Assessment of spawning movement activity contributed to an assessment of the Commonwealth environmental watering objectives related to **"supporting breeding and recruitment by native fish"** and **"support ecosystem functions that relate to longitudinal and lateral connectivity**".

key outcomes:

- **Movement behaviours of tagged Murray cod were consistent with spawning related movements during Commonwealth environmental water delivery** (which also coincided with the known spawning season of this species). Commonwealth environmental flows provided conditions suitable for the spawning of this species, which is supported by the movement patterns of tagged Murray cod as well as the presence of drifting cod larvae two weeks to one month after behaviours consistent with spawning related movements.
- Tagged silver perch made large scale movements during Commonwealth environmental water delivery, which supports the objective of increasing longitudinal connectivity throughout the mid-Murrumbidgee River.

10 Fish movement in response to Commonwealth environmental water delivery in the Murrumbidgee River

Freshwater fish are highly mobile and are known to exhibit specific movement patterns during development (Koehn and Nicol 1996, Jackson, Peres-Neto *et al.* 2001). For example, adult Murray cod exhibit complex seasonal movement patterns in alignment with their predictable spawning season (Koehn, McKenzie *et al.* 2009), whilst juvenile Murray cod seek out complex woody structures for protection against larger predators (Jones and Stuart 2007). In some species, specific movement patterns have been observed in response to changes in discharge, water level, water temperature, food availability and accessibility to suitable habitat (Reynolds 1983, Agostinho, Gomes *et al.* 2007, Jones and Stuart 2007). For example, golden perch in the Murray-Darling Basin move large geographical distances in response to rising water levels (Reynolds 1983). It is anticipated that delivery of Commonwealth environmental flows within the predictable spawning season of large-bodied native fish in the Murrumbidgee River may initiate a fish movement response in large-bodied native fish.

Fish movements occurring in response to Commonwealth environmental water delivery can be assessed using a number of monitoring techniques including radio tracking, passive integrated transponder systems and acoustic tracking (Adams, Beeman *et al.* 2012). For this study, acoustic tracking is the most suitable as it records the location of tagged fish in the study reach when they are within the detection range of the receiver units. Receiver units are strategically placed at regular intervals along the river so that both small and large movements can be detected. When a tagged fish swims within the detection range of the acoustic receiver, the unique identification number of the tagged fish as well as the date and time of the detection is recorded. A movement of a tagged fish is defined as 'detections on two or more acoustic receivers' so that directionality and the distance moved can be calculated. Overall, movement patterns of tagged fish are assessed by calculating the number of acoustic receivers they have passed within a set timeframe (this can be in both upstream and downstream directions). In the case of environmental water delivery, the strategic placement of acoustic receivers can provide information on timing of movements, distances travelled, correlation of movement with increases in discharge as well as evidence of spawning-related behaviours. This information can then inform the delivery success of Commonwealth environmental water as well as advise the future planning of events to maximise fish movement and spawning related outcomes.

The specific aim of this monitoring component is to examine potential spawning-related movement in large-bodied native fish in association with the delivery of Commonwealth environmental water. Spawning by large bodied fish typically occurs over a defined period. For example, Murray cod spawn between mid-October and late-November (Humphries 2005). It was hypothesised that the delivery of water, at an optimal temperature (17 – 18°C) delivered during the spawning season, would increase water levels for an extended period, thereby increasing nest inundation and availability, potentially leading to greater spawning success. For example, the spawning migration and parental care behaviour exhibited by Murray cod (Rowland 1983) means that its spawning response to environmental flows can be tracked with the acoustic array. We would expect that following delivery of an appropriately timed environmental flow, Murray cod males and females would undertake upstream or downstream movements consistent with actively seeking out a suitable mate and nest site. This would then be followed by a short period of inactivity (spawning), after which males would remain sedentary for a period of approximately ten days while guarding their eggs and larvae in the nest.

10.1 Methods

Fish Collection

To collect fish for acoustic tagging, multi-pass electrofishing was performed in the study reach in the mid-Murrumbidgee River throughout September 2012 prior to the Commonwealth environmental release. Prior to surgical implantation of the acoustic tag, fish were anaesthetised in an oxygenated tank containing 50 mg/L benzocaine (ethyl-p-amino benzoate). The gill movements of fish were monitored until it became shallow and irregular indicating the fish was under anaesthesia. The fish were then measured and weighed to ensure the suitability for acoustic tagging (the acoustic tag must remain below or near 2% of the fish's body weight). Acoustic tags were surgically implanted into individuals of four large bodied native fish species; Murray cod (n=27) and trout cod (n=6) which exhibit nesting behaviours were tagged. Golden perch (n=5) and silver perch (n=2) that are known to move in response to flow delivery were tagged to determine if the flow provided a secondary benefit of connectivity for these species (Appendix 2. Details of Acoustic Array). Surgery to implant acoustic tags followed the procedure described in (Butler, Mackay *et al.* 2009) (Plate 13).

Plate 13 (a) Surgery to implant acoustic tag into a golden perch and (b) Murray cod with acoustic tag implanted, ready to be sutured, given antibiotics and released.

Deployment of Acoustic Array

An array of 20 acoustic receivers (VEMCO Ltd., Halifax, Nova Scotia, Canada) were deployed in the Murrumbidgee River system between Berembed Weir and Yanco Weir (Figure 26). Acoustic receivers record the date, time and identity of acoustic tagged fish swimming within the detection range of the receiver units. Receivers were deployed during the week beginning 24 September 2012, with 18 receivers installed in the Murrumbidgee River channel and one receiver at the confluence of each of Old Man Creek and Yanco Creek to detect movement into tributaries (further details are provided in Appendix 2. Details of Acoustic Array). The acoustic array provided continuous monitoring of the movement of tagged fish throughout the study period.

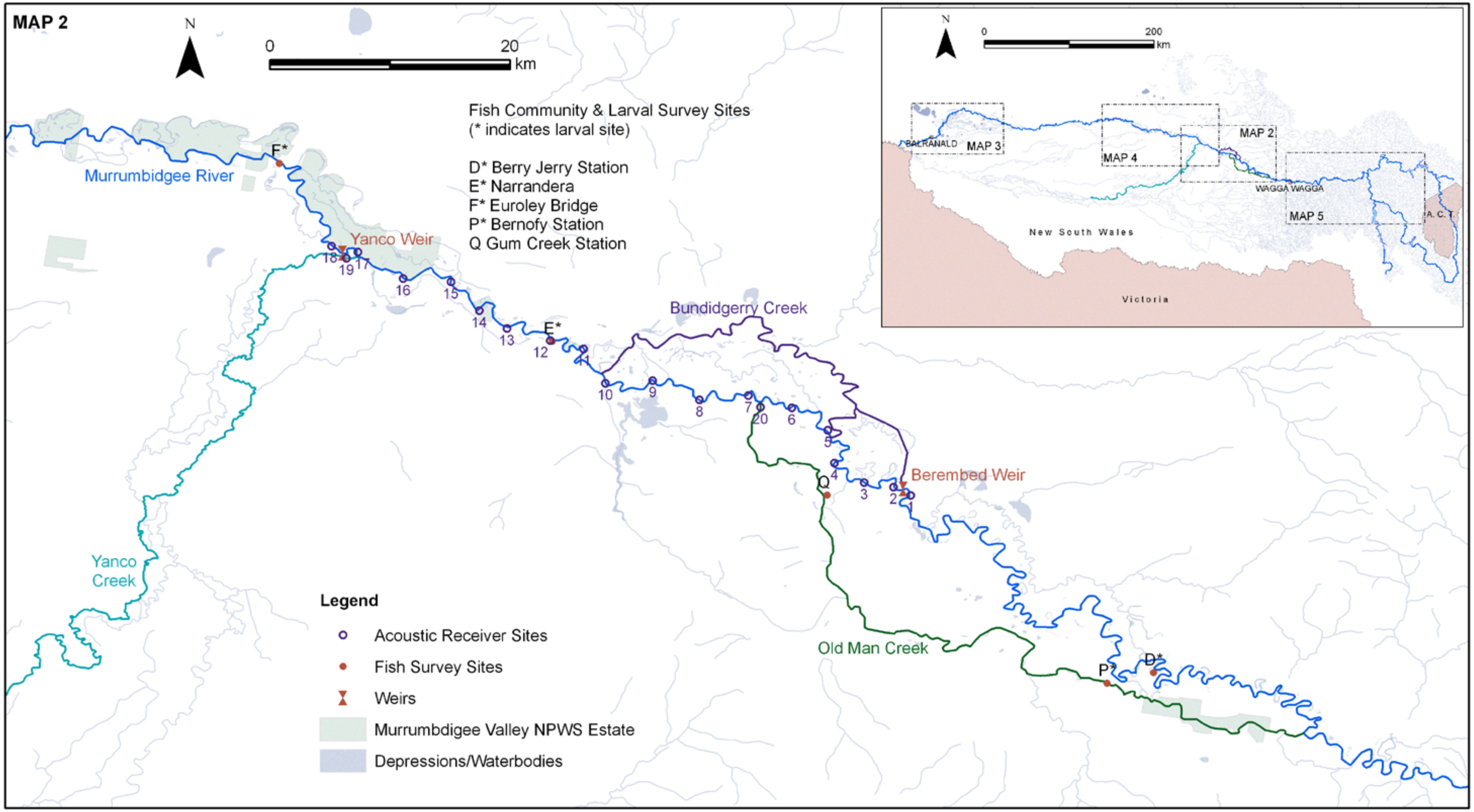


Figure 26 Distribution of larval and community fish monitoring sites and acoustic receiver sites in the mid-Murrumbidgee River and Old Man Creek.

Movement data were downloaded from the acoustic array in January, April and July 2013. Prior to analyses, single detections were removed (Clements, Jepsen *et al.* 2005) and the detection data were visualised using Eonfusion software (Myriax Software Pty Ltd) by reviewing fish track movement to identify and exclude false detections. All remaining data were plotted on a spatial representation of the Murrumbidgee River to generate time series movement videos (see results sections for each species). Movement metrics were then generated on a daily basis to correlate with flow parameters (discharge ML/day) and water level (metres; detailed data analysis methods in Appendix 2).

Displacement and activity metrics were used to assess fish movement patterns during the period of Commonwealth environmental water delivery. Displacement is a representation of the geographical distance and direction that a fish moved during the study period, whilst activity is a measure of the amount of movement that occurred during that geographical displacement. For example, a fish may geographically move 10 km upstream in one day (displacement of 10 km). However, that same fish may have travelled up to 50 km as it swam back and forth between potential feeding grounds, or looking for a mate (activity). Therefore, displacement figures are compared with activity to get a view of the overall distances that fish move, but also the characteristics of those movement patterns.

10.2 Results

Fish movement data were collected for a 288 day period from 27 September 2012 to 12 July 2013. During this period, 24 acoustic tagged fish were recorded within the study area and a total of 208,205 detections were downloaded from 13 of the 20 acoustic receivers.

Murray cod

Out of the 27 Murray cod tagged, 17 were detected during the study period, and one is known to have been removed from the study population by an angler. Murray cod movement was monitored between Berembed Weir and Yanco Weir, with the only movements by this species detected from the confluence of Old Man Creek and the Murrumbidgee River to five kilometres downstream of the Narrandera town boat ramp.

Mean displacement of Murray cod is used as a measurement of specific spawning related movement, whereby a movement upstream or downstream followed by a period of sedentary behaviour (flat displacement line) is considered to be consistent with spawning related behaviour. The peak movement period (mean displacement) for Murray cod was September to December 2012, which coincided with the delivery of Commonwealth environmental water and the Murray cod spawning season. Throughout the period of Commonwealth environmental water delivery, Murray cod exhibited small, localised movements up to 2.5 kilometres in both upstream and downstream directions (Figure 27). During this time, changes in movement direction (from upstream to downstream and from downstream to upstream) were associated with small peaks in flow and tended to occur directly after a change in discharge levels, suggesting that daily change in discharge may be a trigger for small scale movements for this species (Figure 27). These small scale movements during the spawning season may indicate that tagged fish were actively seeking mates and spawning. Following these localised movements, fish underwent a period of sedentary behaviour (as indicated by 'flat lines' in black displacement line) indicating that during this time male fish may have been guarding the eggs and larvae in their nests post-spawning and female fish may have remained in the spawning location for an extended period.

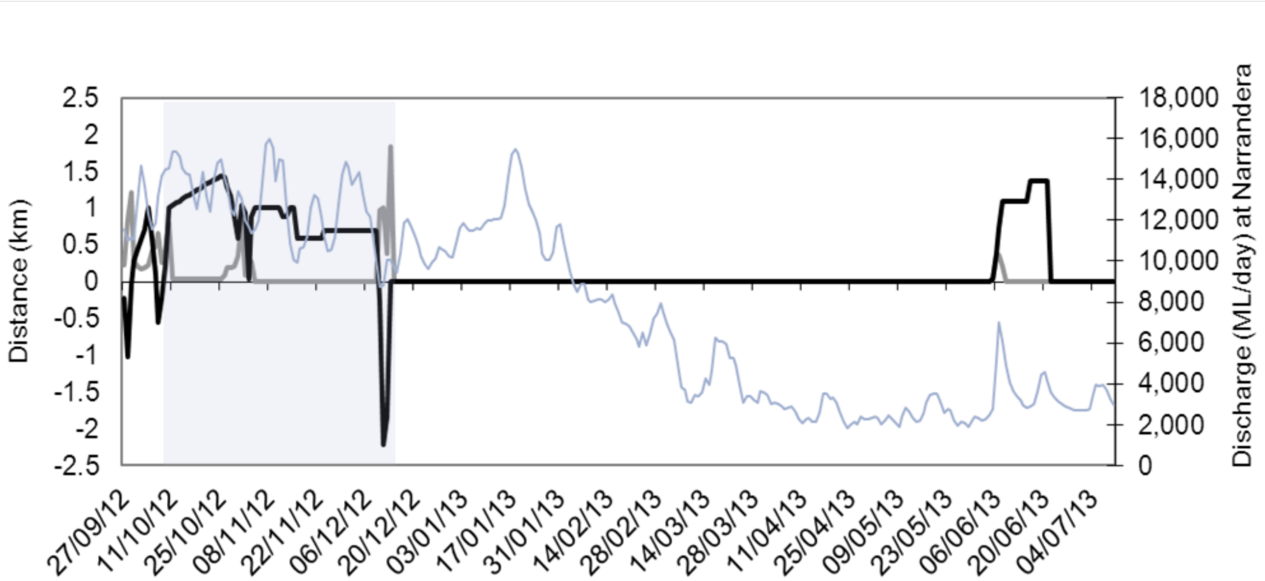


Figure 27 Mean displacement (left axis, black) of Murray cod in relation to activity (left axis, grey) and discharge at Narrandera (ML/day; blue hydrograph). Data are based on 17 fish that were detected during the study period. Upstream movement is positive and

downstream movement is negative. The shaded square represents the 2012 CEW environmental fresh.

Although mean displacement movement patterns offer an overall picture of the movement patterns and characteristics of the tagged Murray cod population before, during and after Commonwealth environmental water delivery, movement patterns of each tagged fish can be examined to identify individual fish that may have been exhibiting specific spawning related movement (Figure 28). The movement behaviours of four tagged Murray cod (one male and three females) were consistent with spawning related movement. All four fish exhibited small peaks in movement (both upstream and downstream), followed by periods of sedentary behaviour, where fish do not move for an extended period (ranging from approximately two weeks to one month; represented by a ‘flat line’ in movement line) (Figure 28). The timing of this movement pattern occurred from mid-September through to mid-October, making it plausible that these movements were spawning related. Other individuals of this species exhibited different movement patterns, with one tagged fish making a rapid downstream movement in mid-December before returning to its starting location (light purple line), whereas other fish remained relatively sedentary throughout the period of Commonwealth environmental water delivery as well as for the remainder of the study period (indicated by continuous ‘flat lines’; these fish were scanned continuously on one acoustic receiver). Interestingly, one Murray cod made a rapid upstream movement in early June 2013 in direct response to a sharp increase in discharge of approximately 2,000 ML/day (dark purple line).

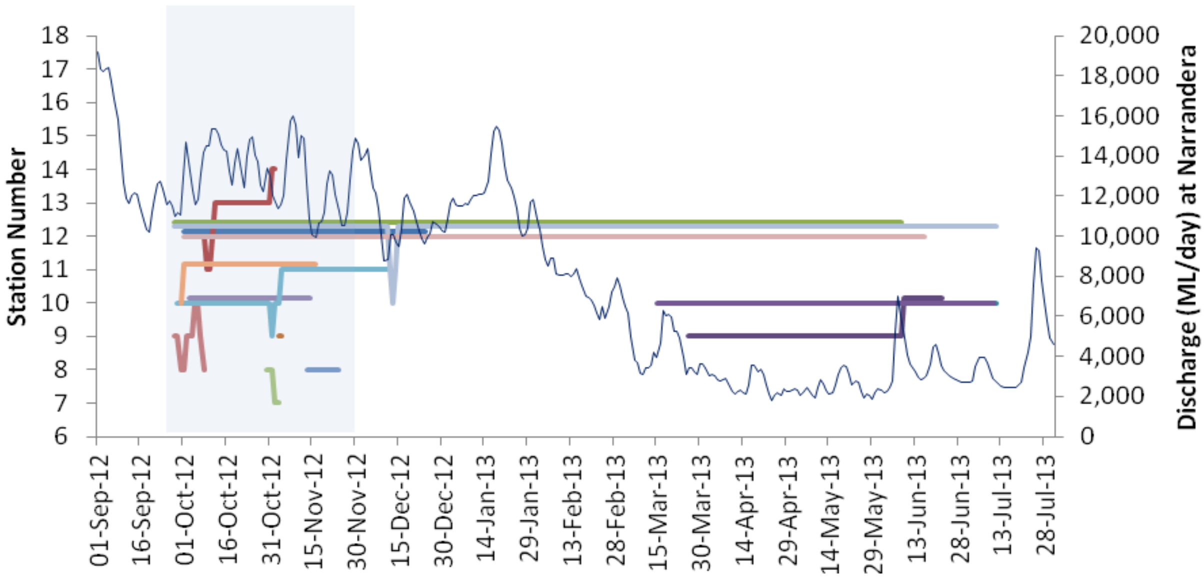


Figure 28. Individual movement patterns of 17 Murray cod during the study period and discharge (ML/day) at Narrandera (blue hydrograph). Each coloured line represents one tagged Murray cod that was in the detection range of the acoustic receivers. Straight lines indicate detections for each individual fish, whereas white space indicates times when no fish were detected on each station. Station Numbers represent each acoustic receiver, with Station 6 situated 500 metres downstream of the confluence of Old Man Creek and the Murrumbidgee River and Station 18 situated one kilometre downstream of Yanco Weir. The shaded square represents the 2012 CEW environmental fresh.

Trout cod

Five of the six trout cod tagged were detected during the study period. Tagged trout cod were moving within a ten kilometre range; from Buckingbong boat ramp down to approximately three kilometres upstream of Narrandera boat ramp. This suggested that tagged trout cod displayed a relatively small home range which was close to their original tagging location. Mean displacement of trout cod suggested that the peak period of movement was within the period of Commonwealth environmental water delivery (Figure 29). Trout cod exhibited downstream movement of up to 10 kilometres in association with small flow peaks during the study period, and activity levels (grey line) were comparable to displacement levels (black line), indicating that tagged fish made direct movements rather than swimming back and forth between receivers. Most downstream movements occurred directly after small peaks in discharge, with the largest movement made after the small flow peak in late November.

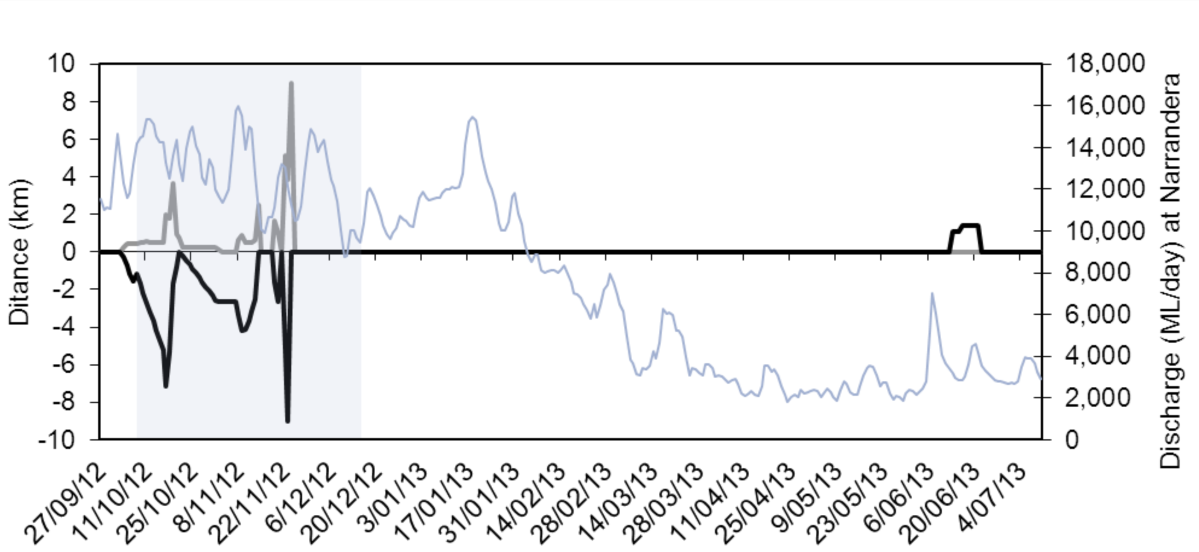


Figure 29. Mean displacement (left axis, black) of trout cod in relation to activity (right axis, grey) and discharge at Narrandera (ML/day; blue hydrograph) based on five fish that were detected during the study period. Upstream movement is positive and downstream movement is negative. The shaded square represents the 2012 CEW environmental fresh.

Individual trout cod movement patterns indicated that three females were active within the Commonwealth environmental watering period (Figure 30). Movement patterns of females suggest that they may have been looking for mates or suitable spawning habitat during the period of Commonwealth environmental watering, as indicated by the sharp increases and decreases in movement lines (orange, purple and light blue). Two other trout cod were not detected during the period of environmental watering, but were detected December 2012 through to July 2013 (light green and dark green lines). Straight movement lines indicate that these individuals were being consistently detected on the same receiver, suggesting that these fish were exhibiting a small home range (swimming close by to one receiver on a daily basis and never travelling enough distance to be detected on the next closest receiver). This demonstrates that during this time (December 2012 through to July 2013) these two trout cod inhabited a home range of approximately four kilometres (the average distance between two acoustic receivers). As this species has been known to spawn from September onwards (dependent upon water temperature), tagged fish may have exhibited additional movement patterns (potentially spawning-related) before the acoustic array was deployed in late September 2012.

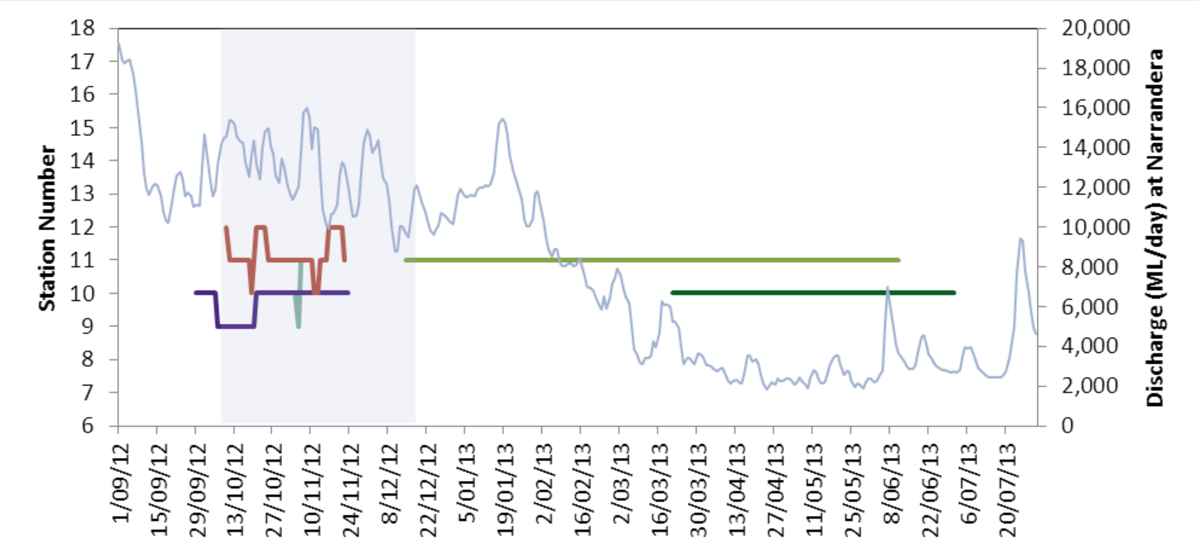


Figure 30. Individual movement patterns of six trout cod during the study period and discharge at Narrandera (ML/day; blue hydrograph). Each coloured line represents one tagged trout cod that was in the detection range of the acoustic receivers. Straight lines indicate detections for each individual fish, whereas white space indicates times when no fish were detected on each station. Station Numbers represent each acoustic receiver, with Station 6 situated 500 metres downstream of the confluence of Old Man Creek and the Murrumbidgee River and Station 18 is situated one kilometre downstream of Yanco Weir. The shaded square represents the 2012 CEW environmental fresh.

Silver perch

Records of silver perch movement were over a much larger geographic distance compared to Murray cod and trout cod. Mean displacement and mean activity calculations were not made for this species given only two individuals were detected and there was no overlap in their movements (Figure 31). One individual undertook rapid upstream and downstream movements that were associated with small changes in discharge within the Commonwealth environmental watering period (green line). This silver perch is believed to have left the study area, travelling downstream of Yanco Weir and was then detected upstream of Yanco Weir. High flows provided during the Commonwealth environmental water period facilitated movement of this silver perch over the weir in order to migrate upstream. Future high flows may enable this fish to re-enter the study reach and be tracked prior to tag expiration. A similar movement pattern is seen for the silver perch detected outside of the Commonwealth environmental watering period, with rapid large scale movements associated with very small peaks in discharge (orange line). However, this silver perch also remained sedentary for a period of approximately one month, which may indicate that this fish was feeding or found suitable habitat to ‘rest’ after making large scale movements.

