Department of Primary Industries

FISHERIES FINAL REPORT SERIES | NO. 150

Short-term intervention monitoring of a fish community response to an environmental flow in the mid and lower Macquarie River: 2014/2015 watering year

A report prepared for the Commonwealth Environmental Water Office

Stocks J.R., Scott K.F, Rodgers M.P., Walsh C.T., van der Meulen D.E and Gilligan D.

Published by the NSW Department of Primary Industries

Short-term monitoring of a fish community response to an environmental flow in the mid and lower Macquarie River: 2014/2015 watering year, NSW DPI – Fisheries Final Report Series No. 150

First published March 2016

ISSN 2204-8669*

More information

Stocks J.R., Scott K.F., Rodgers M.P., Walsh C.T., van der Meulen D.E and Gilligan D., Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay, NSW 2315, Australia

www.dpi.nsw.gov.au

Acknowledgments

Australian Government
Department of the Environment

Cover image: Jerom Stocks

*Before July 2004, this report series was published by NSW Fisheries as the 'NSW Fisheries Final Report Series' with ISSN 1440-3544. Then, following the formation of the NSW Department of Primary Industries it was published as the 'NSW Department of Primary Industries – Fisheries Final Report Series' with ISSN 1449-9967. It was then published by Industry & Investment NSW as the 'Industry & Investment NSW – Fisheries Final Report Series' with ISSN 1837-2112. It is now published as the 'NSW Trade and Investment – Fisheries Final Report Series' with ISSN 2204-8669.

Contents

Contents ... i

List of tables ... iv

List of figures ... v

Acknowledgments ... vii

Non-technical summary ... viii

Objectives ... viii

Key words ... viii

Summary ... viii

Introduction ... 1

Methods ... 4

Study sites ... 4

Zone 1: Macquarie River Burrendong Dam to Dubbo ... 4

Zone 2: Macquarie River Gin Gin to Warren ... 4

Zone 3: Macquarie Marshes ... 4

Zone 4: Lower Macquarie River (below the Macquarie Marshes) ... 4

Monitoring timing ... 7

Monitoring protocol ... 8

Analytical methodology ... 8

Fish community composition ... 8

Fish health and condition index ... 9

Fish recruitment ... 9

Results ... 12

Fish community composition ... 12

Recruitment and daily aging ... 27

Murray cod ... 27

Eel-tailed catfish ... 29

Bony bream ... 32

Australian smelt ... 34

Un-specked hardyhead ... 36

Common carp ... 39

Murray–Darling rainbowfish ... 42

Fish health and fish condition index ... 45

Common carp condition index ... 45

Murray cod condition index ... 45

Golden perch condition index ... 45

Bony bream condition index 46
Proportion of catch suffering a health condition 48
Water quality 50
Discussion 54
The role of environmental flows in the recruitment of fish 54
Golden perch 54
Murray cod 55
Bony bream 55
Eel-tailed catfish 56
Australian smelt 56
Un-specked hardyhead 56
Murray–Darling rainbowfish 57
Spangled perch 57
Common carp 57
Evaluation of the October to December 2014 Commonwealth and NSW environmental water release on native fish recruitment 58
Variation in fish community composition over a lotic gradient 59
SRA indicators 59
Burrendong Dam thermal curtain 59
Fish recruitment in the Macquarie Marshes 60
Fish condition 60
Considerations in the design of recruitment response monitoring 61
Fish stocking 61
Sampling interval 61
Experimental control 62
Daily age validation and first ring formation 62
Spawning, hatch dates and abiotic conditions 64
Conclusions and recommendations 66
References 68
Appendices 76
Appendix 1 – Murray Darling Basin Authority – Sustainable Rivers Audit Protocol for Fish Theme sampling – Implementation Period 8: 2012–13 76
Introduction 76
Prerequisites 76
Sampling principles 76
Deployment of sampling methods 77
Bait-trap placement 78

Measurement of individuals and subsampling 78
Species list 79
Voucher specimens 82
Fish health and condition 83
Appendix 2 – Sample site photographs 84
Appendix 3 – Sample site coordinates 91
Appendix 4 – Captured species photographs 92
Appendix 5 – Recruitment length cut-offs 94
Appendix 6 – Historic fish community monitoring data for the Macquarie River 95
Appendix 7 – Water diversion schematic for the Macquarie System 96
Appendix 8 – Native fish stocking within the Macquarie River 97

List of tables

Table 1 Total catch by sampling zone and round from standardised fishing (SRA protocol) over the three sampling events. 13
Table 2 Results of Tukey's HSD pairwise comparisons of native species richness between: a) zones within each round of sampling; and b) between sampling rounds within each zone. 14
Table 3 Results of Tukey's HSD pairwise comparisons of proportion of recruits between: a) zones within each round of sampling; and b) between sampling rounds within each zone. 16
Table 4 SRA indicators and overall Fish Condition Index (ndxFS) scores calculated from Round 3 of sampling within the Macquarie River for each sampling site. 21
Table 5 Summary table displaying SRA indicators and overall fish index scores calculated from Round 3 of sampling for each zone. 22
Table 6 Results of a) PERMANOVA test examining fish community composition; b) pairwise comparison of main effect 'round'; and c) pairwise comparison of main effect 'zone' 23
Table 7 Fish condition indices for large-bodied species by sampling round and zone. 46
Table 8 Results of Tukey's HSD pairwise comparisons of condition index for common carp and Murray cod between: a) zones within each round of sampling; and b) between sampling rounds within each zone. 47
Table 9 Average water quality measurement at 0.2m depth for each sampling site during each round of sampling. 51
Table 10 Species of the Macquarie River systems and details of the associated daily age validation studies. 63
Table 11 Egg incubation period for fish species sampled in the Macquarie River. 65

List of figures

Figure 1 Environmental Outcomes Framework (CEWO, 2013). ... 3
Figure 2 Location of sample sites within each of the four sampling zones on the Macquarie River. ... 6
Figure 3 Flows past Marebone Weir from 1 June 2014 to 28 May 2015 by water source. ... 7
Figure 4 Box-and-whisker plot illustrating proportion of juvenile recruits captured from standardised fishing (SRA protocol) during each sampling round. ... 15
Figure 5 Length frequency composition from standardised fishing (SRA protocol) of each species within four sampling zones over three sampling rounds. Lengths are fork length for forked tailed fish and total length for all other species. ... 17
Figure 6 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity in community composition between sampling rounds. ... 24
Figure 7 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity in community composition between sampling zones. ... 24
Figure 8 Coherence plots grouping species that exhibited similar patterns in presence and abundance between samples. ... 25
Figure 9 Daily aged otolith of a 55 mm total length (TL) Murray cod. ... 28
Figure 10 Length-at-age data for Murray cod with growth function fitted. ... 28
Figure 11 Frequency of back-calculated hatch dates for daily aged juvenile Murray cod sampled from Zone 2 of the Macquarie River over three sampling events. ... 29
Figure 12 Daily aged otolith of a 74 mm total length (TL) eel-tailed catfish. ... 30
Figure 13 Length-at-age data for eel-tailed catfish with growth function fitted. ... 31
Figure 14 Frequency of back-calculated hatch dates for daily aged juvenile eel-tailed catfish sampled from Zone 1 of the Macquarie River over three sampling events. ... 31
Figure 15 Daily aged otolith of a 56 mm fork length (FL) bony bream. ... 32
Figure 16 Length-at-age data for bony bream with growth function fitted. ... 33
Figure 17 Frequency of back-calculated hatch dates for daily aged juvenile bony bream sampled during standardised fish community sampling (SRA protocol) within Zone 4 of the Macquarie River over three sampling events. ... 33
Figure 18 Daily aged otolith of a 27 mm fork length (FL) Australian smelt. ... 34
Figure 19 Length-at-age data for Australian smelt with von Bertalanffy growth function fitted. 35
Figure 20 Frequency of back-calculated hatch dates for daily aged juvenile Australian smelt sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events. ... 35
Figure 21 Daily aged otolith of a 19 mm fork length (FL) un-specked hardyhead. ... 37
Figure 22 Length-at-age data for un-specked hardyhead with von Bertalanffy growth function fitted. ... 37
Figure 23 Frequency of back-calculated hatch dates for daily aged juvenile un-specked hardyhead sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events. ... 38
Figure 24 Daily aged otolith of a 52 mm fork length (FL) common carp. ... 40
Figure 25 Length-at-age data for common carp with growth function fitted. ... 40
Figure 26 Frequency of back-calculated hatch dates for daily aged juvenile common carp sampled during standardised fish community sampling (SRA protocol) from: a) Zone 3; and b) Zone 4 of the Macquarie River over three sampling events. ... 41

Figure 27 Daily aged otolith of a 14 mm fork length (FL) Murray–Darling rainbowfish. 43
Figure 28 Length-at-age data for Murray–Darling rainbowfish with von Bertalanffy growth function fitted. 43
Figure 29 Frequency of back-calculated hatch dates for daily aged juvenile Murray–Darling rainbowfish sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events. 44
Figure 30 The percentage of individuals affected by a range of symptoms of disease or parasites for each round of sampling throughout the Macquarie River during the 2014/2015 watering year. 49
Figure 31 The percentage of individuals of each species affected by symptoms of disease or parasites for each round of sampling throughout the Macquarie River during the 2014/2015 watering year. 49
Figure 32 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity of water quality variables between sampling rounds. 53
Figure 33 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity of water quality variables between sampling zones. 53

Acknowledgments

We thank New South Wales Fisheries personnel who provided technical advice and assistance. Gratitude is greatly expressed to Sam Davis for assistance in the project design and fund sourcing. We must also thank property owners who allowed access to the sampling sites. This study was funded by the Commonwealth Environmental Water Office. Specimens were collected under animal research authority No. 14/13 granted by the Primary Industries (Fisheries Animal Care & Ethics Committee) and scientific collection permit P01/0059(A).

Non-technical summary

Short-term monitoring of a fish community response to an environmental flow in the mid and lower Macquarie River: 2014/2015 watering year

Principal investigators: Jerom Stocks, Karen Scott, Michael Rodgers, Dylan van der Meulen, Chris Walsh and Dean Gilligan

Address: NSW Department of Primary Industries

Batemans Bay Fisheries Office

PO Box 17

Batemans Bay, NSW 2536

Tel: 02 4478 9105. Fax: 02 4472 7542

Objectives

There are obligations under the Basin Plan to report on the contribution of Commonwealth environmental water to environmental objectives. This study was developed to follow guiding principles of the Environmental Outcomes Framework underpinning the management of Commonwealth environmental water. The sampling regime adopted provides an opportunity to examine both short-term responses, as reported here, and long-term outcomes of environmental water delivery. Short-term monitoring of fish communities in association with a single watering season provides information to assess the response of native fish reproduction, recruitment and condition to the delivery of environmental water under the specific antecedent and natural flow conditions.

Although short-term changes in diversity and abundance may be apparent due to immigration and juvenile recruitment of fish, it is more likely that significant changes will manifest in the longer term. Continued long-term monitoring of fish communities in the mid and lower Macquarie River would provide information to assess additional long-term outcomes which align with the Environmental Outcomes Framework, including changes in native fish diversity, abundance and population structure.

Key words

Abundance; Diversity; Environmental flows; Fish condition; Fish recruitment; Macquarie River; Fish community health; Daily aging

Summary

During the 2014/2015 watering year 28,483 ML of Commonwealth and NSW environmental water was delivered to the Macquarie River and core areas of the northern and southern marshes from Burrendong Dam from 5 October 2014 until 12 December 2014. The water was delivered to meet the water requirements of the inner floodplain vegetation of the Macquarie Marshes and support native fish in the Macquarie River. Expected short-term responses to the environmental water delivery included increased reproduction and subsequent recruitment of native fish species and an increase in native fish condition.

Recruitment data collected over a single watering year suggests native fish species of the mid-lower Macquarie River, from opportunistic and equilibrium life-history guilds, benefitted from the provision of environmental water during the spring and early summer of 2014/2015.

The broad aims of this study were to: 1) assess the current health status of the fish community throughout the mid and lower Macquarie River; and 2) examine the fish community response to an environmental water delivery through the mid and lower Macquarie River during the 2014/2015 watering year. These broad aims were addressed more specifically by examining fish species diversity and abundance, juvenile recruitment and fish condition indices over a lotic gradient throughout the Macquarie River system.

Three rounds of standardised fish community sampling captured 5,307 individual fish and decapod crustaceans from 20 sites partitioned into 4 spatially distinct zones throughout the mid and lower Macquarie River. Eighteen species were captured, including 12 native fish species, 4 exotic fish species (plus a hybrid) and 2 native decapod species. In general, native fish species richness was significantly lower within, and downstream of, the Macquarie Marshes compared with sites sampled upstream. The overall condition of the fish community within the Macquarie River declined along a downstream gradient from ‘poor’ below Burrendong Dam to ‘extremely poor’ in the Macquarie Marshes and downstream to the Barwon River confluence. State and nationally listed threatened species were present, including the eel-tailed catfish (*Tandanus tandanus*), silver perch (*Bidyanus bidyanus*), trout cod (*Maccullochella macquariensis*) and Murray cod (*Maccullochella peelii*); however, these species were collected in patchy, low abundances.

Evidence of newly recruited juvenile cohorts following the environmental water release during October to December 2014 (Rounds 2 and 3 of sampling) was apparent for a number of species, including Australian smelt, carp-gudgeon, Murray cod, un-specked hardyhead, flatheaded gudgeon, eel-tailed catfish, Murray–Darling rainbowfish and common carp. To examine recruitment in more detail, seven species representing three reproductive life-history guilds (periodic, equilibrium and opportunistic) were selected for analysis of spatial and temporal variation in recruitment through daily age analysis. The classification of these species to the varying reproductive life-history guilds was based on the expected associations between reproduction and river flows. From daily aging, back-calculated hatch dates of small individuals of each target species were examined in relation to hydrological parameters, including water temperature and river discharge. This was to identify if hatch dates/spawning coincided with a specific feature of the hydrograph (i.e. environmental water releases).

The successful recruitment of Murray cod was almost entirely constrained to Zone 2 (Gin Gin to Warren), where the highest abundances of mature Murray cod were captured. The majority of daily aged Murray cod had back-calculated hatch dates between 28 September and 2 December 2014 when water temperatures ranged from 18 to 25 °C. This approximately coincided with the release of environmental water from Burrendong Dam, though some individuals had hatch dates prior to the arrival of environmental water. While this increase in discharge may not have been required to trigger a spawning event, the increased flow may have boosted primary production that facilitated successful recruitment.

Recruitment data for eel-tailed catfish indicate the primary spawning period was between 27 November 2014 and 31 January 2015. This coincides with water temperatures reaching approximately 20 °C and moderate discharge (~300–1,200 ML/day). It is commonly recognised that flooding is not required to initiate spawning for this species; however, increased flow as a result of the environmental water release may have boosted primary production and subsequently facilitate successful recruitment.

No juvenile golden perch or silver perch were sampled within the Macquarie River during the three rounds of sampling between August 2014 and April 2015. It is recognised that significant flow events are required to trigger spawning within these species. It is likely that there were no flow events within the Macquarie River during the 2014/2015 study period that were large enough to cue spawning or result in successful recruitment of juveniles.

Juvenile bony bream were primarily caught downstream of the Macquarie Marshes during Round 1 of sampling. The majority of daily aged bony bream had back-calculated hatch dates between 13 June and 7 July 2014. This coincided with water temperatures of approximately 13 °C and simultaneous flow events within both the Macquarie Marshes and Barwon River. It is hypothesised that juvenile bony bream emigrated from the Macquarie Marshes or Barwon River where they were spawned during a flow event into Zone 4, downstream of the Macquarie Marshes. These findings add significant information to existing literature on the biology of bony bream; extending the known breeding season and highlighting a relationship between flow and recruitment.

Juvenile recruitment of common carp was most prolific within the Macquarie Marshes (Zone 3) and downstream of the Macquarie Marshes (Zone 4). Peaks in hatch date frequency were associated with the leading edge of flow pulses and during sustained periods of increased flow. Hatch dates coincided with water temperatures as low as 10 °C during periods of increased flow. Rising river levels likely enhanced spawning activity through the inundation of spawning habitat, such as floodplains or riparian vegetation, and/or enhanced primary production that facilitated successful recruitment.

Small-bodied opportunistic species, including Australian smelt, un-specked hardyhead and Murray–Darling rainbowfish, showed that peaks in hatch date frequencies generally occurred during the receding tails of flow events or during sustained periods of increased flow, particularly in association with the spring/early summer environmental water release of 2014. The specific response of each species is discussed in further detail within the report.

A variable offtake curtain was installed on Burrendong Dam in 2014 to help reduce the impacts of cold water pollution downstream of the dam. Data from the present study indicate successful recruitment occurred during the 2014/2015 watering year in a number of native species within Zone 1, directly below Burrendong Dam. However, low abundances and poor recruitment of Murray cod was observed in Zone 1 compared with Zone 2, approximately 150 km downstream. It is likely the fish community response to the cold water mitigation will manifest over a number of years. Therefore, data from the 2014/2015 sampling will contribute to data that should be collected over a larger temporal scale.

This study details important considerations in the design and data interpretation of recruitment monitoring studies. In addition, it will further contribute to the development of adaptive flow management plans and the increasing body of knowledge required in the effective use of environmental water to benefit native fish communities.

Introduction

The regulation of rivers through the construction of dams, weirs and other diversional structures has altered natural flow regimes and the associated ecological processes for many inland river systems of Australia (Gehrke et al., 1995; Bunn and Arthington, 2002). Typically, the natural flow regimes of dryland rivers are highly variable, with periods of flooding punctuating extended dry periods. The productivity of dryland river and marsh ecosystems is therefore highly dependent on periods of increased flow (Puckridge et al., 1998; Kingsford et al., 1999; Bunn et al., 2006; Arthington and Balcombe, 2011). High flow events and floodplain inundation have been identified as the source and delivery mechanism for basal carbon within riverine ecosystem food webs (Gawne et al., 2007). Flooding also provides habitat, nesting grounds and resources for a range of fauna, including wetland-dependent waterbirds (Kingsford and Johnson 1998), herpetofauna and other aquatic and terrestrial species (Brock, 1998).

Fish are critically dependent on flows. Fish assemblages in dryland rivers have evolved life-history strategies attuned to environmental triggers (Sternberg and Kennard, 2013), particularly flow regimes (Bunn and Arthington, 2002). High flow events provide spawning triggers (Reynolds, 1983), boost primary production that facilitates successful recruitment and provide connectivity between habitats (Balcombe et al., 2006, 2007). Temporal changes in native fish abundances have been shown to respond positively to periods of increased flow (Balcombe and Arthington, 2009). Flow largely influences the range of physical habitat available to fish at a number of life-history stages. Larvae, juveniles and adults have been shown to exploit inundated floodplain habitat (Balcombe et al., 2007; Rolls and Wilson, 2010). Enhanced recruitment of native fish has been associated with periods of increased flow (Balcombe and Arthington, 2009). Balcombe and Arthington (2009) attribute this to food-rich ephemeral environments made available as a result of the inundation of backwater and floodplain habitat. Furthermore, within the main river channel, sediment transport and scouring during high flow events is essential to maintenance of deep pools and the input of large woody debris habitat critical for the persistence of native fish species.

Given the extensive literature detailing the importance of river flow to native fish diversity, abundance and recruitment, the restoration of riverine ecosystems is being addressed by providing environmental flows in regulated systems (OEH, 2013). Enhanced native fish spawning and recruitment have resulted from environmental watering events (King et al., 2010). However, the timing, duration and magnitude of the water delivery events should take into account life-history characteristics of the resident native fish species (King et al., 2003; Rolls et al., 2013; Rayner et al., 2015). Hence, the use of adaptive flow management plans that account for species-specific biological traits could optimise outcomes for native fishes (Baumgartner et al. 2014).

Fish are powerful tools used in ecological assessment of aquatic environments (Harris, 1995). Fish have been used as an indicator of aquatic ecosystem health in several large river health monitoring programs in south-eastern Australia (Davies et al., 2010). Advantages associated with this include: i) fish are relatively long-lived and mobile, reflecting both short- and longer-term and local- to catchment-scale processes; ii) they occupy higher trophic levels within aquatic ecosystems and, in turn, express impacts on organisms at lower trophic levels; iii) they are relatively easily and rapidly collected and can be sampled non-destructively; iv) they are typically present in most waterbodies; and v) the biological integrity of fish assemblages can be easily assessed and interpretation of indicators is relatively intuitive. Further, as fish have a high public profile, with significant recreational, economic and social values, they foster substantial public interest (MDBC, 2004).

Flows within the mid Macquarie River, Macquarie Marshes and lower Macquarie River are affected by the flow regulating activities of Burrendong Dam. A number of smaller fish passage barriers also exist on the main river channel (Rayner et al., 2008) and within its floodplains

(Steinfeld and Kingsford, 2013). River regulation has led to a significant reduction in the long-term average annual flows reaching the Macquarie Marshes (Ren and Kingsford, 2011). Furthermore, cold water pollution as a result of a deep-water offtake from Burrendong Dam has significantly affected biological processes of fish for up to 300–400 km downstream (Astles et al., 2003). During summer, thermal stratification within the dam can exceed >10 °C (Astles et al., 2003). The release of this cold, sometimes anoxic hypolimnetic water can affect growth, survival, redistribution, activity and recruitment of native fish species (Astles et al., 2003; Todd et al., 2005) and in some cases can lead to the complete loss of non-tolerant fish species (Todd et al., 2005). Mitigation measures for cold water pollution below Burrendong Dam involved retrofitting a submerged curtain to the existing offtake to increase discharge temperatures. It is likely the fish community response to the cold water mitigation will manifest over a number of years. Therefore, data from the 2014/2015 sampling will contribute to data that should be collected over a larger temporal scale.

During the 2014/2015 water year, 28,483 ML of (Commonwealth and NSW) environmental water was delivered from Burrendong Dam down the Macquarie River to meet the water requirements of the inner floodplain vegetation of the Macquarie Marshes and support native fish in the Macquarie River. In relation to fish, the water was expected to provide access to suitable fish habitat, promote fish movement and provide cues for spawning, recruitment and migration of native fish. The delivery of the water was to be linked to a natural timing trigger (5,000 ML or more over a 3-day period at Baroona Gauging Station) between 15 August and 5 October 2014. However, this natural timing trigger did not eventuate. Consequently, the water was released from Burrendong Dam on 5 October 2014. An additional 9,337 ML of Commonwealth environmental water was approved to provide a second peak for native fish if there was a trigger of 3,000 ML over 3 days at Baroona while environmental releases were underway. However, this second trigger did not eventuate so no additional water was provided. In addition to the in-stream effects, it was expected that the volume of 28,483 ML would support the inundation of approximately 5,000 hectares of semi-permanent wetland vegetation in the South and North Marshes subsystems, including reedbeds, some water couch/mixed marsh areas and some inner river red gum woodlands.

Aspects of native fish diversity, abundance, reproduction, growth, survival and dispersal were identified by Gawne et al. (2013) as priority indicators relevant to monitoring outcomes of environmental flow delivery. Few studies have examined the response of fish to environmental watering within the Macquarie River system (Growns and Gehrke, 2005; Rayner et al., 2009, 2015). In the present study, aspects of these processes were monitored to examine the response of fish to environmental flow delivery in the mid and lower Macquarie River during the 2014/2015 watering year. Short-term expected responses to the environmental water delivery investigated in this study included increased recruitment of native fish species and an increase in native fish condition (Figure 1). Continued monitoring of these fish communities over time will provide information to assess additional long-term outcomes which align with the CEWO Environmental Outcomes Framework (Figure 1).

Figure 1 Environmental Outcomes Framework (CEWO, 2013).

Basin Plan Objectives	Basin Outcomes		5 year Expected Outcomes	1 year Expected Outcomes	*Related Cause and Effect Diagram (Reference only)*
Biodiversity (Basin Plan S. 8.05)	Ecosystem diversity				*Landscape Ecosystem Diversity*
			• Species diversity		*Within Ecosystem Diversity*
	Species diversity	Vegetation	• Vegetation diversity		*Landscape Vegetation Diversity*
				• Reproduction • Condition	*Vegetation Condition and Reproduction*
			• Growth and survival	• Germination • Dispersal	*Vegetation Recruitment and Extent*
		Macroinvertebrates	• Macroinvertebrate diversity		*Within Ecosystem Macroinvertebrate Diversity*
		Fish	• Fish diversity		*Landscape Fish Diversity*
				• Condition	*Fish Condition*
				• Larval abundance • Reproduction	*Fish Reproduction*
			• Larval and juvenile recruitment		*Fish Larval Growth and Survival*
		Waterbirds	• Waterbird diversity		*Landscape Waterbird Diversity*
			• Waterbird diversity and population condition (Abundance and Population structure)	• Survival and condition	*Waterbird Survival and Condition*
				• Chicks	*Waterbird Reproduction*
				• Fledglings	*Waterbird Recruitment and Fledging*
		Other vertebrate diversity		• Young	*Other Vertebrate Reproduction*
			• Adult abundance		*Other Vertebrate Growth and Survival*
Ecosystem Function (Basin Plan S. 8.06)	Connectivity			• Hydrological connectivity including end of system flows	*Hydrological Connectivity (including end of system flows)*
				• Biotic dispersal and movement	*Biotic Dispersal*
				• Sediment transport	*Sediment Transport*
	Process			• Primary productivity (of aquatic ecosystems)	*Primary Production*
				• Decomposition	*Decomposition*
				• Nutrient and carbon cycling	*Nutrient and Carbon Cycling*
Resilience (Basin Plan S. 8.07)	Ecosystem resilience		• Population condition (individual refuges)	• Individual survival and condition (Individual refuges)	*Individual Refuges*
			• Population condition (landscape refuges)		*Landscape Refuges*
				• Individual condition (Ecosystem resistance)	*Ecosystem Resistance*
			• Population condition (Ecosystem recovery)		*Ecosystem Recovery*
Water quality (Basin Plan S. 9.04)	Chemical			• Salinity	*Salinity*
				• Dissolved oxygen	*Dissolved Oxygen*
				• pH	*pH*
				• Dissolved organic carbon	*Dissolved Organic Carbon*
	Biological			• Algal blooms	*Algal Blooms*

Methods

Study sites

The Macquarie River below Burrendong Dam was partitioned into four spatially, geomorphologically and hydrologically distinct zones at the landscape scale. Analysis of riverine fish assemblages and decapod crustaceans was undertaken within each of the four catchment zones. The delineation of the zones is detailed below and displayed in Figure 2. Five sampling sites within each of the four zones were selected from pre-existing, randomly chosen sampling locations (Astles et al., 2003; Growns and Gehrke, 2005; Davies et al., 2008; Gilligan et al., 2010) or new, randomly selected sampling locations (Appendix 3). Due to difficulties in selecting an appropriate unregulated control river system based on similarity in fish diversity/abundance and abiotic river characteristics, fish community sampling was constrained to the Macquarie River.

Zone 1: Macquarie River Burrendong Dam to Dubbo

This zone is a ~100 km stretch of river below Burrendong Dam to Dubbo. Due to earlier cold water pollution from a deep-water offtake in Burrendong Dam, it contains relatively low abundances of a number of native species (Astles et al., 2003). Sampling within this zone presented an opportunity to quantify the benefits of: 1) the environmental water delivery; and 2) mitigation measures of cold water pollution and the effects on the depleted native fish assemblage.

Zone 2: Macquarie River Gin Gin to Warren

This zone is a ~100 km stretch of river above the Macquarie Marshes, between Gin Gin and Warren. Native fish species within this zone are in relatively higher abundance than in adjacent sampling zones. However, species diversity and abundance have been negatively impacted by cold water pollution (Astles et al., 2003).

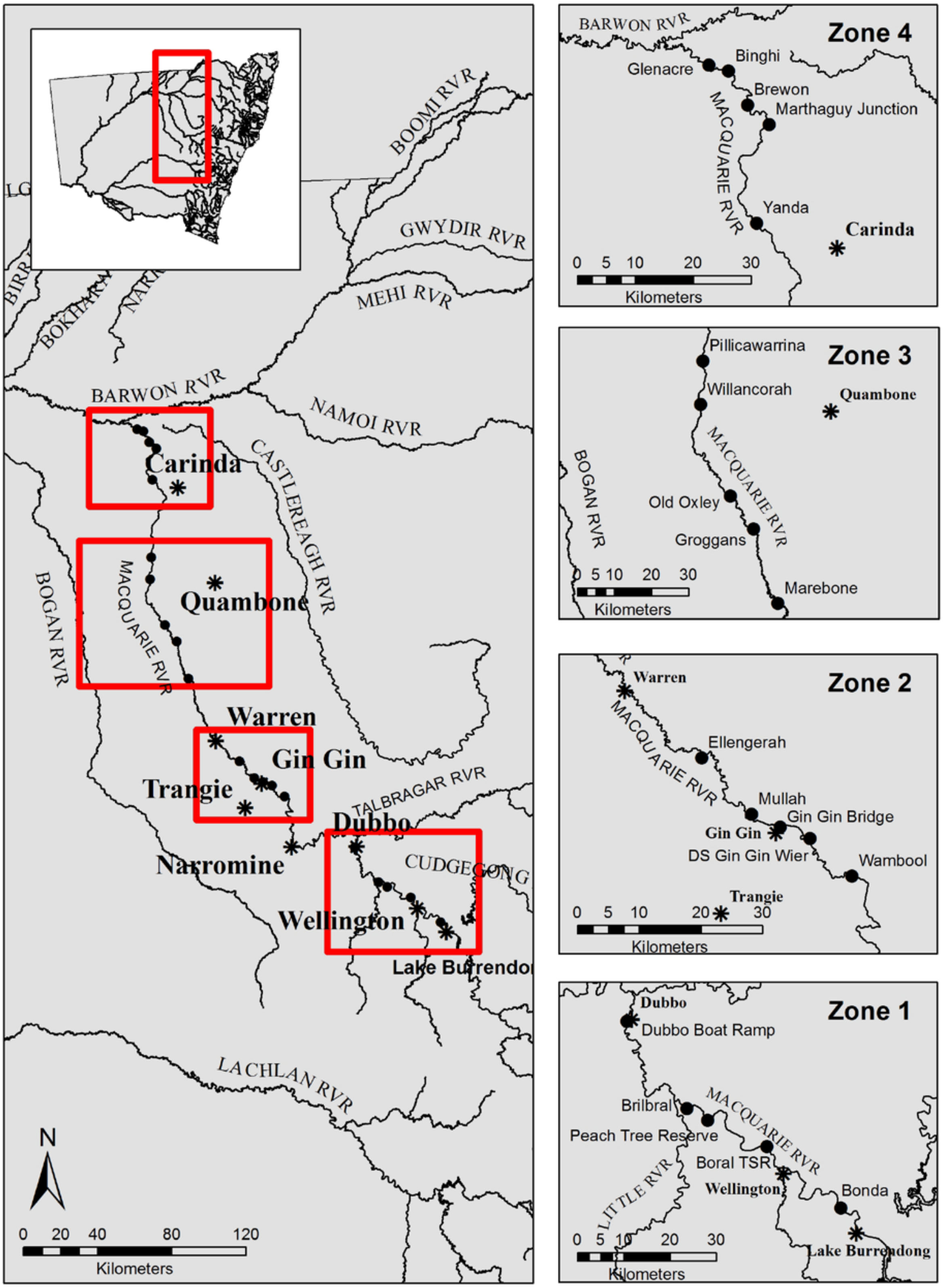
Zone 3: Macquarie Marshes

This complex wetland system is fundamentally different to the main channel zones. It is dominated by ephemeral wetlands that retain water for limited periods during flow events. The 28,483 ML of environmental water was expected to support the inundation of approximately 5,000 hectares of semi-permanent wetland vegetation in the South and North Marshes subsystems, including reedbeds, some water couch/mixed marsh areas and some inner river red gum woodlands. The five fish community sampling sites within the Macquarie Marshes were constrained to the main Macquarie River channel due to access limitations and water availability of the ephemeral wetlands.