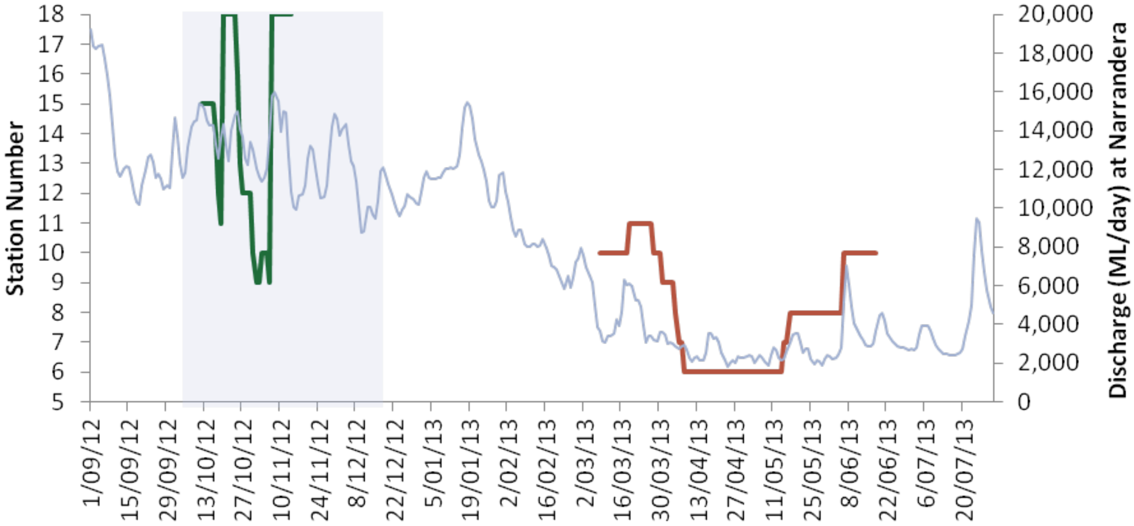


Figure 31. Individual movement patterns of two silver perch during the study period and discharge at Narrandera (ML/day; blue hydrograph). Each coloured line represents one tagged silver perch that was in the detection range of the acoustic receivers. Straight lines indicate detections for each individual fish, whereas white space indicates times when no fish were detected on each station. Station Numbers represent each acoustic receiver, with Station 6 situated 500 metres downstream of the confluence of Old Man Creek and the Murrumbidgee River and Station 18 is situated one kilometre downstream of Yanco Weir. The shaded square represents the 2012 CEW environmental fresh.

Golden perch

Five golden perch (two females, three of unknown sex) were implanted with acoustic tags on 10 September 2012, ranging from 374 mm (798 g) to 470 mm (1.52 kg). No detection data was recorded for any golden perch during the study period.

10.3 Discussion

The movement pattern observed for Murray cod suggested that some individuals were leaving their home range to seek a mate, spawn and then nest for a period of time (males). Interestingly, female Murray cod also exhibited movement patterns consistent with this, suggesting that females may be remaining at spawning locations after spawning, potentially looking for another mate or feeding. The presence of some individuals that did not undertake similar movements does not necessarily contradict this and may simply indicate that these individuals did not spawn. A study of hatchery Murray cod demonstrated that over a three year period, less than half of all broodfish spawned (Rourke, McPartlan *et al.* 2009). Therefore, it is possible that wild fish do not spawn every year, which could account for the lack of migration by some individuals. It is likely that those fish that did move were undertaking spawning migrations given that drifting cod larvae were sampled within the study reach (Narrandera) in mid-November, approximately two weeks to one month after these movement patterns were exhibited (refer section 13 spawning and recruitment). This indicates that Commonwealth environmental water delivered to support the recruitment of this iconic species provided suitable environmental conditions during the Murray cod spawning season to encourage nesting and spawning.

Movement patterns of trout cod suggest that females were making localised movements during the period of Commonwealth environmental water delivery. The trout cod spawning season can begin as early as September (Cadwallader 1977) and has also been found to overlap with the Murray cod spawning season in mid-October to November (Koehn and Harrington 2006). Therefore, female trout cod movement patterns may be consistent with fish actively seeking a mate, but there is also the possibility that these movements are not true spawning related movements as spawning may have occurred earlier in September, before the fish were tagged. Further continuous monitoring using this acoustic array will determine whether the peak movement period for this species is in fact from October to November, or whether there are much larger movements made by both females and males in September.

Silver perch are known to make long-distance spawning migrations (Reynolds 1983). However, most weirs in the Murrumbidgee River lack fishways and are a major barrier to movement by this species during periods of low flow. The Commonwealth environmental water delivered during 2012 was sufficient to submerge Yanco weir and thus facilitated the movement of one of the tagged silver perch upstream over this weir. Since then, this fish has travelled downstream of the weir and will be unable to travel upstream until flows facilitate a high enough water level for movement. Silver perch have been known to make spawning migrations, whereby they move both upstream and downstream in equal distances (Reynolds 1983). High water levels facilitated by Commonwealth environmental water delivery has enabled the upstream migration of this silver perch, and future high flows should allow this fish to complete further spawning migrations above barriers within the Murrumbidgee system.

No golden perch were detected during the study period. Given these fish were tagged prior to the deployment of the acoustic array, it is possible the fish moved out of the detection area via Old Man Creek or Yanco Creek, or by moving downstream beyond the acoustic array, and are yet to return. Alternatively, fish may have died or have been removed from the river by anglers. This species is capable of long migrations (Reynolds 1983, O'Connor, O'Mahony *et al.* 2005) and it is more likely that all the individuals left the study area soon after tagging. If the fish make a return migration to the study reach, they will be detected by the acoustic array.

Overall, flows delivered with the aim of providing suitable environmental conditions to allow for large-bodied fish to successfully spawn and recruit coincided with behaviour consistent with spawning related movement by some Murray cod. As drifting cod larvae were detected within the study area in mid-November, this indicates that this species successfully spawned during the period of Commonwealth environmental water delivery. Monitoring of large-bodied native fish movement in the Murrumbidgee River into the future will provide additional information on movements associated with differing flow regimes, as well as the long term benefits of Commonwealth environmental water delivery.

Fish spawning and recruitment

Flow plays an important role in the life-cycle of native fish from the larval to the adult stage (Humphries, King *et al.* 1999, Humphries, Serafinia *et al.* 2002, King, Humphries *et al.* 2003). Commonwealth environmental watering in the Murrumbidgee River targeted the spawning and recruitment of Murray cod by inundating spawning habitat for a prolonged period. ***The key objectives of the Commonwealth environmental watering action were to support breeding and recruitment of native fish and support the habitat requirements of native fish.*** From September to December 2012, larval fish communities were surveyed weekly in the Murrumbidgee River and a control site on Old Man Creek to assess fish spawning responses to environmental watering.

Key outcomes

- 519 cod larvae (*Maccullochella* spp.) were captured, with **a peak in abundance coinciding with the Commonwealth environmental water delivery period.**
- Ten young-of-year fish were collected including three Murray cod, two golden perch, two redfin perch and one carp.
- The abundance of drifting cod larvae was positively related to temperature, microinvertebrate abundance and turbidity.
- River blackfish (*Gadopsis marmoratus*), Australian smelt (*Retropinna semoni*) and carp gudgeon (*Hypseleotris* spp.) larvae were also collected during the sampling period in small numbers, as well as juvenile carp gudgeon and juvenile Australian smelt. Very few exotic fish larvae were collected.

11 Support breeding and recruitment of native fish

The successful spawning and recruitment of native freshwater fish species is highly dependent on environmental conditions that promote growth and survival (Rolls, Growns *et al.* 2013). Important environmental factors that influence spawning and recruitment include food availability at critical larval stages (Cushing 1990), suitability of habitat (Copp 1992), predation (Copp 1992), water temperature (Rolls, Growns *et al.* 2013) and flow variability (King, Tonkin *et al.* 2009). For example, changing flow variability towards a natural flow regime directly influences the survival of eggs and larvae (King, Tonkin *et al.* 2009). Flow plays an important role in the life-cycle of native fish from the larval to the adult stage, where water may inundate habitat needed for reproduction, or stimulate in-stream migration to spawning habitat to find a mate and establish nest sites (i.e. Murray cod) (Humphries, King *et al.* 1999, King, Humphries *et al.* 2003).

Increased flow may inundate river or wetland habitat needed for reproduction, while also releasing nutrients and increasing productivity of microinvertebrates, a key prey item for the first feed of all species of native fish (Devries, Stein *et al.* 1998). Spawning occurs over a defined period; trout cod generally spawn between the start and end of September, and Murray cod usually spawn between mid-October and late-November (Humphries 2005). The nesting cycle takes 10-14 days, after which the eggs are deposited and subsequently take approximately seven days to hatch, with larvae remaining in the nest for another seven days (Rowland 1983)

An objective of the 2012-13 Commonwealth environmental watering action in the Murrumbidgee River was to provide spawning outcomes for large-bodied fish, including Murray cod (*Maccullochella peelii*) and trout cod (*Maccullochella macquariensis*). These species are long-lived, annual spawners that are highly mobile and exhibit parental care of eggs and larvae (Anderson, Morison *et al.* 1992, Humphries, King *et al.* 1999). Adult fish move and spawn in response to increasing temperatures and photoperiod (Rowland 1983, Humphries 2005, Koehn and Harrington 2006, King, Tonkin *et al.* 2009). However, appropriate flows are essential to inundate spawning habitats, with water covering nests for at least one month. We hypothesised that increased flows delivered within the known spawning season will boost the cohort size of successful recruits (due to spawning habitat being inundated for a longer period of time), beyond what is observed in a year with average flows (King, Tonkin *et al.* 2009). This will occur as increased water levels mobilise nutrients, drive primary productivity and increase availability of microinvertebrates (Devries, Stein *et al.* 1998).

In 2012-13, the trigger to commence the Commonwealth watering action was a rise in water temperature to values critical for spawning for these species (typically 15-16°C for trout cod and 17-18°C for Murray cod (Humphries 2005). Water was initially delivered to rapidly inundate potential spawning habitat, whilst also stimulating a movement response in adult fish (see previous section). Water levels were then maintained long enough for adults to locate mates, construct nests (large-bodied fish only) and spawn. Nests must remain inundated until eggs hatch, as a drop in water level will likely damage eggs or result in nest abandonment by adults (Butler, Mackay *et al.* 2009). The water period lasted from early September until late December to cover the reproductive nesting period for Murray cod and trout cod.

11.1 Methods

Collection of larvae and eggs

Weekly monitoring for the presence of larvae and eggs was conducted at three sites in the Murrumbidgee River and one site in Old Man Creek (a reference site that did not receive environmental water) from 10 September to 21 December 2012. Drift nets were used to capture larvae in their drift phase (immediately after leaving the nest at approximately seven days old) and light traps were used to capture larvae that were actively foraging for food in shallow areas of the river (approximately 15 days old or older). Larval drift net sampling intensity was determined using an occupancy probability detection model based upon data previously collected in the Murrumbidgee River. Twelve drift nets were set at each sampling site for two nights per week, and eight light traps were set at each sampling site for one night per week.

Collection of Young of Year fish

Fish community sampling was done in May/June 2013 to target the young of year (YOY) of large-bodied native fish that may have been spawned in association with the delivery of environmental flows in October-December 2012. These YOY Murray cod would be large enough (more than 60 mm) to be efficiently captured using electrofishing, whilst also young enough to be aged to within an accuracy of one day (less than 180 days old). Due to the unexpected low catches of YOY fish captured by electrofishing, additional fyke netting (using small and large fyke nets) was conducted at eight sites in the mid-Murrumbidgee to specifically target native YOY fish.

Age estimation and back-dated spawning times

Age estimation of young of year fish and a sub-sample of larval cod were conducted by Fish Ageing Services Pty Ltd, Queenscliff. In total, 229 larval cod were sent to be aged. However, due to considerable damage to the larvae within the drift nets, only 132 were able to be daily aged. These included a total of 84 larvae from Euroley Bridge, 40 larvae from Narrandera, four larvae from Berry Jerry and six larvae from Old Man Creek. Daily ages are used to back-calculate spawning dates to determine if spawning occurred during the period of Commonwealth environmental water delivery.

Data analysis

Statistical analyses were focused on catch per unit effort (CPUE); standardised to *Maccullochella* spp. larvae captured per megalitre of water flowing through larval drift nets. Few cod larvae were captured in light traps. Therefore, they were omitted from the analysis. Capture rates of other species were too low for statistical analysis. The number (CPUE) of drifting cod larvae collected on each sampling night (two sampling nights per week per site) were combined for each sampling week for statistical analysis.

Change point analysis

To pinpoint the timing of spawning, relative to season and flow, we examined changes in the abundance of cod larvae over time (weeks) by estimating the point at which mean abundance significantly changed. We did this by calculating the optimal positioning of a mean change point using the change point package (Killick and Eckley 2010), available within R software(R Development Core Team, 2012).

We took a robust approach by fitting a Bayesian Poisson change point model to Mac-CPUE. We tested whether the time series data collected for larval cod abundance can be stratified to multiple regimes or states. Our main quantities of interest in the change point analysis were the number, the timing, and the magnitude of regime changes. Sites were divided based on the presence of environmental water action. Specifically, the three Murrumbidgee River sites of Berry Jerry, Euroley Bridge, and Narrandera were grouped and compared to the single Old Man Creek site. For this analysis we relied on the MCMCpack package (Lourival, Drechsler *et al.* 2011), available within R software(R Development Core Team, 2012). Details are shown in the Appendix 1 Data analysis.

We examined the effects of multiple water indices on larval cod abundances across the four sites. As this involved a large number of indices that are likely correlated, we initially followed a variable reduction approach for the nutrients and chlorophyll. We carried out this analysis using the nFactors package (Raiche and Magis 2010), available within R software(R Development Core Team, 2012). Factor analysis of nutrient data indicated that these can be represented well using a single factor explaining 93% and 91% of the variance in Old Man Creek and the three Murrumbidgee River sites, respectively.

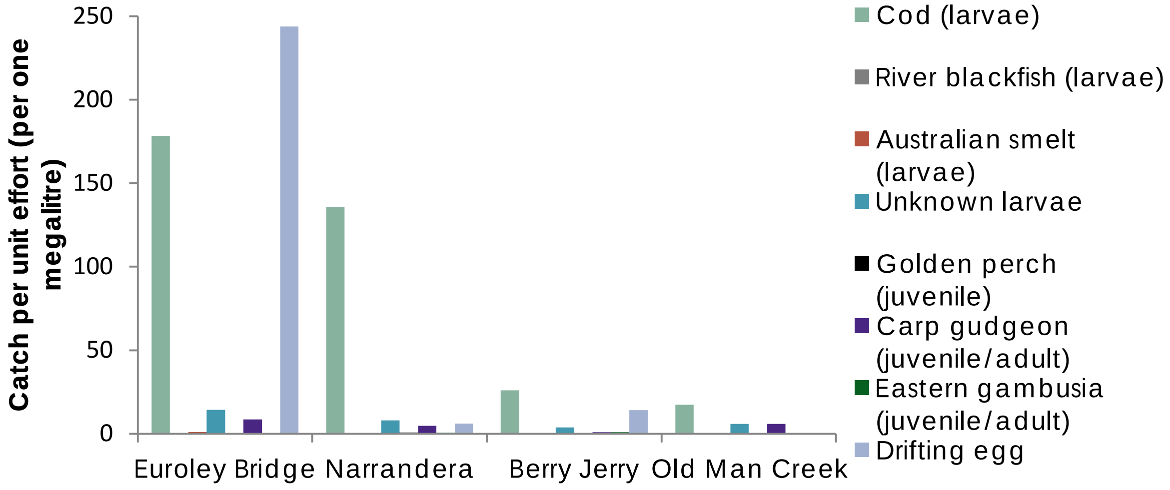
We developed Generalized Linear Regression Models for larval cod abundance response in relation to nine predictor variables: nutrients and carbon, chlorophyll a, microcrustacean density, turbidity, nutrient component 1 (from variable reduction) and Chlorophyll component 1 (from variable reduction). The flow and physical parameters that were used in the analysis were discharge (ML/day), water level (metres), and water temperature (°C). Sites were included as a discrete fixed term in the model. These values were acquired from the NSW Live Rivers database (accessed Monday 5th August, 2012). Details on the Generalised Linear Model and model selection process are shown in the Appendix 1. The model selection process generated a table showing the significance of relationships of the key selected variables with larval cod abundance as well as graphs showing the direction of these relationships.

11.2 Results

Occurrence and abundance of larvae

A total of 583 larvae, 100 juveniles/adults and 239 drifting eggs were captured during the 15 weeks of larval sampling from 10 September 2012 to 21 December 2012 in the three Murrumbidgee River sites (Berry Jerry, Narrandera and Euroley Bridge) and one Old Man Creek site. Five native species (larvae and juveniles/adults) and one alien species (adults only) were captured (Figure 32). Larval cod (*Maccullochella* spp.) were the most abundant species captured, with higher abundances in larval drift nets compared to light traps (Figure 32a and b). However, light traps captured a wider range of species, including river blackfish, larval carp gudgeon and larval Australian smelt (Figure 32b). Two river blackfish were captured at Berry Jerry on 9 November, aged 36 and 39 days, indicating they were spawned in the last week of September 2012. Daily ageing of cod larvae suggest that larvae were spawned during Commonwealth environmental water delivery (which also coincided with their spawning season) (Figure 33). Calculations based upon daily ages indicated that spawning occurred from mid-October through to early December.

(a)



(b)

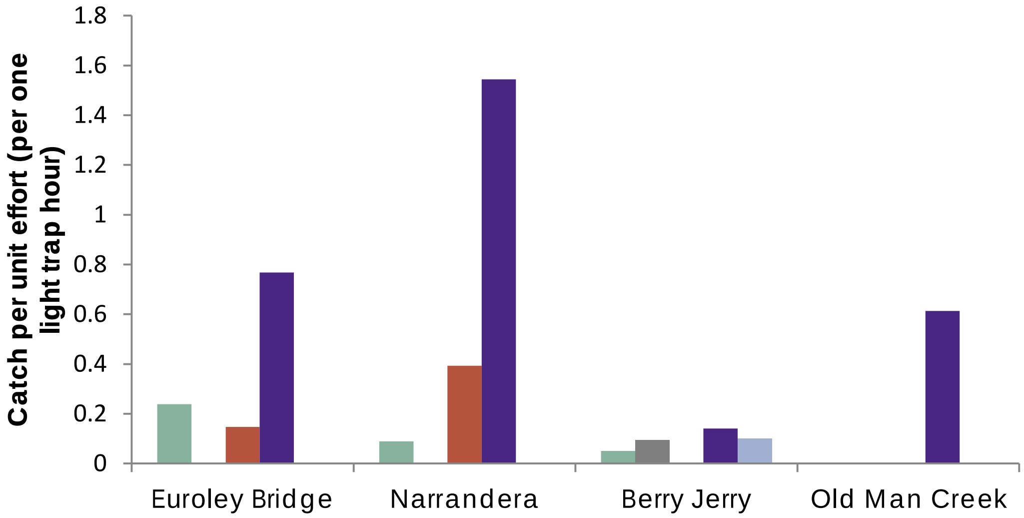


Figure 32 Fish abundance at larval survey sites in (a) larval drift nets (catch per unit effort to one megalitre) and (b) light traps (catch per unit effort to one trap hour).

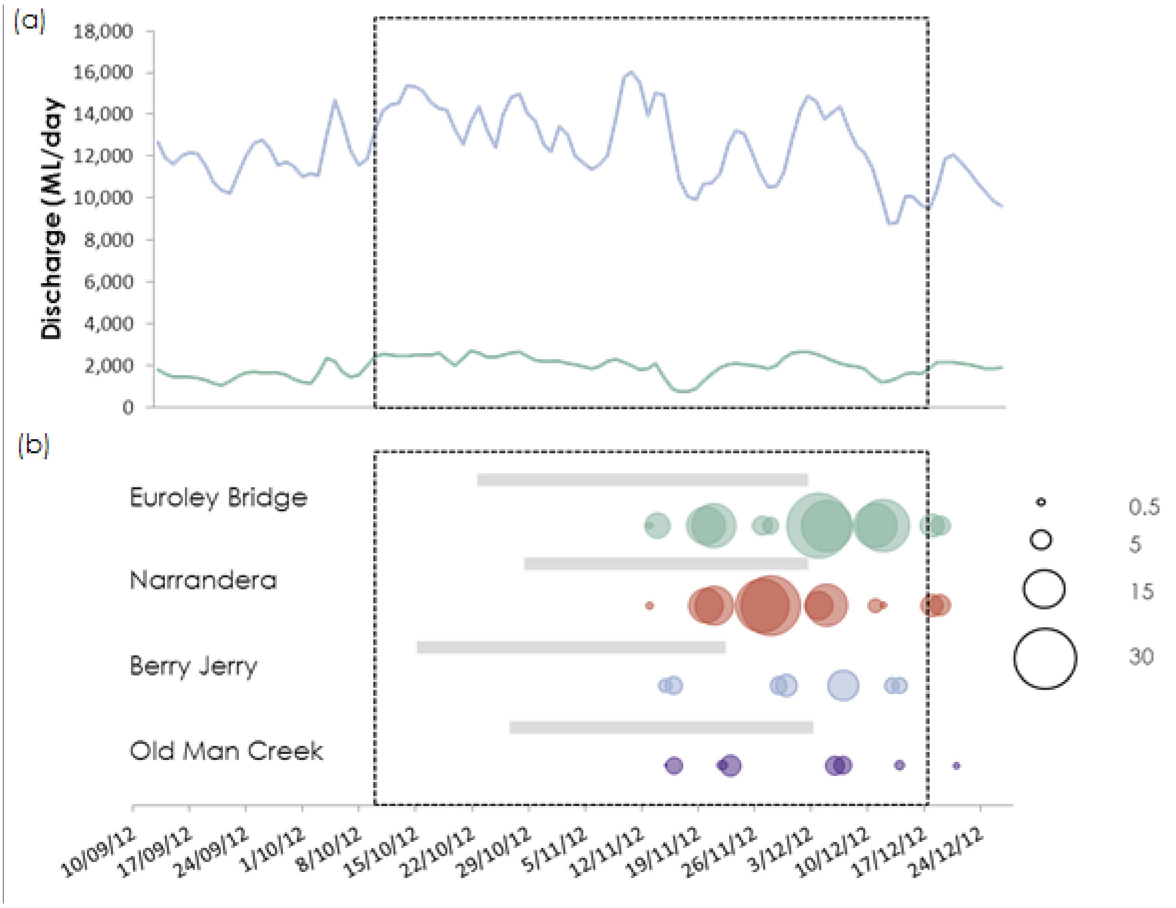


Figure 33. (a) Discharge (ML/day) at Narrandera (blue line) and Old Man Creek at Kywong (green line) gauges during larval sampling period and (b) Catch per unit effort (to one megalitre) of Maccullochella spp. larvae captured in drift nets (bubbles) and back-calculated spawning dates of Maccullochella spp. larvae that were able to be daily aged.

Timing of larval cod drift

Significant changes in larval cod abundance occurred between 12 and 19 November 2012 at the four survey sites (Figure 34). The strongest increase in mean larval cod abundance was noted in Euroley Bridge and Narrandera. Considering the three Murrumbidgee River sites (Berry jerry, Euroley and Narrandera) the change point analysis indicated that the strongest shift in larval cod abundance occurred in week 10 (12/11/2012) with an additional shift in week 15 (17/12/2012). Similar timing of spawning occurred in Old Man Creek, although the abundance of larval cod was much lower than at the Murrumbidgee River sites.

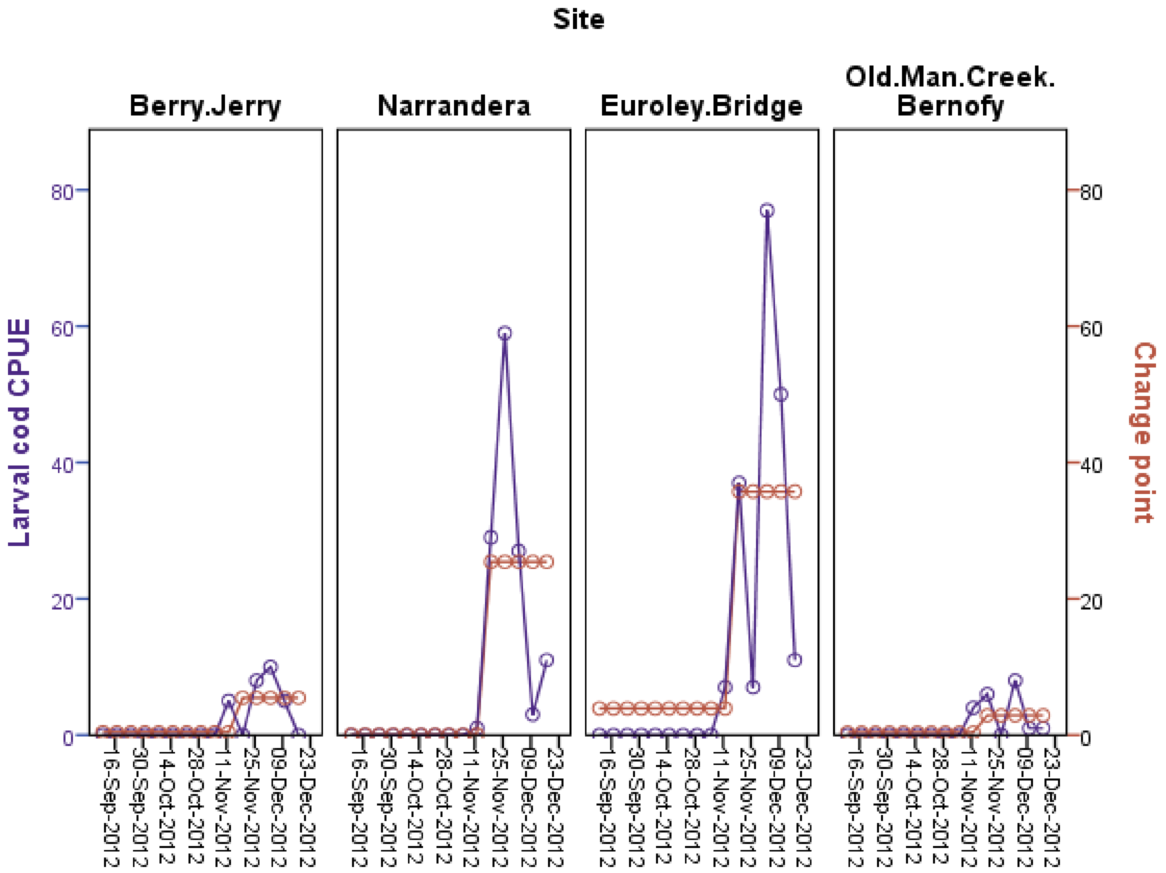


Figure 34 Larval cod (Maccullochella spp) CPUE during the survey period and the identified change point.

Relationships between larval cod abundance, flow and other co-variates

As described in the data analysis section (page 110) Generalised Linear Regression Models were employed to identify the best set of variables that could explain differences in larval cod abundances. All possible combinations of variables were considered and from these two most parsimonious combinations were identified by their high AICc values (a method of ranking models based on how well they explain the change in abundance relative to the number of explanatory variables). Both models included electrical conductivity, water temperature, turbidity and nutrients (component1), river height, microcrustacea density, and location (of the monitoring sites); the second model also included chlorophyll a. The most parsimonious model (i.e., the model with the least number of predictor variables) was highly significant, explaining 80% of the observed difference in cod larval abundance (Table 8).

Multiple comparisons (using Tukey Contrasts) indicated there were significant differences in larval cod abundance between the three Murrumbidgee River sites (Berry Jerry, Narrandera and Euroley Bridge, which received Commonwealth environmental water) and Old Man Creek (the control site that did not receive Commonwealth environmental water). The categorical variable, site, had a very strong effect on larval cod abundances with particular reaches producing more larval cod than others. Importantly, temperature, turbidity and microcrustacea abundance had a positive effect on cod larval abundance (Figure 35). However, river height, electrical conductivity, and nutrients had a negative effect on larval cod abundance. It should be noted that there were very large confidence intervals around the variable river heights.

Young-of-year fish

Fish community electrofishing and additional targeted fyke netting resulted in a total of 10 YOY fish captured, including three Murray cod, two golden perch, two redfin perch and one carp. Daily aging indicated that only one of the Murray cod captured was a YOY (80 mm long), with a spawning date in late January. This gives an indication that the spawning for this species was ongoing through to January (past the larval sampling period for 2012/13) in Old Man Creek where the fish was captured. Two individual YOY Golden perch were captured, one of which was calcein marked, indicating it was from a stocked population.

Table 8 Model-averaged coefficients

Variable	Code	Estimate	Std. Error	Adjusted SE	z value	Pr(>|z|)
(Intercept)		-5.85	2.68	2.78	2.11	0.04
Electrical conductivity	HOR_EC	-93.18	10.31	10.70	8.71	<0.001
Water temperature	HOR_temp	0.87	0.10	0.11	8.11	<0.001
Turbidity	HOR_Turb	0.07	0.01	0.01	9.05	<0.001
Nutrient.Comp.1	Nut.Comp.1	-0.23	0.04	0.04	5.50	<0.001
Berry Jerry	Berry.Jerry	2.97	0.58	0.60	4.94	<0.001
Euroley Bridge	Euroley.Bridge	3.53	0.62	0.65	5.47	<0.001
Narrandera	Narrandera	4.91	0.86	0.89	5.50	<0.001
River height (m)	Water.level	-2.05	0.39	0.40	5.08	<0.001
Microcrustacea abundance	Zoops	0.14	0.04	0.04	3.69	<0.001

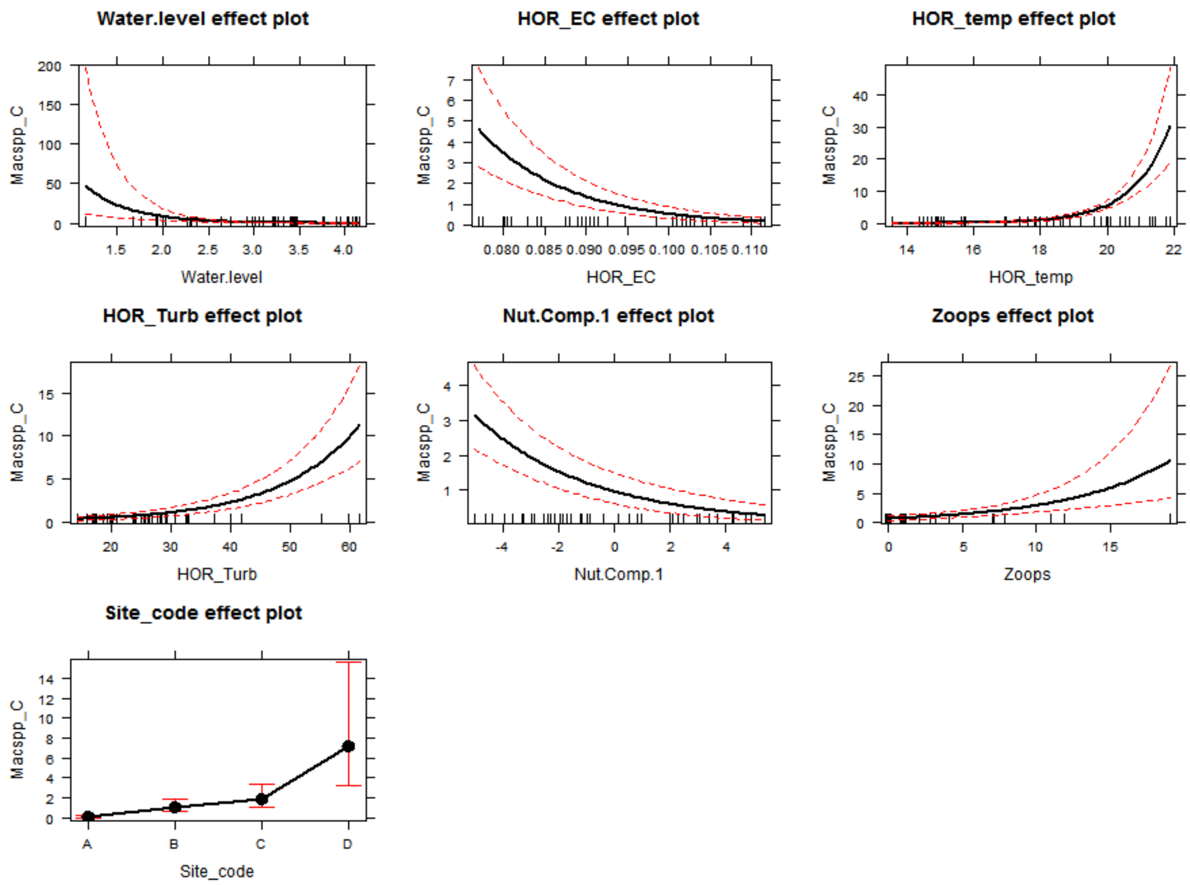


Figure 35 Response of larval cod abundance (black line) to predictors in the generalised linear model; red lines show confidence intervals (see Table 8 for explanation of variables)

11.3 Discussion

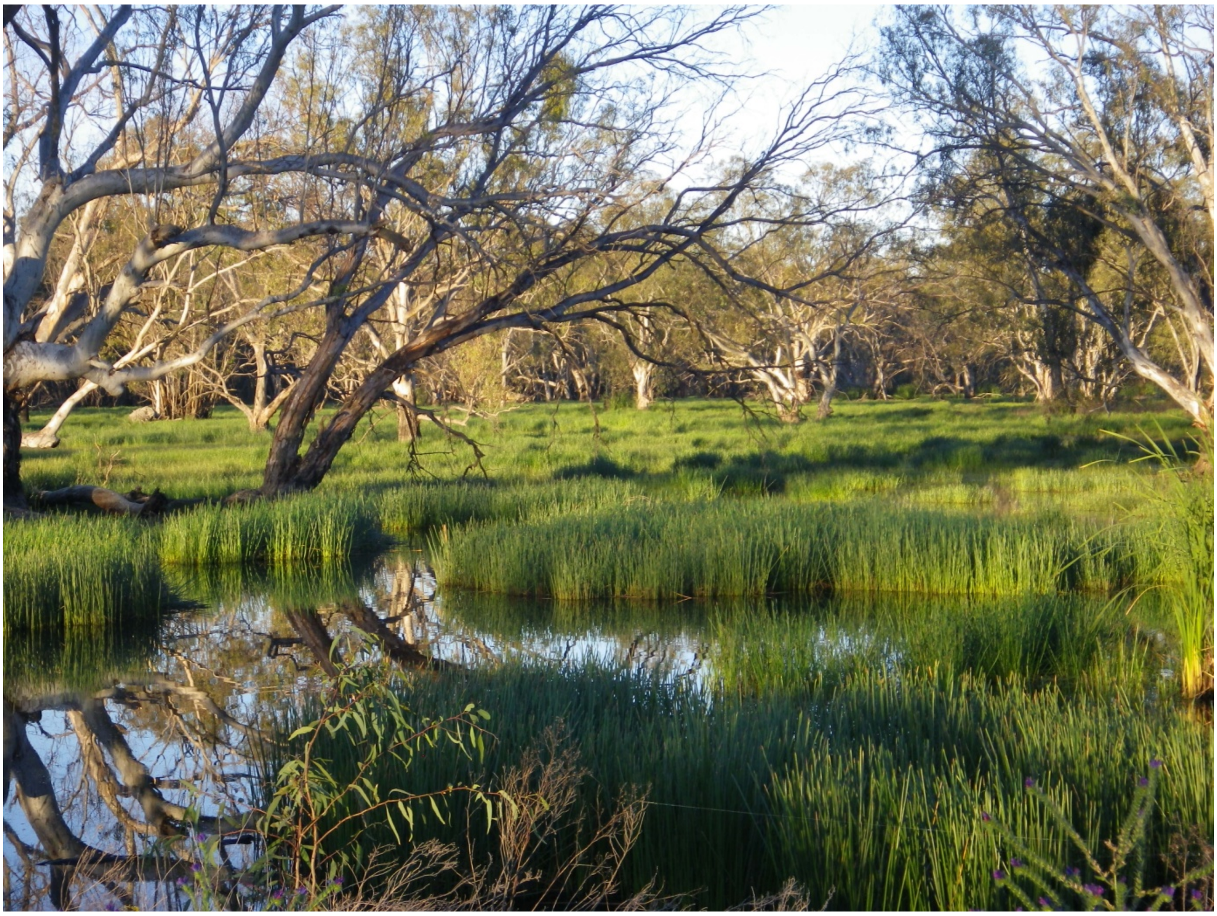
There was a defined period of Murray cod spawning and larval drift in the Murrumbidgee River, with the highest abundances between 12 and 17 November (see Figure 34). This coincided with higher densities of microinvertebrates (zooplankton) between 26 October and 7 December. The detection of a peak larval drift period is in contrast to other studies in which abundances of drifting cod larvae have remained relatively steady throughout the spawning and larval drift season (Humphries 2005). Larval cod drift in Old Man Creek had a similar peak period; however, abundances were much lower than those in the Murrumbidgee River sites (Figure 34). Inter-site variability in drifting larval cod abundances has been found previously (Koehn and Harrington 2006). However, in this study, the highest larval cod abundances coincided with the areas of highest abundances of adult Murray cod captured during fish community sampling, with more than three times as many adult Murray cod captured at Narrandera and Euroley Bridge compared to Berry Jerry (Murrumbidgee River) and Old Man Creek (see section 9). This suggests that the adult cod population may also be an influential factor on the abundance of larval cod encountered within river reaches, as would be expected. In addition to this, significant differences in the relationship between larval cod abundance and environmental co-variates in the Murrumbidgee River and Old Man Creek suggested that a combination of environmental factors, as well as the size of the adult population, are influencing larval drift at each study site.

In the Murrumbidgee River, the peak cod larval drift period occurred within the period of Commonwealth environmental water delivery, and water temperature was positively correlated with larval abundances, suggesting that water temperatures during the period of water delivery were ideal to facilitate spawning in Murray cod. In addition, water temperature has also been known to have a strong effect on development rates of Murray cod larvae (Humphries 2005), and productivity of microinvertebrate communities (Balcombe, Bunn *et al.* 2005). Therefore, increased temperatures during the period of Commonwealth environmental water provided suitable conditions not only for spawning but also for microinvertebrate community growth, making the vital first-food source readily available for newly hatched drifting larvae. This is indicated by the positive relationship between larval cod CPUE and microinvertebrate densities. Conversely, water level had a negative relationship with larval cod abundance, suggesting that larval cod may have been moved downstream from the sampling areas during peak flows (Schludermann, Tritthart *et al.* 2012).

Turbidity levels throughout the period of larval sampling were within the recommended levels for lowland river systems (ANZECC water quality guidelines 2000). The positive relationship found between drifting larval cod abundances and turbidity suggests that higher turbidity levels may have potentially protected larvae from predators during the drift phase, as has been shown previously (Utne-Palm 2002). Although water temperature and microinvertebrate densities were positively correlated with larval cod drift, there were very few young of year Murray cod or trout cod captured after the delivery of the Commonwealth environmental water. This result suggests that while environmental conditions during the Commonwealth environmental flows were suitable for spawning and larval drift, development to young of year stage may not have been as successful as expected. Further annual fish community monitoring will provide information on the recruitment success of yearly cohorts post 2012-Commonwealth environmental water delivery.

Overall, the presence and abundance of drifting cod larvae in the Murrumbidgee River demonstrates that spawning occurred during Commonwealth environmental water delivered in 2012. The positive relationship between larval abundance, water temperature and microinvertebrates indicates that **conditions provided by Commonwealth environmental water delivery were sufficient to enable spawning, leading to the presence of drifting larvae in the Murrumbidgee River**.

Supporting wetland flora and fauna



Mercedes swamp Yanga National park (Lowbidgee) October 2012

In this section we explore the responses of wetland fauna and flora to Commonwealth environmental watering actions. This section covers three key wetland regions; the mid-Murrumbidgee wetlands, the river red gum wetlands of the Lowbidgee floodplain and the Western Lakes. The following Commonwealth environmental watering objectives were assessed.

- Support breeding and recruitment of native fish.
- Maintain health of existing extent of riparian, floodplain and wetland native vegetation communities.
- Provide reproduction and recruitment opportunities for riparian, floodplain and wetland native vegetation communities.
- Support the habitat requirements of waterbirds.
- Support breeding of colonial nesting waterbirds.
- Support breeding and recruitment of other native aquatic species, including frogs, turtles, invertebrates.
- Support habitat requirements of other native aquatic species, including frogs, turtles, invertebrates.

Vegetation

Gooragool Lagoon (mid-Murrumbidgee)

In the past, the wetlands of the mid-Murrumbidgee reconnected with the Murrumbidgee River in all but the driest years. However, decreases in river water levels and the loss of natural freshes due to river regulation has reduced the number of reconnections and many of the wetlands had been dry for over decade. We have been monitoring the recovery of aquatic vegetation communities in 11 wetlands (8 treatment plus 3 control sites) in the mid-Murrumbidgee since they refilled naturally in 2010. Commonwealth environmental water was utilised in 2011-12 with the aim of promoting the recovery of aquatic vegetation communities. **In 2012-13, the key objectives of the Commonwealth environmental watering actions in the Murrumbidgee Catchment with respect to vegetation was to *"maintain health of existing extent of riparian, floodplain and wetland native vegetation communities"***. Wetlands in the mid-Murrumbidgee did not receive Commonwealth environmental water in 2012-13 and the majority of wetlands were dry by early February 2013. Wetlands in the western lakes received environmental water in September 2012, and the recovery of riparian communities and tree conditions is being monitored by Dr Heather McGinness of CSIRO as part of a separate project.

Key findings

- There were significant changes in vegetation community composition over the three water years. This was driven by three major plant functional groups: terrestrial damp species (Tdr) and emergent species (Ate) which both decreased in cover from 2011-12 to 2012-13 and low-growing amphibious fluctuation tolerators (Atl) which increased in cover from 2011-12 to 2012-13
- There was an increase in the percentage cover of terrestrial exotic vegetation species in 2012-13 as the wetlands dried out.

12 Maintain health of existing extent of riparian, floodplain and wetland native vegetation communities

Aquatic and semi-aquatic vegetation is important to wetland and river health, and can help predict the response of aquatic species such as frogs and waterbirds following inundation. The amount of vegetation in a wetland (percent cover) and the types of species present (community composition) can determine the availability of oviposition (egg laying location) sites for macroinvertebrates (Humphries 1996), and calling and spawning locations for frogs (Wassens, Hall *et al.* 2010). Aquatic vegetation also supports wetland nutrient cycling, food webs and zooplankton communities (Warfe and Barmuta 2006).

When a wetland is inundated the change in vegetation communities can be driven by three key mechanisms: 1) growth and flowering of existing vegetation present in the wetland, 2) sprouting from underground rhizomes and 3) germination from seed. Growth of existing vegetation and sprouting from rhizomes allows for a more rapid increase in cover than germination and growth of seedlings (Plate 14).

Extended dry periods can reduce the ability of aquatic vegetation to respond to environmental watering. Most aquatic and semi-aquatic species that occur in semi-permanent wetlands will die back after a few months of being dry, and rhizomes of spike rush *Eleocharis* spp. (a dominant species in wetlands of the Murrumbidgee) will perish after three to four years (Reid and Capon 2011). Depending on the species, seeds of wetland plants can remain viable for between five and 10 years (Brock, Nielsen *et al.* 2003, Tuckett, Merritt *et al.* 2010). This all means that the longer wetlands have remained dry, the slower their recovery can be. In particular, the diversity and percent cover of aquatic and semi-aquatic vegetation after environmental watering is likely to be lower in wetlands that have remained dry the longest.

Long-term environmental watering strategies typically seek to maintain the viability of aquatic vegetation communities by ensuring that viable rhizomes and healthy seed banks are maintained, which is usually achieved through regular watering. However, severe drought conditions in the Murrumbidgee Catchment through 2001-2009 coupled with consumptive water demand meant that it was not possible to maintain the natural inundation frequencies for the mid-Murrumbidgee wetlands. Historically these wetlands would have filled every year but they remained dry or only filled once between 2000 and 2009.

Plate 14 Example of rapid growth of tall spike rush (*Eleocharsis spaculata*) from rhizomes in Yanga national park: Mercedes swamp December 2007 (Top) and Mercedes swamp in January 2008 (Bottom) three weeks after environmental watering.

Since the mid-Murrumbidgee wetlands refilled naturally in 2010, the recovery of aquatic vegetation communities has been very slow. Environmental releases targeting wetlands in the mid-Murrumbidgee region in 2011 were successful in promoting some recovery of aquatic and semi-aquatic vegetation (Wassens, Watts *et al.* 2012). Ideally the mid-Murrumbidgee wetlands would have been targeted again with environmental watering in 2012 to sustain the recovery of aquatic vegetation communities.

12.1 Methods

Monitoring of vegetation follows the methods used previously in the mid-Murrumbidgee by Wassens *et al.* (2012). Vegetation species and their percent cover were assessed at 11 (eight treatment plus three control) wetlands, every two months between August 2012 and April 2013.

During the surveys, vegetation is assessed at three permanently marked 30 m transects containing 30 x 1 m^2 quadrats, which start at the high water line and run towards the centre of the wetland. Within each 1m^2 quadrat, each plant (terrestrial and aquatic) is identified to species where possible and the percentage of the quadrat covered by that species is recorded along with the percentage cover of leaf litter, bare ground and open water. Each species identified was placed into a functional group according to (Brock and Casanova 1997).

The change in the percent cover of each functional group between wetlands and water years was analysed in PRIMER Version 6 using repeated measures analysis of variance on the Euclidean distances between site x wateryears – equivalent to a standard ANOVA but with permutation tests of significance (PERMANOVA) that does not have an assumption of normality as with least squares ANOVA. See Appendix 1 Data analysis for further details).

12.2 Results

Maintenance of vegetation community

The repeated measures analysis of the vegetation data confirmed the pattern of the MDS plots, which showed differences among the survey years (**Figure 36**). Planned contrasts showed that the vegetation communities changed significantly from 2010-11 to 2011-12 (Pseudo-F = 4.4, P (perm) = 0.003) and from 2011-12 to 2012-13 (Pseudo-F = 4.3, P(perm) = 0.002) (see Appendix 3. Vegetation functional groups-repeated measures analysis of variance for full output).

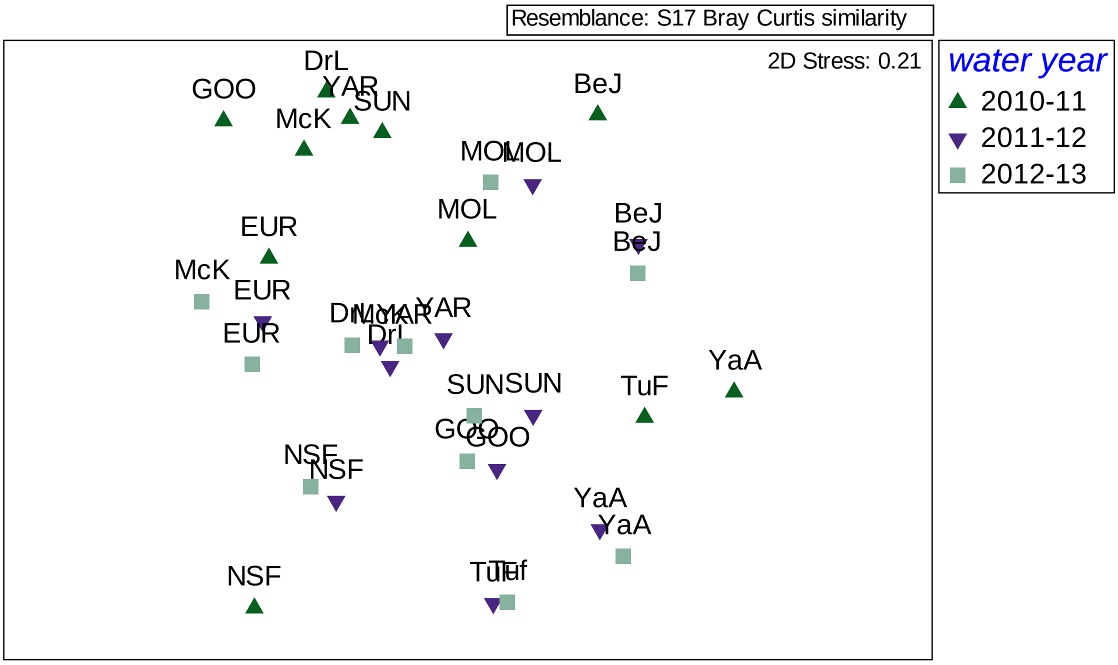


Figure 36 A MDS plot is a way of visualising the similarities between vegetation communities (types of species and their percent cover) in different wetlands and within the same wetland over successive years. The closer the points on the plot are to one another, the more similar their vegetation communities. This MDS plot represents the vegetation communities over the three water years (only wetlands that were monitored across all three water years have been included). Codes relate to wetland names. BeJ (Berry Jerry), MOL (Mollies), DrL (Dry Lake), YaA (Yanco Ag), TuF (Turkey Flat), SUN (Sunshower), GOO (Gooragool,), YAR (Yarrada), McK (McKennas), NSF (Narrandera State Forest).

Three plant functional groups; terrestrial damp species (Tdr) and both emergent (Ate) and low-growing (Atl) amphibious fluctuation tolerators were largely responsible for driving the change in vegetation communities over the three water years. All three groups increased significantly in cover between 2010-11 and 2011-12. Native terrestrial damp species then declined significantly again from 2011-12 to 2012-13, while the emergent and amphibious groups did not change significantly between 2011-12 and 2012-13 (Figure 37).

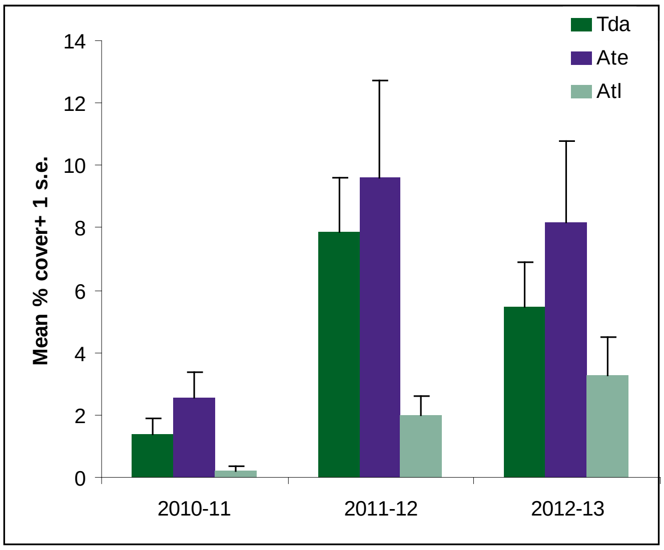


Figure 37 Change in the mean percent cover of native terrestrial damp (Tda), Amphibious fluctuation tolerators emergent (Ate) and Amphibious fluctuation tolerators low growing (Atl) vegetation groups across all wetland sites between 2010-11, 2011-12 and 2012-13 water years.

Native species

Overall, the native vegetation species far exceeded exotic species in both species diversity and percent cover (Figure 38). There was a significant increase in the percent cover of terrestrial vegetation species over the three water years for both native (Tdr) and exotic (Tdr*) species (Pseudo-F = 3.9, P(perm) = 0.0284). There is some indication that vegetation communities in wetlands that had been historically dry for shorter periods, for example, Berry Jerry (BeJ) and Sunshower (SUN), recovered more quickly in response to Commonwealth environmental watering than wetlands that had been historically dry for longer periods such as Mckennas Lagoon (McK).