Zone 4: Lower Macquarie River (below the Macquarie Marshes)

This is a ~100 km stretch of river below the Macquarie Marshes, between Bells Bridge and the Barwon River confluence. As no substantial tributary inputs accompanied the 5 October environmental water release, the flow did not reach Zone 4. During Round 1 of sampling (September 2014), the Macquarie River downstream of the Marthaguy Creek confluence was flowing at approximately 77 ML/day and provided connectivity to the Barwon River. During Round 2 (December 2014), only small puddles remained at two of the five sampling sites while the remaining sites were completely dry (Appendix 2, Plates 2.16b–2.20b). And during Round 3 (April 2015), the Macquarie River had not flowed since late October 2014 and the pools at each site had been completely dry since January 2015 (J. Ellis and F. Masman, property owners, pers. comm.). However, a ‘domestic and livestock’ water delivery diverted to Bulgeraga Creek and the North Marsh Channel at Marebone Regulator (see Appendix 7) had recently (approximately 1–2 days prior) restored flows to 23 ML/day at two of the five study sites (flow recorded at Carinda Gauging Station), though this flow had not yet reached the lower three sites in Zone 4 during Round 3 of sampling (April 2015).

**Figure 2	Location of sample sites within each of the four sampling zones on the Macquarie River.**



Note: Sample site coordinates are provided in Appendix 3.

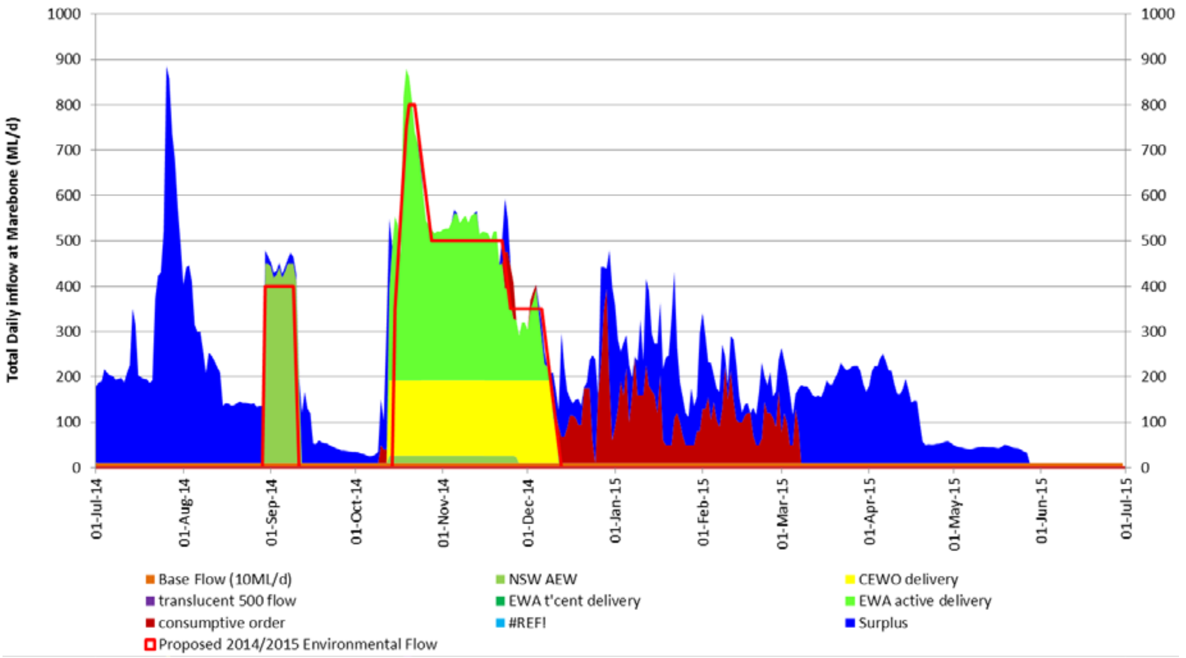
Monitoring timing

Managed environmental flows in 2014/2015 were separated into two events, being:

- a September piggyback flow into the Eastern Marshes of 5,299 ML, delivered in response to a stock and domestic replenishment flow into this subsystem (Figure 3)
- a flow to the Southern and Northern Marshes that was released from Burrendong Dam on 5 October 2014 and reached Marebone on 13 October 2014 in the absence of a prescribed tributary flow trigger. This flow (28,483 ML) continued until 12 December 2014 at Marebone (Figure 3).

Sampling at all sites within Zones 1–3 (five sites per zone) was conducted on three occasions associated with the October 2014 flow event. The first round of sampling (Round 1) was conducted in August/September 2014, prior to the 5 October environmental water release. The second round of sampling (Round 2) was conducted ~60–75 days after the flow peak had passed through each zone (December 2014/January 2015). Round 2 of sampling was conducted to quantify a recruitment/immigration response of fish to the environmental water release. The final round of sampling (Round 3) was conducted in March/April 2015 to quantify the final outcome of recruitment of the fish assemblages at the end of the breeding season. Sampling within Zone 4 (below Macquarie Marshes) was constrained due to varying water availability during sampling rounds. During Round 1, all five sites within Zone 4 were sampled; however, during Rounds 2 and 3, only two sites were sampled on each occasion (Appendix 3).

Figure 3 Flows past Marebone Weir from 1 June 2014 to 28 May 2015 by water source.



Note: NSW AEW = New South Wales Annual Environmental Water; CEWO = Commonwealth Environmental Water Office; EWA = Environmental Water Allowance.

Source: Macquarie–Cudgegong Water Resource Area Annual Environmental Watering Plan.

Monitoring protocol

Sampling followed the standard methods for riverine fish as specified by the Sustainable Rivers Audit (SRA) and detailed in Appendix 1. However, given the priority outcomes of the short-term monitoring involved investigating the response of fish condition, reproduction and recruitment to environmental water delivery, further sampling effort was required to achieve minimum sample sizes for target species (see section: 'Fish recruitment'). Consequently, the following additional protocols and augmentations were conducted:

- The individual weight and length of all 'large-bodied' species were measured.
- Additional electrofishing effort (outside SRA protocol) was conducted to achieve target sample sizes required for calculation of condition indices (target sample size ≥20 individuals per zone for each large-bodied species). However, individuals captured during the additional sampling did not contribute to the fish assemblage analyses.
- Additional electrofishing effort (outside SRA protocol) and seine netting (6 mm mesh) was performed at selected sites within each zone to supplement catches of young-of-year fish and achieve target sample sizes. For large-bodied species, a target of 50 individuals within each zone to a maximum of 130 mm total length (TL) were retained for daily aging. For small-bodied species, 50 individuals within each zone covering the entire size range of the species were retained for daily aging. A pilot aging study was conducted to determine 'maximum length cut-offs' (the approximate maximum fish length for which daily aging was feasible) for juveniles of each species retained for daily aging. Specimens were euthanased and frozen rather than preserved in ethanol to prevent sample shrinkage (Smith and Walker, 2003a).
- Ten replicate baited opera house traps were set as per the SRA unbaited shrimp traps to generate catch per unit effort (CPUE) data on decapod crustaceans (yabbies and shrimps).
- Water quality parameters stratified by depth (surface and 1 m intervals) were collected at each of the sites. Water quality measurements recorded included temperature, dissolved oxygen, pH, turbidity and conductivity. These data were supplemented by New South Wales (NSW) Office of Water gauging station data.

Analytical methodology

Fish community composition

The catch from each electrofishing operation and bait traps for each sampling event per site was pooled for analysis. Multivariate analyses of the fish assemblage composition were performed in PRIMER 7.0 (Plymouth Marine Laboratory). To compare spatial and temporal variation in the fish community composition, species abundances were transformed to the fourth root with the addition of a 'dummy' variable after shade plot inspection. Similarities between fish assemblages for each sample were calculated using a Bray–Curtis similarity matrix (Bray and Curtis, 1957). Non-metric multi-dimensional scaling (nMDS, PRIMER v7) ordination plots were constructed for visual comparisons of dissimilarity between community composition for factors of zone and sampling event based on the Bray–Curtis similarity matrix.

Permutational analysis of variance (ANOVA)/multivariate ANOVA (MANOVA) (PERMANOVA, PRIMER v7; Anderson, 2001) was used to test for any significant differences in the fish community composition between zones and sampling rounds.

Coherence plots were constructed to group species that were functionally similar between sampling sites. These were constructed using an index of association resemblance measure where a cluster analysis and similarity profile analysis (SIMPROF) test was performed on the variables/species. In addition, a RELATE test was used to examine for linearity in change of the community composition along a riverine gradient. To do so, multivariate patterns in species abundance from Zone 1 through to Zone 4 were compared against a serial resemblance matrix. A rank correlation was then performed and compared with results from randomly permuted samples.

Using the SRA data analysis methodology described by Robinson (2012), eight fish metrics were derived from the data collected during Round 3 of sampling. These metrics were then aggregated to produce three fish condition indicators. These indicators were then aggregated to derive an overall Fish Condition Index (ndxFS). The SRA-derived indicators were: 1) expectedness (provides a comparison of existing catch composition with historical fish distributions); 2) nativeness (an indicator of the dominance of native versus exotic fish in the assemblage); and 3) recruitment (an indicator of the extent of native fish recruitment within the zone). Indicator scores were scaled between 0 and 100 and were condition rated as 'extremely poor' (0–20), 'very poor' (21–40), 'poor' (41–60), 'moderate' (61–80) and 'good' (81–100).

Fish health and condition index

Length and weight data collected for Murray cod, golden perch, common carp and bony bream during each sampling event were used in the calculation of a 'condition index' for each fish. Established length/weight relationships for each species (MDBC, 2004; NSW Department of Primary Industries (DPI), unpublished data) were used to estimate the 'expected weight' of individuals based on their length. The relative body condition of each individual was calculated as: recorded weight divided by expected weight

Values >1 indicate better-than-average condition, while values <1 indicate poorer-than-average condition relative to established length–weight relationships in NSW. Changes in the mean body condition for each species were analysed using parametric univariate ANOVA using zone (n = 4) and sampling event (n = 3) as factors. To examine pairwise comparison a Tukey's HSD (honest significant difference) test was performed.

In addition, using rapid visual assessment for parasites and disease (SRA protocol; see Appendix 1), the proportion of fish of each species affected by a health condition was calculated.

Fish recruitment

Fish sampling

Juvenile specimens for daily age determination were collected during each of the three sampling rounds using the standardised methodology described in 'Monitoring protocol' and Appendix 1, and additional measures, as detailed in 'Monitoring protocol', for the construction of growth functions. Seven species representing three reproductive life-history guilds (periodic, equilibrium and opportunistic) were selected for analysis of spatial and temporal variation in recruitment during the 2014/2015 watering year. The classification of these species to the varying reproductive life-history guilds was based upon the expected associations between reproduction and river discharge (Schiller and Harris, 2001; Growns, 2004; Zeug and Winemiller, 2008). Species from similar reproductive guilds are predicted to respond to environmental variation, including flow variation, in similar ways (Humphries et al., 1999). The current study examined the recruitment response of the following species during the 2014/2015 watering year:

- periodic species—golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*), bony bream (*Nematalosa erebi*), common carp (*Cyprinus carpio*), spangled perch (*Leiopotherapon unicolor*)
- equilibrium species—Murray cod (*Maccullochella peelii*) and eel-tailed catfish (*Tandanus tandanus*)

- opportunistic species—Australian smelt (*Retropinna semoni*), un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*), Murray–Darling rainbowfish (*Melanotaenia fluviatilis*).

Each of the three reproductive guilds is described in Zeug and Winemiller (2008):

- Periodic strategists have characteristics that are adaptive in environments where resources for larvae and juveniles are patchy in space and time. Species with this strategy usually have contracted breeding seasons synchronised with favourable periods that are relatively predictable between years. Species of this guild are characterised by delayed maturation, high fecundity and large adult size.
- Equilibrium strategists are characterised by greater parental investment per offspring and relatively low inter-annual variation in recruitment. This strategy is proposed to be associated with resource limitation and/or high threat of predation mortality for early life stages.
- Opportunistic strategists have characteristics that allow them to quickly colonise new habitats. Species of this guild are characterised by small adult size, extended breeding seasons and high reproductive output.

Proportion of recruits

The proportion of new recruits within populations was derived using a similar process to that applied to generate recruitment metrics for the SRA (Robinson, 2012). For large-bodied and generally longer-living species (>3 years), an individual was considered to be a recruit if the body length was less than that of a 1 year old of the same species. For small-bodied and generally short-lived species that reach sexual maturity in less than 1 year, recruits were considered to be those individuals that were less than the species' known average length at sexual maturity. The recruitment length cut-offs used for both large- and small-bodied species were derived from existing length-at-age data from scientific literature (see Appendix 5). The proportion of new recruits collected during each sampling was analysed for factors of zones and sampling round using parametric univariate ANOVA.

Otolith processing and daily aging

We employed the methodology described in Stocks et al. (2014) to examine and enumerate daily growth rings in otoliths of juvenile specimens. For all target species, with the exception of common carp, the sagittal otoliths (sagittae) were extracted and mounted on a microscope slide using crystalbond mounting adhesive (Structure Probe Inc., West Chester, Pennsylvania, USA). For common carp, the lapilli were extracted and mounted for aging (Vilizzi and Walker, 1999). Otoliths were polished by hand to the core longitudinally from the proximal surface, or from the dorsal and ventral margins for larger specimens (i.e. Murray cod), on 9 μm lapping film followed by 0.5 μm alumina slurry until daily growth increments became visible. A camera (Q-Imaging, MicroPublisher 5.0 RTV, Canada) attached to a compound microscope collected an image of each otolith examined (for example, see Figure 9). Multiple images were collected throughout the polishing process and the images re-stitched prior to aging due to the varying ring visibility with section thickness between primordium and otolith margins. Sectioned otoliths were viewed under a compound microscope using transmitted light at 25× magnification. Daily rings were counted radially from the primordium to outer otolith edge (see Figure 9) using ImageJ, a digital image analysis program (http://rsb.info.nih.gov/ij/). A 20% re-read of randomly chosen otoliths was used to calculate a coefficient of variation for the two reads using the equation described in Campana (2001).

Recruitment and hydrography

For highly abundant species, a random sample of approximately 50 individuals covering the species' size range were aged. Multiple growth functions were fitted to length-at-age data for each species to assess which model provided the best fit. Linear regressions provided the best fit for length-at-age data of juvenile large-bodied species. On the other hand, von Bertalanffy growth functions were fitted to the length-at-age data of small-bodied species using Equation 1:

$$L_t = L_\infty \cdot (1 - e^{-k(t-t_0)}) \qquad (1)$$

where L_t is the length (mm) at age t (days), L_∞ is the asymptotic length (mm), k is the rate at which the function approaches L_∞ and, t_0 is the theoretical age (days) at length zero.

For large-bodied species, where high abundances of juveniles were caught during the standardised SRA sampling, and for all small-bodied species, fish ages were estimated from length measurements using the derived species growth model equations. Estimates of fish age were not extrapolated beyond the largest fish aged when constructing the growth functions. However, for species where low abundances of juveniles were captured during standardised sampling (i.e. Murray cod, eel-tailed catfish and bony bream), all captured juveniles were daily aged and their hatch dates plotted as detailed above (i.e. no fish ages were estimated from the growth model). Additional sampling effort was performed to increase catches of juvenile Murray cod and eel-tailed catfish (i.e. 6 mm seine hauls for catfish and additional electrofishing time for Murray cod). Consequently, abundance comparisons of hatch date frequency data for Murray cod and eel-tailed catfish are not comparable to other species due to the additional sampling effort performed outside SRA protocol.

The back-calculated hatch dates of young-of-year target species collected during each round of standardised sampling (SRA protocol) was plotted with water temperature and river discharge to identify if hatch/spawning dates coincided with a specific feature of the hydrograph (i.e. the environmental water releases).

Water quality

Water quality parameters for each sample were compared between zones and sampling rounds using multivariate analysis. Data were firstly transformed (log transformation applied to skewed distributions), then normalised and used to construct a Eucladian distance dissimilarity matrix. Non-metric multi-dimensional scaling (nMDS, PRIMER v7) ordination plots were constructed for visual comparisons of dissimilarity between water quality parameters of each sampling zone based upon the matrix. A permutational ANOVA/MANOVA (PERMANOVA, PRIMER v7, Anderson 2001) was used to test for any significant differences in environmental variables with zone and sampling event as factors.

Results

Fish community composition

From three rounds of standardised sampling, 5,307 individual fish and decapod crustaceans were captured from 20 sites on the Macquarie River. In total, 18 species were captured, including 12 native fish species, 4 exotic fish species (plus a hybrid) and 2 native decapod species (Table 1). (Note: freshwater prawns (*Macrobrachium*) and shrimp (Atyidae spp.) were not differentiated, all individuals were combined under the common name 'long-arm prawn' and counted as a single species). In general, native species richness was significantly lower within, and downstream of, the Macquarie Marshes compared with sites sampled upstream of the Macquarie Marshes. The greatest native species richness occurred within Zone 1, where 10 native fish species were caught. The lowest native species richness occurred within Zone 4, where four native species were caught (Table 1). Exotic species richness was similar between all zones, ranging from three to four species per zone (Table 1). When exotic species richness was examined by site, significant zone ($F_{3,42}$ = 3.247, P = 0.031) and sampling round ($F_{2,42}$ = 5.314, P = 0.009) effects were observed, but the interaction term was non-significant ($F_{6,42}$ = 0.549, P = 0.768). Pairwise comparisons of exotic species richness showed a significant difference between Zone 2 and Zone 4 (P = 0.030) and Round 1 and Round 3 (P = 0.006). Native species richness varied little within zones between sampling rounds; however, numerous significant differences were observed between zones (Tables 1 and 2). When examining native species richness for each sample, a significant zone × round interaction term was observed ($F_{6,42}$ = 3.389, P = 0.008). Results of pairwise test comparing: 1) native species richness between zones within each round of sampling: and 2) native species richness between sampling rounds within each zone are displayed in Table 2. Total abundance varied between sampling rounds ($F_{2,51}$ = 4.09, P = 0.022). During Round 1, 65.55 ± 6.74 standard error (SE) individuals were sampled per site; in Round 2, 129.06 ± 20.76 individuals were sampled per site; and in Round 3, 106.00 ± 19.71 individuals were sampled per site.

The proportion of new recruits throughout the Macquarie River increased after the environmental watering (Figure 4). When the proportion of new recruits collected during each sampling was analysed against the factors of zones and sampling round, a significant zone × round interaction term was observed ($F6,42$ = 4.506, P = 0.001). Results of pairwise test comparing: 1) proportion of recruits between zones within each round of sampling; and 2) proportion of recruits between sampling rounds within each zone are displayed in Table 3.

Visual comparison of length frequency compositions within species illustrated variation between zones and sampling rounds (Figure 5). The appearance of newly recruited juvenile cohorts during Rounds 2 and 3 of sampling (post environmental water release) was apparent for the following species: Australian smelt, carp-gudgeon, Murray cod, un-specked hardyhead, flatheaded gudgeon, eel-tailed catfish, Murray–Darling rainbowfish and common carp (Figure 5). The incremental growth in length of dominant cohorts could also be observed between sampling rounds (Figure 5).

Table 1 Total catch by sampling zone and round from standardised fishing (SRA protocol) over the three sampling events.

Common name	Scientific name	Zone 1			Zone 2			Zone 3			Zone 4		
		Round 1	Round 2	Round 3	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3	Round 1	Round 2	Round 3
Silver perch	*Bidyanus bidyanus*				1								
Goldfish	*Carassius auratus*	2	4	7	2		3	26	7	43	7	5	8
Yabby	*Cherax destructor*		1				1	3	5	8	65	11	
Un-specked hardyhead	*Craterocephalus*	2	32	93	1	16	47						
Common carp	*Cyprinus carpio*	126	89	80	70	81	88	146	106	84	121	19	5
Eastern gambusia	*Gambusia holbrooki*	4	159	47		5	36		7	14	11	15	3
Carp–goldfish hybrid							1						
Carp-gudgeon spp.	*Hypseleotris spp.*	4	102	6	1	5	2	9	18	17	33	4	
Spangled perch	*Leiopotherapon unicolor*									1	1	29	3
Golden perch	*Macquaria ambigua*	16	22	18	19	18	30	13	3	4	3	3	
Long-arm prawn	*Macrobrachium australiense &*	9	137	98	3	273	76	67	205	99	52	23	1
Trout cod	*Maccullochella macquariensis*	1											
Murray cod	*Maccullochella peelii*	2	1	9	54	79	81	5	10	4			
Murray–Darling	*Melanotaenia fluviatilis*	51	134	324	56	35	113			14			
Bony bream	*Nematalosa erebi*	1	1				3	18	2	24	48	15	10
Redfin perch	*Perca fluviatilis*			1									
Flatheaded gudgeon	*Philypnodon grandiceps*	60	278	92									
Australian smelt	*Retropinna semoni*	90	181	172	102	49	16						
Eel-tailed catfish	*Tandanus tandanus*	5	4	15	1	1	1						
Total		*373*	*1145*	*962*	*310*	*562*	*498*	*287*	*363*	*312*	*341*	*124*	*30*

Note: In Zone 4 during Rounds 2 and 3 of sampling, only 2 of 5 sites were sampled on each occasion due to the river being dry (see Appendix 3)

Table 2 **Results of Tukey's HSD pairwise comparisons of native species richness between: a) zones within each round of sampling; and b) between sampling rounds within each zone.**

a)

Round 1				
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				
Zone 2				
Zone 3				
Zone 4				

Round 2				
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1			***	
Zone 2			*	
Zone 3				
Zone 4				

Round 3				
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1			*	**
Zone 2			*	**
Zone 3				
Zone 4				

b)

Zone 1			
	Round 1	Round 2	Round 3
Round 1		*	
Round 2			
Round 3			

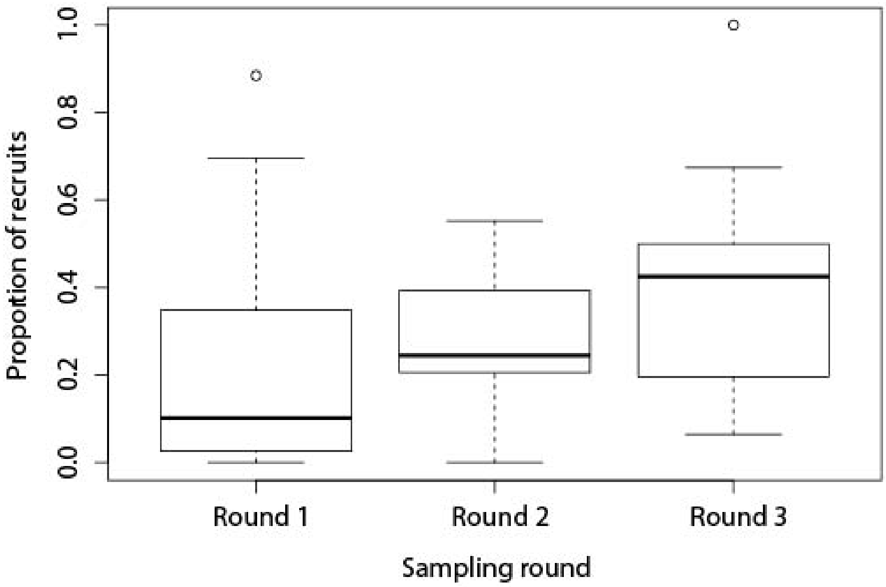
Zone 3			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 2			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 4			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Note: *** = $P < 0.0001$; ** = $P < 0.001$; *= $P < 0.05$; blank = $P > 0.05$; shaded = not applicable.

Figure 4 Box-and-whisker plot illustrating proportion of juvenile recruits captured from standardised fishing (SRA protocol) during each sampling round.



Note: Individuals were classified as new recruits using length thresholds detailed in Appendix 5.

Table 3 Results of Tukey's HSD pairwise comparisons of proportion of recruits between: a) zones within each round of sampling; and b) between sampling rounds within each zone.

a)

Round 1				
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				**
Zone 2				**
Zone 3				**
Zone 4				

Round 2				
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				
Zone 2				
Zone 3				
Zone 4				

Round 3				
	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				*
Zone 2			*	
Zone 3				
Zone 4				

b)

Zone 1			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 3			
	Round 1	Round 2	Round 3
Round 1			**
Round 2			
Round 3			

Zone 2			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 4			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Note: *** = P < 0.0001; ** = P <0.001; *= P < 0.05; blank = P > 0.05; shaded = not applicable.

Figure 5 **Length frequency composition from standardised fishing (SRA protocol) of each species within four sampling zones over three sampling rounds. Lengths are fork length for forked tailed fish and total length for all other species.**

Key: Blue histogram = Round 1 of sampling; Red histogram = Round 2; and Green histogram = Round 3.

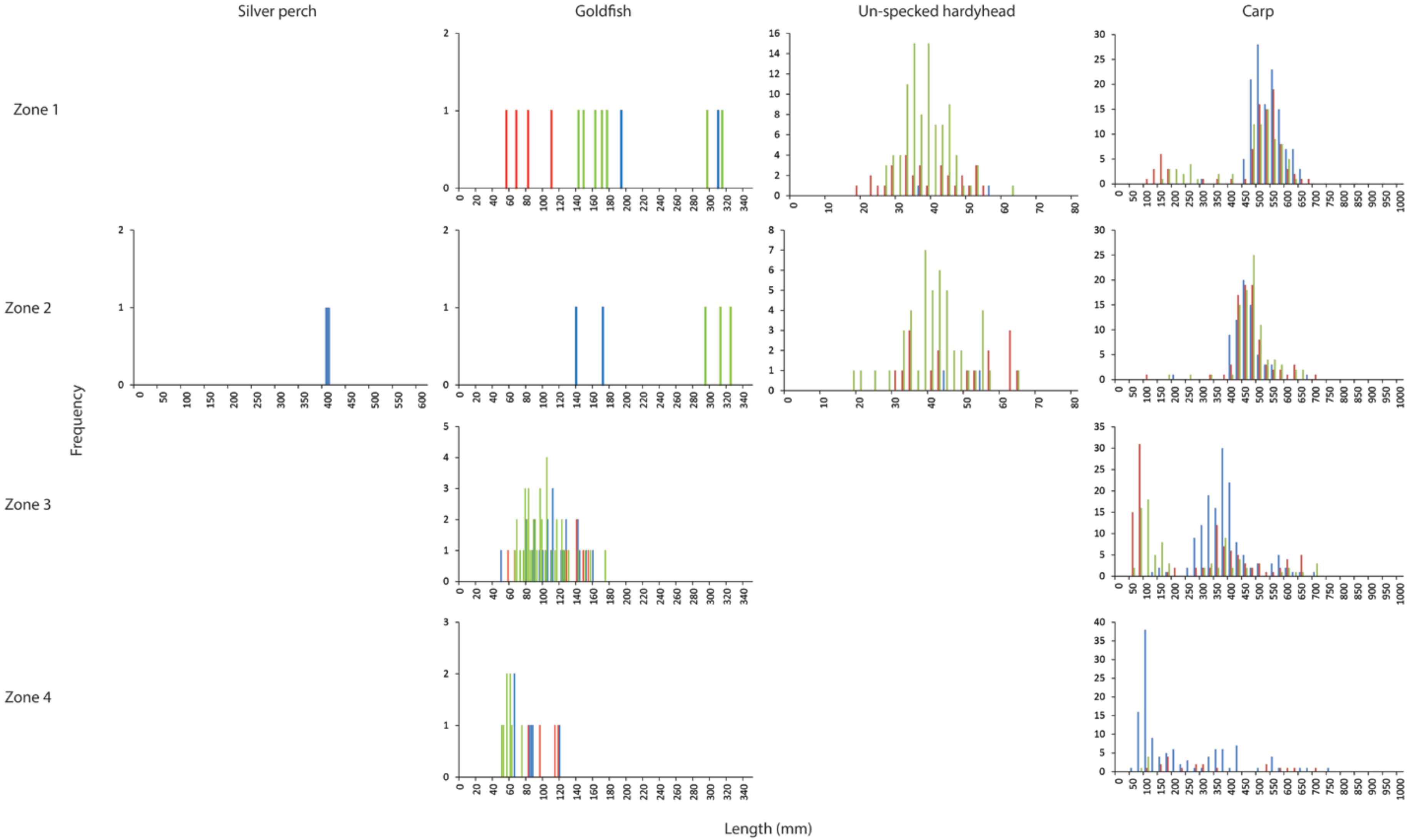


Figure 5 (cont'd). Length frequency composition from standardised fishing (SRA protocol) of each species within four sampling zones over three sampling rounds. Lengths are fork length for forked tailed fish and total length for all other species.