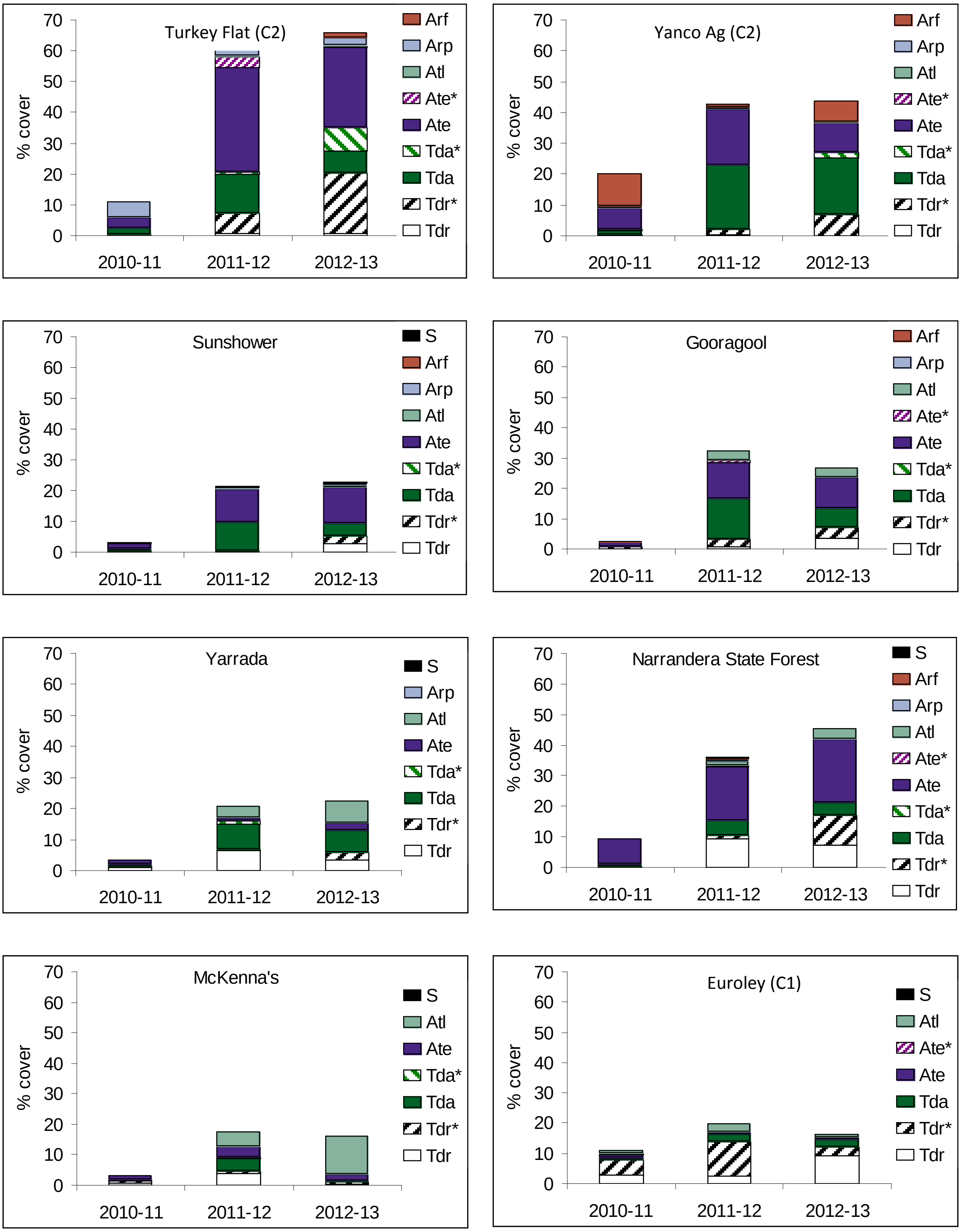


Figure 38 Example of the change in vegetation functional groups over time at key oxbow lagoon wetlands in the Mid-Murrumbidgee. Sites are ordered in relation to the number of years dry before rewetting from most frequently flooded (Turkey Flat C2) to least frequently flooded (Euroley (C1) Control site 1).

12.3 Discussion

The key objective of the Commonwealth environmental watering action with respect to vegetation was to "***maintain health of existing extent of riparian, floodplain and wetland native vegetation communities***". However, capacity constraints within the Murrumbidgee River meant that it was not possible to achieve enough height in the River to reconnect with the mid-Murrumbidgee wetlands, and, as a result, all sites were drying down during 2012-13. Environmental watering in the previous year (2011-12) had benefited vegetation communities in many of the wetlands. However, in 2012-13 there was an increase in terrestrial species while the percent cover of aquatic vegetation species remained stable or declined. The recovery of vegetation communities in the mid-Murrumbidgee wetlands to their pre-drought condition (Plate 15) will require a long-term commitment to Commonwealth environmental watering.

McKennas summer 1999 (Photo James Maguire)

McKennas from the same point - summer 2013

Plate 15 The rate of recovery of aquatic vegetation communities decreases with increasing numbers of years dry: McKenna Lagoon in 1999 and after being refilled for two years in 2012.

Waterbirds

In 2012–13 we undertook ground surveys for waterbirds in the mid-Murrumbidgee and Lowbidgee wetlands to assess waterbird responses in wetlands targeted for environmental watering and to complement long-term aerial waterbird surveys carried out each spring. The results of our ground surveys allowed us to look at differences in total waterbird abundance, species diversity and breeding activity among the different wetlands to assess the health of the wetlands and the status of waterbird populations in the Murrumbidgee Catchment. The key objectives of the Commonwealth environmental water were to **"*Support the habitat requirements of waterbirds and Support breeding of colonial nesting waterbirds*".**

Key findings

- We recorded 48 waterbird species.
- Waterbird abundance and diversity was significantly higher at wetlands which had received Commonwealth environmental water.
- We observed two threatened species (NSW *TSC Act 1995*) and six species listed on one or more migratory bird agreements Australia has with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA) at wetlands that received Commonwealth environmenal water.
- Colonial nesting waterbird breeding was limited because key rookery sites did not receive Commonwealth environmental water in 2012-13. However, twelve species were observed nesting and/or with broods of young.

13 Support the habitats, breeding and recruitment of waterbirds

13.1 Introduction

Waterbirds can provide a useful indicator of the health of wetlands and floodplains, as their populations can be linked to large-scale wetland availability and local-scale wetland condition. We undertook ground surveys for waterbirds in wetlands in the mid-Murrumbidgee, Lowbidgee floodplain and Western Lakes in 2012–13 to assess waterbird species diversity, maximum abundance and breeding activity. These surveys were a continuation of previous monitoring of waterbird populations in the Murrumbidgee Catchment to track waterbird responses to environmental watering and the recovery of wetlands following the 2000 to 2009 drought.

Using waterbirds as an indicator of wetland health can provide a number of advantages, as they are a generally conspicuous group making them relatively easy to measure, and their abundance and diversity can be related to wetland area, the health of wetland vegetation and the abundance of their food resources, e.g. microcrustacea, fish and aquatic vegetation (Kingsford 1999). This means that, generally, wetlands in good condition, which have vegetation in good health and a complex of habitats with varying water depths, tend to support the greatest diversity of waterbird species and highest waterbird abundance (Kingsford and Norman 2002, Kingsford, Porter *et al.* 2012). Waterbird breeding, in particular, can provide a useful index of the effectiveness of wetland management. Colonially-nesting species, such as egrets and ibis, are particularly sensitive to flood duration and require adequately timed flows of sufficient duration, depth and extent to allow birds to pair up, build nests, lay eggs, and raise and fledge their young successfully (Scott 1997, Kingsford and Auld 2005).

A combination of aerial and ground surveys is the preferred approach for monitoring waterbird populations in floodplain wetlands (Baldwin, Nielsen *et al.* 2005). Aerial surveys can be used to determine the distribution of waterbirds and for making a rapid cost-effective assessment of relative abundance (Kingsford 1999, Kingsford and Porter 2011) and to locate breeding colonies. Ground surveys can provide more accurate data on smaller scale abundances, species composition, the presence of threatened and/or cryptic species, and the timing and extent of waterbird breeding events (Baldwin, Nielsen *et al.* 2005).

13.2 Methods

We carried out repeated ground surveys in 11 wetlands in the mid-Murrumbidgee region (**Figure 3**) in August, October and December 2012 (most sites had dried down by December so surveys were not continued into 2013), and 10 wetlands in the Western Lakes region in October and December 2012, and February and May 2013 (see Appendix 4 Waterbird species list and functional groups). Ground surveys were also carried out in 22 wetlands in the Lowbidgee floodplain in October 2012, to include nine sites on private properties in the Nimmie-Caira (five wetlands) and North Redbank (four wetlands) systems, and 13 wetlands in Yanga National Park (**Figure 4**). The October surveys of the Lowbidgee floodplain and Western Lakes were timed to coincide with the Eastern Australian Annual Wetland Bird Aerial Survey conducted by the University of New South Wales (the Lowbidgee region was flown on 18 October 2012). During the ground surveys, waterbirds were counted using binoculars (8 x 30 mm) and/or a telescope (20 – 60X zoom). Replicate ground counts were conducted over two separate days (one morning and one afternoon) within each survey period to estimate maximum waterbird abundance and species diversity in each wetland. Surveys were carried out for a minimum of 20 minutes in each survey site, except where the wetland was dry. Total counts for each waterbird species, any evidence of breeding activity (nesting and/or the presence of young) and water levels were recorded during each survey.

Depending on the type and size of the wetland a point or transect survey method was used to survey waterbirds. The *point survey method* is based on the BirdLife Australia Area Radius Method, whereby all birds observed from one or more survey points within the wetland are recorded. During the survey as much of each wetland as possible was accessed. The *transect method* was used for large or linear waterbodies, whereby species are recorded as a running tally as the observer walks/ drives along the edge of the wetland. Total counts for each waterbird species and any evidence of breeding activity (nesting and/or the presence of young) were recorded during each survey. Waterbird counts were stored in the Atlas of NSW Wildlife maintained by OEH.

An additional aerial survey was undertaken by OEH in November 2012 to search for active waterbird breeding colonies in the Lowbidgee floodplain. Historical waterbird breeding sites in the Redbank, Nimmie-Caira and mid-Murrumbidgee wetlands were also checked during the spring ground survey to locate active nests and assess water levels.

13.3 Results

In total, 48 waterbird species were recorded across the wetlands surveyed in the Murrumbidgee Catchment in 2012–13 (Appendix 4 Waterbird species list and functional groups). Six waterbird species listed on one or more migratory bird agreements Australia has with Japan (JAMBA), China (CAMBA) and the Republic of Korea (ROKAMBA) were recorded. This included three migratory shorebird species which were recorded in the Western Lakes region: red-necked stints (*Calidris ruficollis*), ruddy turnstone (*Arenaria interpres*) and sharp-tailed sandpipers (*Calidris acuminata*). These migratory species were most likely using the Western Lakes as a staging site enroute to non-breeding wetland habitat in southern Australia. Freckled duck (*Stictonetta naevosa*) and blue-billed duck (*Oxyura australis*), which are listed as vulnerable species in NSW (*TSC Act 1995)* were also recorded in the Western Lakes.

Thirty-two waterbird species were recorded in the mid-Murrumbidgee wetlands during repeat ground surveys undertaken from August – December 2012. This included glossy ibis (*Plegadis falcinellus)* and eastern great egret (*Ardea modesta*), which are listed on bilateral migratory bird agreements. Overall, total waterbird abundance was low in the mid-Murrumbidgee wetlands during the 2012 surveys and no wetland habitat was available for most of the summer and autumn 2013 with all sites dry by February 2013.

The Western Lakes had the largest wetland area, and therefore, supported the greatest diversity and abundance of waterbirds during the spring 2012 surveys compared to the other wetland regions (Figure 39). The Western Lakes received environmental water in September 2012. Numbers of waterbirds peaked in the

Western Lakes in December 2012 when nearly 20,000 waterbirds were recorded during the surveys (Figure 40). This large count was dominated by a large total count of black-tailed native-hens (*Gallinula ventralis*) when around 10,000 birds were recorded across multiple sites within the Western Lakes (Appendix 4). Large counts of dabbling ducks, for example grey teal (*Anas gracilis*), Pacific black duck (*Anas superciliosa*) and pink-eared duck (*Malacorhynchus membranaceus*) were also recorded, with this group making up to 40% of total counts for each survey month, excluding the December 2012 survey (Figure 40). Total numbers of fish-eating species, in particular small grebes and whiskered terns (*Chlidonias hybrida*), and small resident waders, black-winged stilts (*Himantopus himantopus)* and red-kneed dotterels (*Erythrogonys cinctus)*, also peaked during the December 2012 surveys. Waterbird numbers declined over summer in the Western Lakes (Figure 40) alongside the drying down of many of the wetlands, including Hobblers Lake, Upper Cherax Swamp, Reed bed, Penarie and Paika creeks.

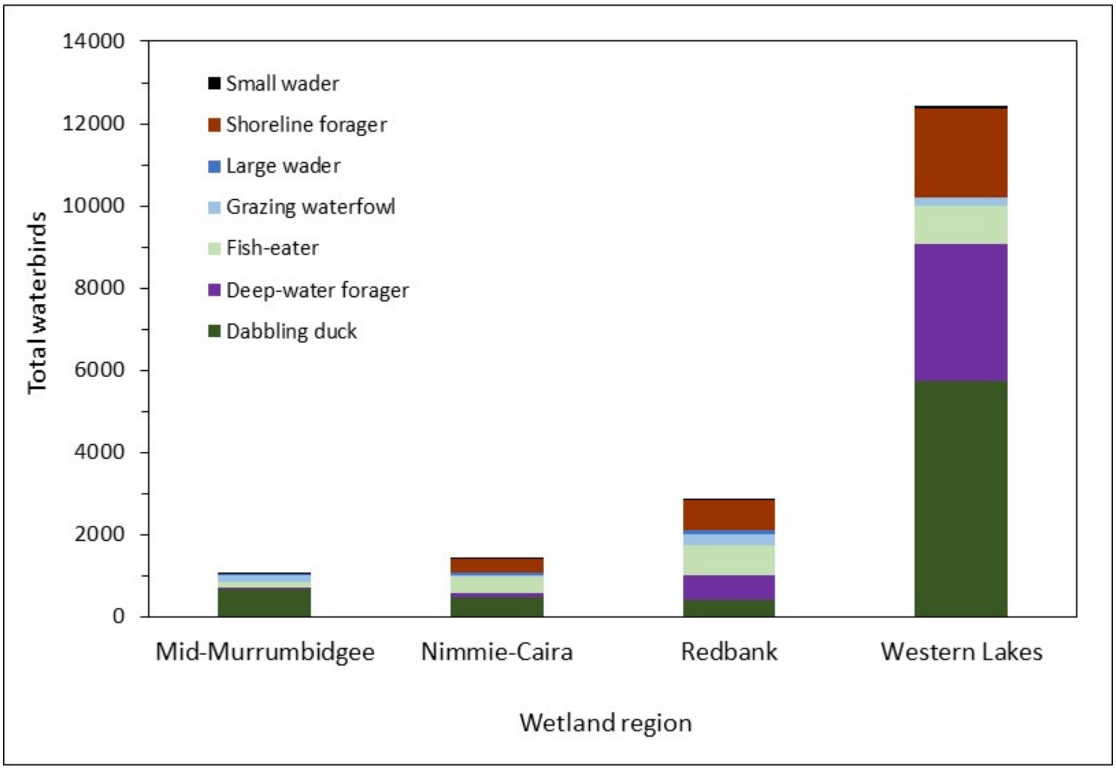


Figure 39 Composition of waterbird communities observed within each wetland region during ground surveys in October 2012.

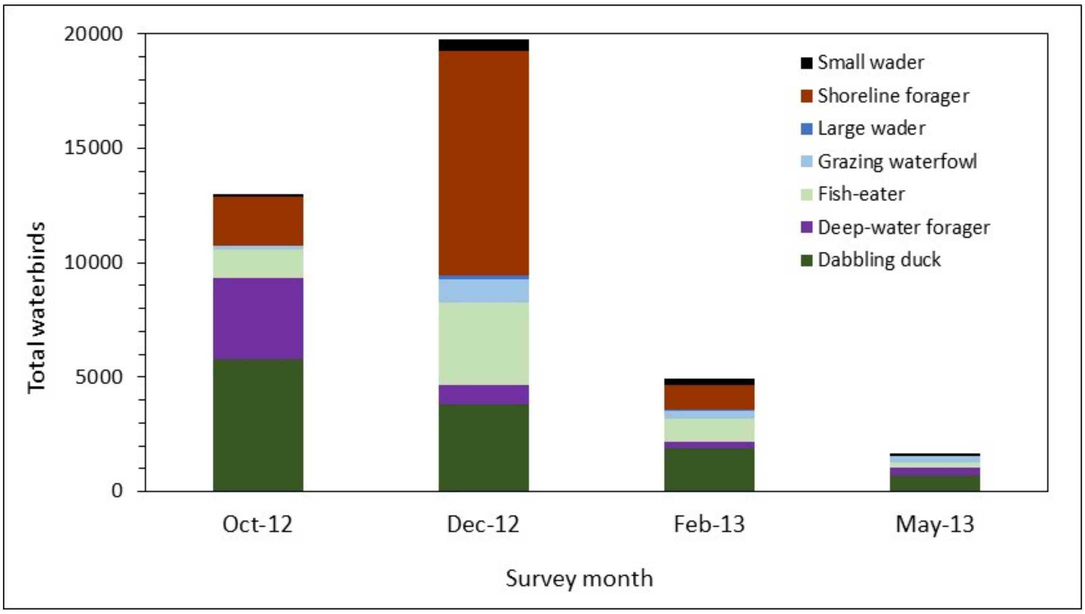


Figure 40 Maximum counts of each of the seven waterbird feeding guilds recorded in the Western Lakes during the 2012-13 surveys**.**

The aerial and ground surveys in spring 2012 indicated that colonial waterbird breeding was limited across the Murrumbidgee Catchment, with only small numbers (< 10 nests) of darters and cormorants detected breeding in Yarrada Lagoon in the mid-Murrumbidgee wetlands (a site that has supported breeding in three consecutive years (2010, 2011 and 2012)), Paika Lake in the Western Lakes region, Tarwille swamp, Wagourah Lake and Top Narockwell in Yanga National Park, and Maude Lagoon in the Nimmie-Caira system. Paika Lake was the only site in the Western Lakes that supported waterbird breeding, with small numbers of nesting little black cormorants (*Phalacrocorax sulcirostris*) and pied cormorants (*Phalacrocorax varius*) observed during the 2012-13 surveys. The largest concentration of nesting colonial waterbirds was observed in Tarwille swamp, in Yanga National Park, where four Australian white ibis (*Threskiornis molucca)*, 84 little pied cormorants (*Microcarbo melanoleucos)* and three yellow-billed spoonbills (*Platalea flavipes)* nested (Rick Webster, NPWS, *pers. obs*). Although no formal surveys were undertaken, glossy ibis also nested in Telephone Bank in the Nimmie-Caira system in 2012–13 (J. Maguire, OEH, *pers. comm.*). There were also multiple pairs of black swans (*Cygnus atratus)* with broods across wetlands in the Redbank system.

13.4 Discussion

Overall, the waterbird monitoring detected a high diversity of waterbird species across the Murrumbidgee Catchment in 2012-13 with very large numbers of waterbirds (> 20,000 birds) recorded in the Western Lakes which received Commonwealth environmental water in 2012. Waterbird breeding activity was limited and waterbird numbers were generally low in wetlands that did not receive environmental watering or natural inflows. Wetlands that have historically provided breeding habitat for colonially-nesting species were not inundated to the extent required to initiate breeding in spring and summer months. However, colonial waterbird breeding events do not typically occur every year, rather they are normally associated with large-scale natural flooding, as seen in 2010-11 where six wetlands in the Lowbidgee floodplain supported significant numbers (ranging from hundreds to many thousands) of nesting waterbirds (Brandis, Ryall *et al.* 2011, Spencer, Thomas *et al.* 2011).

Frogs

Recently metamorphosed Perons tree frog (*Litoria peronii*) from the mid-Murrumbidgee wetlands

Three key responses were examined with respect to frog populations and communities: **(1) the presence of adult frogs,** which is an indicator of long-term ecological outcomes of Commonwealth environmental watering actions and is influenced by recruitment into the population between water years as well as immigration, **(2) calling activity**, which is used as a measure of the behavioural response related to the initiation of breeding by individuals present in the wetland, and **(3) tadpole abundance**, which is an indicator of the success of breeding attempts within the wetland. The Commonwealth environmental watering objectives related to frogs were ***"Support habitat requirements of other native aquatic species, including frogs, turtles, invertebrates"*** and ***"Support breeding and recruitment of other native aquatic species, including frogs, turtles, invertebrates"***.

The key outcomes:

- Six frog species, including the vulnerable southern bell frog (*Litoria raniformis*) were recorded.
- Breeding activity (the presence of tadpoles and juvenile frogs (metamorphs)) was recorded in four of the six species.
- Breeding activity, as measured by the number of tadpoles, differed significantly among wetland regions with areas receiving either Commonwealth environmental water (Western Lakes) or natural overbank flows (Lowbidgee) supporting higher numbers of tadpoles than the mid-Murrumbidgee wetlands, which did not receive inflows.

14 Supporting, habitat, breeding and recruitment of other native aquatic species: Frogs

14.1 Introduction

Frogs are important components of floodplain wetlands and their tadpoles can make up a signifincant proportion of aquatic biomass. The response of frog communities to environmental watering actions can be influenced by the timing and size of the flow, the characteristics of the wetlands, particular vegetation cover, and the past wetting and drying regimes, which can determine the size and composition of the resident frog community. Wetlands that have been dry for extended periods can have small or non-existent resident frog communities, and, in these cases, the frog response can be influenced by the rate of immigration. In this study we considered three key frog responses, as follows.

1. The presence and relative abundance of adult frogs, which is an indicator of long-term ecological outcomes of environmental water actions and is influenced by recruitment into the population between water years, population persistence and immigration.

2. Calling activity, which is a behavioural response and is a good indicator of the initiation of breeding by individuals present in the wetland

3. Tadpole abundance, which is an indicator of the success of breeding attempts within the wetland.

Frogs and tadpoles were surveyed on five occasions between August 2012 and April 2013, in wetlands through the mid-Murrumbidgee, Lowbidgee and Western Lakes. The three regions have vastly different flooding histories, habitat characteristics and were subject to different flow regimes in 2012-13. Only one region, the Western lakes received Commonwealth environmental water in September 2012, while Lowbidgee received natural overbank flows in August 2012, and the mid-Murrumbidgee wetlands did not receive any inflows and were drying out. As the three different wetland regions were subject to differing flow regimes we expected that the number of adults, calling activity and tadpole communities, would differ among the three regions and over the 2012-13 water year.

14.2 Methods

The diversity and abundance of frog species occurring through the Murrumbidgee along with their calling activity were estimated for a 20 minute period in each wetland during each survey period (August, October, December 2012, February and April 2013). In the mid-Murrumbidgee, surveys of frog calling have been conducted since November 2010 (Wassens and Amos 2011) while surveys of the Lowbidgee have been conducted as part of this monitoring project since August 2012 with past surveys occurring from 2008-2011 see (Spencer, Thomas *et al.* 2011). The Western Lakes survey sites did not receive water until September 2012 and as a result these wetlands were only surveyed on four occasions in 2012-13 (October, December 2012, February and April 2013).

As frogs are most active at night, we use a small spotlight to search for frogs after dark. Two teams of surveyors walked slowly along the edge of the wetland searching for frogs in the water, along the water's edge and also those foraging or moving in terrestrial habitats immediately next to the wetland (Wassens, Watts *et al.* 2011, Wassens, Watts *et al.* 2012). Surveys were timed with each team surveying for 20 minutes (giving 40 minutes search time in total) and the number of frogs of each species that are observed or heard during this period are recorded.

Recruitment

Tadpoles were monitored in 12 wetlands spread over the three wetland regions (mid-Murrumbidgee, Lowbidgee and Western Lakes) in association with wetland fish surveys (see section 9). Four wetlands were surveyed in each of the survey regions: McKenna's, Yarrada, Sunshower and Euroley lagoons (mid-Murrumbidgee) (see Figure 3 and Figure 4), Piggery Lake, Two bridges Swamp, Mercedes Swamp and Waugorah Lagoon (Lowbidgee), and Paika Lake, Hobblers Lake, Cherax Swamp and Penarie Creek (Western Lakes).

The wetlands were selected for monitoring on the basis of the representativeness (how similar they are) to other wetlands in each region, the likelihood of them receiving environmental flows or if they are suitable control sites (not likely to receive environmental water). As fish and tadpole abundances can change over time, surveys were conducted every two months, from August through to April.

Four different methods were used to capture tadpoles and fish: sweep netting, bait traps, and fyke netting (large and small). Sweep netting involves using a large D-bottom net which is swept rapidly around the edge of the wetland in fringing vegetation and can give a general indication of the presence of tadpoles. Bait traps and fyke nets, which have been shown to have a high probability of detection for tadpoles (Wassens, Watts *et al.* 2011) were also used. Five bait traps (dimensions 25 x 10 cm, 2 mm mesh) were set overnight at each site. Four small (2 x 2 m wings, 2 mm mesh) larval fyke nets were left overnight (for about 12 hours) at each site. Large fyke nets (10 x 5 m wings, 5 mm mesh) were also set overnight where wetlands were of a suitable depth (>80 cm) to target large-bodied fish.

Tadpoles were identified to species, or in the case of spotted marsh frog (*Limnodynastes tasmaniensis*) and barking marsh frog (*L. fletcheri*) tadpoles which are indistinguishable, grouped into a complex (*Limnodynastes* sp). The development stage of tadpoles was estimated for a subset of 50 individuals per net.

At the same survey sites, recruitment of juvenile frogs was estimated by recording the body length (referred to as snout-to-vent length) of a subset of 20 *spotted marsh frog* and *barking marsh frog*s to give an indication of the age structure of the population, with the presence of very small frogs indicating successful metamorphosis. These measurements were only taken on the two most common frog species as they are present at all wetlands in the monitoring project (allowing for comparisons among wetlands) and these species are abundant enough to ensure that we can collect enough individuals to allow for statistical analysis of differences among sites.

14.3 Results

Overall, 7264 individuals of six frog species, the plains froglet (*Crinia parinsignifera*), barking marsh frog (*Limnodynastes fletcheri*), spotted marsh frog (*Limnodynastes tasmaniensis*), inland banjo frog (*Limnodynastes interioris*), Peron's tree frog (*Litoria peronii*) and southern bell frog (*Litoria raniformis*) were recorded between August 2012 and April 2013 (Plate 16). Four of the six species occurred in all three regions (the mid-Murrumbidgee, Lowbidgee and Western Lakes) while the inland banjo frog was only recorded in mid-Murrumbidgee and Lowbidgee and the southern bell frog was only recorded at one wetland (Piggery Lake) in the Lowbidgee (Figure 41).

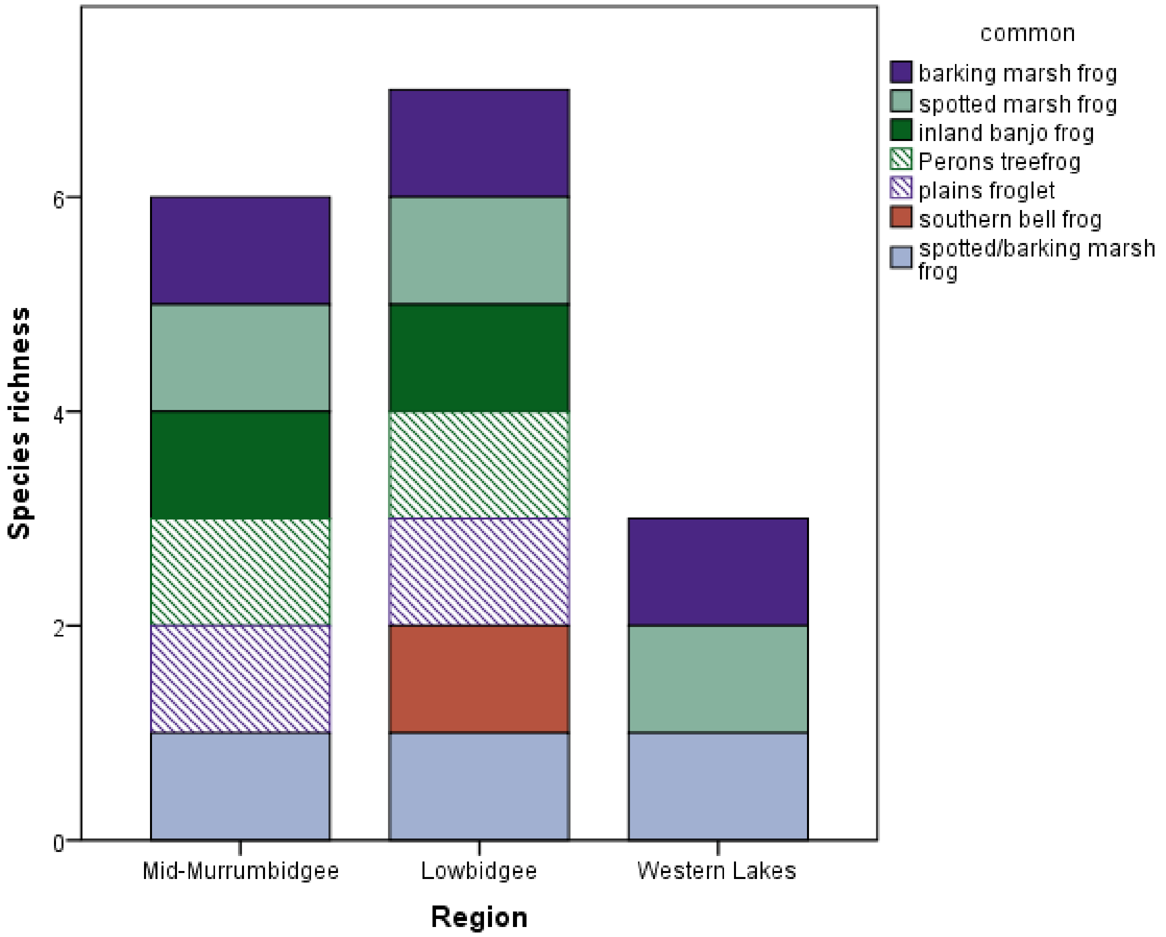


Figure 41 Composition of frog communities within the three survey regions

barking marsh frog (*Limnodynastes fletcheri*) Widespread and common

spotted marsh frog (*Limnodynastes tasmaniensis*) Widespread and common

inland banjo frog (*Limnodynastes interioris*) Restricted range, locally common

plains froglet (*Crinia parinsignifera*) Widespread and common

southern bell frog (*Litoria raniformis*) Rare Vulnerable (EPBC Act 1999)

Perons tree frog (*Litoria peronii*) Widespread and common

Plate 16 Important frog species recorded during the 2013-13 monitoring in the mid and lower Murrumbidgee wetlands

Calling and breeding activity

As three regions were subject to differing flow regimes, with the Lowbidgee receiving overbank flows in August 2012, the Western Lakes receiving Commonwealth environmental water in September 2012 and the mid-Murrumbidgee wetlands receiving no inflows through the 2012-13 water year, we expected that breeding responses measured by the number of calling individuals and tadpoles, would differ among the three regions (mid-Murrumbidgee, Lowbidgee and Western Lakes) and over time (August 2012 to April 2013). Overall, the number of individuals of each species changed between August and April, and there were differences in the number of adults, calling individuals and tadpoles in each region (Figure 42). In particular, calling activity and tadpoles was highest in the Lowbidgee.

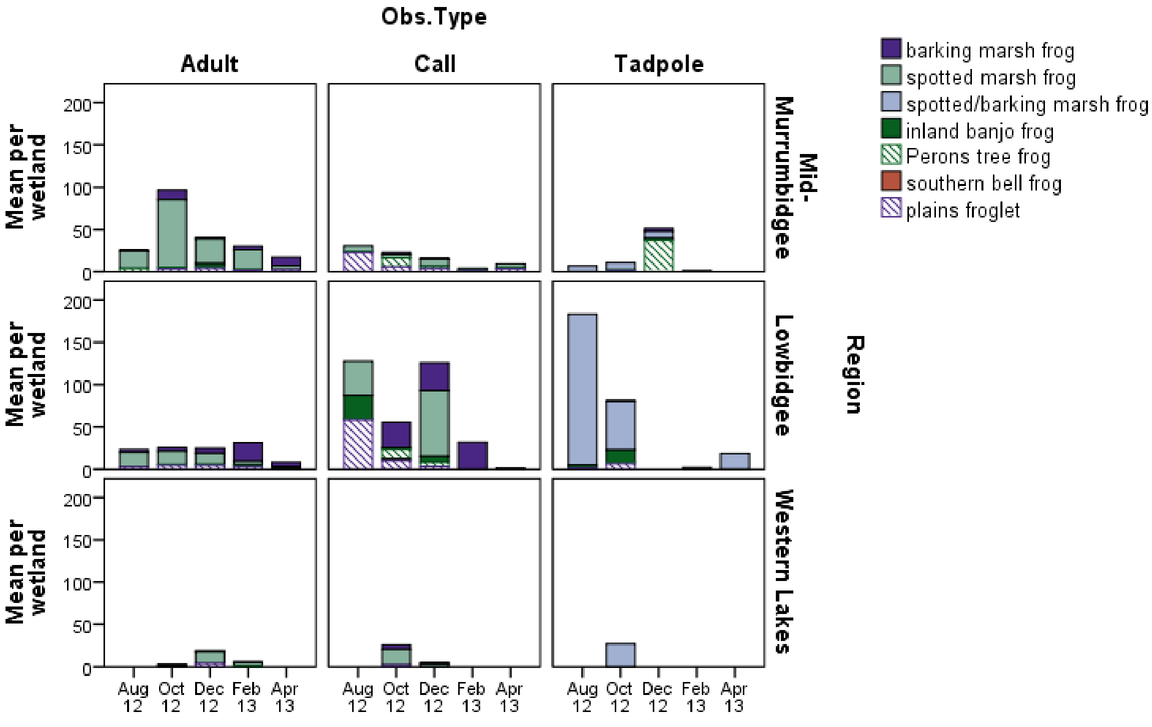


Figure 42 Summary of adult observations, calling activity and tadpole abundances within the three survey regions between August 2012 and April 2013

In order to identify the range of responses that occurred before, during and after watering it is useful to break down these responses into the number of adults, calling individuals and tadpoles for each species. We can then employ generalised linear models to test whether any observed differences are statistically significant. Looking at Figure 43, we can see that calling by inland banjos was limited to August in sites in the Lowbidgee (coinciding with overbank flows into occupied wetlands) (GLM time x location, W 5.243, $p = 0.022$), and inland banjo frog tadpoles were present in the Lowbidgee wetlands in October and December (see Figure 43) but there were not sufficient numbers of individuals to conduct statistical comparisons between regions or survey periods. The plains froglet also called during August in both the Lowbidgee and the mid-Murrumbidgee wetlands. However, the number of calling individuals were significantly higher in the Lowbidgee sites compared to the mid-Murrumbidgee sites (W 86.946, $p <0.001$). Similar numbers of the Perons tree frog called in October in both the mid-Murrumbidgee and the Lowbidgee wetlands (W 0.622, $p = 0.430$), suggesting that calling activity by resident individuals may not have been closely linked to wetland region or inflows.

Looking at Figure 44, the spotted marsh frog and barking marsh frog and their tadpoles occurred across all three wetland regions. There was little difference in the number of adults present in the Lowbidgee and mid-Murrumbidgee wetlands, but few individuals were recorded in the Western Lakes. Despite the similarities in the number of adults present, there was limited calling activity by the barking marsh frog in the mid-Murrumbidgee sites, compared to the Lowbidgee sites (*L. fletcheri*) (7.091, $p = 0.029$) and there were no differences in spotted marsh frog (*L. tasmaniensis*) activity between the wetland regions (W 2.986, $p = 0.225$).

Tadpole abundance was highly variable between wetlands within each region, and, as a result, while the average number of tadpoles was higher in the Lowbidgee than the mid-Murrumbidgee or Western Lakes (Figure 44), the differences between wetland regions were not significant (W 0.560, $p = 0.756$). However, there was a significant interaction between the region and the percent cover of aquatic vegetation, suggesting that breeding outcomes may have been influenced by vegetation cover within individual wetlands (W 21.211, $p < 0.001$).

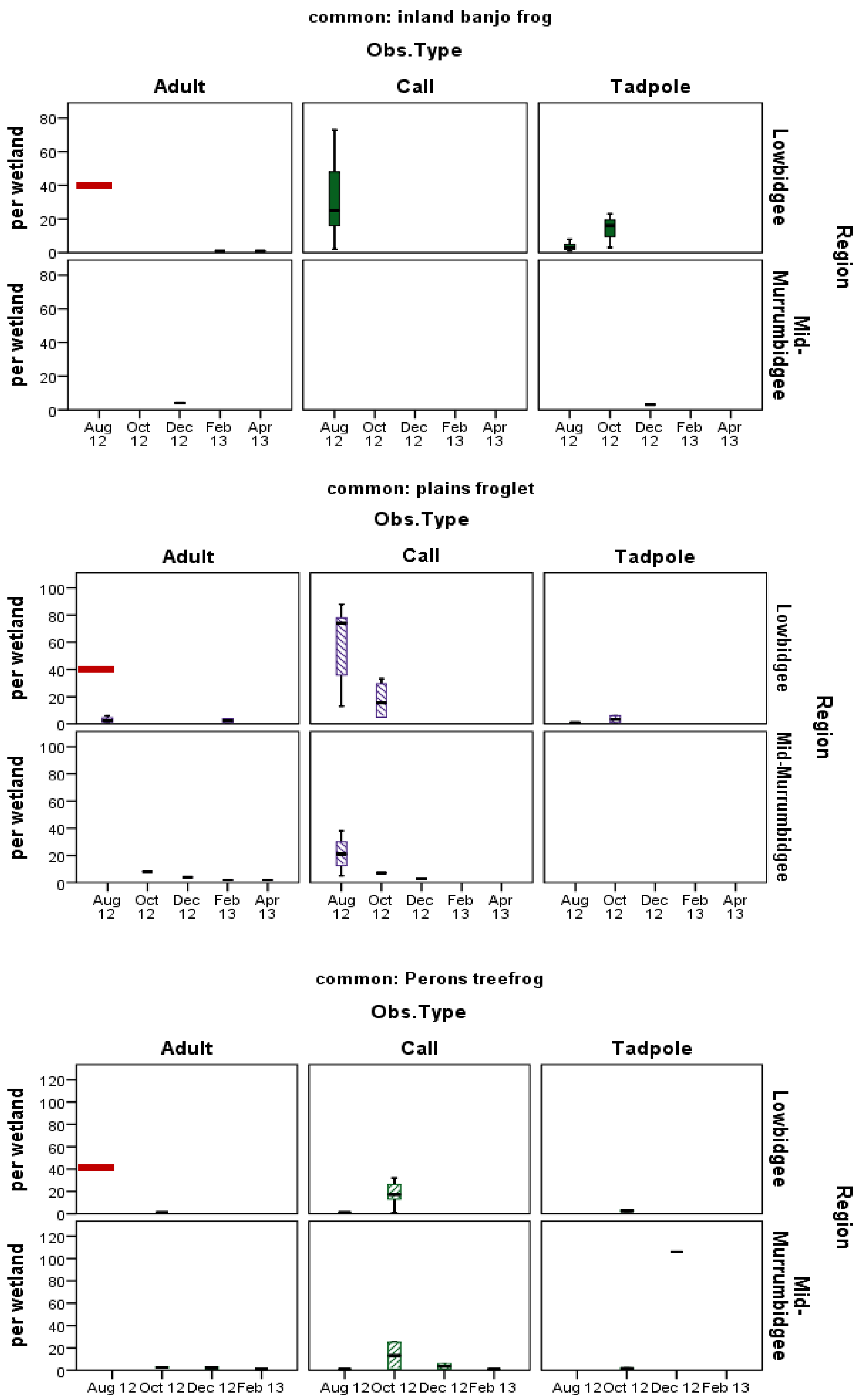


Figure 43 Number of adults, calling activity and tadpoles for the Inland banjo frog, plains froglet and Perons tree frog in each region (note that Western lakes has been excluded because no individuals of these species were recorded)(red line indicates inflow period)

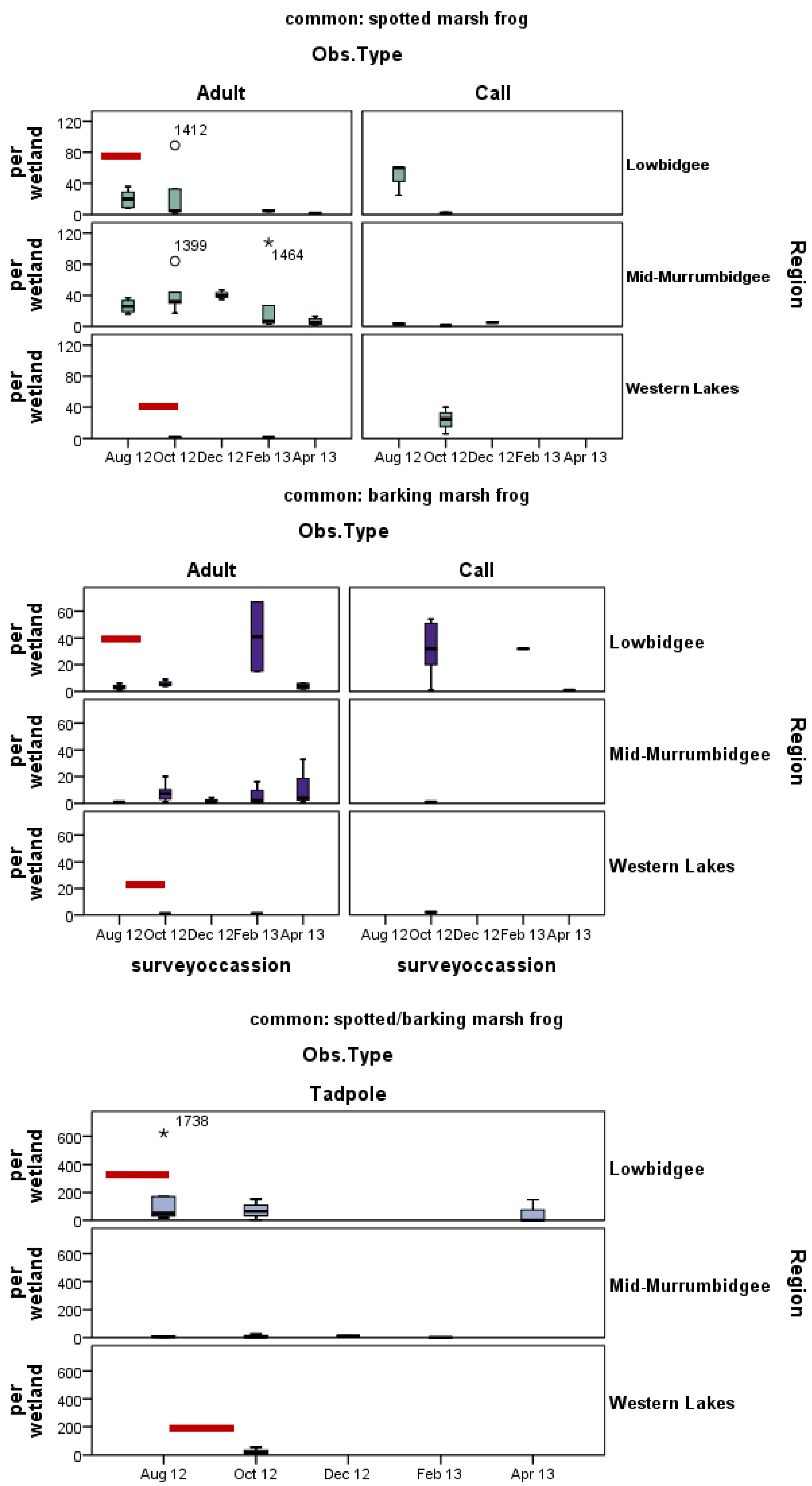


Figure 44 Summary of the number of adults, calling activity and tadpoles for the spotted marsh frog and barking marsh frog and their tadpoles in each region (red line indicates inflow period).

14.4 Discussion

Frogs were monitored in three different wetland regions in the Murrumbidgee Catchment that were each subject to a different flow regime. Overall, the two regions that received inflows in 2012 (either naturally due to overbank flows in the Lowbidgee or as part of the Commonwealth environmental watering actions in the Western Lakes) had significantly higher levels of calling activity and higher tadpole abundances than the mid-Murrumbidgee wetlands that did not receive any inflows.

Some parts of the Western Lakes (Cherax, Hobblers and Penarie creek), which was the focus of the Commonwealth environmental watering actions in 2012, had been dry for an extended period of time (in some instances more than 80 years). The Western Lakes had a very small population of adult frogs present when the watering commenced in September 2012 and given the length of time that some sites had been dry it is most likely that individuals present in these wetlands had immigrated into the wetlands from surrounding areas as they filled. Given the very small number of adult frogs present, surprisingly high numbers of spotted and barking marsh frog tadpoles were recorded. This suggests that the Commonwealth environmental water did produce conditions suitable to support breeding and recruitment by resident frogs in the Western Lakes. The presence of carp screens is also likely to have contributed to successful recruitment outcomes for frogs in the Western Lakes.

Turtles

We assessed the distribution, abundance and age structure of freshwater turtles in the mid-Murrumbidgee wetlands using large fyke nets set during August, October and December 2012. We used information collected during these surveys to assess the responses of freshwater turtles to environmental watering and natural flooding in the previous water year (2011-12) and to identify important breeding and refuge habitats in the mid-Murrumbidgee wetlands to guide priorities for environmental watering in future years. The Commonwealth environmental watering objectives related to turtles were ***"Support habitat requirements of other native aquatic species, including frogs, turtles, invertebrates"*** and ***"Support breeding and recruitment of other native aquatic species, including frogs, turtles, invertebrates"***.

Key findings

- We recorded three freshwater turtle species across the five survey wetlands in the mid-Murrumbidgee: the Macquarie River turtle *Emydura macquarii macquarii*, broad-shelled turtle *Chelodina expansa* and eastern long-necked turtle *Chelodina longicollis* (Plate 17).
- The broad-shelled turtle, which is considered to be declining through the Murray Darling basin, was recorded at two sites in the Mid-Murrumbidgee, Euroley and Yarrada Lagoons, adjacent to the Murrumbidgee River.
- Hatchlings of the Macquarie River turtle were detected in three of the five wetlands sampled in the mid-Murrumbidgee (Yarrada, Sunshower and McKennas lagoons) and hatchling Eastern long-necked turtles were detected breeding in McKennas lagoon.

15 Supporting habitat, breeding and recruitment of other native aquatic species: Freshwater turtles

15.1 Introduction

Freshwater turtles depend on wetland and riverine ecosystems to live and reproduce. They are particularly vulnerable to the effects of river regulation, as they are long-lived animals with delayed sexual maturity and generally low reproductive success (Rizkalla and Swihart 2006). Reduced flooding frequency and flooding extent is thought to negatively impact the survival of adult turtles and their young (Chessman 2011).

Three key turtle species occur in the Murrumbidgee Catchment: the broad-shelled turtle (*Chelodina expansa*, listed as threatened in Victoria and considered to be near threatened in NSW), the eastern long-necked turtle (*Chelodina longicollis*) and the Macquarie River turtle (*Emydura macquarii*) (**Plate 17**). While all three species occur within the main river channel, wetlands are particularly important as feeding and nursery habitats for turtles (Chessman 1988, Chessman 2011). In general, the distribution of freshwater turtles is determined by distance from the main river channel or permanent waterbodies. However, floodwaters can facilitate the movement of highly mobile species such as the eastern long-necked turtle between permanent refugia and temporary wetland habitats, which can have abundant food resources (Chessman 2011).

15.2 Methods

Turtle populations were sampled using large fyke nets, which are set during the wetland fish and tadpole surveys of the mid-Murrumbidgee wetlands only. The large fyke nets were set up so that turtles are able to access the water surface and, therefore, are not harmed while held in traps. Water levels were only sufficient in the mid-Murrumbidgee wetlands for large fyke nets to be used during the August, October and December 2012 surveys. As excluder grids were used on the small fyke nets deployed in the Lowbidgee wetlands, we were not able to assess turtle populations in the Lowbidgee wetlands in 2012-13.

On retrieval of the nets, turtles were identified to species as per (Chessman 1988) and the length and width of each turtle's shell was measured to the nearest mm, before each turtle was released back into the wetland. By collecting information on size distributions of turtles, turtle age, whether turtle populations are breeding and levels of recruitment into local populations can all be estimated. The presence of adults alone suggests a lack of successful recruitment of young turtles in recent years, which makes a population vulnerable to local extinction.

15.3 Results

We caught all three turtle species known to occur in the Murrumbidgee Catchment in the mid-Murrumbidgee wetlands during the 2012-13 surveys: the broad shelled-turtle, the eastern long-neck turtle and the Macquarie River turtle (Plate 17). The broad-shelled turtle was absent from the mid-Murrumbidgee wetlands during previous surveys in 2011-12 (Wassens, Watts *et al.* 2012). The 2012-13 surveys indicated that this species had colonised Euroley and Yarrada lagoons, sites located adjacent to the Murrumbidgee River.

Macquarie River turtle (Juvenile)

Broad-shelled turtle

Eastern long-necked turtle

Plate 17 Freshwater turtles recorded during surveys of the mid-Murrumbidgee wetlands in 2012-13.

Almost twice as many turtles were caught in 2012-13 (16 turtles) compared to the 2011-12 (nine turtles) surveys (Figure 45). In total, eight turtles were caught during the October 2012 surveys and eight turtles during the December 2012 surveys. All three species were absent during surveys of the wetlands in August 2012 when water temperatures were low and at a time of year when turtles are generally less active. Turtles were most abundant at Euroley lagoon where six turtles (2 broad-shelled turtles and four long-necked turtles) were caught in December 2012. No turtles were caught in Gooragool Lagoon during the 2012-13 surveys).

Based on information collected on size structure there was evidence of breeding in Macquarie River turtles in three of the five wetlands sampled (Yarrada, Sunshower and McKennas lagoons) in 2012-13. We recorded small numbers of recently hatched Macquarie River turtles in both the 2011-12 (seven turtles) and 2012-13 (four turtles) surveys (Figure 46). No adult Macquarie River turtles were caught during the 2012-13 surveys. Eastern long-necked turtles were detected breeding in McKennas lagoon only, where a new hatchling (carapace 55 mm in length) was recorded in the December 2012 surveys.

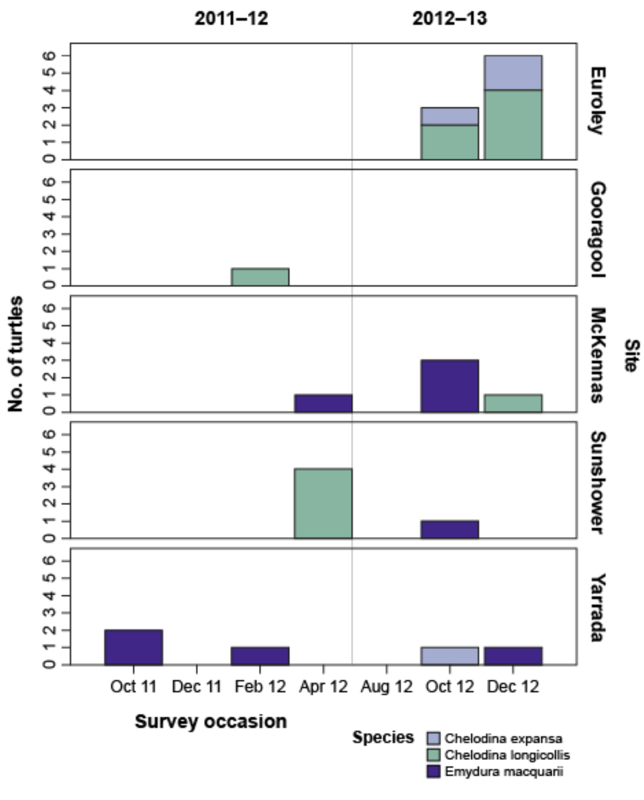


Figure 45 Distribution of turtle species caught in the five wetlands sampled in the mid-Murrumbigdee wetlands in 2011-12 and 2012-13.