Key: Blue histogram = Round 1 of sampling; Red histogram = Round 2; and Green histogram = Round 3.

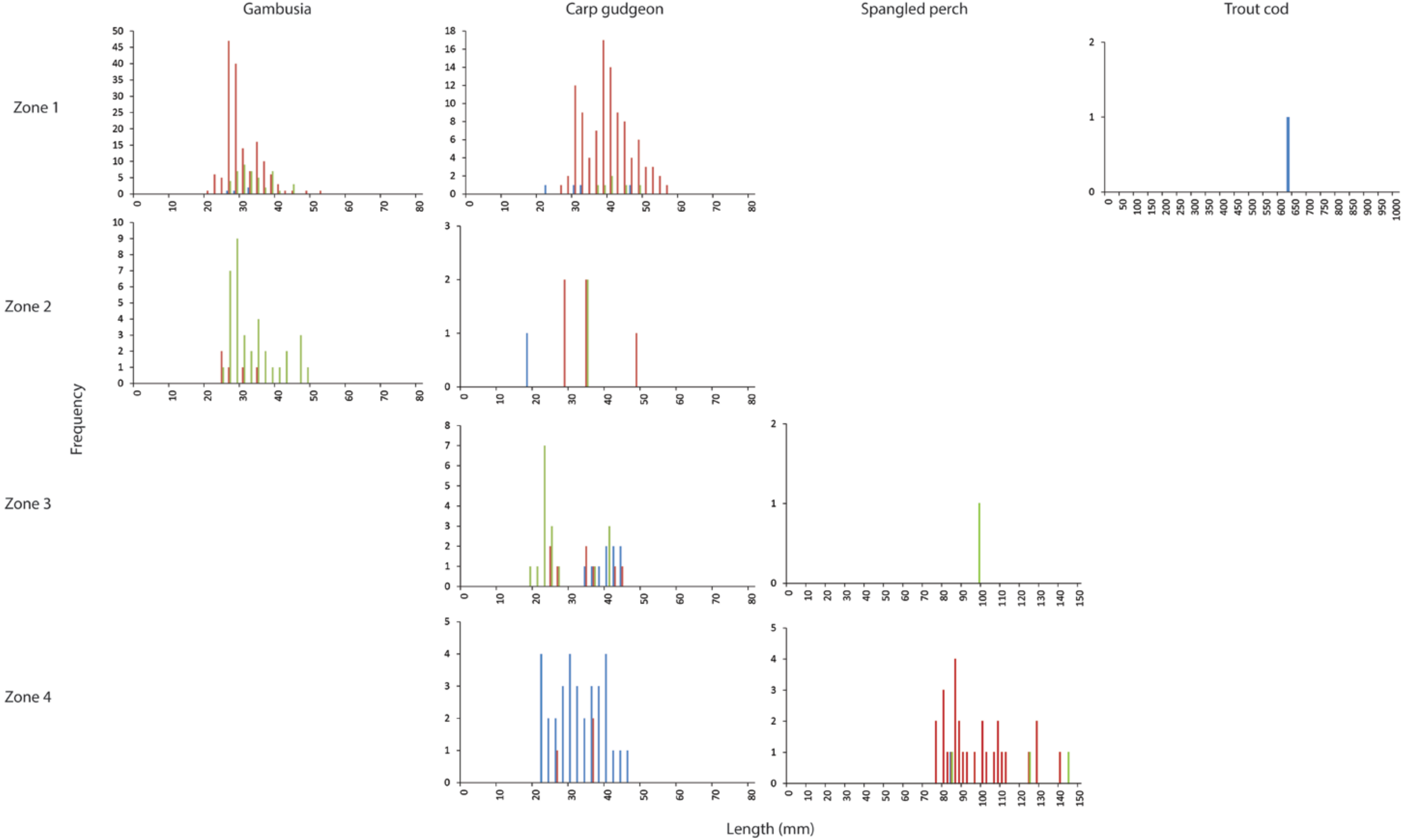


Figure 5 (cont'd). Length frequency composition from standardised fishing (SRA protocol) of each species within four sampling zones over three sampling rounds. Lengths are fork length for forked tailed fish and total length for all other species.

Key: Blue histogram = Round 1 of sampling; Red histogram = Round 2; and Green histogram = Round 3.

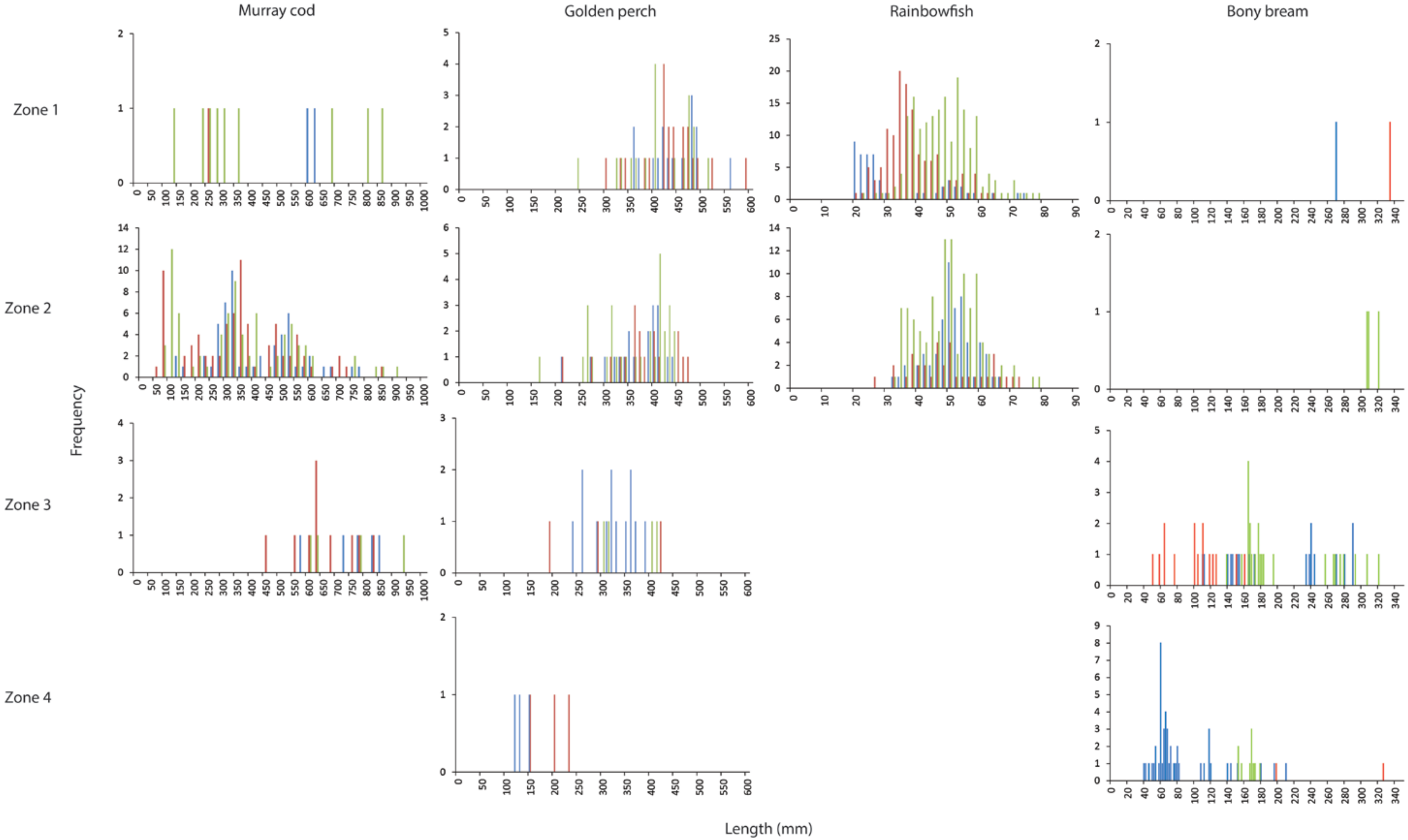
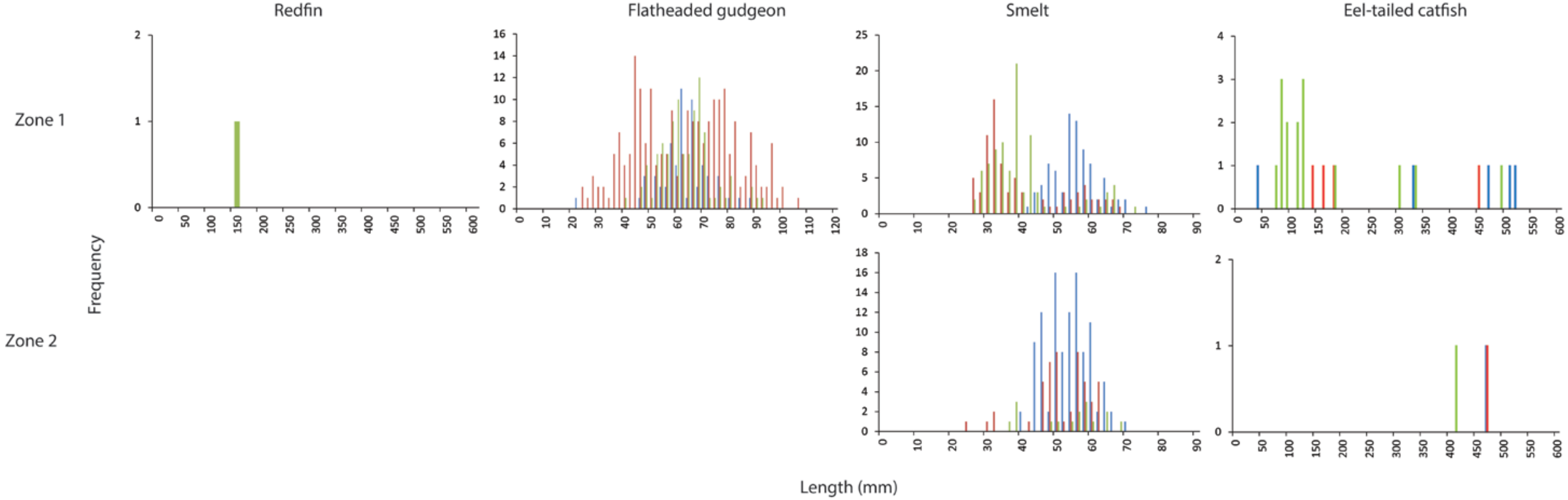


Figure 5 (cont'd). Length frequency composition from standardised fishing (SRA protocol) of each species within four sampling zones over three sampling rounds. Lengths are fork length for forked tailed fish and total length for all other species.

Key: Blue histogram = Round 1 of sampling; Red histogram = Round 2; and Green histogram = Round 3.



The highest score of an SRA indicator occurred within Zone 1 and Zone 2 where 'nativeness' was characterised as 'moderate'. Within all other zones, all indicator scores ranged from 'extremely poor' to 'poor' (Tables 4 and 5). After aggregation of the 'expectedness', 'recruitment' and 'nativeness' indicators, the SRA fish condition index characterised the fish assemblages of Zone 1 and Zone 2 as in 'poor' condition and Zone 3 and Zone 4 as 'extremely poor' condition when benchmarked across the Macquarie catchment management area (Tables 2.4 and 2.5).

Table 4 SRA indicators and overall Fish Condition Index (ndxFS) scores calculated from Round 3 of sampling within the Macquarie River for each sampling site.

Site	Zone	Recruitment	Nativeness	Expectedness	ndxFS
Dubbo Boat Ramp	Zone 1	46.2	67.6	60.2	47.5
Peach Tree Reserve	Zone 1	46.2	37.4	60.2	39.4
Brilbral	Zone 1	46.2	77.6	46.6	44.3
Boral TSR	Zone 1	46.2	70.3	65.0	51.0
Bonada	Zone 1	46.2	61.9	46.6	39.8
Mullah	Zone 2	37.6	87.5	46.6	40.4
Gin Gin Bridge	Zone 2	37.6	81.9	53.1	43.6
Ellengerah	Zone 2	37.6	66.1	46.6	36.8
Wambool	Zone 2	37.6	42.1	46.6	32.6
DS Gin Gin Weir	Zone 2	37.6	71.8	60.2	44.5
Willancorah	Zone 3	4.2	28.3	22.0	3.9
Pillicawarrina	Zone 3	4.2	12.1	14.7	0.5
Marebone	Zone 3	4.2	76.4	22.0	11.4
Groggans	Zone 3	4.2	45.0	33.2	11.6
Old Oxley	Zone 3	4.2	17.6	33.2	5.9
Marthaguy Junction	Zone 4	0.0	67.0	3.6	8.3
Yanda	Zone 4	0.0	0.0	0.1	0.0

Note: Three sites in Zone 4 were not sampled during Round 3 because they were dry (see Appendix 3).

Table 5 Summary table displaying SRA indicators and overall fish index scores calculated from Round 3 of sampling for each zone.

Zone	Recruitment	Nativeness	Expectedness	ndxFS
Zone 1	Poor (46.2 ± 0)	Moderate (62.96 ± 6.87)	Poor (55.72 ± 3.82)	Poor (44.4 ± 2.23)
Zone 2	Very poor (37.6 ± 0)	Moderate (69.88 ± 7.89)	Poor (50.62 ± 2.71)	Poor (39.58 ± 2.21)
Zone 3	Extremely poor (4.2 ± 0)	Poor (35.88 ± 11.58)	Very poor (25.02 ± 3.60)	Extremely poor (6.66 ± 2.16)
Zone 4	Extremely poor (0.0 ± 0)	Poor (33.50 ± 33.50)	Extremely poor (1.85 ± 1.75)	Extremely poor (4.15 ± 4.15)

Note: Categorisation of Sustainable Rivers Audit (SRA) indicator scores are also presented (‘extremely poor’ = 0–20; ‘very poor’ = 21–40; ‘poor’ = 41–60; ‘moderate’ = 61–80; ‘good’ = 81–100); values are presented as averages ± standard error (SE).

Multivariate analysis of fish community composition suggested no significant interaction between sampling round × zone (Table 6a). However, there was a significant main effect for sampling round and zone (Table 6a). Pairwise comparisons indicated the fish community was significantly different between each of the sampling zones and each of the sampling rounds (Tables 6b and 6c, respectively). For visual comparison, nMDS plots display dissimilarity in the fish community composition between sampling rounds and sampling zones (Figures 6 and 7, respectively).

Table 6 Results of a) PERMANOVA test examining fish community composition; b) pairwise comparison of main effect 'round'; and c) pairwise comparison of main effect 'zone'.

a)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Zone	2	29,420	9,806.70	17.638	0.0001	9,918
Round	3	6,144	3,072.00	5.5252	0.0001	9,938
Zone × round	6	2,838.9	473.15	0.8510	0.6729	9,915
Residual	42	23,352	556.00			
Total	53	63,318				

b)

Groups	t	P(perm)	Unique perms
Round 1, Round 2	2.5157	0.0003	9,961
Round 1, Round 3	2.3673	0.0001	9,955
Round 2, Round 3	2.0620	0.0018	9,958

c)

Groups	t	P(perm)	Unique perms
Zone 1, Zone 2	3.4172	0.0001	9,949
Zone 1, Zone 3	4.1919	0.0001	9,941
Zone 1, Zone 4	4.4195	0.0001	9,962
Zone 2, Zone 3	4.8241	0.0001	9,962
Zone 2, Zone 4	6.6195	0.0001	9,945
Zone 3, Zone 4	1.7949	0.0158	9,968

Note: PERMANOVA = permutational analysis of variance (ANOVA)/multivariate ANOVA (MANOVA); df = degrees of freedom; SS = sum-of-squares; MS= mean squares

Figure 6 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity in community composition between sampling rounds.

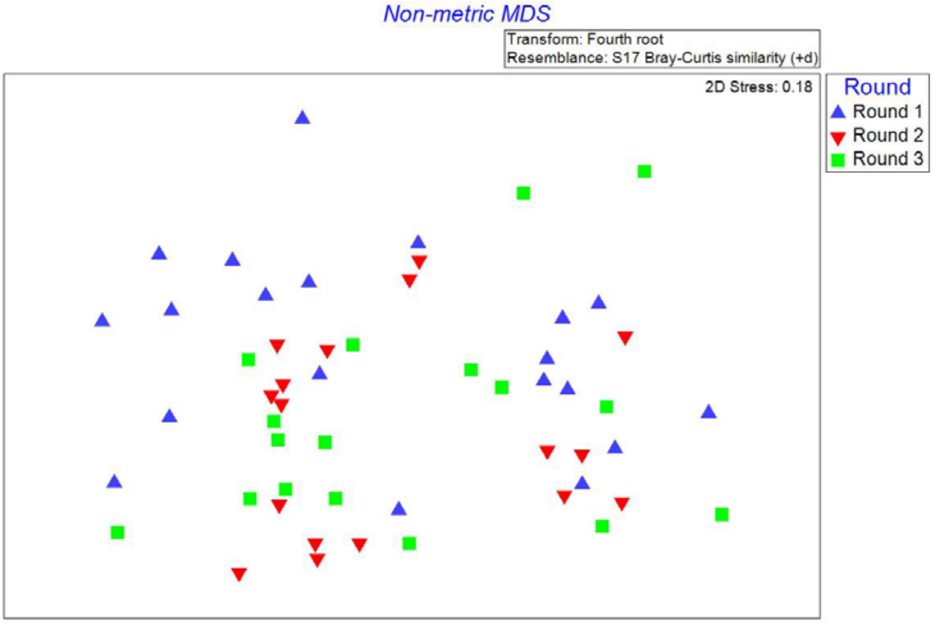
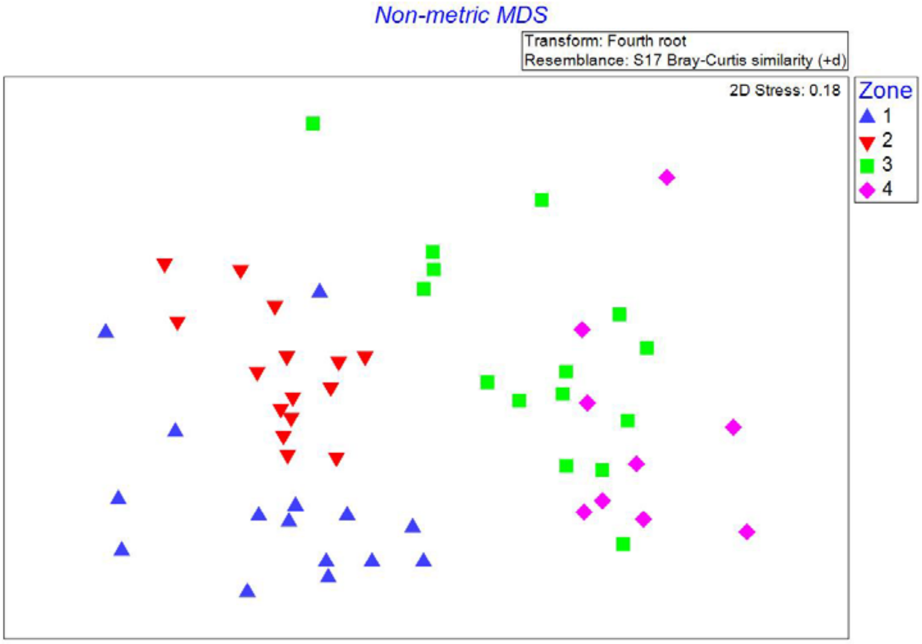


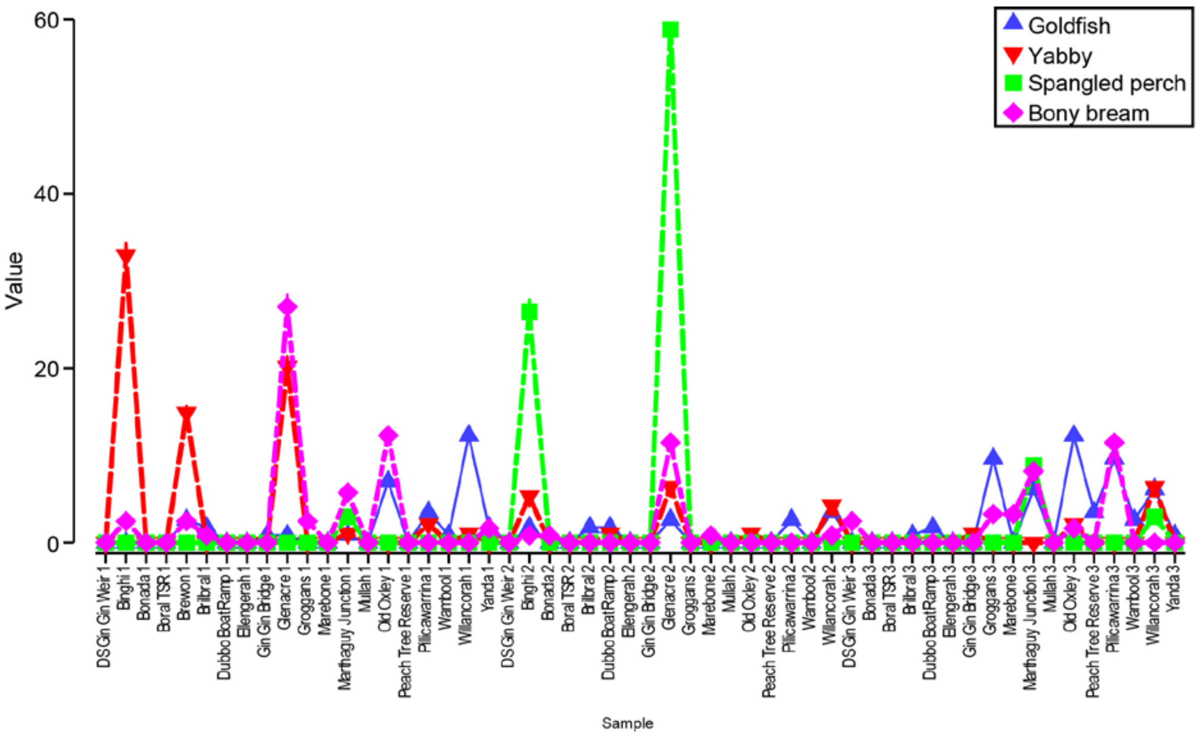
Figure 7 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity in community composition between sampling zones.

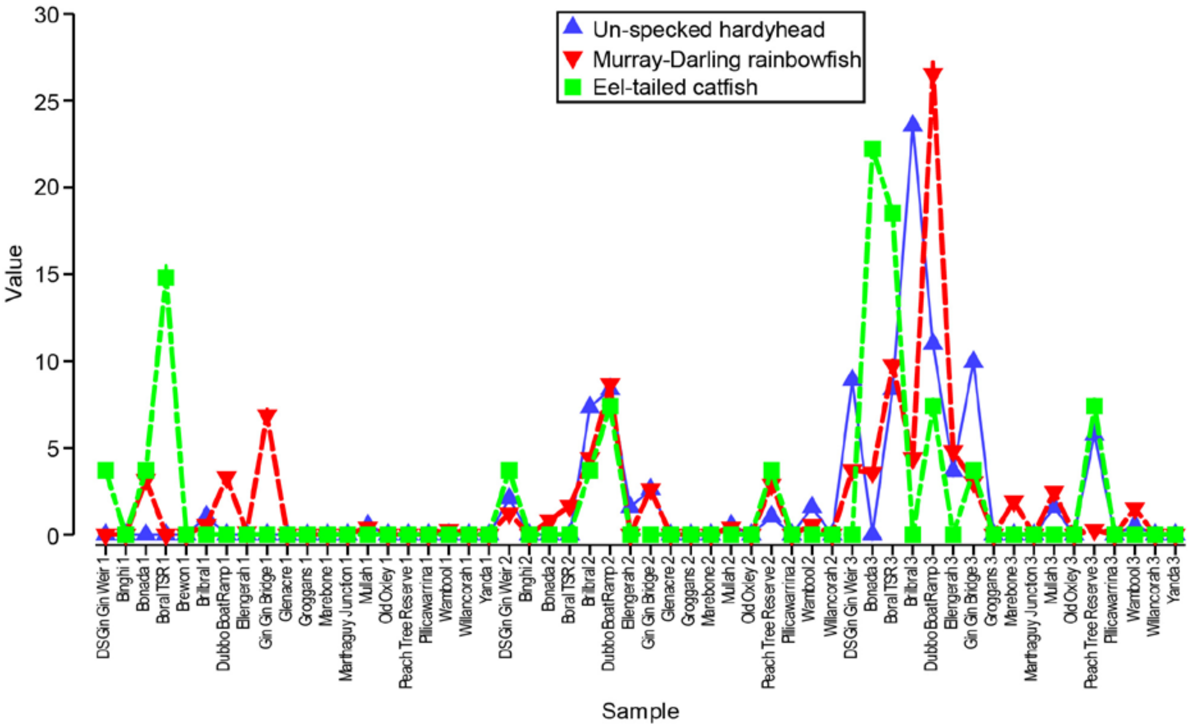


Coherence plots were constructed to distinguish species which were functionally similar between samples. When rare species were excluded, the SIMPROF test identified five groups of functionally similar species, including: 1) goldfish, yabby, spangled perch and bony bream; 2) un-specked hardyhead, Murray–Darling rainbowfish and eel-tailed catfish; 3) flatheaded gudgeon and Australian smelt; 4) common carp, golden perch, long-arm prawn and Murray cod; and 5) eastern gambusia and carp-gudgeon (Figure 8). The RELATE test

(Primer v7) found seriation in the fish community composition along a riverine gradient from Zone 1 through to Zone 4 (*Rho* = 0.333, *p* = 0.001, permutations = 999).

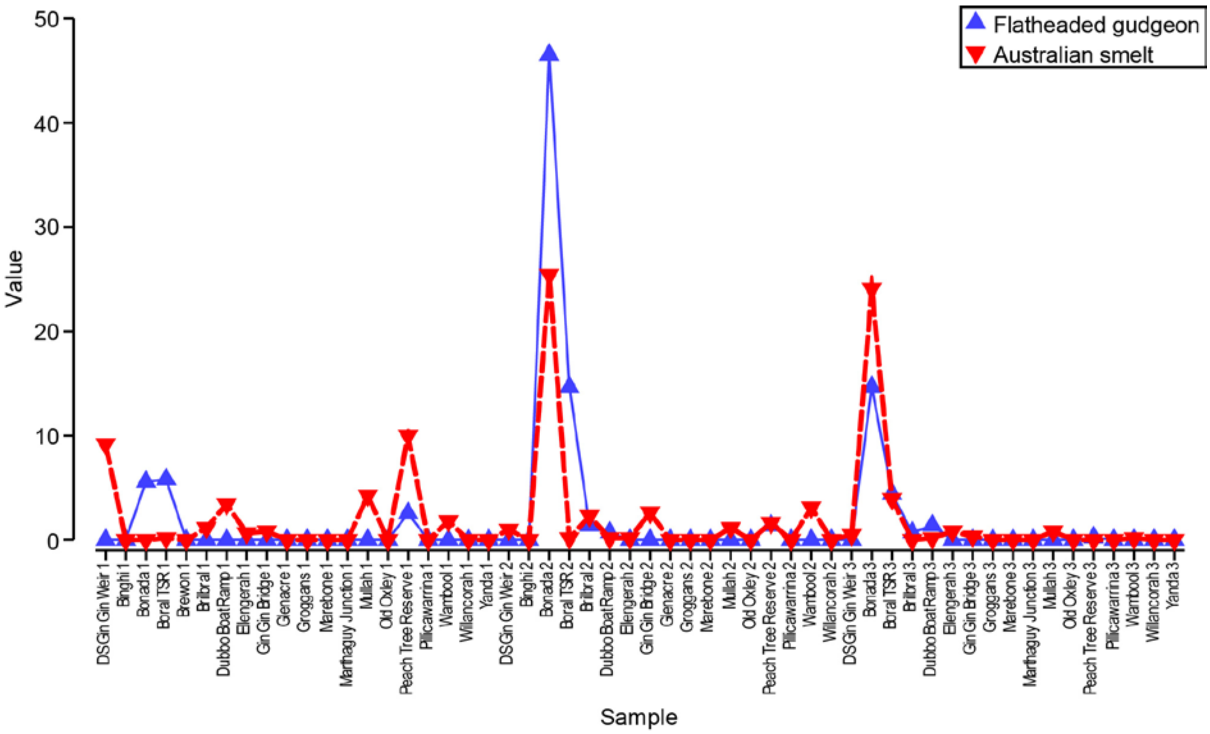
Figure 8 Coherence plots grouping species that exhibited similar patterns in presence and abundance between samples.