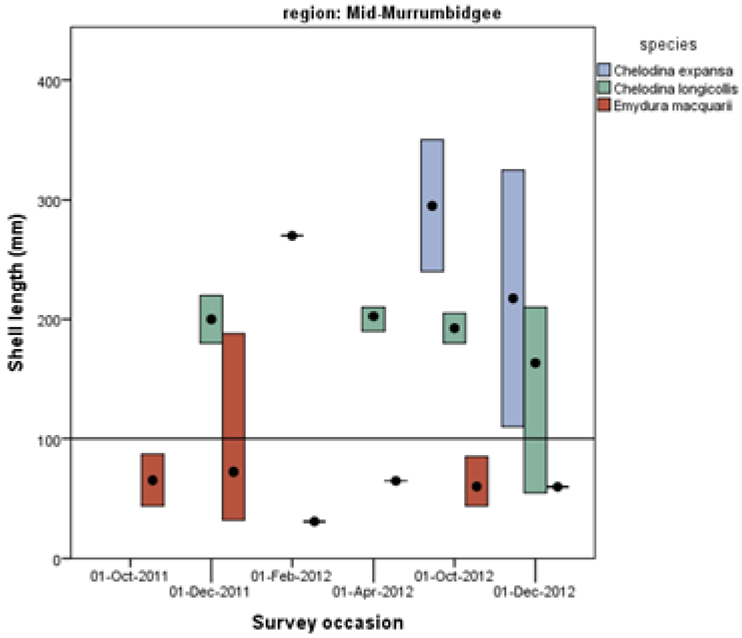


Figure 46 Population size structure of three turtle species caught in the mid-Murrumbidgee wetlands in 2011-12 and 2012-13. Note that *C. expansa* were caught in the 2012-13 surveys only.

15.4 Discussion

Although the total number of turtles caught during the survey was low, the 2012-13 surveys indicated that freshwater turtles had expanded their range across the mid-Murrumbidgee wetlands colonising sites that had received Commonwealth environmental water and natural floodwaters in 2011-12. Environmental water delivered to the wetlands in 2011 allowed turtles to colonise wetlands close to the river channel, namely Euroley and Yarrada lagoons. Following widespread natural flooding in March 2012, long-necked turtles and Macquarie River turtles were able to move further up the floodplain into wetlands such as McKennas lagoon and breed in these sites in spring 2012. Future environmental watering actions should target the reconnection of the mid-Murrumbidgee wetlands to support further turtle breeding and allow for the movement of juvenile turtles back to more permanent habitats.

16 Synthesis ecological responses to Commonwealth environmental water in wetlands

We employed a monitoring framework that included ecosystem components that were expected to respond to Commonwealth environmental flows over a range of spatial and temporal scales. Wetland ecosystems are complex, and their response to Commonwealth environmental watering actions can be facilitated or in some cases hindered by a range of parameters present in the wetland. For example, while water is the overriding influence on wetland ecosystems, a strong response by microinvertebrates following the delivery of Commonwealth environmental water can facilitate native fish recruitment.

In previous sections we considered the responses of individual taxonomic groups and ecosystem processes to environmental watering. In this section, we draw together these individual responses in wetlands to quantify the contribution of Commonwealth environmental watering actions in achieving watering objectives related to wetlands (Option 5). In this section, we consider three hydrological parameters:

- the number of days above the commence to fill levels for each region,
- the cumulative number of days that the wetlands received water from 1 July 2012 (the start of the 2012-13 water year), and
- the number of years the wetland has received some water in the past decade.

We also consider water quality and vegetation parameters, and densities of predators and food availability. Conceptual models for three key measured responses (frog breeding, small bodied native fish and microcrustacea) were constructed prior to the development of statistical models. A conceptual model is simply a visual representation of how we understand the ecological processes are interacting to influence a specific ecosystem response, given our knowledge of the system (which is based on past data from the system and other published studies).

Supporting breeding and recruitment of other native aquatic species, including frogs, turtles and invertebrates

To identify the importance of flow on native species breeding and recruitment, we developed a conceptual model to describe the interaction between flow, predator densities, vegetation and water quality parameters needed to influence breeding outcomes in the spotted and barking marsh frogs (*Limnodynastes* spp.), measured in terms of total abundance of their tadpoles (Figure 47).

Overall, the number of days over the commence to fill levels in the wetlands in the 30 days prior to sampling (High-flow.days.30d) had a positive effect on frog breeding (i.e. the total number of tadpoles) (effect size z =12.1), that is there were more tadpoles on average at wetlands that had received water for a larger number of days than at wetlands that did not receive water or that received water for a few days only. While the number of years that the wetland had been dry in the previous decade has a negative effect on frog breeding, i.e. the longer the wetland had been dry the smaller the frog breeding response (effect size z = -9.5).

Interestingly, the number of adult frogs did not affect the recruitment outcomes, and a large number of adult frogs present in a wetland did not guarantee a strong breeding response. This finding was most likely driven by wetlands in the mid-Murrumbidgee region where a large adult population was produced following the 2011-12 Commonwealth environmental watering actions (see Wassens et al 2012 for details). These adults were unable to breed in 2012-13, because the wetlands did not receive any Commonwealth environmental water. While introduced gambusia are often listed a key tadpole predator they had no effect on tadpole abundance in the wetlands, and numbers of native predatory carp gudgeon had a weak positive association with tadpole abundance.

The key message that can be drawn from this model is that, at least in the short term, wetlands that have been dry for extended periods prior to receiving Commonwealth environmental water can be expected to have lower frog recruitment levels than wetlands that have been targeted with environmental water for longer more frequent periods. With this in mind, it is still clear that the **Commonwealth environmental watering in 2012-13 made a significant contribution to achieving the objective of *Supporting breeding and recruitment of other native aquatic species (frogs).*** This was achieved both by maintaining important habitat variables for frog breeding, such as aquatic vegetation, and by providing flow conditions suitable for breeding and the survival of tadpoles. The positive impact of Commonwealth environmental watering on wetland fauna is likely to increase over time as natural wetting and drying patterns are restored.

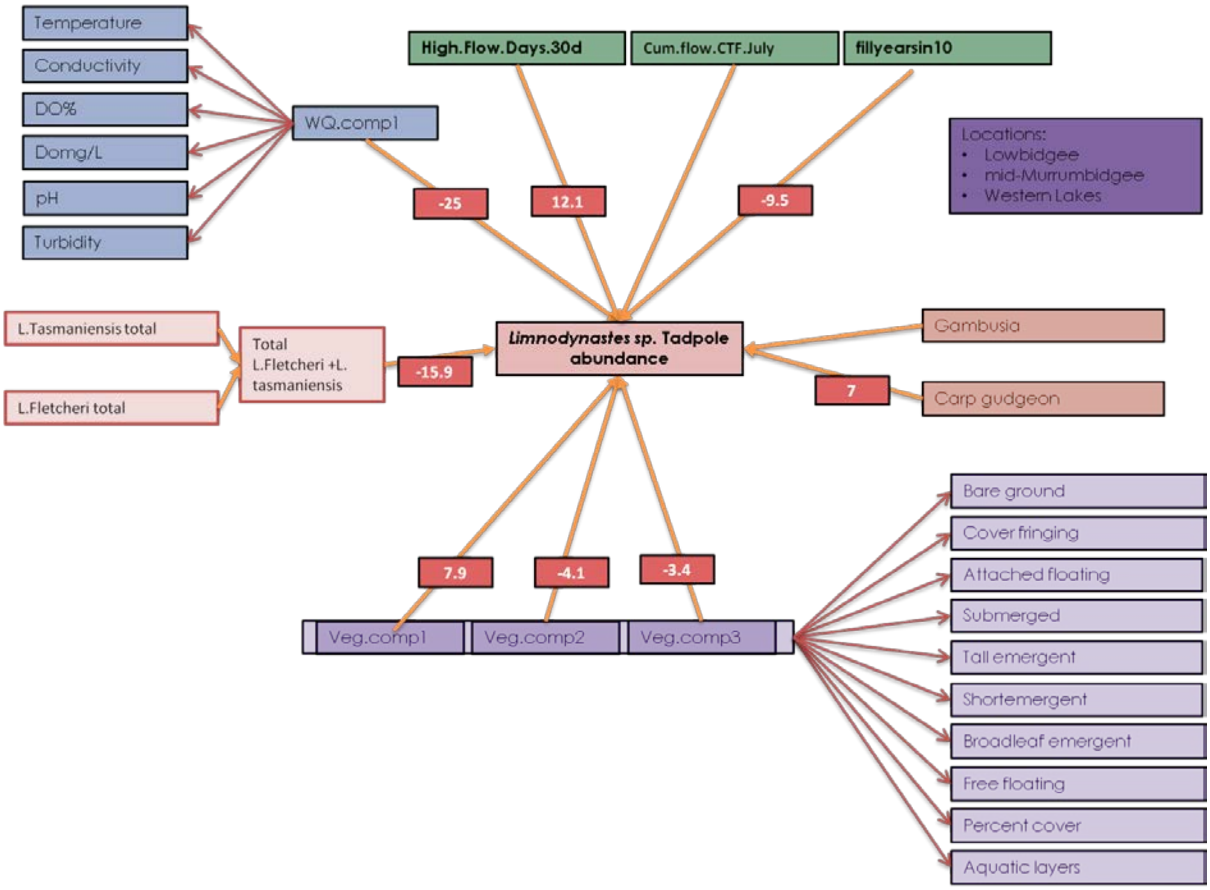


Figure 47 Conceptual model with effect sizes (number inside brick coloured boxes) for barking/spotted marsh frog breeding in wetlands through the Murrumbidgee. Positive effect sizes indicate a positive relationship between the response variable and the explanatory variable(s) while negative numbers indicate a negative relationship. The magnitude of the effect size represents the strength of the relationships.

Plate 18 Recently metamorphosed barking marsh frog; this species is sensitive to prolonged dry periods and requires inflows into wetlands to trigger breeding.

Supporting habitat requirements for fish-Microcrustacea

Microcrustacea are a critical food source for larval fish and play an important role in wetland food chains. The conceptual model developed for microcrustacea was similar in many respects to the model developed for frog breeding, with components related to flow, water quality and vegetation parameters, and gambusia densities. We expected all these variables to interact to influence the densities of key microcrustacean taxa; copepods, cladocerans and ostracods (Figure 48).

The total density of microcrustacea increased with the increasing number of days that the wetland had received water over the 30 days prior to sampling (effect size z = 3), and dramatically decreased with increasing number of years that the wetland had been dry in the previous decade (effect size z = -14.8). Although gambusia diet includes microcrustaceans, in this study they had a positive effect on the density of microcrustaceans (effect size z = 12.9). Declining water quality as wetlands dried had a strong negative effect on density of microcrustaceans (effect size z = -16.6).

Some of the key messages that can be drawn from the microcrustacean model are similar to those for breeding frogs; firstly, that flows in the 30 days prior to sampling promote higher densities of microcrustaceans; and, secondly, that, at least in the short term, wetlands that have been dry for extended periods prior to receiving Commonwealth environmental water can be expected to have lower densities of microcrustaceans than wetlands that have been targeted with environmental water for longer periods. The response of microcrustaceans to declining water quality as wetlands dry highlights the need to manage the timing of drying when fish and other fauna are relying on microcrustaceans for food. The **Commonwealth environmental watering in 2012-13 made a significant contribution to achieving the objective of *Supporting breeding and recruitment of other native aquatic species (invertebrates)*** by inundating productive and regularly flooded wetlands, while also restoring flows to habitats that had remained dry for many decades. This should have helped to restore the egg bank in the lake system, which contributes unique biodiversity to the Murrumbidgee system. In these systems, the positive impact of Commonwealth environmental watering on wetland fauna is likely to increase over time as natural wetting and drying patterns are restored and egg banks recover.

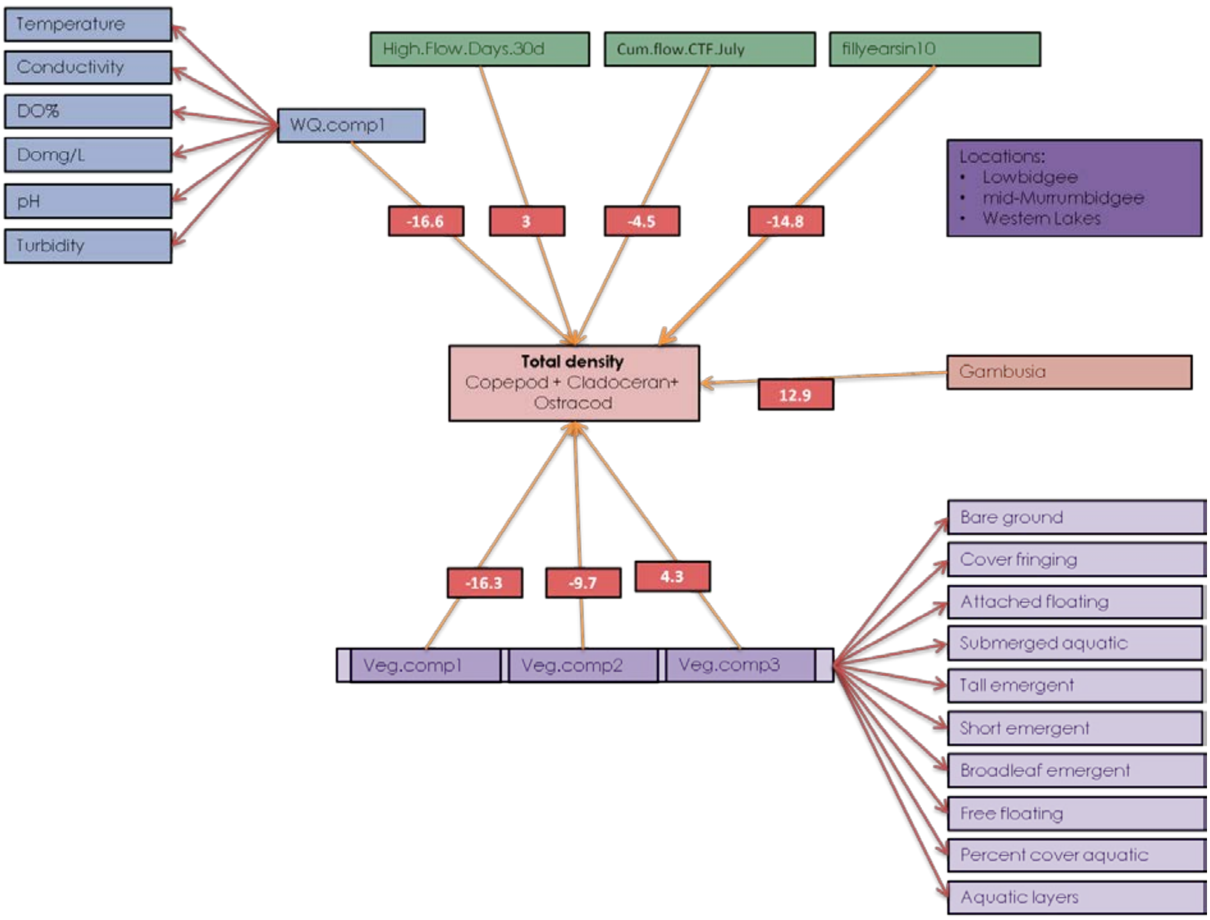


Figure 48 Conceptual model with effect sizes (numbers inside the brick coloured boxes) for total microcrustacean in wetlands through the Murrumbidgee. Positive effect sizes indicate a positive relationship between the response variable and the explanatory variable(s), while negative effect sizes indicate a negative relationship, the magnitude of the effect sizes represents the strength of the relationships.

Supporting breeding and recruitment by native fish (wetlands)

Water is a critical factor for fish and the Commonwealth environmental watering actions which filled the Western Lakes facilitated significant recruitment of native carp gudgeon. It is however interesting to consider how the flow parameters that were important for frogs and microcrustacea affect this common and widespread native fish (Figure 49). Considering the conceptual model there is a clear positive relationship between the abundance of carp gudgeon and food availability (total density of microcrustacea) and microcrustacea size. Carp gudgeon consume a range of microinvertebrates, (Balcombe and Humphries 2006) and can actively structure microcrustacea communities through selective predation with some microcrustacea taxa such as *Copepod nauplii* increasing in abundance in the presence of carp gudgeon (Nielsen, Hillman *et al.* 2000).

Unlike tadpoles and microcrustacea, which increased in abundance with increasing connection to the river, carp gudgeon abundances actually decreased with increasing connection (e.g high flow days in 30 effect size z = -100 and cumulative flow from July 12 effect size z = -25.2) and increased with increasing number of years dry. As seen in section 2, carp gudgeon quickly colonised the Western Lakes and thrived in an environment that was largely free of competition or predation by other native and introduced fish. Similar booms in productivity of carp gudgeon have been recorded elsewhere e.g (Puckridge, Walker *et al.* 2000). The colonisation and recruitment of carp gudgeon demonstrates a short-term positive outcome from Commonwealth environmental water delivery.

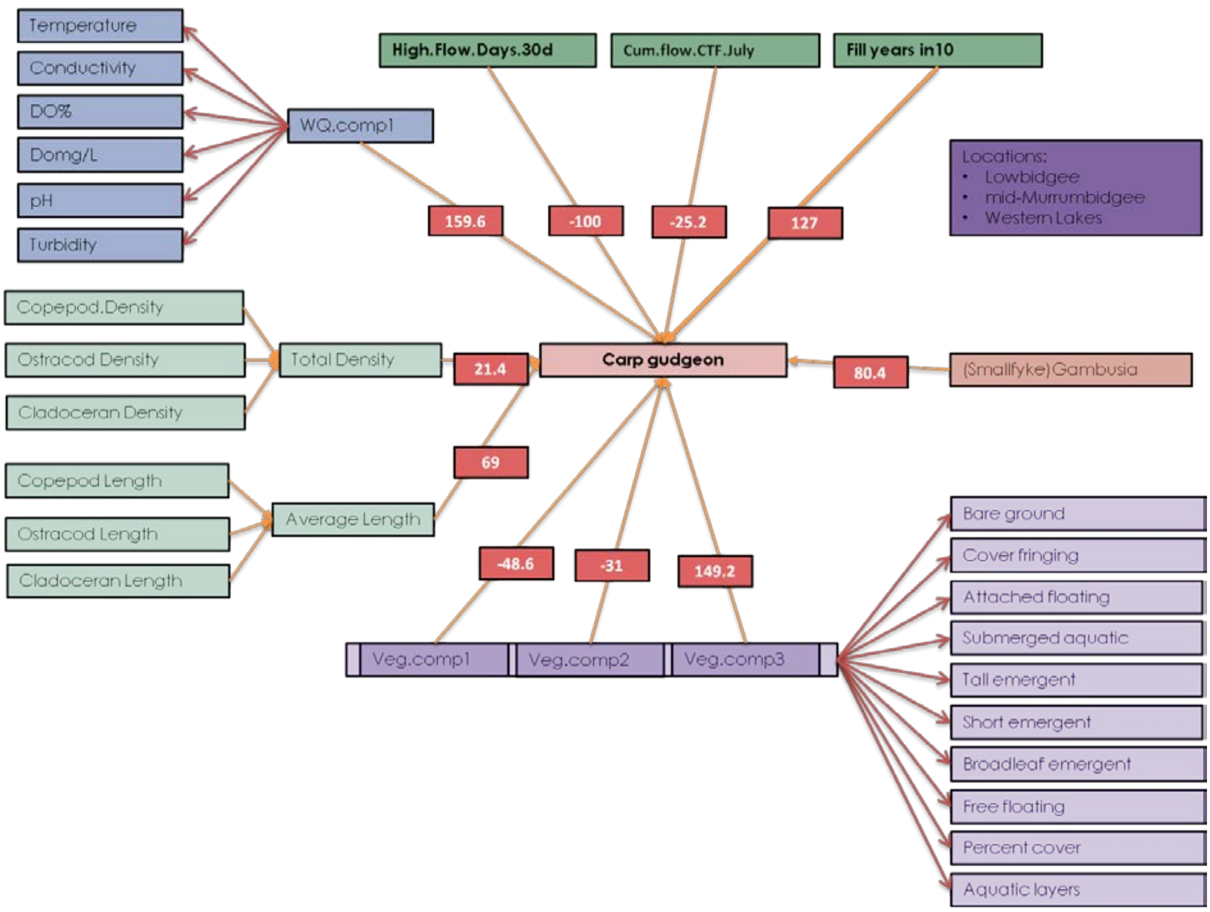


Figure 49 Conceptual model with effect sizes (brick coloured boxes) for carp gudgeon in wetlands through the Murrumbidgee. Positive numbers indicate a positive relationship between the response variable and the parameter while negative numbers indicate a negative relationship, the size of the number represents the strength of the relationships.

Supporting breeding and recruitment by native fish (Rivers)

To identify the importance of flow on breeding and recruitment by native fish in the Murrumbidgee River we developed a conceptual model to help describe the combined effects of flow, water level, nutrients, and water quality parameters needed to influence breeding outcomes in cod larvae (*Maccullochella* spp.), measured in terms of catch per unit effort in drift nets (**Figure 47**). In addition to these ecological parameters, the model also included our control site at Old Man Creek (no Commonwealth environmental flow) versus the treatment sites in the Murrumbidgee River (which received Commonwealth environmental flow) (Figure 47).

Significantly higher abundances were observed at the river sites, Berry Jerry (effect size z = 4.95), Narrandera (effect size z = 5.50), and Euroley (effect size z = 5.74), all of which received environmental water, compared to Old Man Creek, which did not receive environmental water. Water quality measures had the strongest effect on cod larvae. Two water quality parameters showed a strong positive relationship with the abundance of larvae; turbidity (effect size z = 9.05), and temperature (effect size z = 8.11). Microcrustacean total density also had a positive effect on abundance of cod larvae (effect size z = 3.69). Dissolved oxygen concentrations did not contribute to explaining observed variation in recruitment outcomes and were therefore excluded from the final model. This was likely a combined effect of both a strong negative correlation with water temperature (r = -0.83) which resulted in model co-linearity and due to oxygen levels in the river remaining relatively stable throughout the environmental watering event. Similarly, discharge was excluded from the final model which was correlated with water levels (r = -0.85), which had a negative effect on abundance of larvae.

The key findings that are drawn from this model is that, at least in the short term, river sites that receive Commonwealth environmental water can be expected to have higher cod spawning levels compared with sites such as Old Man Creek that were not targeted with environmental water. The **Commonwealth environmental watering in 2012-13 made a significant contribution to achieving the objective of *supporting breeding in native fish.*** This was achieved both by maintaining important water levels, water quality conditions and nutrient levels that supported microcrustacean densities required for larval survival. The positive impact of Commonwealth environmental watering on fish spawning is likely to increase over time as connectivity between the river and wetlands are restored, providing further boosts in productivity within the river and providing access for some species to wetland nursery habitats.

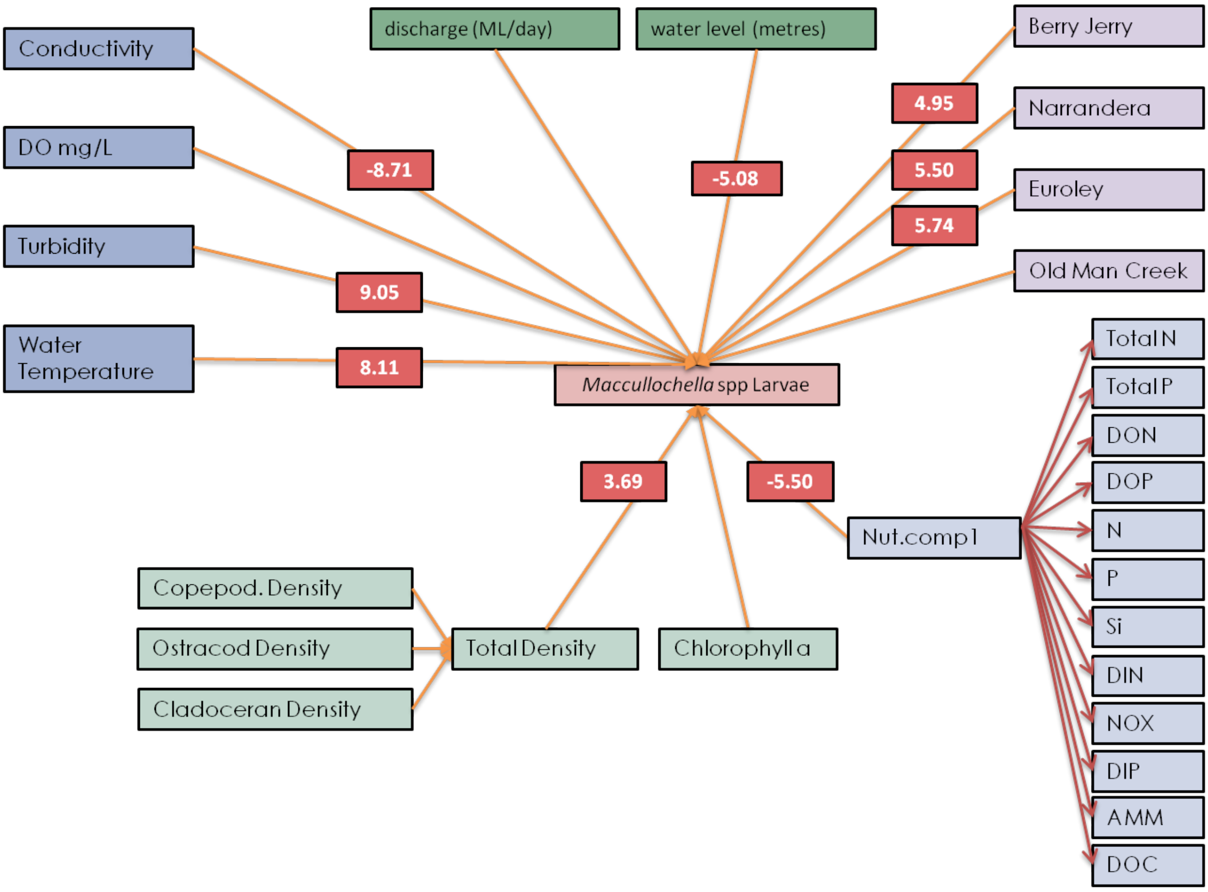


Figure 45 Conceptual model with effect sizes (numbers in brick coloured boxes) for larval cod (*Maccullochella* spp.) in the Murrumbidgee River. Positive effect sizes indicate a positive relationship between the response variable and the explanatory variable(s) while negative effect sizes indicate a negative relationship; the magnitudes of the effect sizes indicate the relative strengths of the relationships.