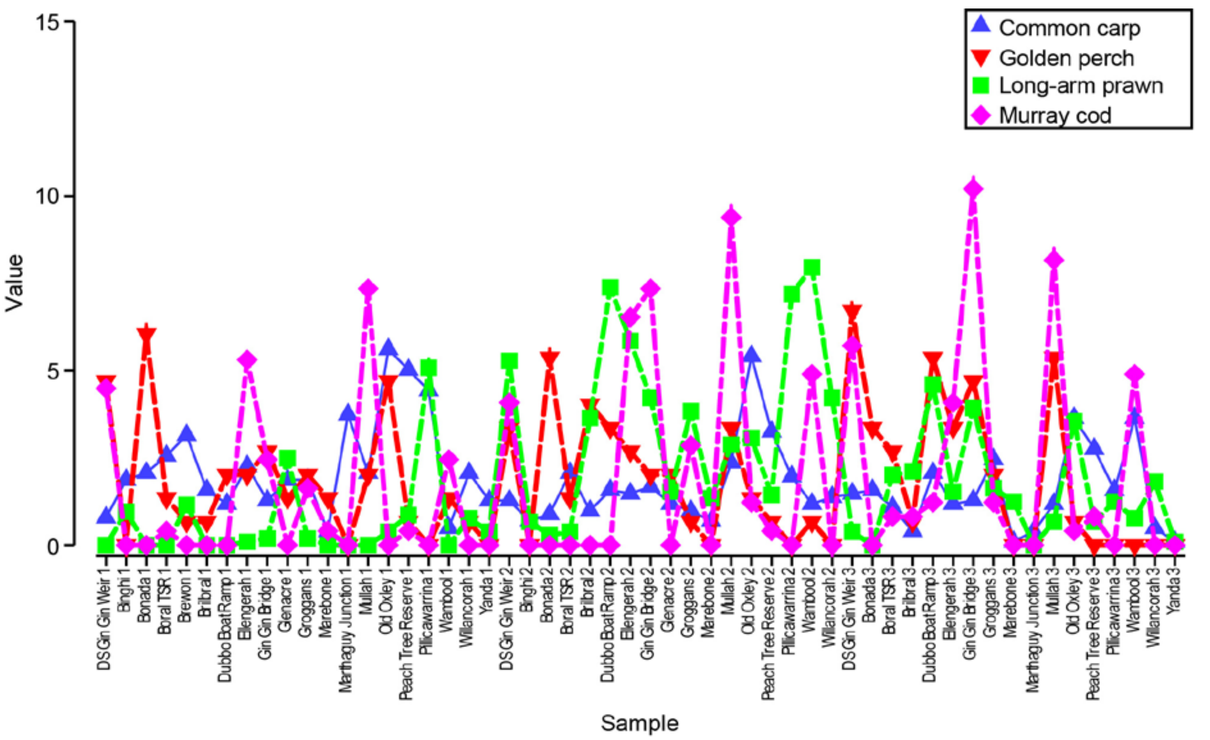




(*continued*)

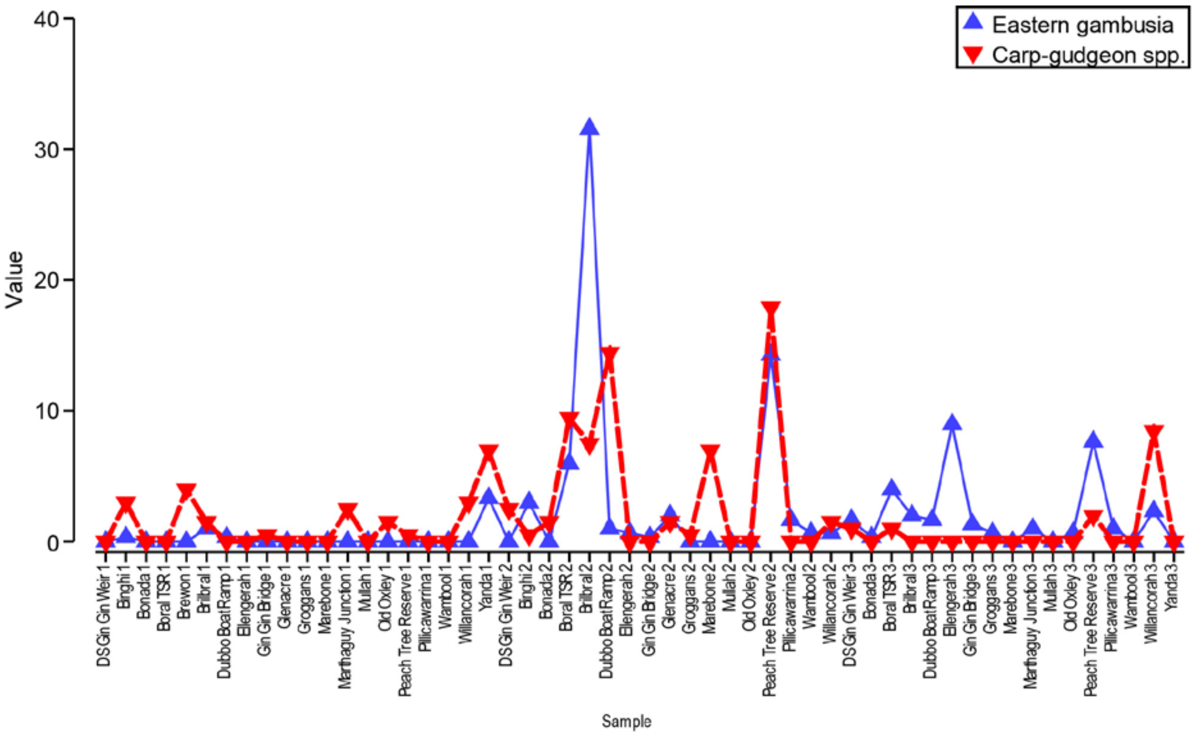
Figure 8 (cont'd). Coherence plots grouping species that exhibited similar patterns in presence and abundance between samples.





(*continued*)

Figure 8 (cont'd). Coherence plots grouping species that exhibited similar patterns in presence and abundance between samples.

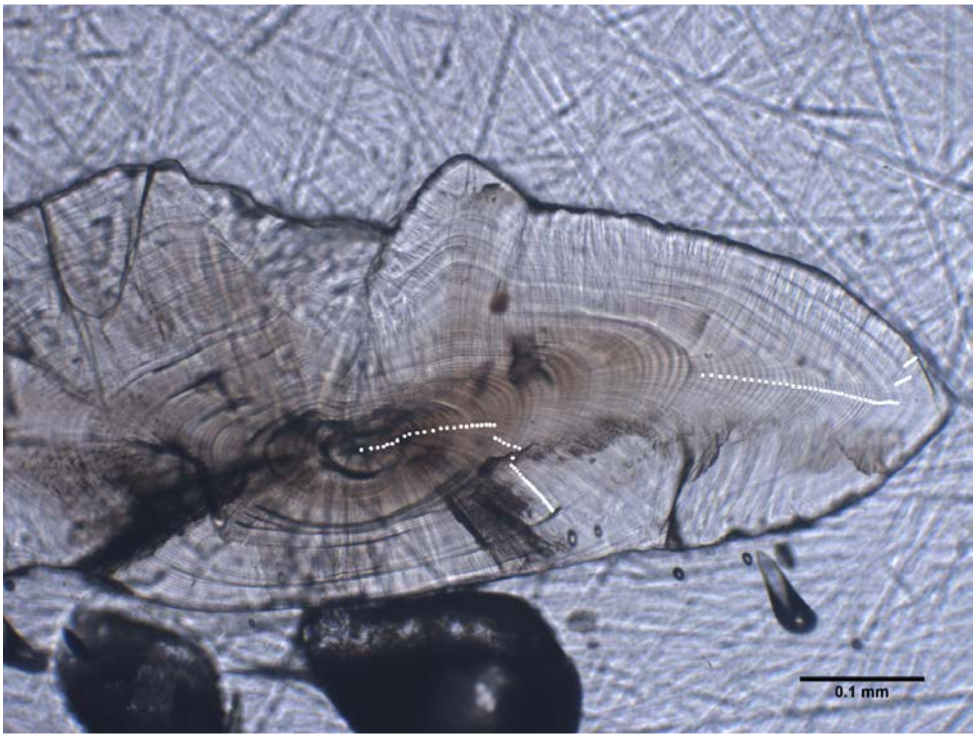


Recruitment and daily aging

Murray cod

All juvenile Murray cod (n = 40, <113 mm TL) collected in Rounds 2 and 3 of the fish community sampling within Zone 2 were daily aged from transverse sections of a sagittal otolith (Figure 9). A 20% re-read of Murray cod otoliths by a second observer yielded a coefficient of variation of 2.12%. A linear growth function fitted to juvenile Murray cod length-at-age data provided the best fit and is detailed in Figure 10. The majority of daily aged fish had back-calculated hatch dates between 28 September and 2 December 2014 with water temperatures ranging from 18 to 25 °C (Figure 11). This approximately coincided with the environmental water reaching Zone 2 on 9 October, though numerous juveniles had back-calculated hatch dates prior to the arrival of the environmental water (Figure 11). Almost all juvenile Murray cod were sampled within Zone 2 during Rounds 2 and 3 of sampling. No juvenile Murray cod were sampled within Zones 3 and 4, while only one juvenile cod (107 cm TL) was caught in Zone 1 during Round 3 of sampling (Figure 5).

Figure 9 Daily aged otolith of a 55 mm total length (TL) Murray cod.



Note: White dots indicate daily growth rings; estimated age of 102 days.

Figure 10 Length-at-age data for Murray cod with growth function fitted.

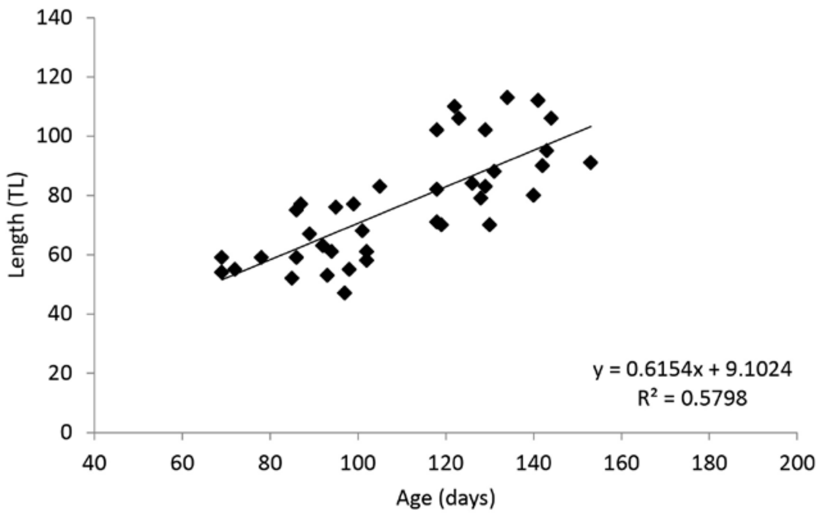
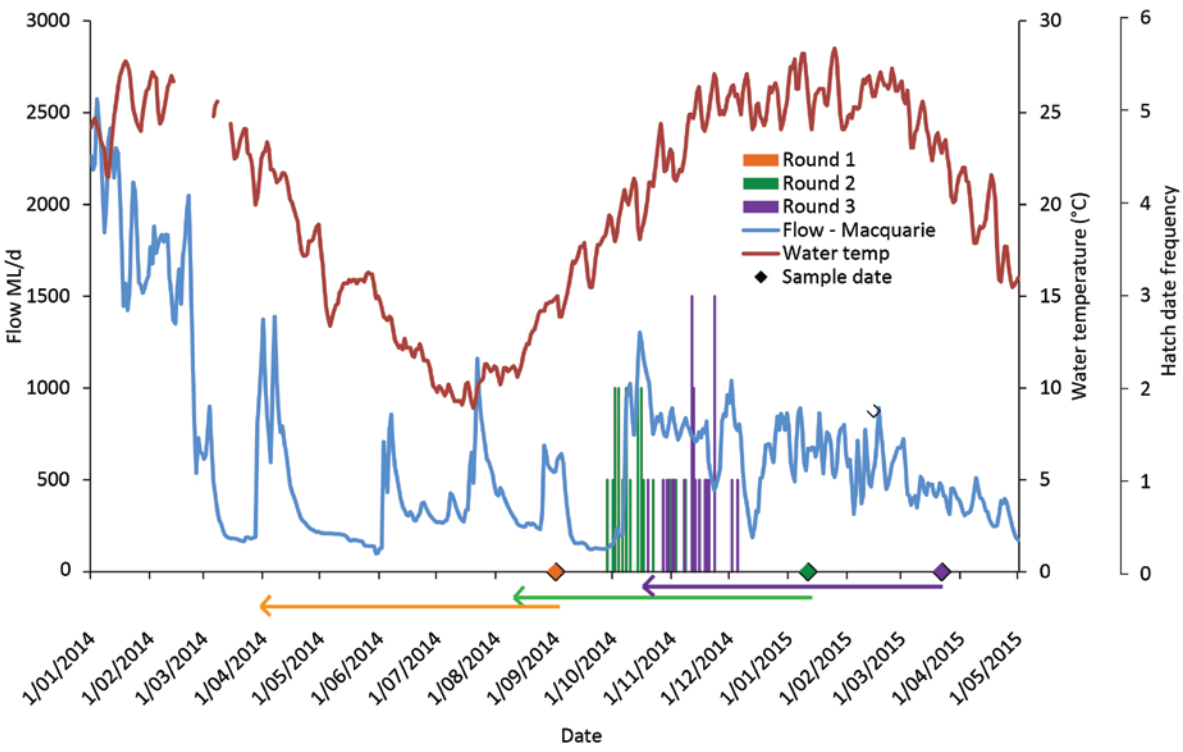


Figure 11 Frequency of back-calculated hatch dates for daily aged juvenile Murray cod sampled from Zone 2 of the Macquarie River over three sampling events.

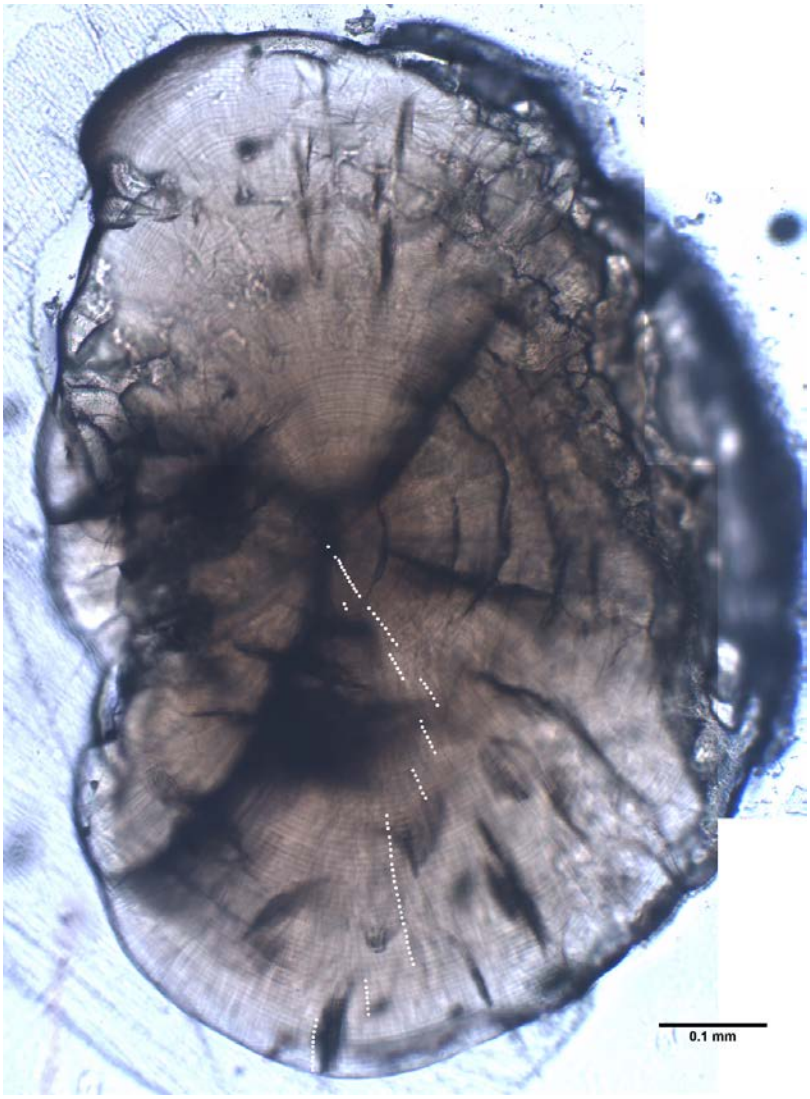


Note: Round 1 = September 2014; Round 2 = January 2015; Round 3 = March 2015; additional sampling effort was performed outside Sustainable Rivers Audit (SRA) protocol. Hydrology and water temperature are displayed (hydrograph data: Gin Gin Gauging Station; water temperature: Baroona Gauging Station). Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event, based upon the maximum size/age to which daily aging was possible. A larger focus period could likely be assigned to Murray cod however no juvenile recruits >153 days old/113 mm TL were sampled during the present study.

Eel-tailed catfish

All juvenile eel-tailed catfish (*n* = 31, <115 mm TL) collected in Round 3 of the fish community sampling within Zone 1 were daily aged from longitudinal sections of a sagittal otolith (Figure 12). A 20% re-read of eel-tailed catfish otoliths by a second observer yielded a coefficient of variation of 2.02%. A linear growth function fitted to juvenile eel-tailed catfish length-at-age data provided the best fit and is detailed in Figure 13. The majority of daily aged fish had back-calculated hatch dates between 27 November 2014 and 31 January 2015. This approximately coincided with water temperatures within Zone 1 reaching 20 °C (Figure 14). Juvenile eel-tailed catfish were exclusively caught within Zone 1, primarily during Round 3 of sampling (Figure 5).

Figure 12 Daily aged otolith of a 74 mm total length (TL) eel-tailed catfish.



Note: White dots indicate daily growth rings; estimated age of 90 days.

Figure 13 Length-at-age data for eel-tailed catfish with growth function fitted.

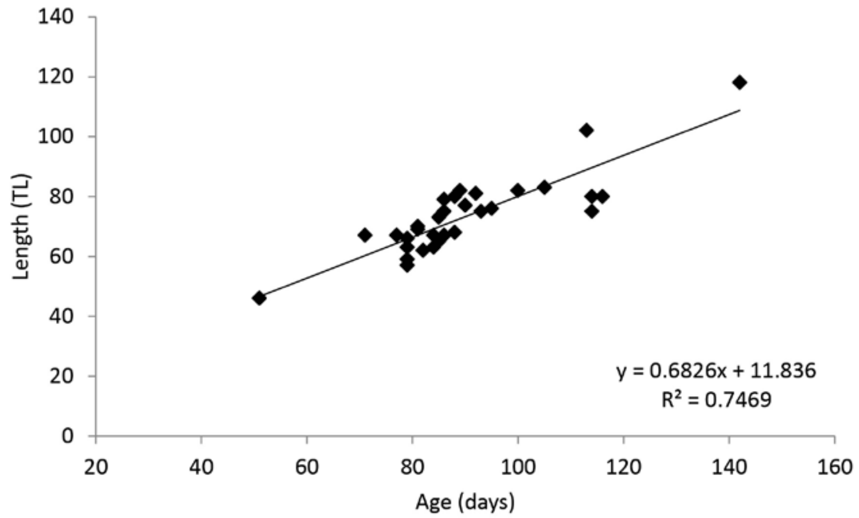
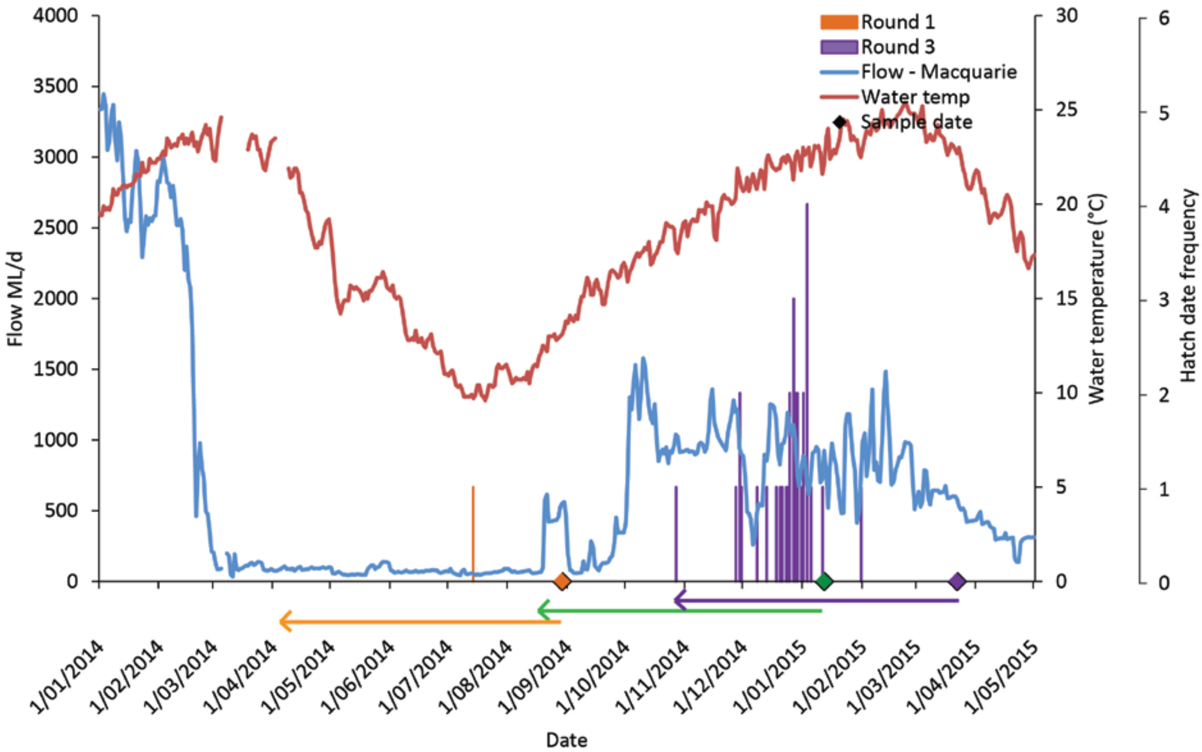


Figure 14 Frequency of back-calculated hatch dates for daily aged juvenile eel-tailed catfish sampled from Zone 1 of the Macquarie River over three sampling events.



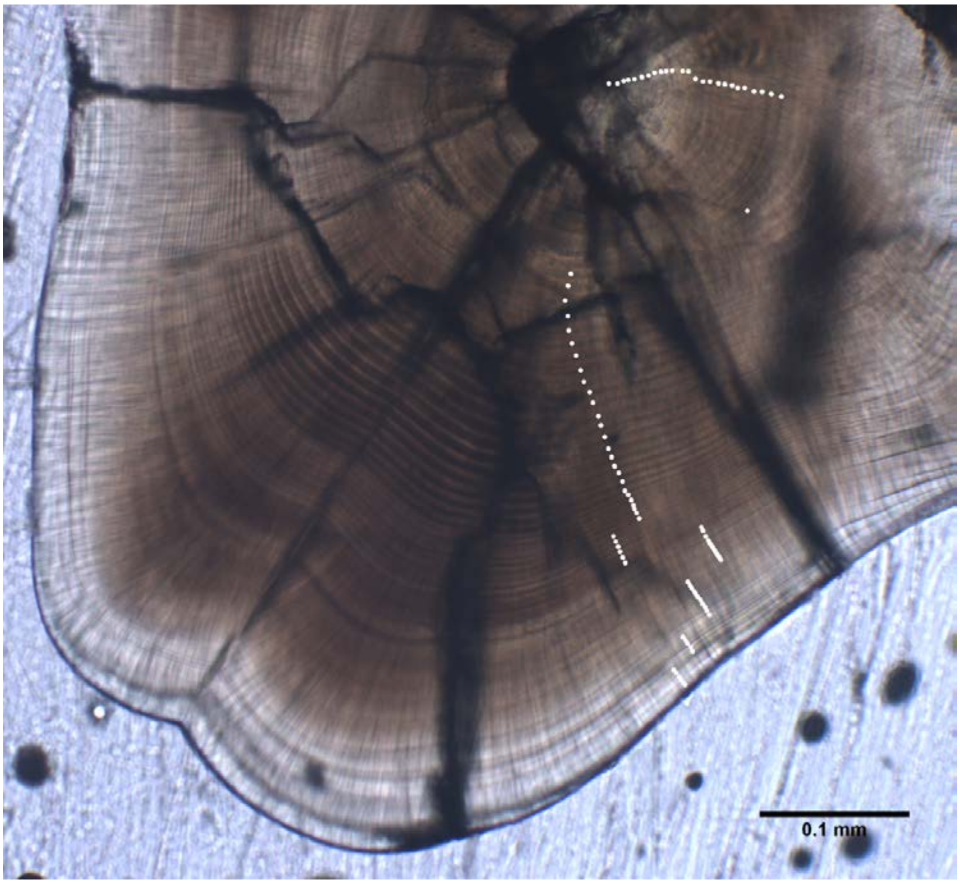
Note: Round 1 = August 2014; Round 2 = January 2015; Round 3 = March 2015; additional sampling effort was performed outside Sustainable Rivers Audit (SRA) protocol. Hydrology and water temperature collected at the 'DS Burrendong' Gauging Station are displayed. Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

Bony bream

All juvenile bony bream (n = 32, <73 mm fork length; FL) collected in Round 1 of the fish community sampling within Zone 4 were daily aged from longitudinal sections of a sagittal otolith (Figure 15). A 20% re-read of bony bream otoliths by a second observer yielded a coefficient of variation of 0.59%. A linear growth function fitted to juvenile bony bream length-at-age data provided the best fit and is detailed in Figure 16. High variability in the growth rates of juveniles was observed, as indicated by the low global R value (R_2 = 0.323). This was of little concern as no fish ages were estimated from lengths using the growth model. Rather all captured juveniles were aged and these data used to construct Figure 17.

The majority of Juvenile bony bream were caught within Zone 4 during Round 1 of fish community sampling (Figure 5). The majority of daily aged fish had back-calculated hatch dates between 13 June and 7 July 2014 (Figure 17). This coincided with water temperatures of approximately 13 °C and a late June 2014 flow pulse in the Macquarie Marshes that was significantly reduced by the time it passed through the Macquarie Marshes and reached Zone 4 (Figure 17). Catches of juvenile bony bream within Zone 4 may therefore be attributed to the downstream dispersal of juveniles from the Macquarie Marshes (Zone 3). Alternatively, the recruitment observed may be associated with the receding tail of a flow event within the Barwon River and a small flow event within the lower Macquarie River that created connectivity between the two river systems (Figure 17).

Figure 15 Daily aged otolith of a 56 mm fork length (FL) bony bream.



Note: White dots indicate daily growth rings; estimated age of 82 days.

Figure 16 Length-at-age data for bony bream with growth function fitted.

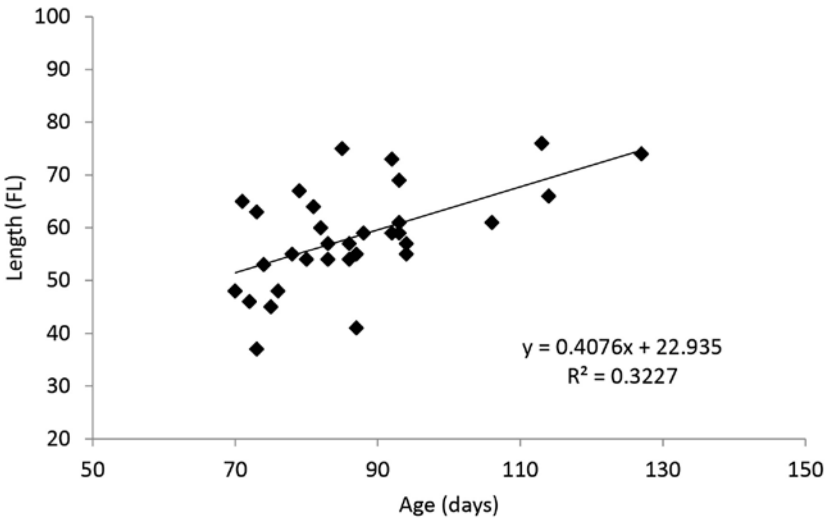
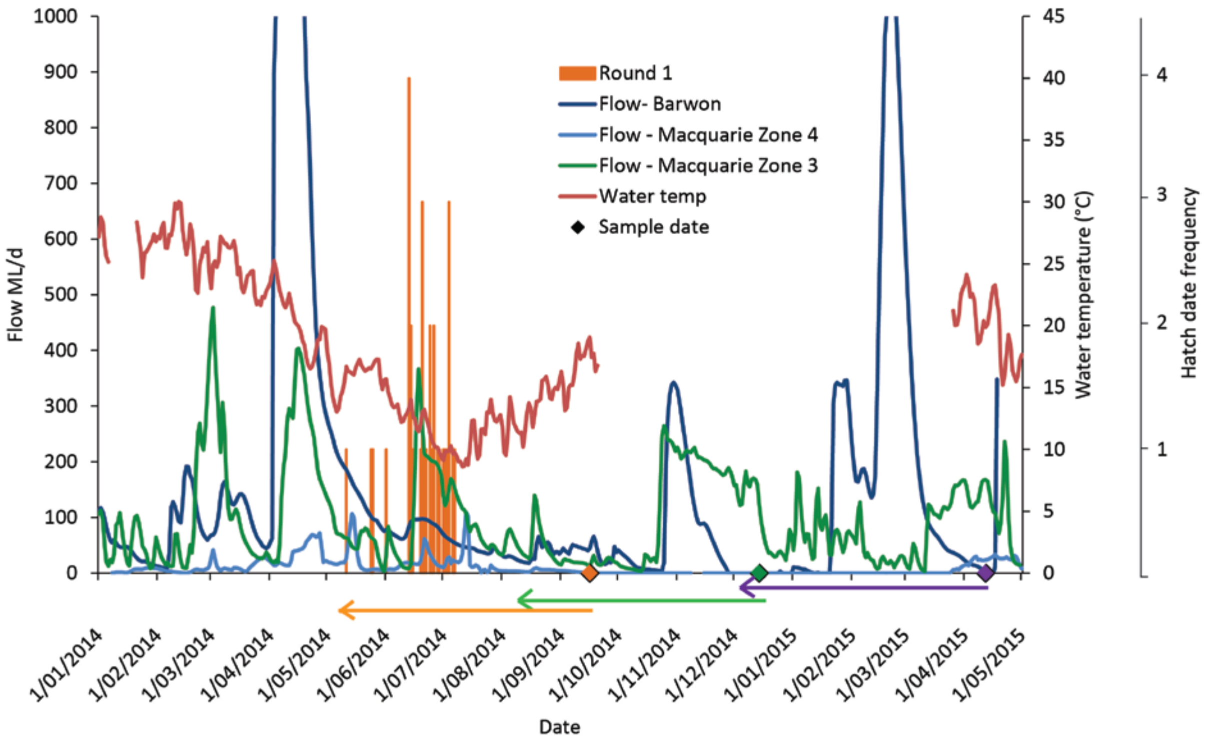


Figure 17 Frequency of back-calculated hatch dates for daily aged juvenile bony bream sampled during standardised fish community sampling (SRA protocol) within Zone 4 of the Macquarie River over three sampling events.

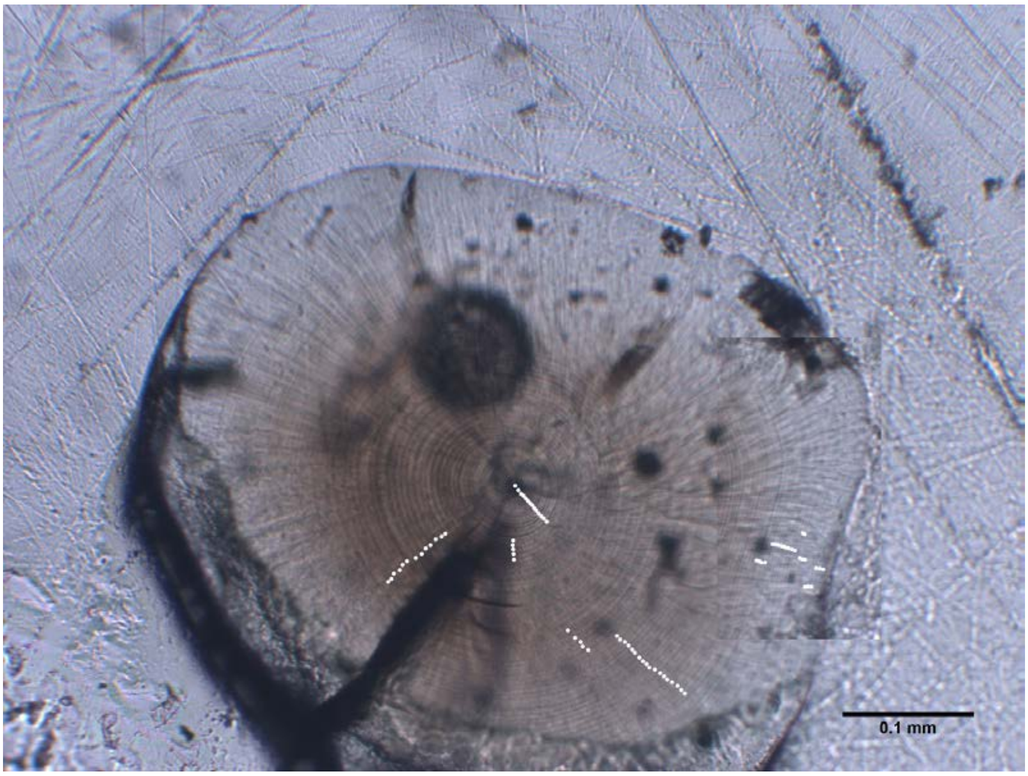


Note: Round 1 = September 2014; Round 2 = December 2014; Round 3 = April 2015; hydrology and water temperature are displayed (hydrograph data for the Macquarie River Zone 3, Macquarie River Zone 4 and Barwon River were collected at Pillicawarrina, Carinda and Geera gauging stations, respectively; water temperature is for Macquarie River at the Carinda Gauging Station. Coloured arrows indicate the ‘focus period’ for each sample. The ‘focus period’ extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

Australian smelt

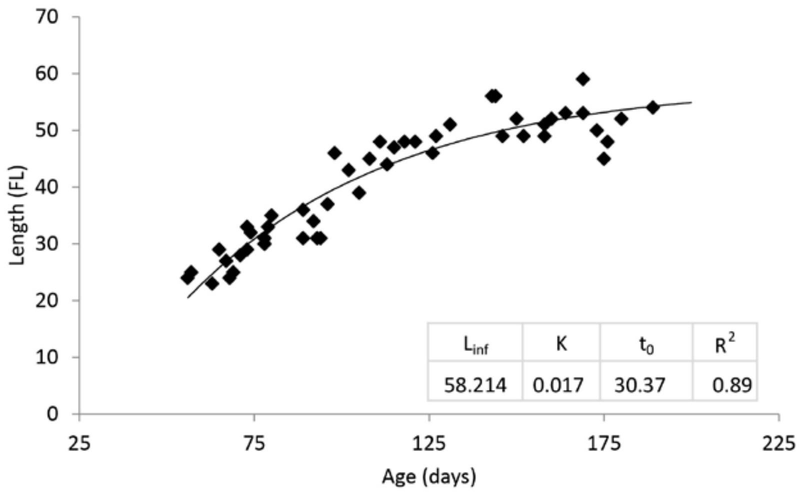
A subsample of 50 Australian smelt (<52 mm FL) collected from Zones 1 and 2 during Round 2 of the fish community sampling were daily aged from longitudinal sections of a sagittal otolith (Figure 18). A 20% re-read of Australian smelt otoliths by a second observer yielded a coefficient of variation of 3.30%. A von Bertalanffy growth function fitted to length-at-age data provided the best fit and is detailed in Figure 19. Back-calculated hatch dates occurred throughout the majority of the study period; however, peaks in hatch dates generally occurred during the receding tails of flow events or during sustained periods of high flow after substantial increases in flow (Figure 20). Australian smelt were caught within Zones 1 and 2 during each of the three rounds of sampling (Table 1 and Figure 5).

Figure 18 Daily aged otolith of a 27 mm fork length (FL) Australian smelt.



Note: White dots indicate daily growth rings; estimated age of 78 days.

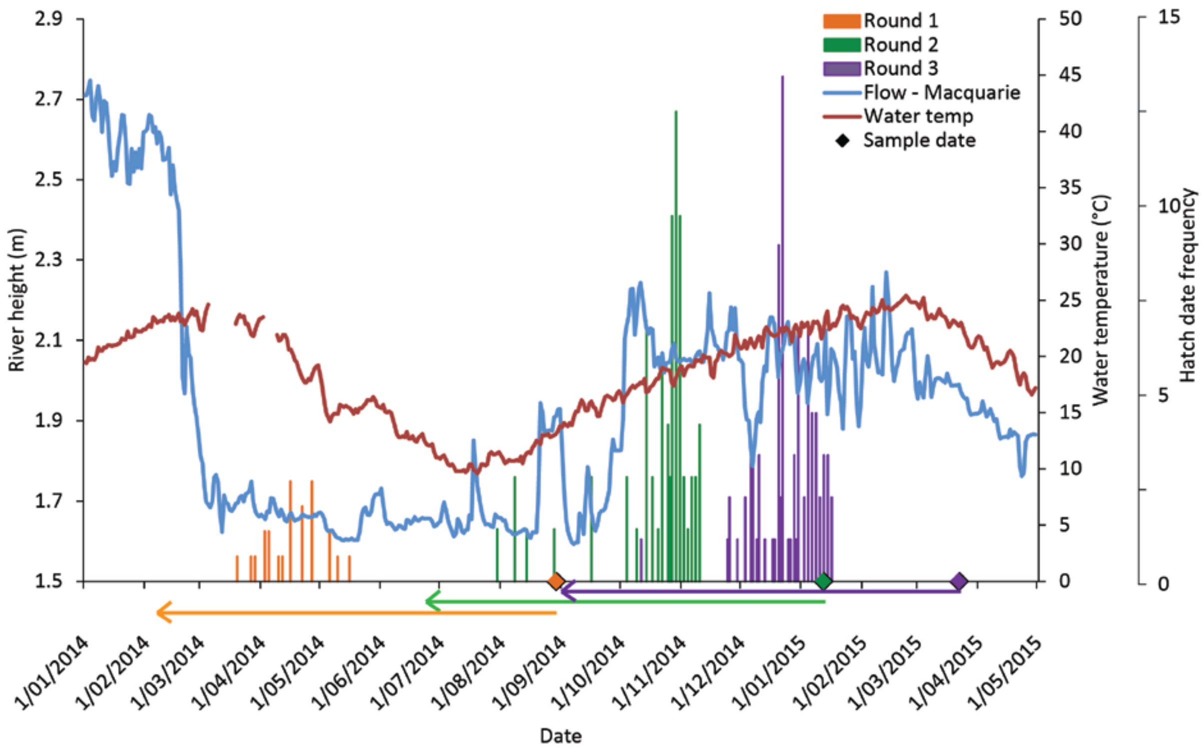
Figure 19 Length-at-age data for Australian smelt with von Bertalanffy growth function fitted.



L_{inf}	K	t_0	R^2
58.214	0.017	30.37	0.89

Figure 20 Frequency of back-calculated hatch dates for daily aged juvenile Australian smelt sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events.

a)

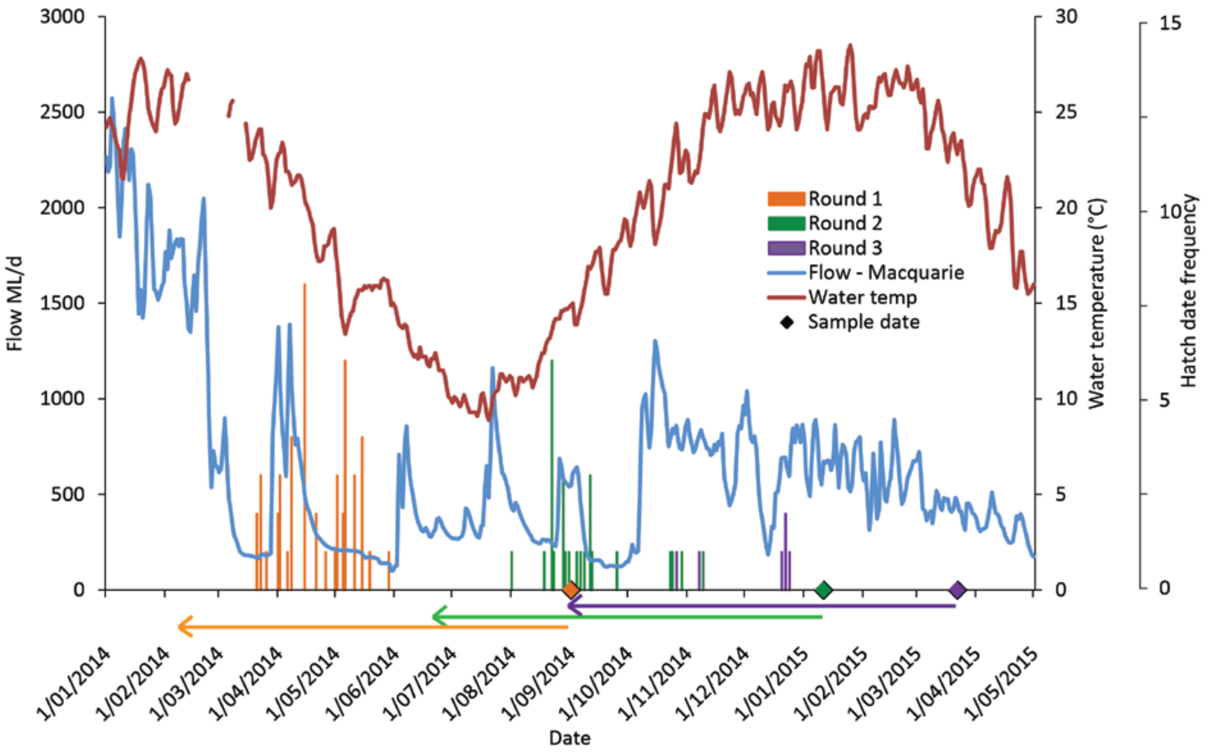


Note: Round 1 = August 2014; Round 2 = January 2015; Round 3 = March 2015; hydrology and water temperature are displayed (hydrograph data: a) Wellington Gauging Station, b) Gin Gin Gauging Station; water temperature: a) DS Burrendong Gauging Station, b) Baroona Gauging Station. Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

(*continued*)

Figure 20 (cont'd). Frequency of back-calculated hatch dates for daily aged juvenile Australian smelt sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events.

b)

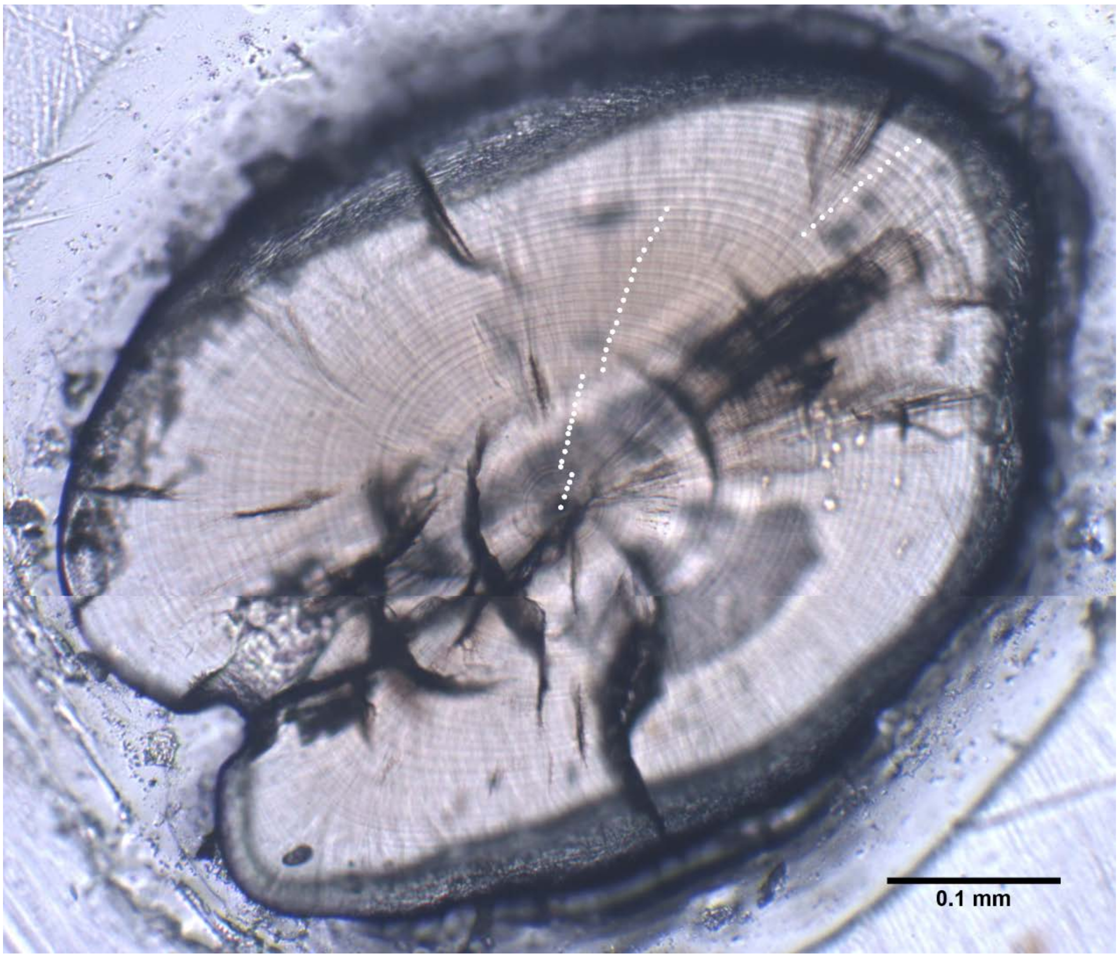


Note: Round 1 = September 2014; Round 2 = January 2015; Round 3 = March 2015; hydrology and water temperature are displayed (hydrograph data: a) Wellington Gauging Station, b) Gin Gin Gauging Station; water temperature: a) DS Burrendong Gauging Station, b) Baroona Gauging Station. Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

Un-specked hardyhead

A subsample of 49 un-specked hardyhead (<60 mm FL) collected from Zones 1 and 2 during Round 2 of the fish community sampling were daily aged from longitudinal sections of a sagittal otolith (Figure 21). A 20% re-read of un-specked hardyhead otoliths by a second observer yielded a coefficient of variation of 2.11%. A von Bertalanffy growth function fitted to length-at-age data provided the best fit and is detailed in Figure 22. Back-calculated hatch dates occurred throughout the majority of the focus period; however, peaks in hatch dates generally occurred during the receding tails of flow events or during sustained periods of increased flow when water temperatures reached 20 °C (Figure 23). Un-specked hardyhead were only sampled within Zones 1 and 2, with very few un-specked hardyhead caught during Round 1 of sampling (Table 1 and Figure 5).

Figure 21 Daily aged otolith of a 19 mm fork length (FL) un-specked hardyhead.



Note: White dots indicate daily growth rings; estimated age of 46 days.

Figure 22 Length-at-age data for un-specked hardyhead with von Bertalanffy growth function fitted.

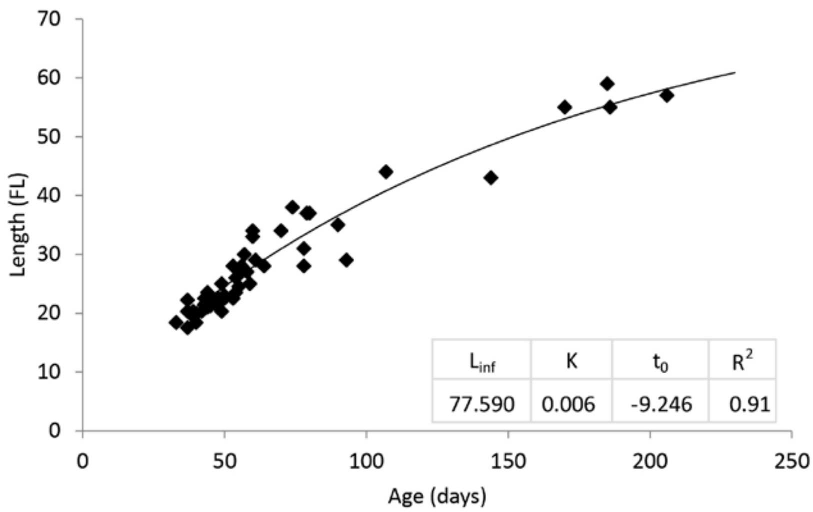
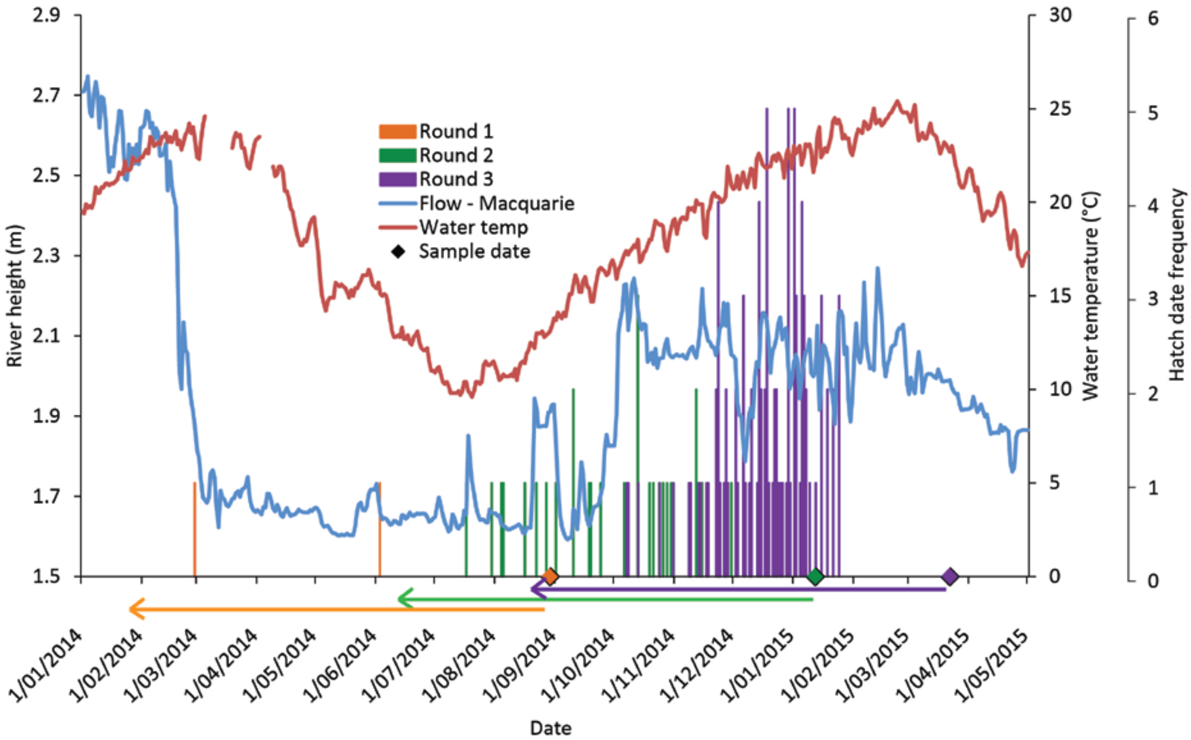


Figure 23 Frequency of back-calculated hatch dates for daily aged juvenile un-specked hardyhead sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events.

a)

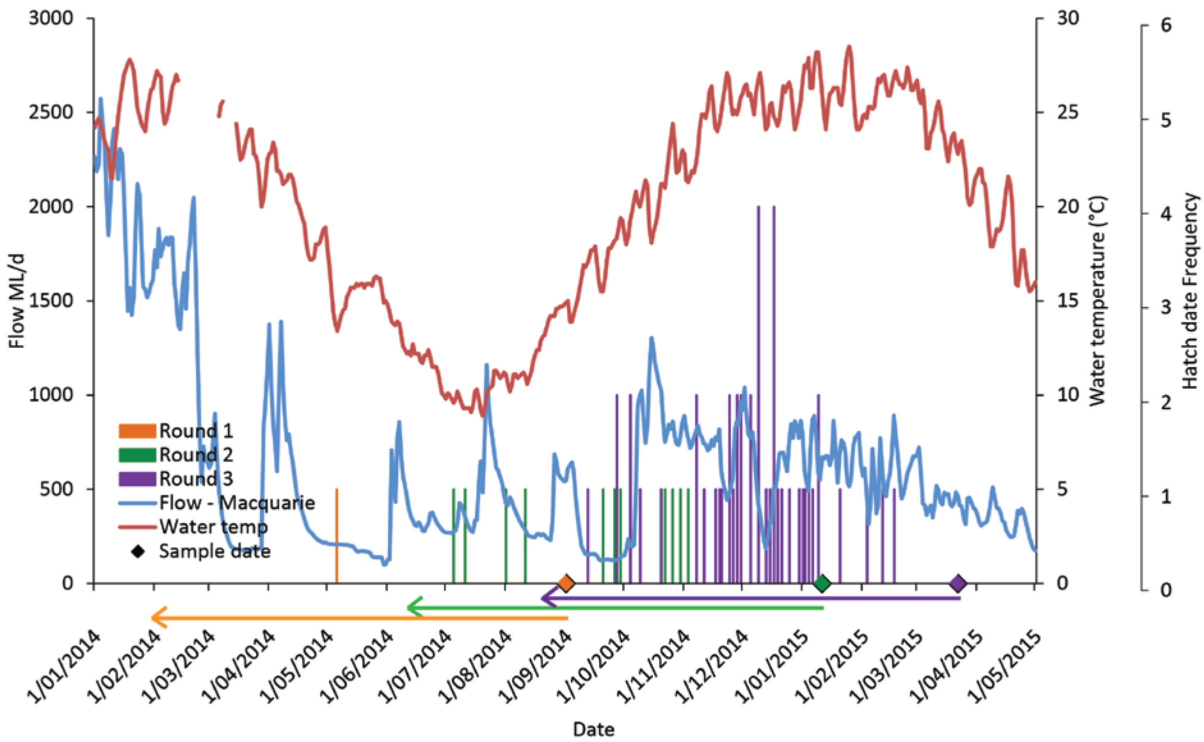


Note: Round 1 = August 2014; Round 2 = January 2015; Round 3 = March 2015; hydrology and water temperature are displayed (hydrograph data: a) Wellington Gauging Station, b) Gin Gin Gauging Station; water temperature: a) DS Burrendong Gauging Station, b) Baroona Gauging Station). Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

(*continued*)

Figure 23 (cont'd). Frequency of back-calculated hatch dates for daily aged juvenile un-specked hardyhead sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events.

b)

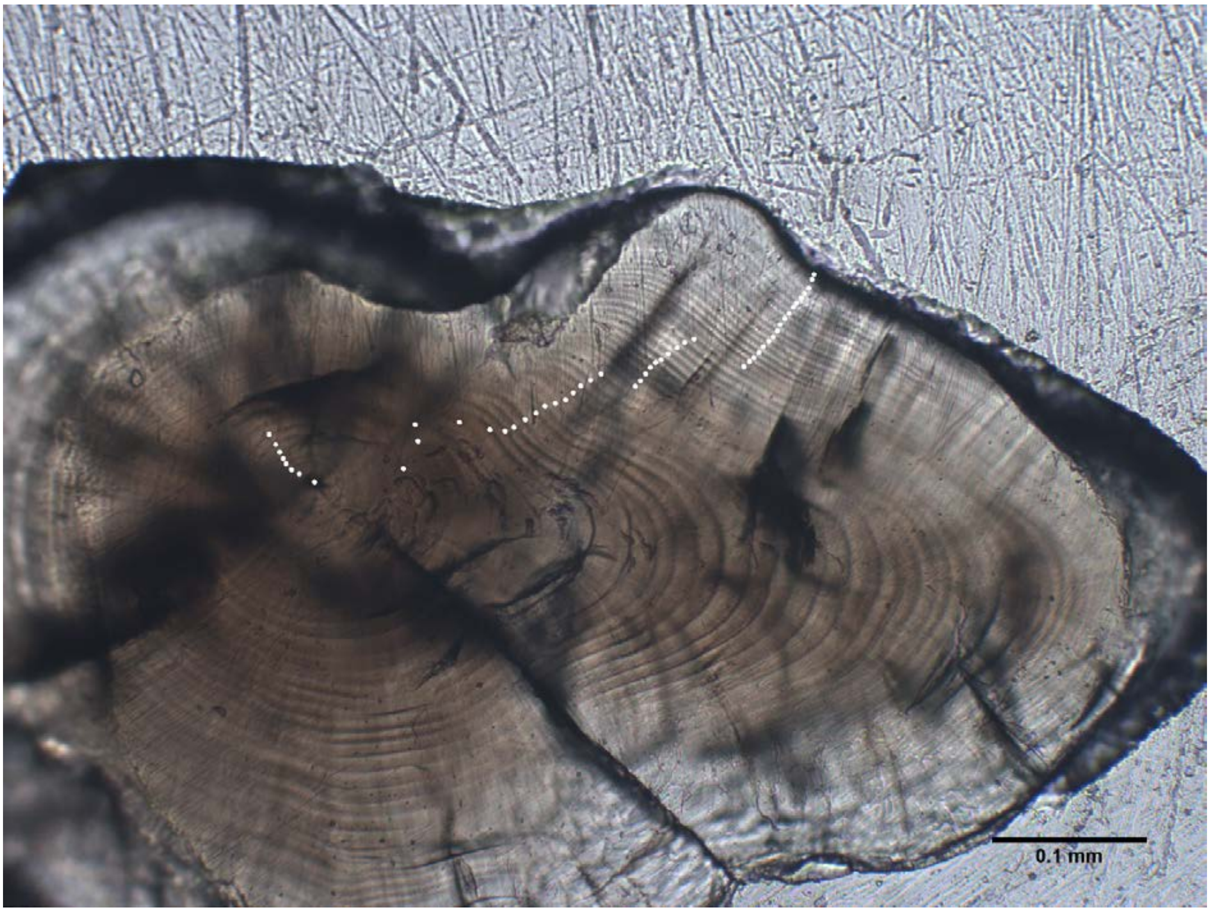


Note: Round 1 = September 2014; Round 2 = January 2015; Round 3 = March 2015; hydrology and water temperature are displayed (hydrograph data: a) Wellington Gauging Station, b) Gin Gin Gauging Station; water temperature: a) DS Burrendong Gauging Station, b) Baroona Gauging Station). Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

Common carp

A subsample of 36 common carp (≤112 mm FL) collected from Zones 3 and 4 during Rounds 2 and 3 of the fish community sampling were daily aged from longitudinal sections of a lapilli otolith (Figure 24). The 'focus period' of common carp was 80 days (approx. 112 mm FL). The interpretability of daily growth increments was not reliable for fish older than 80 days. Similarly, Vilizzi (1998) noted age interpretation was difficult when >80–90 increments were present. This was attributed to morphological change in the lapilli by increased curvature of the sagittal plane (Vilizzi, 1998). A 20% re-read of common carp otoliths by a second observer yielded a coefficient of variation of 1.11%. A linear growth function fitted to length-at-age data provided the best fit and is detailed in Figure 25. Peaks in hatch date frequency were associated with the leading edge of a flow pulse and during sustained periods of increased flow (Figure 26). Hatch dates coincided with water temperatures as low as 10 °C (Figure 26). Juvenile recruitment of common carp was most prolific within and downstream of the Macquarie Marshes (Zones 3 and 4) (Figure 5).

Figure 24 Daily aged otolith of a 52 mm fork length (FL) common carp.