17 Conclusions

To conclude, two Commonwealth environmental watering actions were assessed. In the Murrumbidgee River, the watering actions coincided with a peak in native fish movement and spawning activity. Models developed to describe the relative importance of ecological parameters including flow, identified water temperature, turbidity and microcrustacea abundance as key predictors of larval abundance. As these models were developed using data drawn from a single watering action it is difficult to make definitive conclusions on the success of the water management strategy which focused on maintaining stable, slightly elevated water levels with the view of increasing the availability of nest sites. Monitoring activities through 2013-14 and beyond will allow us to refine water management strategies to optimise the positive benefits of Commonwealth environmental water outcomes for native fish.

The second watering action targeted the Western Lakes. These wetlands had been dry for an extended period of time prior to refilling with Commonwealth environmental water. Overall, the Western Lakes were a productive environment for microcrustaceans, small bodied native fish and waterbirds. Breeding activity by floodplain fauna such as frogs was limited because these taxa have a strong preference for areas that are more frequently inundated and have a higher percentage cover of aquatic vegetation.

Implications for future environmental watering in the Murrumbidgee river system

Two key Commonwealth environmental watering actions were undertaken in the Murrumbidgee river system in 2012-13, 1) in-channel fresh flows from October to December 2012, targeting native large bodied fish, and 2) watering action targeted the Western Lakes system west of the Lowbidgee floodplain.

With respect to in-channel fresh flows, the timing of environmental water delivery coincided with known breeding season of the target species (Murray cod) and triggered movement patterns that were consistent with known spawning behaviours. There were also clear changes in fish community composition before and after the environmental release associated with large scale movement of fish throughout the middle reaches of the Murrumbidgee River. The key assumption underpinning the Commonwealth environmental release was that a substantial rise in water level would increase the availability of nest locations for Murray cod leading to increased breeding activity and larval abundance. However we did not identify a clear, direct relationship between river height or discharge and larval abundance. While nest availability for Murray cod is important, differences in larval abundances between monitoring locations may indicate that other factors, such as adult abundance and channel morphology played a stronger role than discharge or river height. Given this, it may be possible to achieve similar spawning outcomes using smaller volumes of water provided that water levels are stable during the breeding period so that nests are not exposed.

The second watering action targeted the Western Lakes and other wetlands across the Lowbidgee floodplain. Overall the positive outcomes of Commonwealth environmental watering varied between different wetland areas, for example the Western Lakes provided important habitat for waterbirds and contained significantly higher diversity and abundance of waterbirds than other wetlands in Murrumbidgee which in comparison were drying down over 2012-13. River red gum spike rush wetlands adjacent to the Western Lakes were also important in supporting frog breeding and recruitment. In this respect Commonwealth environmental watering actions that support a diversity of wetland types and aquatic communities can help to maximise biodiversity outcomes across the region.

18 Acknowledgements

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Appendix 1 Data analysis

PERMANOVA and analysis of similarities (ANOSIM)

Trends across time were explored graphically with wetlands grouped by geographic region. Permanova (Anderson 2001) was used to test differences among wetland regions, microhabitat and time for 11 dependent variables; taxon richness, cladoceran richness, both density and length of total microcrustaceans, copepods, cladocerans and ostracods, community composition and cladoceran community composition. Pair wise comparisons were done for the significant main effects using PERMANOVA (Anderson 2001). The taxa that characterised each factor (i.e. region, microhabitat and time) were identified using SIMPER (Similarity Percentages, Clarke and Warwick 2001). For the community composition analysis a species matrix of the entire microcrustacean and cladoceran assemblages at regions and microhabitats across time were examined using non -metric -dimensional scaling (NMDS) computed with PRIMER (Clarke and Warwick 2001) on a Bray - Curtis simila of log transformed data. We focused our analysis of taxonomic and community patterns on both the overall species list and also the cladoceran taxa which accounted for 14 of the 18 taxa identified.

Fish community data was analysed using Plymouth Routines in Multivariate Ecological Research (PRIMER). Analyses were performed on both fish abundance and biomass data for sites sampled on the Murrumbidgee River to determine changes before and after the delivery of Commonwealth environmental water. Wetland fish communities were analysed to detect changes in abundance over time using data collected during five sampling occasions (August-October-December-February-April) as well as across wetland regions (mid-Murrumbidgee, Lowbidgee and Western Lakes).

Visual representations of fish abundance and biomass were captured using Principal Components Analysis. Eigenvalues were calculated for a pre-specified five principal components which were used to plot fish community contributions in 2-dimensional space. A vector analysis was used to demonstrate how species contributed to any observed groupings. Statistical differences in Bray-Curtis transformed fish abundances and biomass data were investigated using two-way crossed Analysis of

Similarities (ANOSIM) using region (upper, middle and lower Murrumbidgee River and Old Man Creek) and sampling period (before or after) as factors. A total of 999 Monte Carlo Randomisations were used to calculate probabilities. Similarity Percentages (SIMPER) analysis was used to determine the contribution of individual species to any significant differences identified by ANOSIM. All tests were considered significant at probability values less than 0.05.

Length-frequency distributions of fish species with high abundances were analysed using a Kolmogorov-Smirnov goodness of fit test to determine whether there were significantly larger or smaller individuals (length) among sampling trips (as an indicator of potential recruitment). Tests were considered significant at probability values less than 0.01.

Change point analysis

The approach to fitting a Bayesian Poisson change point model generates a sample from the posterior distribution of a Poisson regression model with multiple change points using the Markov chain Monte Carlo method of Chib (1998). We then compared the models based on the Bayes factors, the ratio of marginal likelihoods, enabling us to identify the most likely number of states observed in Mac-CPUE. A Bayes factor value > 1 means that model is more strongly supported by the data under consideration than an alternative model. We also present the posterior state probabilities indicating the significant shifts in Mac-CPUE.

Generalised linear regression

We reduced the number of nutrient, chlorophyll, water quality and vegetation indices by analysing the number of factors to retain as a principal component by examining the Kaiser-Guttman rule, the parallel analysis, and Scree Test. The Kaiser-Guttman rule states that the number of factors is equal to the number of eigenvalues greater than 1. This is because each of those factors will 1) account for at least as much variance as one of the original variables, and 2) have a positive value for coefficient alpha. The Scree Test is used by drawing a line graph to show the relationship between the number of the factor (on the x-axis) and the value of the eigenvalue (on the y-axis). The acceleration factor (AF) corresponds to a numerical solution to the elbow of the scree plot while the optimal coordinates (OC) corresponds to an extrapolation of the preceding eigenvalue by a regression line between the eigenvalue coordinates and the last eigenvalue coordinates. We carried out this analysis using the nFactors package (Raiche, 2010) available within R software(R Development Core Team, 2012).

Explicitly our Generalised Linear Model has the properties of :

1. Distribution: $MacCPUE_i \sim Poisson(\lambda_i)$

2. Link function: log, i.e., $\log(\lambda_i) = \log(E(\log(MacCPUE_i)) = linear\, predictor$

3. Linear predictor: $L\log(\lambda_i) = \beta 1 * Turbidity + \beta 2 * temp + \beta 3 * Nut.Comp.1 + \beta 4 * Water.level + \beta 5 * EC + \beta 6 * Discharge + \beta 7 * pH + \beta 8 * Chla.Comp.1 + \beta 9 * Zoops + Site + \alpha.$

Our approach was to examine all possible combination using all possible predictor combinations. We then followed a model selection process examining model performance using the second-order Akaike Information Criterion (AICc) (Burnham and Anderson 2002). AICc (second order information criterion) takes into account sample size by increasing the relative penalty for model complexity with small data sets. It is defined as:

AICc = -2*(ln(likelihood)) + 2 K * (n / (n - K - 1))

where likelihood is the probability of the data given a model, K is the number of free parameters in the model and n is the sample size. The model with the lowest AICc reflects the best-fitting model, and all supported hypotheses (i.e., predictor variables) included within 2 AICc units (ΔAICc <2) of the top-supported model are considered comparable (Burnham and Anderson 2002). Predictor coefficients were weighted and averaged for all models that are within ΔAICc <2.

Appendix 2. Details of Acoustic Array

VR2W acoustic receivers are submerged, single channel (69kHz), omni-directional receivers that record date, time and identity of acoustic tagged fish swimming within the detection range of the receiver units. This acoustic array provides coverage of approximately 77 kilometres of river with a mean distance of 4.5 kilometres between receivers. At each site, receivers were located to maximise detection ability by selecting a location that offered the least impediment to reception (i.e. clear of snags or underwater barriers). Receivers were attached to a concrete anchor with a short length of 6mm stainless steel wire, with a float to keep the wire and receiver upright. The concrete anchor with receiver unit attached and float was submerged in the deepest water possible at each site, and an additional length of wire was strung to a nearby tree on the bank to ensure receivers were not swept downstream during the delivery of the flow. Receivers provided continuous monitoring of acoustic tagged fish movement throughout the study period, with data retrieval conducted quarterly (January 2013, April 2013, July 2013) outside of the flow delivery phase.

Data analysis

Data was downloaded from acoustic receivers in January, April and July 2013. Data was stored in a purpose built SQL database. Prior to analyses, single detections were removed (Clements et al 2005) and the detection data were then ground truthed using Eonfusion software (Myriax Software Pty. Ltd.) by reviewing fish track movement to identify and exclude false detections (detections that fall out of sequence). All remaining detection data was plotted on the Murrumbidgee River network to generate time series movement video files. The same data file was uploaded to Eonfusion to calculate a range of movement metrics. Movement metrics were calculated on a daily basis to correlate with flow parameters (discharge ML/day, water level (metres) and temperature (°C). Detections for each transmitter at each receiver was not independent, therefore location and movement metrics were calculated for each transmitter based on time. When a fish was not detected within the set time frame, the location of the fish was assigned evenly to the last known and next known receiver location. If a fish was not detected again during the study period, it was excluded from the analyses. For each tagged fish, a range of movement metrics are calculated, including directional movement (upstream and downstream), daily displacement, cumulative displacement, activity (aggregate daily movement), and travel time between acoustic receivers. Flow parameters (daily discharge (ML/day), water level (m) and temperature (°C)) were used from the Narrandera gauge as it represents the middle mark of the sampling river reach and therefore can be applied to all detections within the reach. Discharge data was overlayed on movement graphs to detect associations between environmental water delivery and possible spawning related movement. As this is the first year of fish movement data collection, statistics are not able to be applied to the data to determine if there is a significant increase or decrease in Murray cod movement during their spawning period which also coincides with period in which environmental water was delivered. In future years, data will be collected on movement patterns during the Murray cod spawning season that does not coincide with environmental water delivery, and can therefore be compared to the 2012/13 data to suggest whether the delivery of water directly influenced the type and amount of movement. Movement data collected in 2012/13 will be assessed to determine whether possible spawning related movements occurred during the environmental water delivery period.

Details of native fish with acoustic tags in 2012/13 (Sex: M=male, F=female, U=unknown). Star (*) next to species name indicates fish was detected during study period. Hash (#) indicates fish that are known to have been removed from the tagged population by anglers (external tag numbers are reported).

Tag date	Species	Length (mm)	Weight (g)	Sex	Tag No.	Tag Location
September 2012						
10-Sep-12	Murray cod*#	600	3,214	F	29992	Buckingbong Station
10-Sep-12	Murray cod	505	1,774	M	30002	Buckingbong Station
10-Sep-12	Murray cod	528	2,034	M	30004	Buckingbong Station
10-Sep-12	Murray cod	705	5,204	M	30007	Buckingbong Station
10-Sep-12	Murray cod*	540	2,104	F	30008	Buckingbong Station
10-Sep-12	Murray cod	715	5,838	F	30010	Buckingbong Station
10-Sep-12	Murray cod	532	2,074	M	30011	Buckingbong Station
12-Sep-12	Murray cod*	516	1,960	F	30013	Buckingbong Station
12-Sep-12	Murray cod*	580	2,810	M	30015	Buckingbong Station
12-Sep-12	Murray cod*	545	2,248	F	30016	Buckingbong Station
13-Sep-12	Murray cod	525	2,484	M	30017	Buckingbong Boat Ramp
13-Sep-12	Murray cod*	730	7,734	M	30018	Buckingbong Boat Ramp
13-Sep-12	Murray cod*	592	2,908	F	30019	Buckingbong Boat Ramp
13-Sep-12	Murray cod*	590	3,048	F	30020	Buckingbong Boat Ramp
14-Sep-12	Murray cod*	528	1,885	M	29993	NFC Pump Station
14-Sep-12	Murray cod*	591	2,784	F	29995	NFC Pump Station
14-Sep-12	Murray cod*	549	2,292	F	29996	NFC Pump Station
14-Sep-12	Murray cod*	514	1,796	M	30024	NFC Pump Station
14-Sep-12	Murray cod	593	3,062	F	30025	NFC Pump Station
14-Sep-12	Murray cod*	640	4,264	M	30026	NFC Pump Station
13-Sep-12	Trout cod*	475	1,426	F	30022	Buckingbong Boat Ramp
13-Sep-12	Trout cod*	564	2,442	M	30021	Buckingbong Boat Ramp
14-Sep-12	Trout cod*	396	852	F	29994	NFC Pump Station
14-Sep-12	Trout cod*	480	1,552	F	30023	NFC Pump Station
10-Sep-12	Golden perch	445	1,402	U	30003	Buckingbong Station
10-Sep-12	Golden perch	431	1,250	F	30005	Buckingbong Station
10-Sep-12	Golden perch	374	798	U	30006	Buckingbong Station
10-Sep-12	Golden perch	380	870	F	30009	Buckingbong Station
10-Sep-12	Golden perch	470	1,520	U	30012	Buckingbong Station
March 2013						
07-Mar-13	Murray cod	600	2,890	U	29822	Buckingbong Boat Ramp
07-Mar-13	Murray cod	761	6,835	F	29823	Buckingbong Boat Ramp
07-Mar-13	Murray cod*	654	3,620	U	29824	Buckingbong Boat Ramp
07-Mar-13	Murray cod*	922	>17,000	M	29825	Buckingbong Boat Ramp
07-Mar-13	Murray cod*	730	4,925	F	29998	Buckingbong Boat Ramp
07-Mar-13	Murray cod*	746	5,885	M	29999	Buckingbong Boat Ramp
07-Mar-13	Murray cod	722	4,855	M	30000	Buckingbong Boat Ramp
07-Mar-13	Trout cod*	511	1,510	F	30001	Buckingbong Boat Ramp
07-Mar-13	Trout cod	543	1,940	F	29860	Buckingbong Boat Ramp
07-Mar-13	Silver perch*	368	915	F	29997	Buckingbong Boat Ramp
07-Mar-13	Murray cod	600	2,890	U	29822	Buckingbong Boat Ramp
07-Mar-13	Murray cod	761	6,835	F	29823	Buckingbong Boat Ramp

Appendix 3. Vegetation functional groups- repeated measures analysis of variance

Functional group	ANOVA results					Interpretation
Tdr*	Source	df	MS	Pseudo-F	P(perm)	Significant effect of water year but neither contrast significant
	Water year	2	45.5	3.85	0.0284	
	Residual	20	11.8			
	2010-11 vs 2011-12	1	11.3	3.59	0.1024	
	2011-12 vs 2012-13	1	36.6	2.57	0.1407	
Tdr	Source	df	MS	Pseudo-F	P(perm)	Significant effect of water year but neither contrast significant (although difference between first 2 years very close to significant)
	Water year	2	16.2	3.75	0.0399	
	Residual	20	4.3			
	2010-11 vs 2011-12	1	21.8	4.55	0.0589	
	2011-12 vs 2012-13	1	0.2	0.05	0.8299	
Tda*	Source	df	MS	Pseudo-F	P(perm)	No effect of water year
	Water year	2	2.0	1.17	0.3895	
	Residual	20	1.7			
Tda	Source	df	MS	Pseudo-F	P(perm)	Significant effect of water year and both contrasts significant
	Water year	2	117.8	10.32	0.0005	
	Residual	20	11.4			
	2010-11 vs 2011-12	1	230.6	12.49	0.0057	
	2011-12 vs 2012-13	1	31.8	9.17	0.0147	
Ate*	Source	df	MS	Pseudo-F	P(perm)	No effect of water year
	Water year	2	0.5	1.72	0.214	
	Residual	20	0.3			
Ate	Source	df	MS	Pseudo-F	P(perm)	Significant effect of water year and difference between first 2 years significant, but no difference between years 2 and 3
	Water year	2	153.0	6.39	0.0029	
	Residual	20	24.0			
	2010-11 vs 2011-12	1	273.4	6.82	0.0197	
	2011-12 vs 2012-13	1	11.0	1.68	0.2278	
Arp	Source	df	MS	Pseudo-F	P(perm)	No effect of water year
	Water year	2	0.1	0.47	0.6644	
	Residual	20	0.3			
Arf	Source	df	MS	Pseudo-F	P(perm)	No effect of water year
	Water year	2	2.0	0.87	0.6473	
	Residual	20	2.3			
Atl	Source	df	MS	Pseudo-F	P(perm)	Significant effect of water year and difference between first 2 years significant, but no difference between years 2 and 3
	Water year	2	25.6	5.51	0.007	
	Residual	20	4.6			
	2010-11 vs 2011-12	1	17.8	8.95	0.0153	
	2011-12 vs 2012-13	1	8.5	2.60	0.1373	
S	Source	df	MS	Pseudo-F	P(perm)	No effect of water year
	Water year	2	0.004	0.61	0.6077	
	Residual	20	0.008			

* Introduced functional group

Appendix 4 Waterbird species list and functional groups

Functional groups of waterbird species (listing under bilateral migratory bird agreements, C = CAMBA, J = JAMBA, R = ROKAMBA; listing under NSW TSC Act 1995, V = Vulnerable). Nomenclature follows (Christidis and Boles 2008)

Family	Common name	Scientific name	Feeding guild
Anatidae	Australasian shoveler	*Anas rhynchotis*	Dabbling duck
	Australian shelduck	*Tadorna tadornoides*	Grazing waterfowl
	Australian wood duck	*Chenonetta jubata*	Grazing waterfowl
	Black swan	*Cygnus atratus*	Deep-water forager
	Blue-billed duck	*Oxyura australis V*	Deep-water forager
	Chestnut teal	*Anas castanea*	Dabbling duck
	Freckled duck	*Stictonetta naevosa V*	Dabbling duck
	Grey teal	*Anas gracilis*	Dabbling duck
	Hardhead	*Aythya australis*	Deep-water forager
	Musk duck	*Biziura lobata*	Deep-water forager
	Pacific black duck	*Anas superciliosa*	Dabbling duck
	Pink-eared duck	*Malacorhynchus membranaceus*	Dabbling duck
Anhingidae	Australasian darter	*Anhinga novaehollandiae*	Fish-eater
Ardeidae	Eastern great egret	*Ardea modesta JC*	Fish-eater
	Intermediate egret	*Ardea intermedia*	Fish-eater
	Nankeen night heron	*Nycticorax caledonicus*	Fish-eater
	White-faced heron	*Egretta novaehollandiae*	Fish-eater
	White-necked heron	*Ardea pacifica*	Fish-eater
Charadriidae	Black-fronted dotterel	*Elseyornis melanops*	Small wader
	Masked lapwing	*Vanellus miles*	Shoreline forager
	Red-capped plover	*Charadrius ruficapillus*	Small wader
	Red-kneed dotterel	*Erythrogonys cinctus*	Small wader
Laridae	Caspian tern	*Hydroprogne caspia JC*	Fish-eater
	Gull-billed tern	*Gelochelidon nilotica*	Fish-eater
	Silver gull	*Chroicocephalus novaehollandiae*	Fish-eater
	Whiskered tern	*Chlidonias hybrida*	Fish-eater
Pelecanidae	Australian pelican	*Pelecanus conspicillatus*	Fish-eater
Phalacrocoracidae	Great cormorant	*Phalacrocorax carbo*	Fish-eater
	Little black cormorant	*Phalacrocorax sulcirostris*	Fish-eater
	Little pied cormorant	*Microcarbo melanoleucos*	Fish-eater
	Pied cormorant	*Phalacrocorax varius*	Fish-eater
Podicipedidae	Australasian grebe	*Tachbaptus novaehollandiae*	Fish-eater
	Great-crested grebe	*Podiceps cristatus*	Fish-eater
	Hoary-headed grebe	*Podicephalus poliocephalus*	Fish-eater
Rallidae	Black-tailed native-hen	*Gallinula ventralis*	Shoreline forager
	Dusky moorhen	*Gallinula tenebrosa*	Deep-water forager
	Eurasian coot	*Fulica atra*	Deep-water forager
	Purple swamphen	*Porphyrio porphyrio*	Shoreline forager
Recurvirostridae	Black-winged stilt	*Himantopus himantopus*	Small wader
	Red-necked avocet	*Recurvirostra novaehollandiae*	Small wader

Family	Common name	Scientific name	Feeding guild
Scolopacidae	Red-necked stint	*Calidris ruficollis JCR*	Small wader
	Ruddy turnstone	*Arenaria interpres JCR*	Small wader
	Sharp-tailed sandpiper	*Calidris acuminata JCR*	Small wader
Threskiornithidae	Australian white ibis	*Threskiornis molucca*	Large wader
	Glossy ibis	*Plegadis falcinellus C*	Large wader
	Royal spoonbill	*Platalea regia*	Large wader
	Straw-necked ibis	*Threskiornis spinicollis*	Large wader
	Yellow-billed spoonbill	*Platalea flavipes*	Large wader

Maximum counts of 32 waterbird species recorded in the 11 survey sites in the mid-Murrumbidgee wetlands in 2012 (Aug – Dec 2012) (^breeding detected, C = CAMBA, J = JAMBA).

Common name	Berry Jerry Lagoon	Dry Lake	Euroley Lagoon	Gooragool Lagoon	McKennas Lagoon	Molleys Lagoon	Narrandera SF	Sunshower Lagoon	Turkey Flats	Yanco Agricultural	Yarrada Lagoon	% occurrence
Australasian grebe	0	5	9	1	8	0	5	5	0	1	0	64
Australasian shoveler	0	2	0	0	0	0	0	0	0	0	0	9
Australian pelican	0	44	0	11	40	0	0	21	0	0	24	45
Australian white ibis	0	4	0	0	8	0	2	1	5	1	0	45
Australian wood duck	10	24	6	80	90^	11	74	4	18	0	10	91
Black swan	0	6^	0	0	0	0	0	0	0	0	0	9
Black-fronted dotterel	0	1	0	0	6	0	0	2	0	0	1	27
Black-tailed native hen	0	0	8	16	22	0	0	0	0	0	0	27
Black-winged stilt	0	12	0	0	0	0	0	0	0	0	0	9
Chestnut teal	0	0	0	2	0	0	0	0	0	0	0	9
Darter	3	5	0	1	8	3	1	1	0	0	8^	73
Dusky moorhen	1	1	0	1	0	0	1	1	0	1	0	55
Eurasian coot	0	119	0	0	1	0	2	0	0	0	2	36
Glossy ibis C	0	0	0	0	0	0	0	8	0	0	0	9
Great cormorant	1	2	0	0	22	3	1	2	2	0	5	73
Great egret J, C	0	1	1	2	3	0	0	2	0	0	2	55
Grey teal	13^	239	62	132	70	2	39	87^	179	12	12	100
Hardhead	1	0	38	1	46	0	0	0	0	0	0	36
Intermediate egret	0	1	0	0	0	0	2	2	1	0	3	45
Little black cormorant	0	0	0	2	41	0	0	1	8	2	18	55
Little pied cormorant	3	0	1	1	6	0	5	1	0	0	4	64
Masked lapwing	0	2	0	2	0	0	1	0	5	0	0	36
Nankeen night heron	0	0	0	2	0	0	4	0	0	0	0	18
Pacific black duck	9^	26	8	37	10	3	24	30	48	36	2	100
Purple swamphen	0	0	1^	0	0	0	0	0	0	2	0	18
Red-kneed dotterel	0	0	3	0	4	0	0	2	1	0	0	36
Royal spoonbill	0	0	0	0	2	0	0	0	0	0	1	18
Straw-necked ibis	0	1	1	2	40	10	0	0	5	2	0	64
Whiskered tern	0	0	0	0	0	0	0	0	1	0	0	9
White-faced heron	0	4	1	20	4	2	7	2	13	11	1	91
White-necked heron	0	4	2	18	1	0	1	1	1	1	2	82
Yellow-billed spoonbill	0	22	2	4	20	0	2	1	1	0	5	73
Maximum total count	36	343	119	290	337	19	113	123	190	62	61	

Total species	8	21	14	19	21	7	16	19	15	10	16	

Maximum waterbird counts recorded in 15 survey sites in the Western Lakes during surveys from October 2012 – May 2013 (^breeding detected, C = CAMBA, J = JAMBA, R = ROKAMBA, V= Vulnerable under NSW TSC Act 1995).