Note: White dots indicate daily growth rings. Estimated age of 51 days.

Figure 25 Length-at-age data for common carp with growth function fitted.

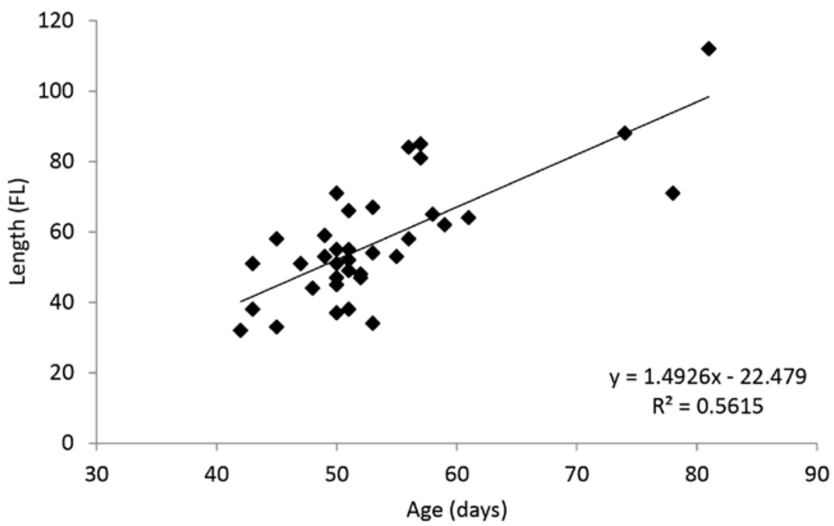
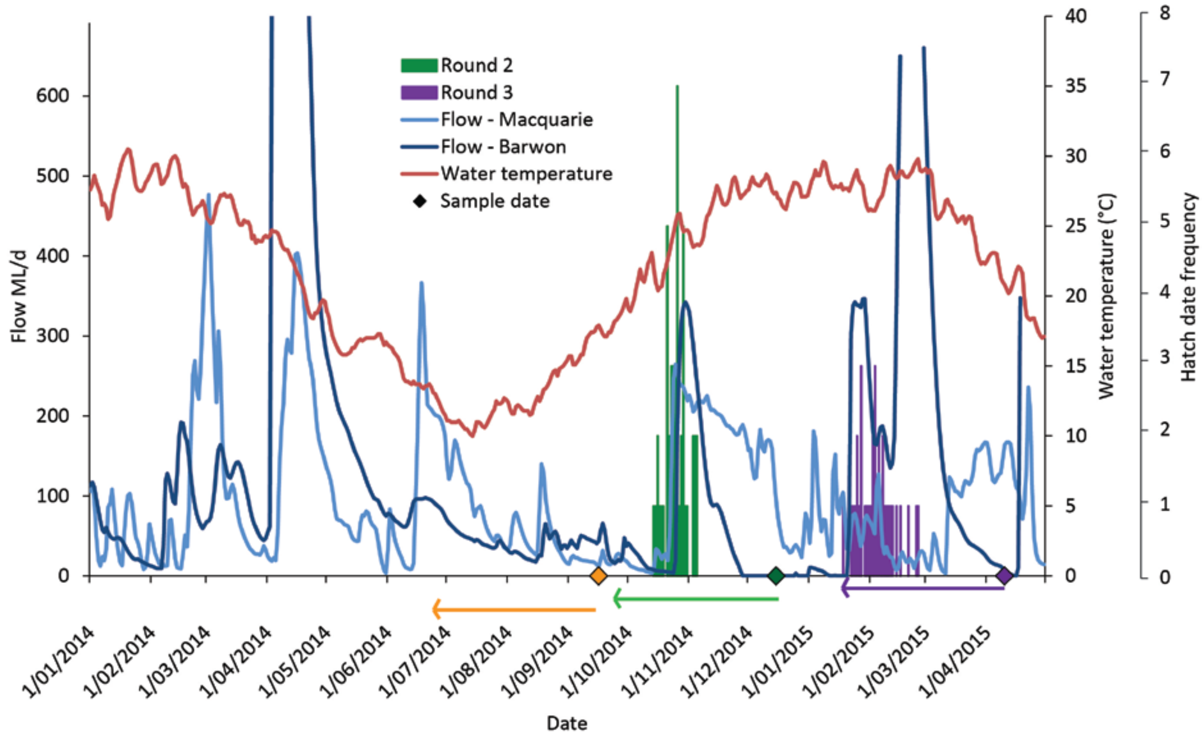


Figure 26 Frequency of back-calculated hatch dates for daily aged juvenile common carp sampled during standardised fish community sampling (SRA protocol) from: a) Zone 3; and b) Zone 4 of the Macquarie River over three sampling events.

a)

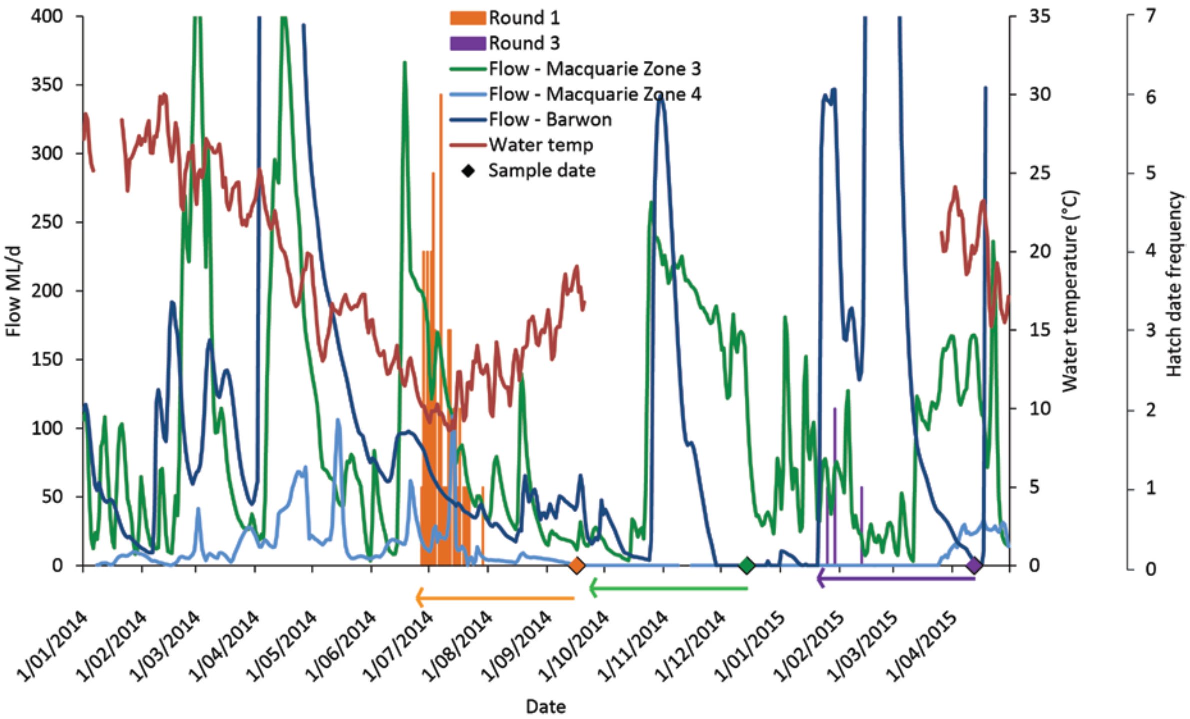


Note: Round 1 = September 2014; Round 2 = December 2014; Round 3 = April 2015; hydrology and water temperature are also displayed (hydrograph data: a) Macquarie River Pillicawarrina Gauging Station and Barwon River Geera Gauging Station, b) Carinda Gauging Station and Barwon River Geera Gauging Station; water temperature: a) Marebone Wier Gauging Station, b) Carinda Gauging Station). Coloured arrows indicate the ‘focus period’ for each sample. The ‘focus period’ extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

(*continued*)

Figure 26 (cont'd). Frequency of back-calculated hatch dates for daily aged juvenile common carp sampled during standardised fish community sampling (SRA protocol) from: a) Zone 3; and b) Zone 4 of the Macquarie River over three sampling events.

b)

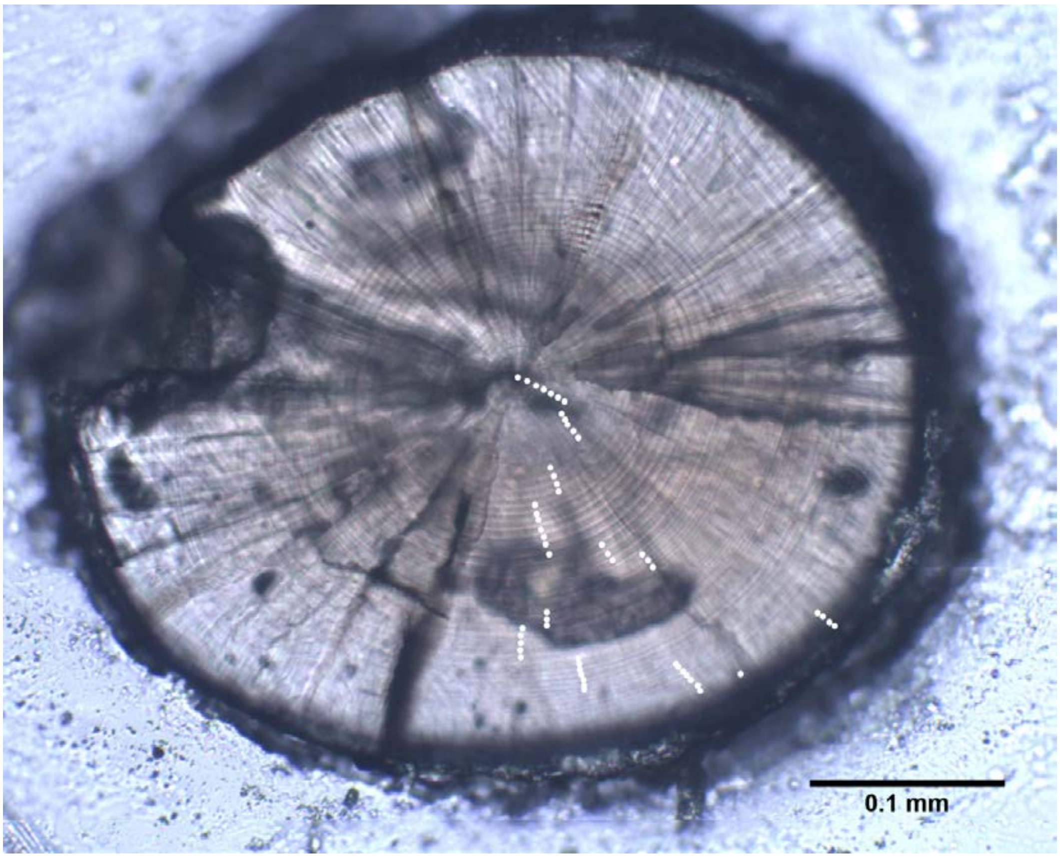


Note: Round 1 = September 2014; Round 2 = December 2014; Round 3 = April 2015; hydrology and water temperature are also displayed (hydrograph data: a) Macquarie River Pillicawarrina Gauging Station and Barwon River Geera Gauging Station, b) Carinda Gauging Station and Barwon River Geera Gauging Station; water temperature: a) Marebone Wier Gauging Station, b) Carinda Gauging Station). Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

Murray–Darling rainbowfish

A subsample of 33 Murray–Darling rainbowfish (<43 mm FL) collected from Zones 1 and 2 during Rounds 1 and 2 of the fish community sampling were daily aged from longitudinal sections of a sagittal otolith (Figure 27). A 20% re-read of Murray–Darling rainbowfish otoliths by a second observer yielded a coefficient of variation of 5.90%. A von Bertalanffy growth function fitted to length-at-age data provided the best fit and is detailed in Figure 28. Back-calculated hatch dates occurred throughout the majority of the study period; however, peaks in hatch date frequencies generally occurred during the receding tails of flow events or during sustained periods of increased flow (Figure 29). Fish spawned over a wide temperature range, from as low as 10 °C to as high as 25 °C (Figure 29). The majority of Murray–Darling rainbowfish were caught within Zones 1 and 2, with none caught within Zone 4 (Table 1 and Figure 5).

Figure 27 Daily aged otolith of a 14 mm fork length (FL) Murray–Darling rainbowfish.



Note: White dots indicate daily growth rings. Estimated age of 55 days.

Figure 28 Length-at-age data for Murray–Darling rainbowfish with von Bertalanffy growth function fitted.

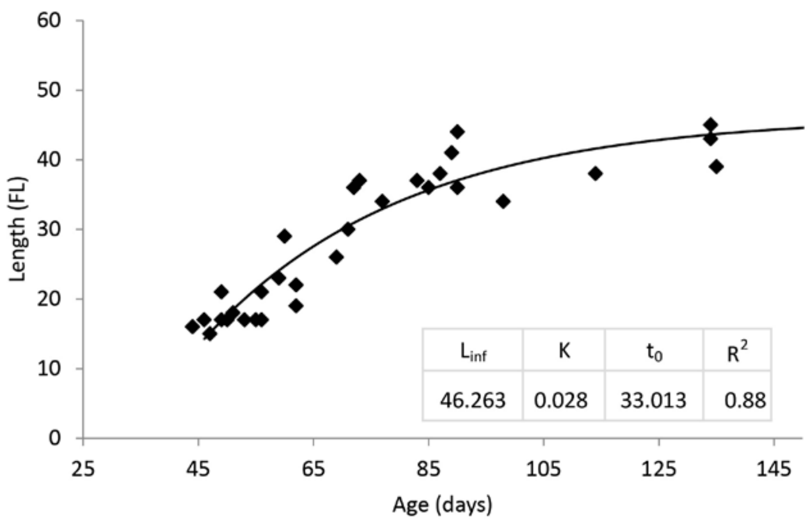
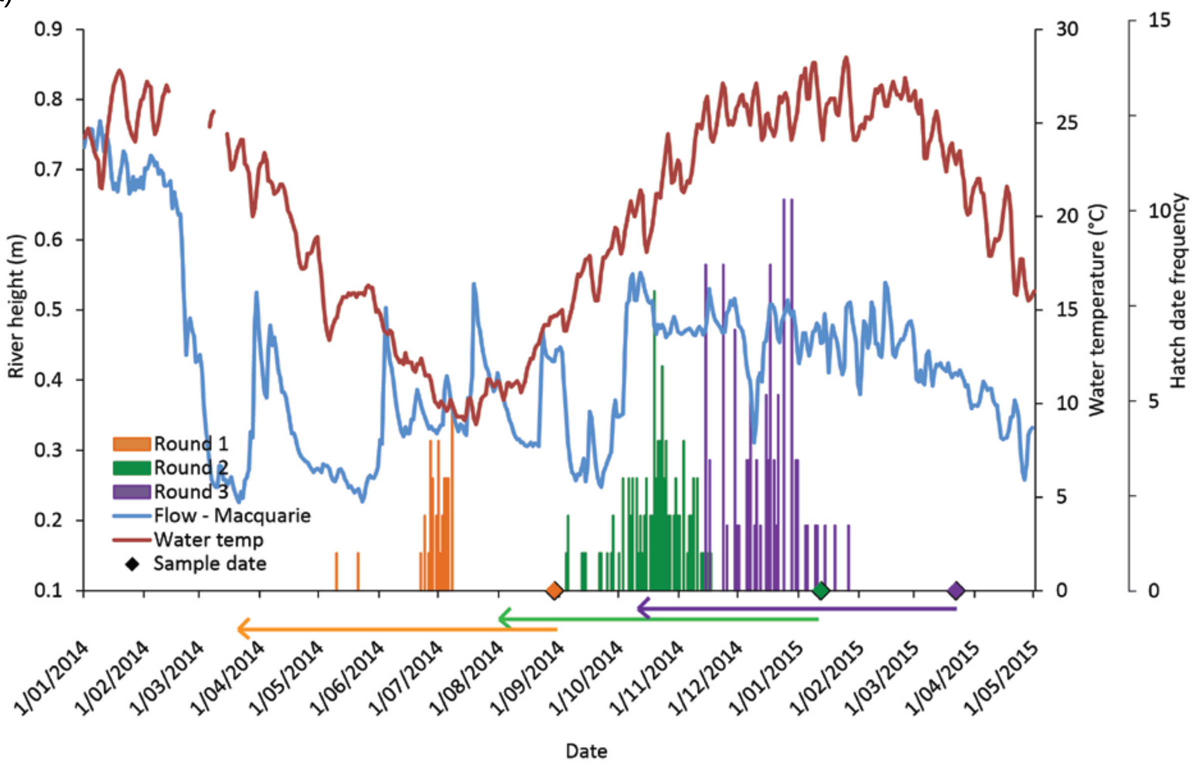


Figure 29 Frequency of back-calculated hatch dates for daily aged juvenile Murray–Darling rainbowfish sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events.

a)

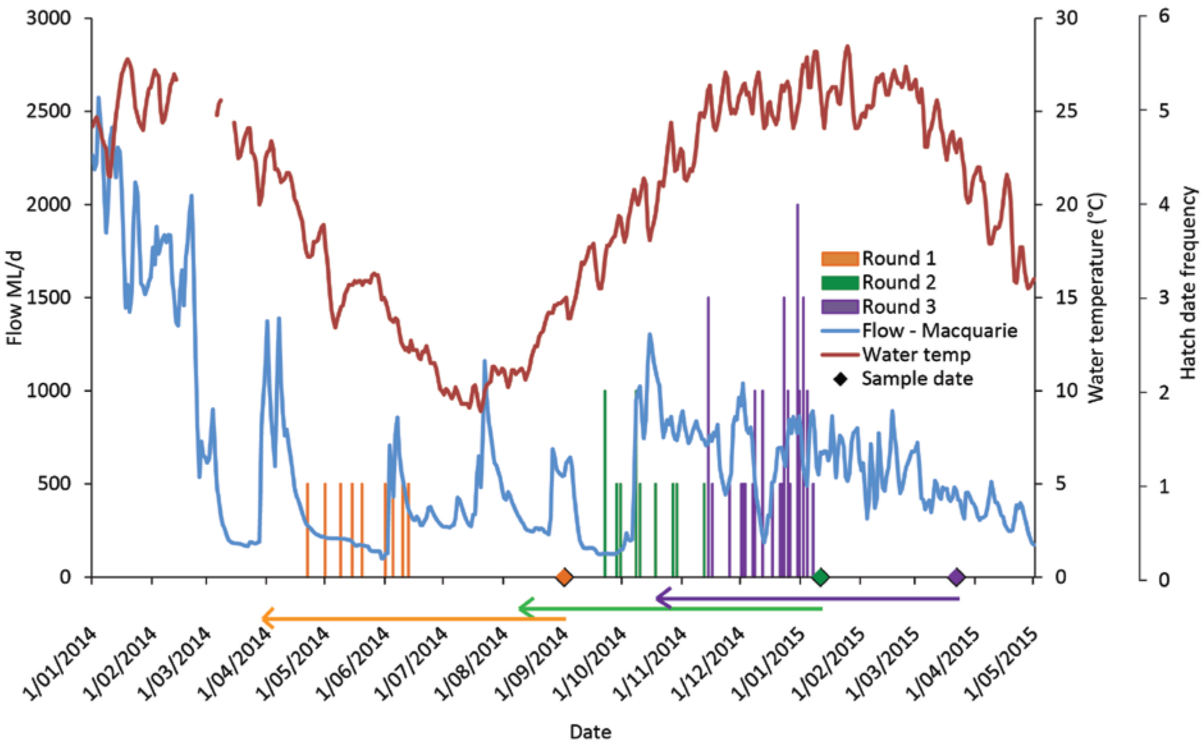


Note: Round 1 = August 2014; Round 2 = January 2015; Round 3 = March 2015; hydrology and water temperature are displayed (hydrograph data: a) Dubbo Gauging Station, b) Gin Gin Gauging Station; water temperature: a) Baroona Gauging Station, b) Baroona Gauging Station). Coloured arrows indicate the ‘focus period’ for each sample. The ‘focus period’ extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

(*continued*)

Figure 29 (cont'd). Frequency of back-calculated hatch dates for daily aged juvenile Murray–Darling rainbowfish sampled during standardised fish community sampling (SRA protocol) from: a) Zone 1; and b) Zone 2 of the Macquarie River over three sampling events.

b)



Note: Round 1 = September 2014; Round 2 = January 2015; Round 3 = March 2015; hydrology and water temperature are displayed (hydrograph data: a) Dubbo Gauging Station, b) Gin Gin Gauging Station; water temperature: a) Baroona Gauging Station, b) Baroona Gauging Station). Coloured arrows indicate the 'focus period' for each sample. The 'focus period' extends to earliest date to which a hatch date could be assigned to fish from each sampling event (based upon the maximum size/age to which daily aging was possible).

Fish health and fish condition index

Common carp condition index

Analysis of common carp condition indices (Table 7) showed a significant interaction between sampling round and zone (F = 20.30, P < 0.001). Results of pairwise tests comparing: 1) fish condition between zones within each round of sampling; and 2) fish condition between rounds within each zone are displayed in Tables 8a and 8b, respectively.

Murray cod condition index

Analysis of Murray cod condition indices (Table 7) showed a significant interaction between sampling round and zone (F = 4.464, P = 0.002). Results of pairwise tests comparing: 1) fish condition between zones within each round of sampling; and 2) fish condition between rounds within each zone are displayed in Tables 8a and 8b, respectively.

Golden perch condition index

Analysis of golden perch condition indices (Table 7) showed no significant interaction between sampling round and zone (F = 0.503, P = 0.774). No significant difference was observed between sampling rounds (F = 1.810, P = 0.167). A significant difference in fish condition was observed between zones (*F* = 27.976, *P* < 0.001), where Zone 1 was significantly greater than Zones 2, 3 and 4 (Table 7).

Bony bream condition index

Analysis of bony bream condition indices showed no significant interaction between sampling round and zone (*F* = 1.457, *P* = 0.233). No significant difference was observed between sampling rounds (*F* = 0.236, *P* = 0.791). A significant difference in fish condition was observed between zones (*F* = 5.664, *P* = 0.002), where Zone 3 was significantly greater than Zone 4 (Table 7).

Table 7 Fish condition indices for large-bodied species by sampling round and zone.

Common carp			
	Round 1	Round 2	Round 3
Zone 1	1.044 ± 0.109	0.922 ± 0.088	0.915 ± 0.09
Zone 2	1.005 ± 0.087	0.944 ± 0.084	0.932 ± 0.081
Zone 3	0.834 ± 0.085	0.872 ± 0.108	0.871 ± 0.074
Zone 4	0.928 ± 0.123	0.861 ± 0.063	
Murray cod			
	Round 1	Round 2	Round 3
Zone 1	1.249 ± 0.015		1.062 ± 0.071
Zone 2	0.986 ± 0.095	0.998 ± 0.118	0.963 ± 0.071
Zone 3	1.207 ± 0.127	1.075 ± 0.08	0.972 ± 0.116
Golden perch			
	Round 1	Round 2	Round 3
Zone 1	1.045 ± 0.119	0.995 ± 0.143	0.958 ± 0.175
Zone 2	0.826 ± 0.113	0.841 ± 0.117	0.796 ± 0.125
Zone 3	0.818 ± 0.104	0.77 ± 0.127	0.8 ± 0.089
Zone 4	0.795 ± 0.027	0.721 ± 0.119	
Bony bream			
	Round 1	Round 2	Round 3
Zone 2			1.008 ± 0.079
Zone 3	0.966 ± 0.161	1.019 ± 0.027	0.972 ± 0.141
Zone 4	0.889 ± 0.119	0.771 ± 0.073	0.813 ± 0.104

Note: Values are mean ± standard deviation (SD).

Table 8 **Results of Tukey's HSD pairwise comparisons of condition index for common carp and Murray cod between: a) zones within each round of sampling; and b) between sampling rounds within each zone.**

a)

Common carp

Round 1	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1			***	***
Zone 2			***	***
Zone 3				***
Zone 4				

Round 2	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1			***	***
Zone 2			***	***
Zone 3				
Zone 4				

Round 3	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				
Zone 2			***	
Zone 3				
Zone 4				

Murray cod

Round 1	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1		**		
Zone 2			***	
Zone 3				
Zone 4				

Round 2	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				
Zone 2				
Zone 3				
Zone 4				

Round 3	Zone 1	Zone 2	Zone 3	Zone 4
Zone 1				
Zone 2				
Zone 3				
Zone 4				

Note: *** = $P < 0.0001$; ** = $P < 0.001$; * = $P < 0.05$; blank = $P > 0.05$; shaded = not applicable.

(*continued*)

Table 8 (cont'd). Results of Tukey's HSD pairwise comparisons of condition index for common carp and Murray cod between: a) zones within each round of sampling; and b) between sampling rounds within each zone.

b)

Common carp

Zone 1			
	Round 1	Round 2	Round 3
Round 1		***	***
Round 2			
Round 3			

Zone 2			
	Round 1	Round 2	Round 3
Round 1		**	***
Round 2			
Round 3			

Zone 3			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 4			
	Round 1	Round 2	Round 3
Round 1		*	
Round 2			
Round 3			

Murray cod

Zone 1			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 2			
	Round 1	Round 2	Round 3
Round 1			
Round 2			
Round 3			

Zone 3			
	Round 1	Round 2	Round 3
Round 1			*
Round 2			
Round 3			

Note: *** = $P < 0.0001$; ** = $P < 0.001$; * = $P < 0.05$; blank = $P > 0.05$; shaded = not applicable; Zone 4 not applicable to Murray cod as none were caught in that zone

Proportion of catch suffering a health condition

The most prevalent health conditions observed over three rounds of fish community sampling throughout the Macquarie River during the 2014/2015 watering year were anchor worms (*Lernaea* spp.), affecting 8.53% of individuals, and wounds, affecting 0.50% of individuals. All other symptoms affected <0.50% of the population (Figure 30). The proportion of the population affected by anchor worms varied between sampling rounds. During Round 1, 5.71% of the population was affected by anchor worms; this increased to 10.59% in Round 2 and remained relatively stable into Round 3 at 9.40% (Figure 30). The species of fish most heavily affected by symptoms of disease and parasites were Murray cod and golden perch (Figure 31). For each of these two species, symptoms were most prevalent during Round 2 of sampling (Figure 31).

Figure 30 The percentage of individuals affected by a range of symptoms of disease or parasites for each round of sampling throughout the Macquarie River during the 2014/2015 watering year.

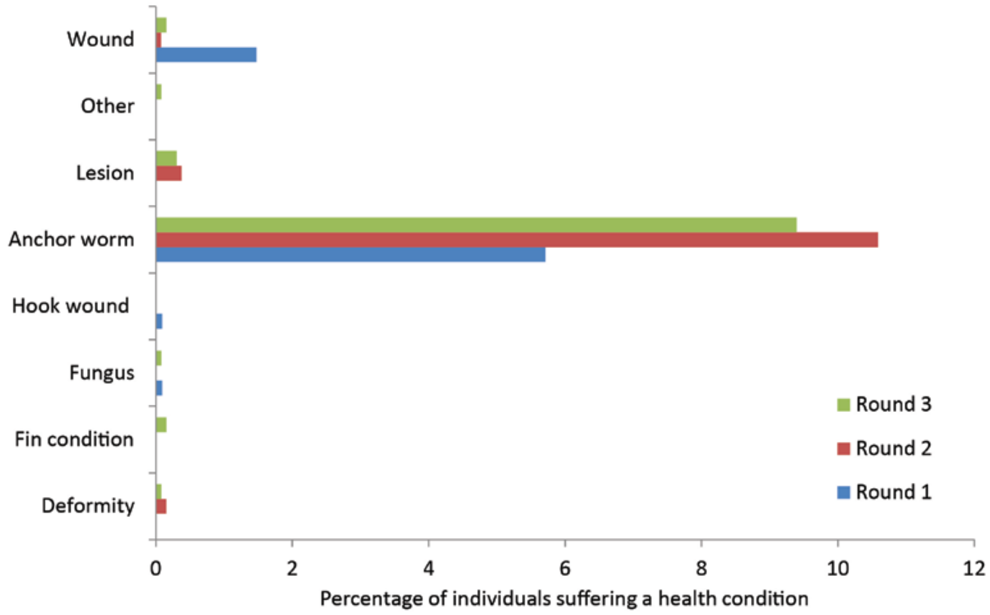
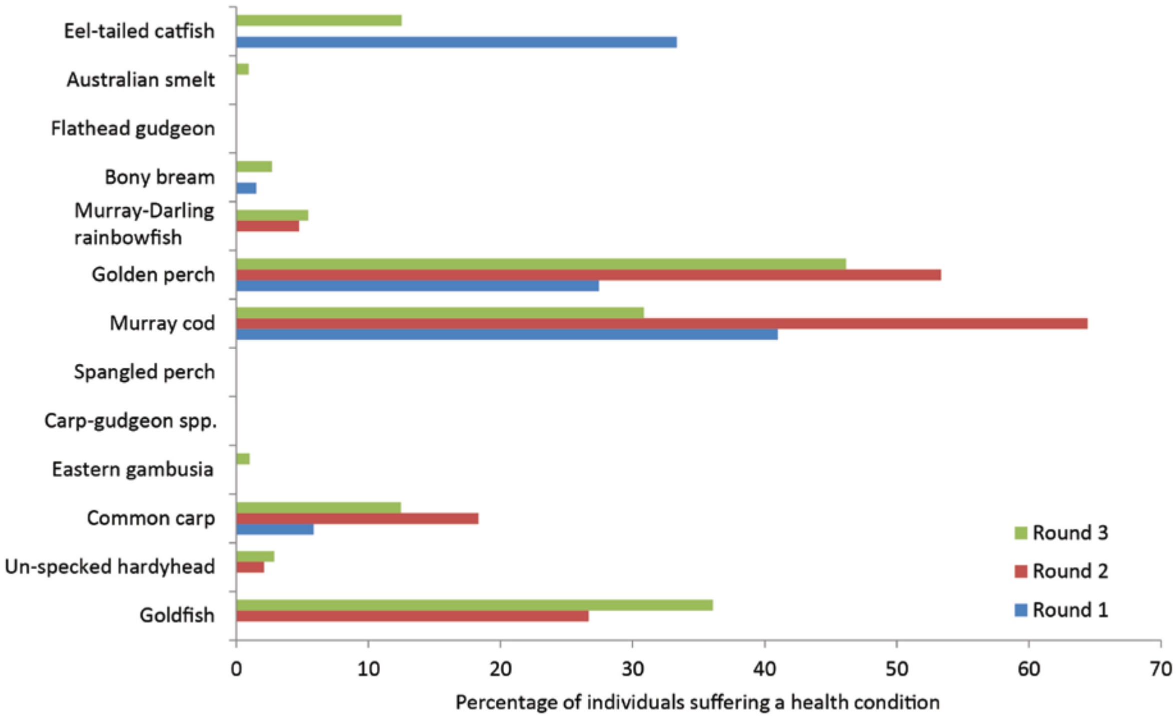


Figure 31 The percentage of individuals of each species affected by symptoms of disease or parasites for each round of sampling throughout the Macquarie River during the 2014/2015 watering year.



Water quality

In most instances, water quality parameters measured throughout the Macquarie River fell within relevant Australia and New Zealand Environment and Conservation Council (ANZECC) guidelines for NSW upland and lowland rivers (ANZECC and ARMCANZ, 2000). However, at a number of locations, water quality parameters were outside the ANZECC trigger values (Table 9). Multivariate analysis of water quality variables illustrated a significant interaction between sampling zone × round ($F_{6,42}$ = 5.677). Pairwise comparisons of the interaction term indicated water quality variables were significantly different between each of the sampling zones within rounds, with the exception of Zone 2 and Zone 3 in Round 1 of sampling. Each of the sampling rounds was also different within each zone, with the exception of Round 2 and Round 3 within Zone 4. Dissimilarity of water quality parameters between sampling rounds and sampling zones are displayed by nMDS plots in Figures 32 and 33, respectively.

Table 9 Average water quality measurement at 0.2m depth for each sampling site during each round of sampling.

		Round 1						Round 2					
Site name	**Zone**	**Water temp. (°C)**	**pH**	**Conductivity (mS.cm^{-1})**	**Dissoled oxygen (% saturation)**	**Turbidity**	**Secchi depth (m)**	**Water temp. (°C)**	**pH**	**Conductivity (mS.cm^{-1})**	**Dissoled oxygen (% saturation)**	**Turbidity**	**Secchi depth (m)**
Bonada	1	12.95	7.89	0.468		0.1	1.76	25.53	8.03	0.403		0	1.52
Boral TSR	1	14.44	9.195	0.4595		10.4	0.99	25.92	8.32	0.4135		4.65	1.3
Peach Tree Reserve	1	14.875	8.055	0.565	81.68	3.95	0.83	28.15	8.485	0.4175	96.94	7.9	0.9
Brilbral	1	15.17	8.165	0.5345	95.22	5.15	0.7	28.35	8.42	0.416	99.13	6.8	1.04
Dubbo Boat Ramp	1	15.255	8.105	0.593	85.97	11.95	0.52	29.365	8.39	0.4255	81.66	12.5	0.77
Wambool	2	13.58	8.575	0.6505		66.75		29.305	8.435	0.4415	88.33	44.85	0.51
DS Gin Gin Weir	2	16.39	8.27	0.76	96.71	24.2	0.4	27.355	8.38	0.4905	80.83	30.9	0.44
Gin Gin Bridge	2	16.36	8.22	0.76	97.93	24.1		29.175	8.46	0.452	73.71	24.55	0.55
Mullah	2	14.99	7.67	0.5665		28.25	0.41	27.395	8.34	0.455	73.63	42.45	0.5
Ellengerah	2	15.925	7.97	0.561		34.2	0.32	27.01	8.65	0.451	81.31	50.65	0.34
Marebone	3	16.145	7.715	0.7425	92.61	26.35	0.36	27.42	8.2	0.449	67.35	60	0.3
Groggans	3	18.685	8.08	0.742	86.69	32.41	0.24	28.775	8.31	0.483	79.83	101.8	0.21
Old Oxley	3	17.32	7.99	0.7365	87.35	42.8	0.19	26.37	8.26	0.4905	69.93	145	0.13
Willancorah	3	14.795	7.72	0.782	65.34	48.5	0.15	24.695	7.835	0.564	47.01	233	0.15
Pillicawarrina	3	18.555	8.21	0.761		51	0.14	24.24	8.215	0.5565	78.58	142.5	0.15
Yanda	4	16.86	8.505	0.81	95.31	83.5	0.18	River dry					
Marthaguy Junction	4	18.635	8.195	0.8015	86.8	59.15	0.23						
Brewon	4	20.435	8.365	0.775	101.06	64.5	0.1						
Binghi	4	20.985	8.25	0.7695	96.83	227	0.1	32.705	8.89	2.22		741.5	0.14
Glenacre	4	19.565	8.125	0.77	95.41	117.5	0.14	25	8.785	1.605	64.43	387	

Table 9 (Cont'd). Average water quality measurement at 0.2m depth for each sampling site during each round of sampling. Shaded values indicate water quality measurements outside ANZECC guidelines.

		Round 3					
Site name	Zone	Water temp. (°C)	pH	Conductivity ($mS.cm^{-1}$)	Dissoled oxygen (% saturation)	Turbidity	Secchi depth (m)
Bonada	1	23.66	8.295	0.431	97.22	0	2.42
Boral TSR	1	24.165	8.19	0.442	106.61	0	1.65
Peach Tree Reserve	1	23.67	8.21	0.442	95.1	0	1.4
Brilbral	1	27.2	8.19	0.4455	100.65	0	1.4
Dubbo Boat Ramp	1	24.58	7.985	0.4505	97.57	3.85	0.92
Wambool	2	24.035	8.225	0.49	98.85	7.15	0.61
DS Gin Gin Weir	2	24.775	8.12	0.49	97.69	3.9	0.87
Gin Gin Bridge	2	25.02	8.505	0.499	107.17	6	0.7
Mullah	2	24.655	8.235	0.4955	105.75	6.8	0.6
Ellengerah	2	23.08	8.155	0.5	97.59	16.4	0.63
Marebone	3	20.225	7.955	0.5035	82.19	37.5	0.37
Groggans	3	19.745	8.335	0.5085	101.48	95.35	0.2
Old Oxley	3	17.785	8.16	0.5205	82.48	46.495	0.2
Willancorah	3	18.61	8.305	0.9975	87.32	154	
Pillicawarrina	3	17.28	8.49	0.521	101.42	190	0.15
Yanda	4	20.47	7.525	0.5945	47.59	0	1.12
Marthaguy Junction	4	20.225	8.24	0.693	76.54	7.2	0.6
Brewon	4	River dry					
Binghi	4						
Glenacre	4						

Figure 32 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity of water quality variables between sampling rounds.

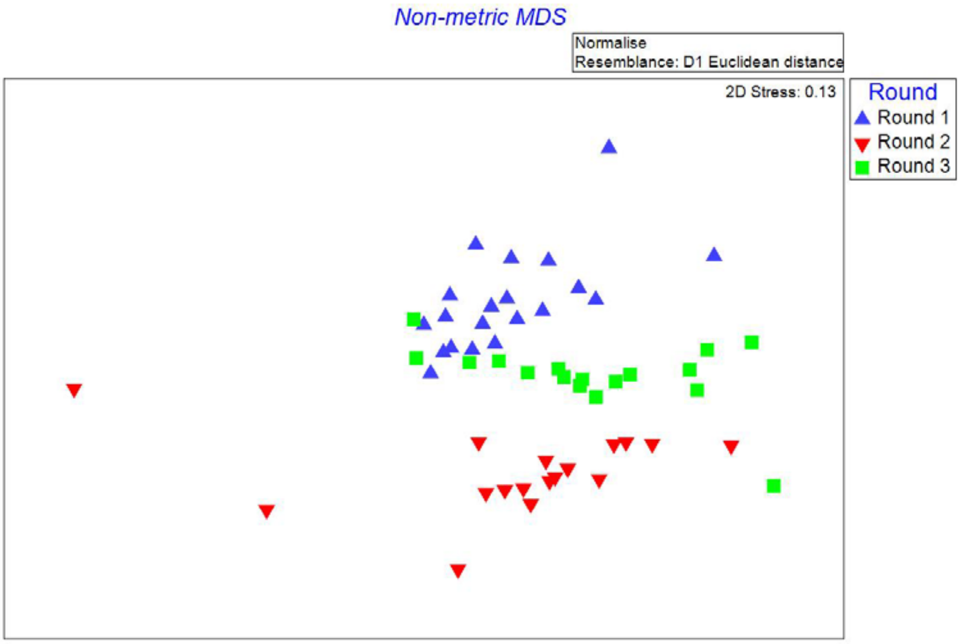
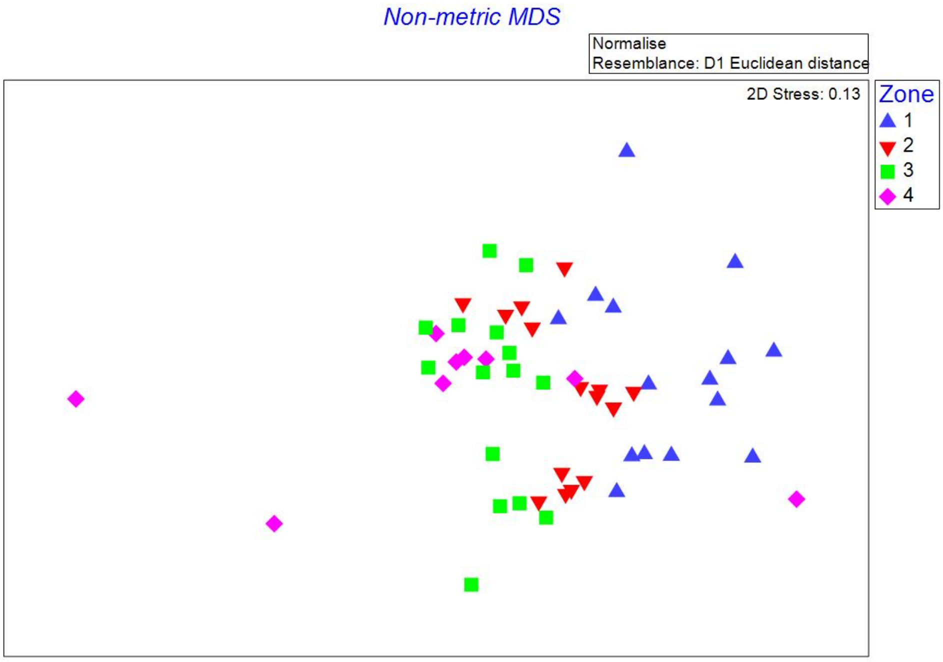


Figure 33 Non-metric multi-dimensional scaling (nMDS) plot illustrating dissimilarity of water quality variables between sampling zones.



Discussion

The role of environmental flows in the recruitment of fish

Typically, the natural flow regimes of dryland rivers are highly variable, with periods of flooding punctuating extended dry periods. The productivity of dryland river and marsh ecosystems is therefore highly dependent on periods of high flow (Puckridge et al., 1998; Kingsford et al., 1999; Bunn et al., 2006; Arthington and Balcombe, 2011). High flow events and floodplain inundation have been identified as the source and delivery mechanism for basal carbon within riverine ecosystem food webs (Gawne et al., 2007). In addition, fish assemblages in dryland rivers have evolved life-history strategies attuned to environmental triggers (Sternberg and Kennard, 2013), particularly flow regimes (Bunn and Arthington, 2002). Three primary mechanisms associated with high flow events within lotic systems have been proposed to facilitate enhanced native fish recruitment: 1) high flow events provide spawning triggers; 2) high flow events boost primary production that facilitates successful recruitment; and 3) during high flow events, additional habitat and food-rich ephemeral environments are made available as a result of the inundation of backwaters and floodplains (Reynolds, 1983; Junk et al., 1989; Harris and Gehrke, 1994; Balcombe et al., 2006, 2007;Balcombe and Arthington, 2009; King et al., 2009). However, the timing, duration and magnitude of such flow events are of critical importance if they are to significantly enhance native fish recruitment. To further complicate the matter, different species have varying life-history characteristics that may respond to different hydrological conditions (King et al., 2003; Rolls et al., 2013; Rayner et al., 2015).

When there is synchrony between the breeding season of a species and conditions optimal for spawning and successful recruitment, strong cohorts can be observed within a population. This is described by the ‘window of opportunity hypothesis’ (WOOH), which states that in any one year, if optimal conditions for recruitment vary temporally, fish that spawn over a protracted period have a recruitment advantage over those that spawn only for a brief period (Humphries et al., 2013). This is because the probability that a proportion of the larvae of protracted spawning species will encounter a period when conditions are optimal for recruitment is greater than for larvae with only a brief spawning period (Humphries et al., 2013). Humphries et al. (2013) indicated that the recruitment of Australian smelt supports this hypothesis. Findings from the present study indicate that the recruitment of other native fish species is also likely to follow this principle, and hence indicates the importance of flow events in the recruitment native fish species.

The following subsections detail the recruitment patterns of a number of species sampled within the Macquarie River during the 2014/2015 watering year. The recruitment of each species is examined in relation to water temperature and hydrological characteristics and compared with that of existing literature when available.

Golden perch

No juvenile golden perch were sampled within the Macquarie River during the three rounds of sampling between August 2014 and April 2015. The smallest fish sampled were 120–145 mm TL (n = 3) in September 2014 within Zone 4. Existing literature details golden perch require increased river discharge to cue spawning (Lake, 1967; Mackay, 1973), and there is speculation over studies that suggest otherwise (Mallen-Cooper and Stuart, 2003) on the basis of the location of spawning (King et al., 2009). For golden perch, spawning is believed to be preceded by a substantial upstream migration (Reynolds, 1983; Mallen-Cooper et al., 1995). In the southern Murray–Darling Basin, the spawning of golden perch occurs primarily from October to December, coinciding with rising and descending limbs of within-channel and overbank flows at water temperatures of 17–25 °C (Rowland, 1983b; Mallen-Cooper and Stuart, 2003; King et al., 2009; Zampatti and Leigh, 2013; Zampatti et al., 2015). The absence of juvenile golden perch throughout the Macquarie River during the 2014/2015 sampling may be associated with: 1) sampling biases (i.e. juvenile golden perch may be less susceptible to electrofishing); or, more probably, 2) no flow event was large enough to cue spawning or result in successful recruitment of juveniles. The latter hypothesis is supported by studies of King et al. (2009) who observed limited recruitment response to smaller flow peaks, both in-channel and small inundation events.

Because golden perch are able to maintain gonadal maturity for an extended period, and do not reabsorb oocytes until February or March (Lake, 1967; Rowland, 1983b; Battaglene, 1991), significant environmental water releases (more than the 28,483 ML of the 2014/2015 watering year) from October to February, when water temperatures are between 17 and 25 °C, may be beneficial for juvenile recruitment.

Murray cod

The majority of daily aged Murray cod had back-calculated hatch dates between 28 September and 2 December 2014 with water temperatures in the range of 18–25 °C. This approximately coincided with the release of environmental water reaching Zone 2 on 9 October, though numerous juveniles had back-calculated hatch dates earlier than the arrival of the environmental water. Existing literature details Murray cod are a temperature-cued spawner, spawning at water temperatures of 16–20 °C and do not require an increase in discharge to trigger a spawning event (Lake, 1967; Rowland, 1983a, 1998; Humphries, 2005; King et al., 2009). Day length or some other undefined consistent inter-annual variable has also been suggested as a spawning cue (King et al., 2009). Multiple juvenile Murray cod had back-calculated hatch dates that coincided with water temperatures up to 25 °C, considerably greater than the upper limit of 20 °C cited in existing literature (Lake, 1967; Rowland, 1983a, 1998). The apparent higher upper limit of water temperature at which hatching occurred may be a result of: 1) Murray cod stocking during late January 2014 (Appendix 8); or 2) variation in the method of recording water temperature between studies (i.e. surface temperatures versus at depth).

While an increase in discharge may not be required to trigger a spawning event, high flow events may increase primary production that facilitates successful recruitment. This is supported by King et al. (2009) who found that Murray cod did not appear to increase their spawning activity in a flood year, but their recruitment was increased, likely through the availability of abundant food resources. Under the ‘window of opportunity hypothesis’, the successful recruitment of cod is restricted to a narrow window of opportunity due to the brief spawning period.

Bony bream

The majority of juvenile bony bream were captured within Zone 4 during Round 1 of fish community sampling. The majority of daily aged bony bream had back-calculated hatch dates between 13 June and 7 July 2014. This coincided with water temperatures of approximately 13 °C and a late June 2014 flow pulse in the Macquarie Marshes that was significantly reduced by the time it passed through the Macquarie Marshes and reached Zone 4 (Figure 17). Catches of juvenile bony bream within Zone 4 may therefore be attributed to the downstream dispersal of juveniles from the Macquarie Marshes (Zone 3).

A second hypothesis for the strong recruitment of juvenile bony bream within Zone 4 during Round 1 of sampling may be associated with the receding tail of a flow event within the Barwon River and a small flow event within the Macquarie River that created connectivity between the two river systems. It is possible that juveniles may have emigrated from the Barwon River to the Macquarie River when the systems were connected. In support of this hypothesis, bony bream as small as 22 mm have been recorded conducting upstream migrations (Baumgartner, 2003). It should be noted that the 130 day ‘focus period’ associated with Round 1 of sampling does not incorporate the leading edge of the April 2014 flow event within the Barwon River and it is therefore likely the hatch date frequency data only capture the tail-end of this earlier recruitment pulse. Analyses of otolith chemistry may provide insight into the recruitment source of juvenile bony bream and potentially reinforce the importance of hydrological connectivity between river systems and/or the importance of wetland ecosystems in the recruitment of bony bream.

Findings of the present study add significant information to existing literature on the biology of bony bream. Earlier studies found that bony bream spawn independently of flooding in December–January in the lower Murray and October–December in NSW at temperatures of 21–23 °C (Llewellyn, 1983; Puckridge and Walker, 1990). This study shows that the spawning window for bony bream is significantly larger than previously thought, and flow events may play a key role in spawning and the subsequent recruitment of the species. A similar study conducted within the Gwydir River system found hatch dates of bony bream coincided with a period of declining flow levels throughout February and March, although peaked at the timing of a brief late February flow pulse (Southwell et al., 2015). In further support of these findings, Gehrke et al. (1995) observed bony bream within the Paroo and Darling catchment to be more abundant after flooding.

Eel-tailed catfish

Recruitment data for eel-tailed catfish indicate the primary spawning period was between 27 November 2014 and 31 January 2015. This coincides with water temperatures reaching approximately 20 °C and moderate discharge (~300–1,200 ML/day). These findings are supported by earlier studies that have observed courtship in October at water temperatures of 20 °C in south-eastern Queensland (Merrick and Midgley, 1981), though it is significantly lower than the 24 °C that Davis (1977) and Lake (1967) suggest is required to initiate spawning from January to March. It is commonly recognised that flooding is not required to initiate spawning for this species (Davis, 1977). However, as is the case for all species, high flow events may boost primary production that facilitates successful recruitment.

Australian smelt

Hatches date frequencies and recruitment data from the present study indicate the recruitment of Australian smelt occurred throughout the majority of the study period at water temperatures as low as 10 °C. However, peaks in hatch date frequencies generally occurred during the receding tails of flow events or during sustained periods of increased flow when temperatures were ≥15 °C. A peak in hatch date frequency within Zone 1 during Round 1 of sampling did not coincide with a flow event within Zone 1; however, it did coincide with a flow event within Zone 2 (i.e. tributary inflow downstream of the Zone 1 gauging station). This suggests that a proportion of juvenile Australian smelt may have conducted an upstream migration from Zone 2 to Zone 1. These findings are supported by earlier studies that suggest Australian smelt have a protracted spawning period (August–April) and begin to breed in winter at water temperatures exceeding 15 °C (Milton and Arthington, 1985; Humphries et al., 2013). Humphries et al. (2013) indicated that the recruitment of Australian smelt supports the 'window of opportunity hypothesis', where although the species has a protracted spawning period, temperature and prey density (responding to river-specific interactions between temperature and discharge) play a key role in the timing and magnitude of successful recruitment.

Un-specked hardyhead

Peaks in the hatch date of un-specked hardyhead commenced in early November, during the receding tails of flow events or during sustained periods of increased flow when water temperatures reached 20 °C. Observations from the present study are supported by existing literature that details un-specked hardyhead have an extended breeding season from mid-October to mid-February; however, earlier studies suggest breeding commences at higher water temperatures (24 °C; Llewellyn, 1979) than observed in this study. Existing literature does not link spawning to increases in discharge; however, evidence from the present study does identify increased recruitment following minor flow events.

Murray–Darling rainbowfish

Back-calculated hatch dates of Murray–Darling rainbowfish occurred throughout the majority of the study period; however, peaks in hatch date frequencies generally occurred during the receding tails of flow events and during sustained periods of increased flow. The present study indicates that Murray–Darling rainbowfish spawned at temperatures as low as 10 °C and as high as 25 °C. Existing literature suggests Murray–Darling rainbowfish are a seasonal breeder, spawning from spring to summer when water temperatures exceed 20 °C—significantly higher than that observed in the present study. Existing literature details rising water levels are not a prerequisite for spawning (Lintermans, 2007, Backhouse and Frusher, 1980); however, evidence from the present study and those of Gilligan et al. (2009) did identify increased recruitment following flow events.

Spangled perch

Very few juvenile spangled perch were sampled within the Macquarie River during the three rounds of sampling between August 2014 and April 2015. One 45 mm spangled perch was sampled in September 2014 (Round 1) while all other fish sampled in December 2014 (Round 2) were >75 mm FL. Existing literature details spangled perch commence spawning around November when surface temperatures reach 26 °C and bottom temperatures 20 °C. Spawning may occur as late as mid-February if temperatures are suitable (Llewellyn, 1973). An increase in water level, although not essential, triggers spawning if temperatures are suitable (Lake, 1967). Within the Paroo and Darling catchment, Gehrke et al. (1995) found spangled perch to be more abundant after flooding.

In the present study, spangled perch were found almost exclusively in Zone 4. Zone 4 experienced loss of most refugia pools during extended periods of no flow from October 2014 to April 2015. It is therefore expected that recruitment would be limited within the lower Macquarie River and population maintenance is possibly supplemented by emigration from the Barwon River.

Common carp

Recruitment of common carp was most prolific within the Macquarie Marshes (Zone 3) and downstream of the Macquarie Marshes (Zone 4) (Figure 5). Peaks in hatch date frequency were associated with the leading edge of flow pulses and during sustained periods of increased flow (Figure 26). Hatch dates coincided with water temperature as low as 10 °C (Figure 26). A large peak in hatch date frequency during the 2014/2015 watering year was associated with the arrival of environmental water in the Macquarie Marshes. Further minor recruitment within Zone 3 during February 2015 was not associated with a flow pulse but rather a sustained period of moderate flow within the Macquarie Marshes (Figure 26). Alternatively, this recruitment may be attributed to a flow pulse in the Barwon River and the subsequent upstream migration of juveniles to the Macquarie Marshes (Figure 26). The absence of common carp recruitment within Zone 3 during Round 1 of sampling, associated with the late June 2014 flow pulse (Figure 26a), may be attributed to the downstream dispersal of juveniles into Zone 4. A peak in hatch date frequencies downstream of the Macquarie Marshes (Zone 4) directly aligns with this aforementioned flow pulse in the Macquarie Marshes (Zone 3). Little of this flow pulse passed through the Macquarie Marshes and reached Zone 4 (Figure 26b). A second hypothesis for the strong recruitment of juvenile carp within Zone 4 during Round 1 of sampling associated the recruitment with the receding tail of a large flow event within the Barwon River (Figure 26) and the subsequent emigration of juveniles from the Barwon into the lower Macquarie. The 80 day ‘focus period’ associated with Round 1 of sampling does not incorporate the leading edge of the

July 2014 flow events within the Barwon River and Macquarie River and therefore it is possible the hatch date frequency data only capture the tail end of this earlier recruitment pulse. No juvenile recruitment of common carp was observed downstream of the Macquarie Marshes during Round 2 of sampling. This is likely attributed to the fact that the Macquarie River downstream of the Macquarie Marshes ceased flowing, with only a small number of refuge pools remaining.

Existing literature on the reproductive biology of common carp is supported by the findings of the present study. Published data indicate common carp have an extended spawning season, generally peaking in spring and continuing into summer when water temperatures are 17–25 °C (Brown et al., 2005; Lintermans, 2007). Rising river levels are not essential for spawning; however, these conditions can enhance spawning activity through the inundation of spawning habitat, such as floodplains or riparian vegetation. Previous studies have indicated common carp recruitment is greatest when high spring flows inundate floodplains and floodplain lakes (Gehrke et al., 1995; Brown et al., 2005; Gilligan et al., 2010).

Evaluation of the October to December 2014 Commonwealth and NSW environmental water release on native fish recruitment

Recruitment data collected over a single watering year suggests native fish species of the mid-lower Macquarie River, from opportunistic and equilibrium life-history guilds, benefitted from the provision of (Commonwealth and NSW) environmental water during the spring and early summer of 2014-2015. Opportunistic small bodied species including Australian smelt, un-specked hardyhead and Murray–Darling rainbowfish, showed peaks in hatch date frequencies during the receding tails of flow events or during sustained periods of increased flow, particularly in association with the October to December 2014 environmental water release.

Peaks in the recruitment of equilibrium species, known to be temperature queued spawners, including Murray cod and eel-tailed catfish occurred during the 2014 Commonwealth and NSW environmental water release. The majority of juvenile Murray cod had hatch dates that coincided with the arrival of environmental water. While this increase in discharge may not have been required to trigger a spawning event, the increased flow may have boosted primary production that facilitated successful recruitment. Recruitment data for eel-tailed catfish indicated the primary spawning period coincided with water temperatures reaching approximately 20 °C and moderate discharge (~300–1,200 ML/day). It is commonly recognised that flooding is not required to initiate spawning for this species; however, increased flow as a result of the 2014 environmental water release may have boosted primary production and subsequently facilitate successful recruitment. Due to difficulties in selecting an appropriate unregulated control river system based on similarity in fish diversity/abundance and abiotic river characteristics, fish community sampling was confined to the Macquarie River. Because of the absence of a control, it is difficult to demonstrate cause and effect and attribute peaks in fish recruitment to the environmental water release. Although the data strongly indicates an association between the recruitment of a number of native fish species and the environmental water release, to fully attribute the successful recruitment to the environmental water release, it is critical that recruitment monitoring be repeated during a year where there is no environmental watering during the breeding season. This additional monitoring would act as a ‘control’ to bring further validity to the results obtained from the present study.

The collection of juvenile bony bream was constrained to the Macquarie River below the Macquarie Marshes. Hatch dates of these juveniles were back-calculated to between 13 June and 7 July 2014. This coincided with water temperatures of approximately 13 °C; a flow pulse within the Macquarie Marshes; the receding tail of a flow event within the Barwon River, and; a small flow event within the lower Macquarie River that created connectivity between the two river systems. Although the recruitment of bony bream was not related to the October 2014 Commonwealth and NSW environmental water release, (due to the absence of flows passing through the Macquarie Marshes and reaching Zone 4) recruitment data highlights the relationship between flows and the recruitment of bony bream and the potential importance of connectivity between the Macquarie and Barwon River. Future environmental water releases within the Macquarie River should aim to create connectivity between the Macquarie River and Barwon River particularly in synchrony with flow events occurring in the Barwon River. This may facilitate immigration of native fish species to the Macquarie River.

No juvenile golden perch, silver perch and spangled perch were sampled within the Macquarie River during the three rounds of sampling between August 2014 and April 2015. Discharges greater than those delivered as part of the October to December 2014 environmental water release (~1,000 ML/day at Baroona) are likely required to cue the spawning of these periodic/flow-dependent species. However, the timing of such flow events must align with the breeding season and spawning temperature thresholds of these native fish species (Rayner et al. 2015).

Variation in fish community composition over a lotic gradient

SRA indicators

The Murray–Darling Basin Authority's (MDBA's) Sustainable Rivers Audit (SRA) program (Davies et al., 2010) established a set of fish assemblage metrics reflecting aspects of fish community 'health' within the Murray–Darling Basin. These metrics can be aggregated into themed indicators (expectedness, recruitment and nativeness) and an overall Fish Condition Index (SRA ndxFS). In general, the overall condition of the fish community of the Macquarie River assessed in the present study declined along a downstream gradient from 'poor' below Burrendong Dam to 'extremely poor' in the Macquarie Marshes and downstream to the Barwon River confluence. The Sustainable Rivers Audit 1, conducted from 2004 to 2007, classified the Macquarie 'Slopes' (incorporating Zone 1 and Zone 2) as 'very poor' and 'Lowland' (incorporating Zone 2 and Zone 3) as 'poor' (MDBC, 2008). More recently, the Sustainable Rivers Audit 2, conducted from 2008 to 2010, classified both the Macquarie 'Slopes' and 'Lowland' as 'extremely poor' (MDBA, 2011). Findings from the present study suggest an improvement in the fish community of Macquarie 'Slopes' from 'extremely poor' to 'poor'; however, such a comparison is not entirely appropriate as this study was confined to the Macquarie River channel, whereas the SRA operates at a catchment scale.