Common name	Hobblers Lake	Upper Cherax	Lower Cherax	Paika Lake East	Paika Lake North	Paika Lake South	Paika Lake West	Penarie Creek
Australasian grebe	100	200	150	1	0	0	3	50
Australasian shoveler	20	8	6	0	8	0	0	1
Australian pelican	1	25	1	8	38	20	110	2
Australian shelduck	0	0	0	1	100	25	2	0
Australian white ibis	0	1	1	1	1	0	0	1
Australian wood duck	0	5	20	17^	700	300	35	75
Black swan	30	9	2	8	75	10	6	0
Black-fronted dotterel	15	0	10	5	0	0	0	2
Black-tailed native hen	800	2000	1500	2000	1500	120	300	800
Black-winged stilt	25	25	18	20	50	20	50	25
Blue-billed duck V	50	0	2	0	0	0	0	0
Caspian tern J,C	0	0	1	1	1	0	0	0
Chestnut teal	0	0	0	0	1	0	0	1
Darter	1	0	1	4	1	12	60	0
Eurasian coot	500	150	70	10	0	30	22	250
Freckled duck V	40	2	2	0	0	0	0	0
Glossy ibis C	0	0	0	0	0	0	0	0
Great cormorant	6	0	4	1	0	250	30	0
Great egret JC	2	20	4	3	1	5	17	1
Great-crested grebe	0	0	0	30	0	66	12	0
Grey teal	1200	500	600	50	500	50	25	3000
Gull-billed tern	0	0	0	10	1	15	6	0
Hardhead	800	500	800	1	150	0	0	1000
Hoary-headed grebe	700	15	500	5	0	8	40	200
Intermediate egret	0	0	0	0	0	0	1	0
Little black cormorant	5	30	8	0	0	50	300^	0
Little pied cormorant	8	5	4	0	0	0	0	0
Masked lapwing	10	0	3	15	50	25	50	3
Musk duck	6	0	0	0	0	1	1	0
Nankeen night heron	0	0	0	0	0	0	0	0
Pacific black duck	50	50	5	10	300	1	6	50
Pied cormorant	0	0	0	1	0	50	20^	0
Pink-eared duck	500	50	200	30	50	2	0	200
Purple swamphen	0	0	0	0	0	0	0	0

Common name	Hobblers Lake	Upper Cherax	Lower Cherax	Paika Lake East	Paika Lake North	Paika Lake South	Paika Lake West	Penarie Creek
Red-capped plover	0	0	0	0	25	0	0	0
Red-kneed dotterel	1	100	15	1	3	0	0	40
Red-necked avocet	0	0	0	0	12	1	0	0
Red-necked stint JCR	0	0	0	0	3	0	0	0
Royal spoonbill	0	16	8	0	15	15	0	13
Ruddy turnstone JCR	0	0	0	0	1	0	0	0
Sharp-tailed sandpiper JCR	0	0	0	0	8	0	0	0
Silver gull	0	0	0	8	6	40	4	0
Straw-necked ibis	0	2	0	20	15	6	1	80
Whiskered tern	0	0	0	20	500	40	30	0
White-faced heron	1	2	1	1	12	2	1	0
White-necked heron	1	4	0	2	0	1	1	0
Yellow-billed spoonbill	2	8	17	0	0	15	0	13
Maximum total count	4874	3727	3953	2284	4127	1180	1133	5807
Total species	27	24	28	29	29	28	26	21

Appendix 5 Generalised linear regression outputs extended results

Wetland frogs breeding

Full model: Model-averaged coefficients

Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.734	0.193	8.999	<0.001
Veg.comp1	0.461	0.076	6.068	<0.001
Veg.comp2	-0.321	0.102	-3.141	0.002
Veg.comp3	-0.408	0.113	-3.601	<0.001
WQ.comp1	-1.213	0.065	-18.664	<0.001
Lowbidgee	1.660	0.234	7.080	<0.001
mid-Murrumbidgee	-2.873	0.353	-8.149	<0.001
SmallfykeGambusia	0.000	0.000	1.548	0.122
SmallfykeCarpgudgeon	0.000	0.000	5.689	0.000
Total.Flet.Tasm	-0.017	0.002	-9.943	<0.001
highFlowDays30d	0.061	0.007	8.384	<0.001
totalFlowSinceJul1	0.000	0.000	0.315	0.753
fillyearsin10	-1.970	0.231	-8.547	<0.001

Run through 2048 model combinations

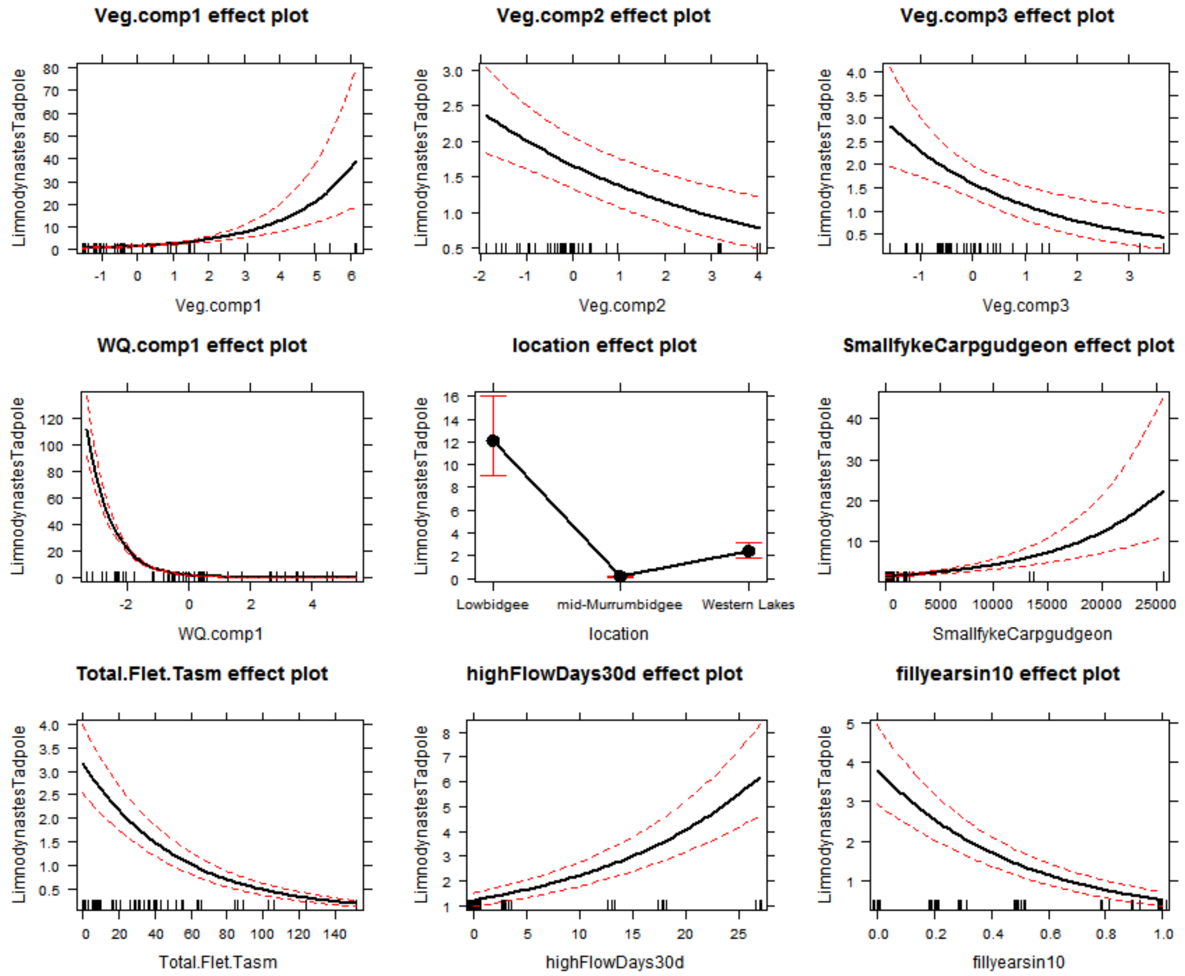
(Intercept)	fillyearsin10	highFlowDays30d	location	SmallfykeCarpgudgeon	SmallfykeGambusia	Total.Flet.Tasm	Veg.comp1	Veg.comp2	Veg.comp3	WQ.comp1	df	logLik	AICc	delta	weight
1.83	-2.00	0.06	+	0.00	-	-0.02	0.51	-0.19	-0.36	-1.27	11.00	-895.98	1820.25	0.00	0.55
1.77	-1.94	0.06	+	0.00	0.00	-0.02	0.47	-0.30	-0.40	-1.21	12.00	-894.54	1820.69	0.44	0.45

Model-averaged coefficients most parsimonious model (excluding 'SmallfykeGambusia')

Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.83	0.14	13.03	<0.001
Veg.comp1	0.51	0.07	7.87	<0.001
Veg.comp2	-0.19	0.05	-4.11	<0.001
Veg.comp3	-0.36	0.11	-3.41	<0.001
WQ.comp1	-1.27	0.05	-24.96	<0.001
Lowbidgee	1.64	0.22	7.60	<0.001
mid-Murrumbidgee	-2.89	0.33	-8.64	<0.001
SmallfykeCarpgudgeon	0.00	0.00	6.95	<0.001
Total.Flet.Tasm	-0.02	0.00	-15.89	<0.001
highFlowDays30d	0.06	0.00	12.13	<0.001
fillyearsin10	-2.00	0.21	-9.47	<0.001

Null deviance: 5739.4 on 53 degrees of freedom
Residual deviance: 1687.4 on 43 degrees of freedom

	Estimate	Std. Error	z value	Pr(>|z|)	
mid-Murrumbidgee - Lowbidgee	-4.5210	0.3058	-14.785	<0.001	***
Western Lakes - Lowbidgee	-1.6347	0.2150	-7.604	<0.001	***
Western Lakes - mid-Murrumbidgee	2.8864	0.3339	8.644	<0.001	***


Veg.comp1 effect plot
Veg.comp2 effect plot
Veg.comp3 effect plot
LimnodynastesTadpole
Veg.comp1
Veg.comp2
Veg.comp3
WQ.comp1 effect plot
location effect plot
SmallfykeCarpgudgeon effect plot
WQ.comp1
Lowbidgee
mid-Murrumbidgee
Western Lakes
location
SmallfykeCarpgudgeon
Total.Flet.Tasm effect plot
highFlowDays30d effect plot
fillyearsin10 effect plot
Total.Flet.Tasm
highFlowDays30d
fillyearsin10

Wetland fish

Full model: Model-averaged coefficients

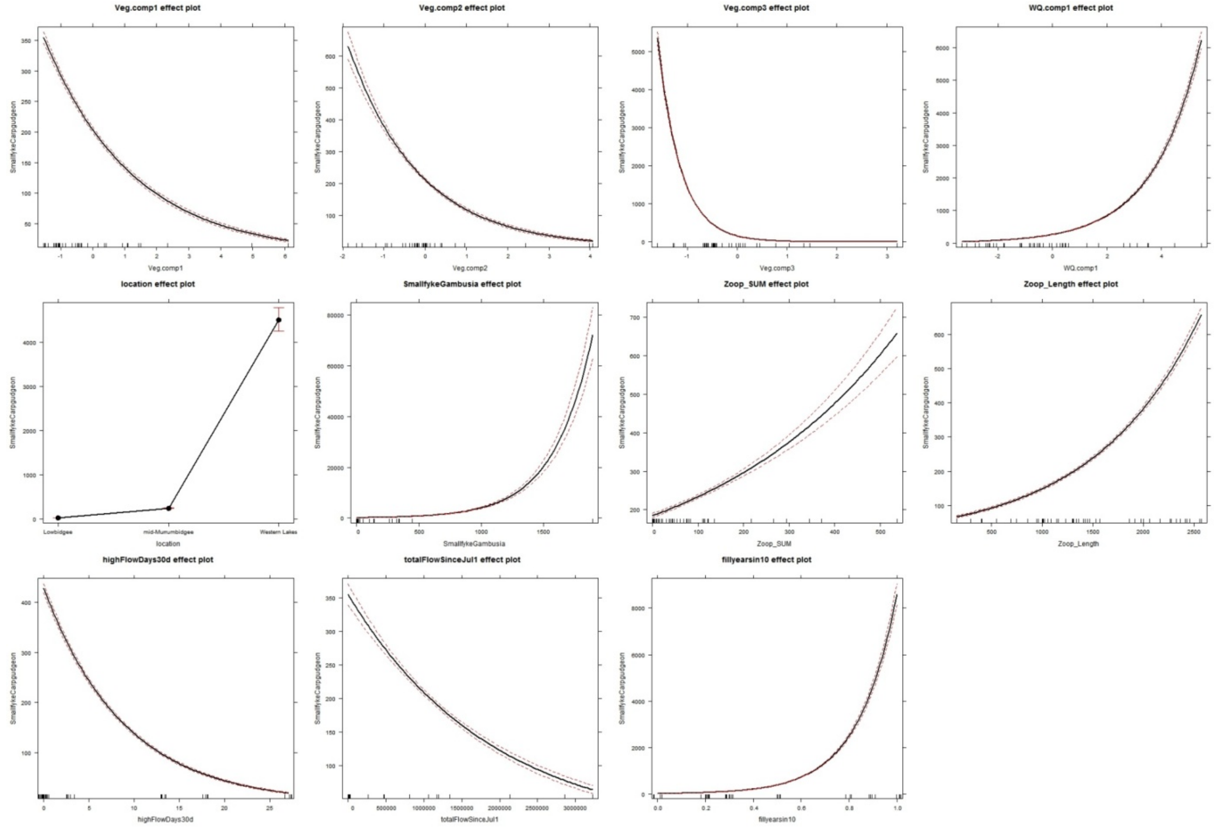
Coefficients:	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	4.74	0.03	160.21	<0.001
Veg.comp1	-0.36	0.01	-48.58	<0.001
Veg.comp2	-0.58	0.02	-31.05	<0.001
Veg.comp3	-2.20	0.01	-149.17	<0.001
WQ.comp1	0.58	0.00	159.59	<0.001
Lowbidgee	-5.21	0.05	-103.12	<0.001
mid-Murrumbidgee	-2.93	0.05	-61.71	<0.001
SmallfykeGambusia	0.00	0.00	80.36	<0.001
Zoop_SUM	0.00	0.00	21.43	<0.001
Zoop_Length	0.00	0.00	68.98	<0.001
highFlowDays30d	-0.11	0.00	-99.98	<0.001
totalFlowSinceJuly	0.00	0.00	-25.24	<0.001
fillyearsin10	6.17	0.05	126.93	<0.001

Null deviance: 244303 on 46 degrees of freedom
Residual deviance: 63773 on 34 degrees of freedom

Run through 2048 model combinations leaves us with the full model (above).

Intercept	fillyearsin10	highFlowDays30d	location	SmallfykeGambusia	totalFlowSinceJul1	Veg.comp1	Veg.comp2	Veg.comp3	WQ.comp1	Zoop_Length	Zoop_SUM	df	logLik	AICc	delta	weight
4.74	6.17	-0.11	+	0.00	0.00	-0.36	-0.58	-2.20	0.58	0.00	0.00	13.00	-32025.20	64087.42	0.00	1.00

	Estimate Std. Error z value Pr(>|z|)
mid-Murrumbidgee - Lowbidgee	2.28808 0.03645 62.77 <0.001 ***
Western Lakes - Lowbidgee	5.21397 0.05056 103.12 <0.001 ***
Western Lakes - mid-Murrumbidgee	2.92589 0.04742 61.71 <0.001 ***


Veg.comp1 effect plot
Veg.comp2 effect plot
Veg.comp3 effect plot
WQ.comp1 effect plot
location effect plot
SmallfykeGambusia effect plot
Zoop_SUM effect plot
Zoop_Length effect plot
highFlowDays30d effect plot
totalFlowSinceJul1 effect plot
fillyearsin10 effect plot
SmallfykeCarpgudgeon
Veg.comp1
Veg.comp2
Veg.comp3
WQ.comp1
location
Lowbidgee
mid-Murrumbidgee
Western Lakes
SmallfykeGambusia
Zoop_SUM
Zoop_Length
highFlowDays30d
totalFlowSinceJul1
fillyearsin10

Microcrustacea models

Full model: Model-averaged coefficients

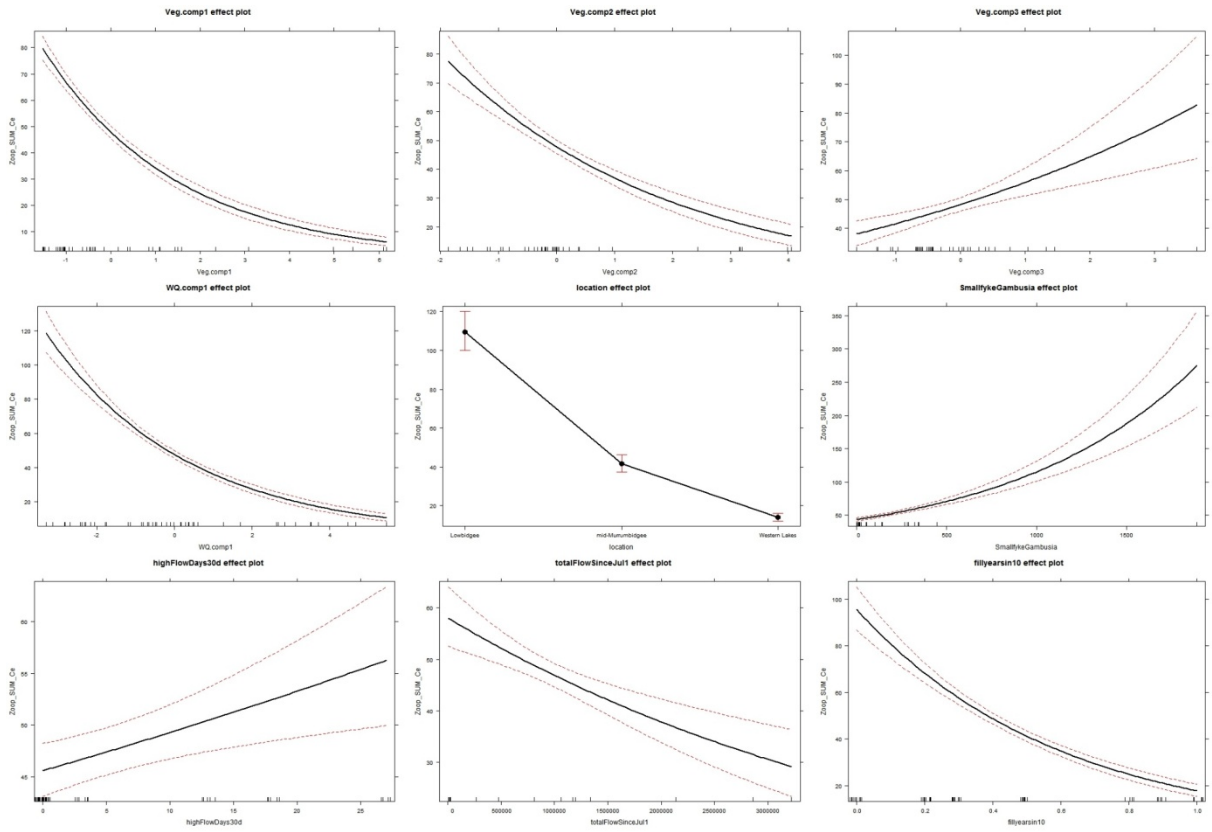
(Intercept)	3.44	0.06	62.16	<0.001
Veg.comp1	-0.33	0.02	-16.35	<0.001
Veg.comp2	-0.26	0.03	-9.69	<0.001
Veg.comp3	0.15	0.03	4.33	<0.001
WQ.comp1	-0.28	0.02	-16.62	<0.001
Lowbidgee	2.06	0.09	22.11	<0.001
mid-Murrumbidgee	1.09	0.10	11.29	<0.001
SmallfykeGambusia	0.00	0.00	12.89	<0.001
highFlowDays30d	0.01	0.00	3.00	<0.001
totalFlowSinceJuly	0.00	0.00	-4.46	<0.001
fillyearsin10	-1.68	0.11	-14.80	<0.001

Null deviance: 6221.9 on 53 degrees of freedom
Residual deviance: 3513.4 on 43 degrees of freedom

Run through 512 model combinations leaves us with the full model (above).

(Intercept)	fillyearsin10	highFlowDays30d	location	SmallfykeGambusia	totalFlowSinceJul1	Veg.comp1	Veg.comp2	Veg.comp3	WQ.comp1	df	logLik	AICc	delta	weight
3.44	-1.68	0.01	+	0.00	0.00	-0.33	-0.26	0.15	-0.28	11.00	-1882.32	3792.92	0.00	1.00

	Estimate Std. Error z value Pr(>|z|)
mid-Murrumbidgee - Lowbidgee	2.28808 0.03645 62.77 <0.001 ***
Western Lakes - Lowbidgee	5.21397 0.05056 103.12 <0.001 ***
Western Lakes - mid-Murrumbidgee	2.92589 0.04742 61.71 <0.001 ***


Veg.comp1 effect plot
Zoop_SUM_Ce
Veg.comp1
Veg.comp2 effect plot
Zoop_SUM_Ce
Veg.comp2
Veg.comp3 effect plot
Zoop_SUM_Ce
Veg.comp3
WQ.comp1 effect plot
Zoop_SUM_Ce
WQ.comp1
location effect plot
Zoop_SUM_Ce
Lowbidgee
mid-Murrumbidgee
Western Lakes
location
SmallfykeGambusia effect plot
Zoop_SUM_Ce
SmallfykeGambusia
highFlowDays30d effect plot
Zoop_SUM_Ce
highFlowDays30d
totalFlowSinceJul1 effect plot
Zoop_SUM_Ce
totalFlowSinceJul1
fillyearsin10 effect plot
Zoop_SUM_Ce
fillyearsin10

Microcrusteaca Length

Full model: Model-averaged coefficients

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	7.24	0.01	760.22	<0.001
Veg.comp1	-0.15	0.00	-45.72	<0.001
Veg.comp2	-0.16	0.01	-26.91	<0.001
Veg.comp3	-0.02	0.01	-2.74	0.01
WQ.comp1	-0.12	0.00	-39.33	<0.001
Lowbidgee	-0.52	0.02	-21.04	<0.001
mid-Murrumbidgee	-0.22	0.02	-10.85	<0.001
SmallfykeGambusia	0.00	0.00	27.54	<0.001
highFlowDays30d	0.00	0.00	-0.44	0.66
totalFlowSinceJuly	0.00	0.00	-3.72	<0.001
fillyearsin10	0.14	0.03	4.58	<0.001

Run through 512 model combinations (take out 'highFlowDays30d')

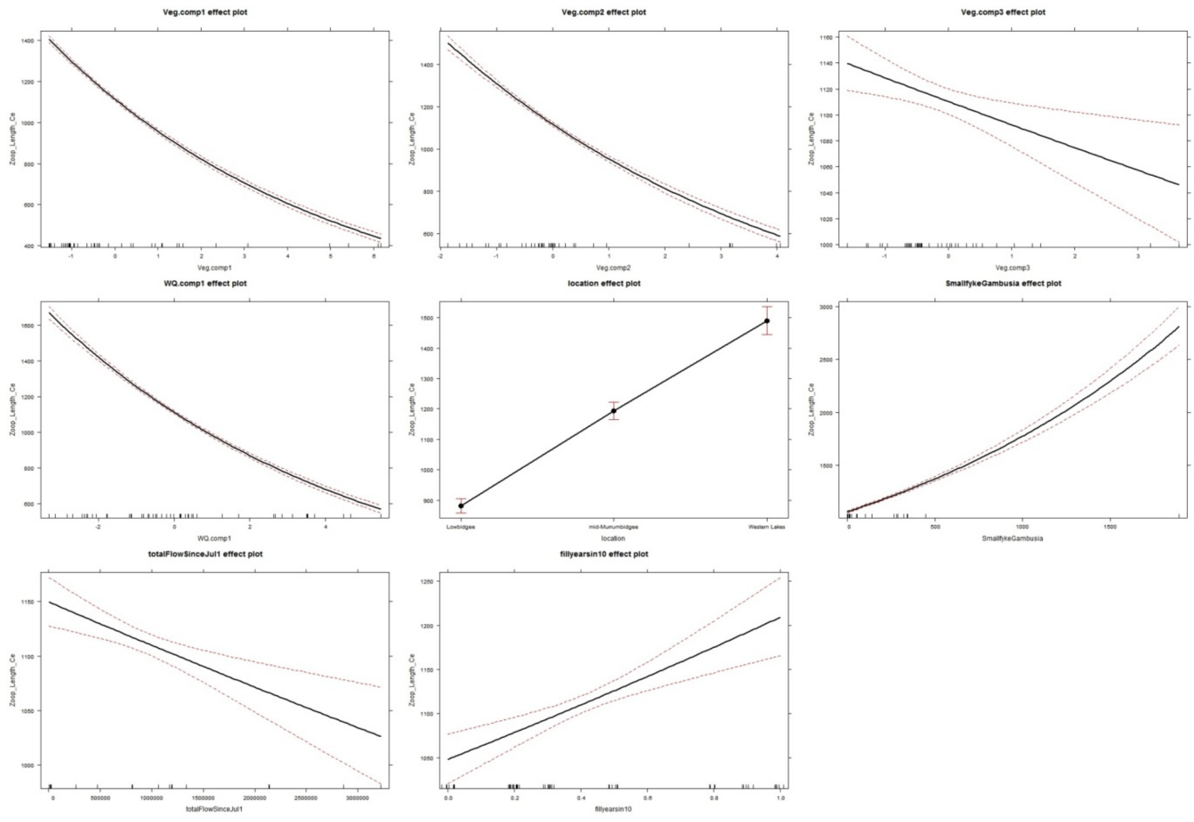
(Intercept)	fillyearsin10	location	SmallfykeGambusia	totalFlowSinceJul1	Veg.comp1	Veg.comp2	Veg.comp3	WQ.comp1	df	logLik	AICc	delta	weight
7.24	0.14	+	0.00	0.00	-0.15	-0.16	-0.02	-0.12	10.00	-10508.42	21041.96	0.00	1.00

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	7.24	0.01	837.33	<0.001
Veg.comp1	-0.15	0.00	-45.72	<0.001
Veg.comp2	-0.16	0.01	-27.14	<0.001
Veg.comp3	-0.02	0.01	-2.87	<0.001
WQ.comp1	-0.12	0.00	-39.43	<0.001
Lowbidgee	-0.53	0.02	-21.18	<0.001
mid-Murrumbidgee	-0.22	0.02	-10.89	<0.001
Small fyke Gambusia	0.00	0.00	27.64	<0.001
Total Flow Since July	0.00	0.00	-3.73	<0.001
Fill years in10	0.14	0.03	4.59	<0.001

Null deviance: 33460 on 53 degrees of freedom

Residual deviance: 20595 on 44 degrees of freedom

	Estimate	Std. Error	z value	Pr(>|z|)	
mid-Murrumbidgee - Lowbidgee	2.28808	0.03645	62.77	<0.001	***
Western Lakes - Lowbidgee	5.21397	0.05056	103.12	<0.001	***
Western Lakes - mid-Murrumbidgee	2.92589	0.04742	61.71	<0.001	***


Veg.comp1 effect plot
Zoop_Length_Ce
Veg.comp1
Veg.comp2 effect plot
Zoop_Length_Ce
Veg.comp2
Veg.comp3 effect plot
Zoop_Length_Ce
Veg.comp3
WQ.comp1 effect plot
Zoop_Length_Ce
WQ.comp1
location effect plot
Zoop_Length_Ce
Lowbidgee
mid-Murrumbidgee
Western Lakes
location
SmallfykeGambusia effect plot
Zoop_Length_Ce
SmallfykeGambusia
totalFlowSinceJul1 effect plot
Zoop_Length_Ce
totalFlowSinceJul1
fillyearsin10 effect plot
Zoop_Length_Ce
fillyearsin10