Burrendong Dam thermal curtain

Cold water pollution as a result of a deep-water offtake from Burrendong Dam has significantly affected biological processes of fish for up to 300–400 km downstream (Astles et al., 2003). During summer, thermal stratification within the dam can exceed >10 °C (Astles et al., 2003). The release of this cold, sometimes anoxic hypolimnetic water can affect growth, survival, redistribution, activity and recruitment (Astles et al., 2003; Todd et al., 2005) of native fish species and in some cases can lead to the complete loss of non-tolerant fish species (Todd et al., 2005).

Mitigation measures for cold water pollution below Burrendong Dam involved retrofitting a submerged curtain to the existing offtake to increase discharge temperatures (State Water, 2015). Preliminary findings indicate that cold water pollution is being reduced, though not eliminated, under the current operation of the thermal curtain. A 3 °C difference between November 2013 and November 2014 water temperatures below Burrendong Dam has been recorded (Gray, 2015). These data were collected with the curtain set at 7 m below the dam surface. It has been suggested the curtain be raised to 5 m to further reduce the impacts of cold water pollution downstream (Gray, 2015).

Data from the present study indicate that successful recruitment occurred during the 2014/2015 watering year in a number of native species within Zone 1, directly below Burrendong Dam. However, within Zone 1, poor abundance and recruitment of Murray cod was observed compared with Zone 2, approximately 150 km downstream. Similar results were observed by Astles et al. (2003) who investigated relationships between fish community composition and temperature regime within the Macquarie River. Astles et al. (2003) attributed the poor abundances of Murray cod to cold water pollution. It is likely the fish community response to the cold water mitigation will manifest over a number of years. Therefore, data from the 2014/2015 sampling would contribute to data that should be collected over a longer temporal scale.

Fish recruitment in the Macquarie Marshes

Limited evidence of native fish recruitment was observed within the main channel system of the Macquarie Marshes during the three rounds of fish community sampling throughout the 2014/2015 watering year. However, the alignment of bony bream hatch dates, caught downstream of the Macquarie Marshes, with a flow pulse within the Macquarie Marshes illustrates the possibility that the Macquarie Marshes was a recruitment source of juvenile bony bream.

Although native species recruitment was low within the Macquarie Marshes, high levels of common carp recruitment were observed, particularly after flow events. Similarly, strong recruitment of common carp was observed in the Macquarie Marshes after monitoring of a small 20,952 ML environmental flow event in February 2008 (Rayner et al., 2009). Rayner et al. (2015) monitored recruitment of native and exotic species in association with widespread flooding of the Macquarie Marshes between July 2010 and February 2011. Recruitment of native species, including bony bream and spangled perch, was observed; however, exotic species (common carp, goldfish and eastern gambusia) had a longer spawning window and recruited earlier than native species due to their lower spawning threshold temperatures (Rayner et al., 2015). From that study, Rayner et al. (2015) identified the importance of the alignment in the timing of environmental water deliveries and spawning temperature thresholds of native species present in the Macquarie Marshes.

It is known that common carp alter ecosystems through both bottom-up and top-down ecological processes with flow-on indirect impacts at multiple trophic levels (Weber and Brown, 2009; Badiou et al., 2011; Weber and Traunspurger, 2014). Primary impacts relate to interspecies competition for resources and aquatic habitat alteration through benthic foraging by adult carp. Adult carp compete with native benthic foraging fishes and both adult and juvenile carp compete for zooplankton with planktivorous fish and the larvae of all native fish species (Fletcher, 1986; Schiller and Harris, 2001). Other direct impacts include potential predation on the eggs and larvae of native fishes (Curtis, 1942; Lachner et al., 1970; Page and Burr, 1997; Schiller and Harris, 2001). Such mechanisms may be responsible for the low abundances and poor recruitment of native species within the Macquarie Marshes; however, as detailed by Gilligan and Rayner (2007) and Hume et al. (1983), the specific impacts of carp are complex and difficult to isolate from other interrelated anthropogenic changes to ecosystems.

Fish condition

It is generally accepted that fish with a high body condition index are typically more resistant to negative environmental factors and have a greater reproductive potential. However, a number of biases exist when comparing condition indices at a short temporal scale when the objective is to assess the impacts of environmental watering events. Changes in condition are likely to be attributed to an increase in the species' gonado-somatic index (GSI) (i.e. gonad development). For most native large-bodied species, an increase in the GSI is seasonal, irrespective of hydrological conditions. However, a further increase in GSI may result from oocyte hydration as a result of favourable hydrological conditions (Lake, 1967; Rowland, 1983b; Battaglene, 1991). To examine temporal change in fish condition with validity, sampling must be repeated over multiple years both during and outside the species' reproductive period.

Considerations in the design of recruitment response monitoring

In an ideal scenario larval sampling should be conducted in addition to recruitment monitoring to examine 'relative recruitment strength'. This would provide insight into whether peaks in recruitment are due to increased spawning activity or increased survival of larval fish due to favourable environmental conditions. Moreover, it should be noted that 'relative recruitment strength' can only be calculated for species where abundances of eggs and/or early larval phase can be quantified (i.e. species with drifting eggs and/or early larval phase). However, when conducted in isolation, recruitment monitoring as employed here has numerous advantages over reproduction monitoring that uses traditional egg and larval sampling methods. Firstly, although fish may spawn, not all spawning events may be successful due to the prevailing environmental conditions necessary for larval survival and subsequent recruitment. Additionally, most mortality occurs during early life-history stages because larvae are likely to be more sensitive to environmental factors than older life stages (Childs et al., 1998; Koehn and Harrington, 2006). As a result, sampling juveniles rather than larval fish and eggs gives a better picture of what is actually surviving and contributing to the population.

Despite the advantages associated with recruitment monitoring, obtaining and interpreting useful data are largely dependent upon the initial design of the monitoring project. The following subsections detail important considerations in the design and interpretation of recruitment monitoring studies with reference to the current study.

Fish stocking

The stocking of native fishes, including Murray cod and golden perch, is conducted by recreational fishing groups within the Macquarie River. Up to now, these stocked fish have not been marked for later identification, creating difficulties in discriminating between stocked and naturally recruited fish. However, stocking records and hatch dates of stocked fishes are maintained by NSW Fisheries and independent hatcheries. This information was used to determine the possibility that captured juveniles were stocked fish. Approximately 4,544 Murray cod, 45–50 mm in length, were stocked on 22 January 2015 within the vicinity of Zone 2 (Appendix 8). The collection of juvenile Murray cod during Round 2 of sampling preceded this stocking event. It is therefore assumed all juveniles caught during Round 2 were naturally recruited. Round 3 of sampling was conducted after the stocking event. Hatchery data indicate these stocked fish were hatched on 10 November 2014. A peak in back-calculated hatch dates of daily aged Murray cod caught during Round 3 of sampling coincides with the hatch date of stocked Murray cod. It is therefore possible that a number of juvenile Murray cod sampled during Round 3 were hatchery-reared fish. In addition, 21,818 golden perch, 40 mm in length, were stocked on the same date at a number of locations within the vicinity of Zone 2 (Appendix 8); however, no juvenile golden perch were caught during sampling throughout the entirety of the Macquarie River. In the future, all native fish stocked into river systems will be batch-marked with calcien (a fluorescent marker) in the hatchery prior to release to facilitate a more accurate assessment of the implications of stocked fish within studies of fish recruitment in the field.

Sampling interval

Fish age estimates used in the construction of hatch date frequency figures (Section: 'Recruitment and daily aging') were not extrapolated beyond the largest fish aged in the species' size-at-age plot (i.e. daily aging becomes difficult and less accurate as a species gets older). Consequently, interpretation of hatch dates for each sample is confined to the period defined by arrows in each hatch date frequency histogram, defined as the 'focus period'. When designing recruitment monitoring projects, multiple sampling events should be conducted at appropriate intervals around the watering event. The sampling intervals should be less than the shortest 'focus period' of all target species' to prevents gaps in hatch date frequency figures. Additionally, the sampling interval should be minimised to reduce biases introduced by mortality. Hatch date frequency figures do not account for changes in exposure time to the chance of mortality. As a result, skewed hatch date frequency graphs, with increased frequency of hatch dates closer to the sampling event, may not be a result of increased recruitment success, but rather, older fish recruited earlier in the focus period have been susceptible to mortality for longer periods and have subsequently been reduced in numbers at the time of sampling. To reduce mortality bias and account for the maximum age that can accurately be assigned to a species, sampling in the present study was conducted on three occasions around the watering event with a 2-month interval between sampling rounds.

Experimental control

Due to difficulties in selecting an appropriate unregulated control river system based on similarity in fish diversity/abundance and abiotic river characteristics, fish community sampling was confined to the Macquarie River. Because of the absence of a control, it is difficult to demonstrate cause and effect and attribute peaks in fish recruitment to the environmental water release. This is particularly the case for Murray cod which are known to spawn irrespective of flow between October and December at water temperatures between 16 and 20 °C (Lake, 1967; Rowland, 1983a, 1998; Humphries, 2005; King et al., 2009). The release of environmental water in October 2014 therefore coincided with the breeding season of Murray cod. While an increase in discharge may not have been required to trigger a spawning event, the high flow event may have boosted primary production that facilitated successful recruitment. To attribute the successful recruitment of Murray cod (and other species) in 2014 to the environmental water release, it is critical that recruitment monitoring be repeated during a year where there is no environmental watering during the breeding season. This additional monitoring would act as a 'control' to bring further validity to the results obtained from the present study.

Daily age validation and first ring formation

An essential component of daily aging studies is the validation of the deposition of daily growth rings, and knowledge of the timing of the formation of the first growth ring. A number of the species investigated in the present study have had daily growth ring formation validated; however, age validation studies are yet to be conducted for a number of species (Table 10). Species can deposit their first major increment at different early life-history events, such as hatching or first exogenous feeding (Geffen, 1992). Consequently, age is expressed as 'estimated age' throughout this report. Nevertheless, aging error margins as a result of the timing of the first ring formation would be minimal given the short intervals between hatching, yolk absorption and exogenous feeding.

Table 10 Species of the Macquarie River systems and details of the associated daily age validation studies.

Species	Daily aging validated?	Reference
Silver perch (*Bidyanus bidyanus*)	×	
Un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*)	×	
Common carp (*Cyprinus carpio*)	✓	(Vilizzi, 1998; Smith and Walker, 2003b)
Carp-gudgeon (*Hypseleotris* spp.)	×	
Spangled perch (*Leiopotherapon unicolor*)	×	
Trout cod (*Maccullochella macquariensis*)	×	
Murray cod (*Maccullochella peelii*)	✓	(Humphries, 2005)
Golden perch (*Macquaria ambigua*)	✓	(Brown and Wooden, 2007)
Murray–Darling rainbowfish (*Melanotaenia fluviatilis*)	×	Validated for eastern rainbowfish (Humphrey et al., 2003)
Bony bream (*Nematalosa erebi*)	×	
Redfin perch (*Perca fluviatilis*)	✓	(Kristensen et al., 2008)
Flatheaded gudgeon (*Philypnodon grandiceps*)	×	
Australian smelt (*Retropinna semoni*)	✓	(Tonkin et al., 2008)
Eel-tailed catfish (*Tandanus tandanus*)	×	

Spawning, hatch dates and abiotic conditions

With knowledge of the incubation period of each species, and the assumption that the first daily growth increment is deposited at the time of hatching, spawning dates in addition to hatch dates can be matched with water temperature and hydrological conditions. The incubation period of each species sampled in the Macquarie River is detailed in Table 11. It should be noted that there are a number of factors that may result in a minor mismatch between estimated hatch dates for each species and the associated abiotic conditions. These include:

- Gauging location: river discharge and water temperature were measured at one gauging station within each zone. On average, it takes approximately 5 days for a flow pulse to travel through a zone. Therefore, there may be up to ±5 days between the alignment of hatch date and river discharge/temperature.
- Fish migration: fish capture locations may be different to the hatch location as a result of fish moving upstream or downstream.
- Aging error: the ageing coefficient of variation calculation for each species fell within the expected reference point of 5% (Campana, 2001). Only minor variation was observed between the two readers' age assignments, particularly in older fish.

Table 11 Egg incubation period for fish species sampled in the Macquarie River.

Species	Incubation period	Reference
Silver perch (*Bidyanus bidyanus*)	1–2 days	(Lake, 1967; Rowland, 1984, 1996; Neira et al., 1998)
Goldfish (*Carassius auratus*)	7 days	(Lintermans, 2007)
Un-specked hardyhead (*Craterocephalus stercusmuscarum fulvus*)	4–7 days	(Lintermans, 2007)
Common carp (*Cyprinus carpio*)	2–6 days	(Winfield and Nelson, 2012)
Carp-gudgeon (*Hypseleotris* spp.)	2 days	(Lintermans, 2007)
Spangled perch (*Leiopotherapon unicolor*)	2 days	(Llewellyn, 1973; Lintermans, 2007)
Murray cod (*Maccullochella peelii*)	5–13 days	(Lake, 1967; Lintermans, 2007)
Golden perch (*Macquaria ambigua*)	1–2 days	(Lake, 1967; Rowland, 1984, 1996; Neira et al., 1998)
Murray–Darling rainbowfish (*Melanotaenia fluviatilis*)	7–9 days	(Backhouse and Frusher, 1980; Reid and Holdway, 1995; Lintermans, 2007)
Trout cod (*Maccullochella macquariensis*)	5-10 days	(Ingrim and Rimmer, 1993)
Bony bream (*Nematalosa erebi*)	–	
Redfin perch (*Perca fluviatilis*)	7–14 days	(Lintermans, 2007)
Flatheaded gudgeon (*Philypnodon grandiceps*)	4–8 days	(Llewellyn, 2007)
Australian smelt (*Retropinna semoni*)	9–10 days	(Milton and Arthington, 1985; Lintermans, 2007)
Eel-tailed catfish (*Tandanus tandanus*)	7 days	(Lintermans, 2007)

Conclusions and recommendations

- Recruitment data collected over a single watering year suggests native fish species of the mid-lower Macquarie River, from opportunistic and equilibrium life-history guilds, benefitted from the provision of Commonwealth and NSW environmental water during the spring and early summer of 2014-2015.
- Small-bodied opportunistic species, including Australian smelt, un-specked hardyhead and Murray–Darling rainbowfish, showed peaks in hatch date frequencies that occurred during the receding tails of flow events or during sustained periods of increased flow, particularly in association with the October to December 2014 environmental water release.
- The majority of juvenile Murray cod had hatch dates coincided with the arrival of environmental water from Burrendong Dam during the spring and early summer of 20142015. While this increase in discharge may not have been required to trigger a spawning event, the increased flow may have boosted primary production that facilitated successful recruitment.
- Recruitment data for eel-tailed catfish indicated the primary spawning period coincided with water temperatures reaching approximately 20 °C and moderate discharge (~300–1,200 ML/day). It is commonly recognised that flooding is not required to initiate spawning for this species; however, increased flow as a result of the environmental water release may have boosted primary production and subsequently facilitate successful recruitment.
- Recruitment data collected from daily aged bony bream adds significant information to existing literature on the biology of bony bream; extending the known breeding season and highlighting a relationship between flow and recruitment.
- Future environmental water releases within the Macquarie River should aim to create connectivity between the Macquarie River and Barwon River particularly in synchrony with flow events occurring in the Barwon River. This may facilitate immigration of native fish species to the Macquarie River.
- Repeated sampling should be conducted over multiple watering years to examine native fish response to a variety of natural and regulated flow scenarios.
- For environmental water deliveries to benefit native fish recruitment, the release of environmental water must align with the breeding season and spawning temperature thresholds of native species targeted by the flow event.
- A small environmental water release (i.e. 28,483 ML) delivered at the appropriate time does likely benefit the recruitment of some equilibrium and opportunistic species within the mid and lower Macquarie River; however, higher discharges (>1,000 ML/day) are likely required to cue the spawning of periodic/flow-dependent species such as golden perch and silver perch.
- The Environmental Outcomes Framework (CEWO, 2013) identifies connectivity in regards to biotic dispersal and movement as an outcome to environmental water delivery (Figure 1). An acoustic telemetry component in future monitoring and evaluation projects on the Macquarie River will provide a means to examine the movement response of fish to the delivery of environmental flows. More specifically, it would demonstrate how environmental water delivery may provide: 1) connectivity between habitats; and 2) a trigger for spawning migrations.

- Analysis of otolith chemistry may provide more certainty about which river system juveniles recruited from; i.e. do flow events that create connectivity between the Barwon River and Macquarie River allow for the emigration of juveniles into the Macquarie River?
- Larval sampling should be conducted in addition to recruitment monitoring to examine 'relative recruitment strength'. This will provide insight into whether peaks in recruitment are due to increased spawning activity or increased survival of larval fish due to favourable environmental conditions.
- Daily age validation should be conducted for species not previously validated.
- Fish community monitoring should continue over a large temporal scale to investigate the efficacy of the variable offtake curtain in mitigating cold water pollution from Burrendong Dam.

References

Anderson, M. J. 2001. A new method for non-parametric multivariate analysis of variance. *Austral ecology*, *26*(1), 32-46.

ANZECC & ARMCANZ 2000. Australian and New Zealand guidelines for fresh and marine water quality. Volume 1, The guidelines /Australian and New Zealand Environment and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand.

Arthington, A. H. & Balcombe, S. R. 2011. Extreme flow variability and the 'boom and bust' ecology of fish in arid-zone floodplain rivers: a case history with implications for environmental flows, conservation and management. Ecohydrology, 4, 708–720.

Astles, K. L., Winstanley, R. K., Harris, J. H. & Gehrke, P. C. 2003. Regulated Rivers and Fisheries Restoration Project—experimental study of the effects of cold water pollution on native fish. NSW Fisheries Office of Conservation: Cronulla.

Backhouse, G. & Frusher, D. 1980. The crimson-spotted rainbowfish, *Melanotaenia fluviatilis* (Castelnau 1878). Victorian Naturalist, 97, 144–148.

Badiou, P., Goldsborough, L. G. & Wrubleski, D. 2011. Impacts of the common carp (*Cyprinus carpio*) on freshwater ecosystems: a review. In: Sanders, J. D. & Peterson, S. B. (eds), Carp: habitat, management and diseases. Nova Science Publishers: New York, pp. 121–146.

Balcombe, S. R. & Arthington, A. H. 2009. Temporal changes in fish abundance in response to hydrological variability in a dryland floodplain river. Marine and Freshwater Research, 60, 146–159.

Balcombe, S. R., Arthington, A. H., Foster, N. D., Thoms, M. C., Wilson, G. G. & Bunn, S. E. 2006. Fish assemblages of an Australian dryland river: abundance, assemblage structure and recruitment patterns in the Warrego River, Murray–Darling Basin. Marine and Freshwater Research, 57, 619–633.

Balcombe, S. R., Bunn, S. E., Arthingon, A. H., Fawcett, J. H., Mckenzie-Smith, F. J. & Wright, A. 2007. Fish larvae, growth and biomass relationships in an Australian arid zone river: links between floodplains and waterholes. Freshwater Biology, 52, 2385–2398.

Battaglene, S. 1991. The golden perch, *Macquaria ambigua* (Pisces: Percichthyidae), of Lake Keepit, NSW. MSc thesis, University of New South Wales.

Baumgartner, L. J. 2003. Fish passage through a Deelder lock on the Murrumbidgee River, Australia. NSW Fisheries Final Report Series No. 57. NSW Fisheries: Cronulla.

Baumgartner, L. J., Conallin, J., Wooden, I., Campbell, B., Gee, R., Robinson, W. A. & Mallen-Cooper, M. 2014. Using flow guilds of freshwater fish in an adaptive management framework to simplify environmental flow delivery for semi-arid riverine systems. Fish and Fisheries, 15(3), 410–427.

Bray, J. R., & Curtis, J. T. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs, 27(4), 325–349.

Brock, P. M. 1998. The significance of the physical environment of the Macquarie Marshes. The Australian Geographer, 29, 71–90.

Brown, P., Sivakumaran, K., Stoessel, D. & Giles, A. 2005. Population biology of carp (*Cyprinus carpio* L.) in the mid-Murray River and Barmah Forest Wetlands, Australia. Marine and Freshwater Research, 56, 1151–1164.

Brown, P. & Wooden, I. 2007. Age at first increment formation and validation of daily growth increments in golden perch (*Macquaria ambigua*: Percichthyidae) otoliths. New Zealand Journal of Marine and Freshwater Research, 41(2), 157–161.

Bunn, S. E. & Arthington, A. H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management, 30, 492–507.

Bunn, S. E., Thoms, M. C., Hamilton, S. K. & Capon, S. J. 2006. Flow variability in dryland rivers: boom, bust and the bits in between. River Research and Applications, 22, 179–186.

Cadwallader, P. L. (1977). JO Langtry's 1949-50 Murray River investigations. Fisheries and Wildlife Division, Victoria.

Campana, S. E. 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. Journal of Fish Biology, 59, 197–242.

CEWO (Commonwealth Environmental Water Office) 2013. The Environmental Water Outcomes Framework. Commonwealth Environmental Water Holder for the Australian Government: Canberra.

Childs, M. R., Clarkson, R. W. & Robinson, A. T. 1998. Resource use by larval and early juvenile native fishes in the Little Colorado River, Grand Canyon, Arizona. Transactions of the American Fisheries Society, 127, 620–629.

Curtis, B. 1942. The general situation and biological effects of the introduction of alien fishes into California waters. California Fish and Game, 28, 2–8.

Davies, P. E., Harris, J. H., Hillman, T. J. & Walker, K. F. 2008. Sustainable Rivers Audit: SRA Report 1—a report on the ecological health of rivers in the Murray–Darling Basin, 2004–2007. Prepared by the Independent Sustainable Rivers Audit Group for the Murray–Darling Basin Ministerial Council. Murray–Darling Basin Commission: Canberra.

Davies, P. E., Harris, J. H., Hillman, T. J. & Walker, K. F. 2010. The Sustainable Rivers Audit: assessing river ecosystem health in the Murray–Darling Basin, Australia. Marine and Freshwater Research, 61, 764–777.

Davis, T. L. O. 1975. Biology of the freshwater catfish Tandanus tandanus Mitchell (Pisces: Plotosidae) in the Gwydir River. New South Wales, Australia, with particular reference to the immediate effects caused by the impoundment of this river by the Copeton Dam. PhD, University of New England.

Davis, T. 1977. Reproductive biology of the freshwater catfish, *Tandanus tandanus* Mitchell, in the Gwydir River, Australia. II. Gonadal cycle and fecundity. Marine and Freshwater Research, 28, 159–169.

Fletcher, A. R. 1986. Effects of introduced fish in Australia. In: DE DECKKER, P. & WILLIAMS, W. D. (eds), Limnology in Australia. Monographiae Biologicae series vol. 61. CSIRO: Melbourne and Dr W. Junk: Dordrecht.

Gawne, B., Merrick, C., Williams, D. G., Rees, G., Oliver, R., Bowen, P. M., Treadwell, S., Beattie, G., Ellis, I., Frankenberg, J. & Lorenz, Z. 2007. Patterns of primary and heterotrophic productivity in an arid lowland river. River Research and Applications, 23, 1070–1087.

Gawne, B., Brooks, S., Butcher, R., Cottingham, P., Everingham, P., Hale, J., Nielson, D., Stewardson, M. & Stoffels, R. 2013. Long Term Intervention Monitoring Project: logic and rationale document, version 1.0. MDFRC Publication No. 01/2013. Murray–Darling Freshwater Research Centre: Wodonga.

Geffen, A. J. 1992. Validation of otolith increment deposition rate. Canadian Special Publication of Fisheries and Aquatic Sciences, 117, 101–113.

Gehrke, P. C., Brown, P., Schiller, C. B., Moffatt, D. B. & Bruce, A. M. 1995. River regulation and fish communities in the Murray–Darling river system, Australia. Regulated Rivers: Research & Management, 11, 363–375.

Gilligan, D., Jess, L., Mclean, G., Asmus, M., Wooden, I., Hartwell, D., Mcgregor, C., Stuart, I., Vey, A., Jefferies, M., Lewis, B. & Bell, K. 2010. Identifying and implementing targeted carp control options for the Lower Lachlan Catchment. NSW Department of Industry and Investment – Fisheries Final Report Series No. 118. Industry & Investment NSW: Sydney.

Gilligan, D. & Rayner, T. 2007. The distribution, spread, ecological impacts and potential control of carp in the upper Murray River. Fisheries Research Report Series No. 14. NSW Department of Primary Industries: Cronulla.

Gilligan, D., Vey, A. & Asmus, D. 2009. Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of environmental, stock and domestic flows. Fisheries Final Report Series No. 110. NSW Department of Primary Industries: Cronulla.

Gray, R. 2015. Effectiveness of cold water pollution mitigation at Burrendong Dam using an innovative thermal curtain. Honours presentation, University of Technology Sydney.

Growns, I. 2004. A numerical classification of reproductive guilds of the freshwater fishes of south-eastern Australia and their application to river management. Fisheries Management and Ecology, 11, 369–377.

Growns, I. & Gehrke, P. 2005. Integrated monitoring of environmental flows: assessment of predictive modelling for river flows and fish. Fisheries Final Report Series No. 74. NSW Department of Primary Industries: Cronulla.

Harris, J. H. 1995. The use of fish in ecological assessments. Australian Journal of Ecology, 20, 65–80.

Harris, J. H. & Gehrke, P. C. 1994. Modelling the relationship between streamflow and population recruitment to manage freshwater fisheries. Australian Fisheries, 6, 28–30.

Heibo, E., & Magnhagen, C. 2005. Variation in age and size at maturity in perch (*Perca fluviatilis* L.), compared across lakes with different predation risk. Ecology of freshwater fish, 14(4), 344-351.

Hume, D. J., Fletcher, A. R. & Morison, A. K. 1983. Interspecific hybridization between carp (Cyprinus carpio L.) and goldfish (Carassius auratus L.) from Victorian waters. Australian Journal of Marine and Freshwater Research, 34, 915–919.

Humphrey, C., Klumpp, D. W. & Pearson, R. 2003. Early development and growth of the eastern rainbowfish, *Melanotaenia splendida splendida* (Peters). II. Otolith development, increment validation and larval growth. Marine and Freshwater Research, 54, 105–111.

Humphries, P., King, A. J. & Koehn, J. D. 1999. Fish, flows and flood plains: links between freshwater fishes and their environment in the Murray–Darling River system, Australia. Environmental Biology of Fishes, 56, 129–151.

Humphries, P. 2005. Spawning time and early life history of Murray cod, *Maccullochella peelii* (Mitchell) in an Australian river. Environmental Biology of Fishes, 72, 393–407.

Humphries, P., Richardson, A., Wilson, G. & Ellison, T. 2013. River regulation and recruitment in a protracted-spawning riverine fish. Ecological Applications, 23, 208–225.

Ingram, B. A., & Rimmer, M. A. 1993. Induced breeding and larval rearing of the endangered Australian freshwater fish trout cod, *Maccullochella macquariensis* (Cuvier)(Percichthyidae). Aquaculture Research, 24(1), 7-17.

Junk, W. J., Bayley, P. B. & Sparks, R. E. 1989. The flood pulse concept in river–floodplain systems. Canadian Special Publication of Fisheries and Aquatic Sciences, 106, 110–127.

King, A. J., Humphries, P. & Lake, P. S. 2003. Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. Canadian Journal of Fisheries & Aquatic Sciences, 60, 773–786.

King, A. J., Tonkin, Z. & Mahoney, J. 2009. Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. River Research and Applications, 25, 1205–1218.

King, A. J., Ward, K. A., O'connor, P., Green, D., Tonkin, Z. & Mahoney, J. 2010. Adaptive management of an environmental watering event to enhance native fish spawning and recruitment. Freshwater Biology, 55, 17–31.

Kingsford, R. T., Curtin, A. L. & Porter, J. 1999. Water flows on Cooper Creek in arid Australia determine boom and bust periods for waterbirds. Biological Conservation, 88, 231–248.

Kingsford, R. T. & Johnson, W. 1998. Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of arid Australia. Colonial Waterbirds, 21, 159–170.

Koehn, J. D. & Harrington, D. 2006. Environmental conditions and timing for the spawning of Murray cod (*Maccullochella peelii peelii*) and the endangered trout cod (*M. macquariensis*) in southeastern Australian rivers. River Research and Applications, 22, 327–342.

Kristensen, P. B., Closs, G. P., Lokman, P. M. & Grønkjær, P. 2008. Otolith formation, microstructure and daily increment validation in juvenile perch *Perca fluviatilis*. Journal of Fish Biology, 73, 1478–1483.

Lachner, E. A., Robins, C. R. & Courtenay, W. R. 1970. Exotic fishes and other aquatic organisms introduced into North America. Smithsonian Contributions to Zoology No. 59. Smithsonian Institution Press: Washington, DC.

Lake, J. 1967. Rearing experiments with five species of Australian freshwater fishes. I. Inducement to spawning. Marine and Freshwater Research, 18, 137–154.

Leggett, R., & Merrick, J. R. (1987). Australian native fishes for aquariums. JR Merrick PublicationsLINTERMANS, M. 2007. Fishes of the Murray–Darling Basin: an introductory guide. Murray–Darling Basin Commission: Canberra.

Llewellyn, L. 1973. Spawning, development, and temperature tolerance of the spangled perch, *Madigania unicolor* (Gunther), from inland waters in Australia. Marine and Freshwater Research, 24, 73–94.

Llewellyn, L. 1979. Some observations on the spawning and development of the Mitchellian freshwater hardyhead *Craterocephalus fluviatilis* McCulloch from inland waters in New South Wales. Australian Zoologist, 20, 269–288.

Llewellyn, L. 1983. The distribution of fish in New South Wales. Special Publication No. 7. Australian Society for Limnology: Sydney.

Llewellyn, L. C. 2007. Spawning and development of the glat-headed gudgeon Philypnodon grandiceps (Krefft, 1864) (Teleostei: Eleotridae). Australian Zoologist, 34, 1–21.

Lorenzoni, M., Corboli, M., Ghetti, L., Pedicillo, G., & Carosi, A. 2007. Growth and reproduction of the goldfish Carassius auratus: a case study from Italy. In Biological invaders in inland waters: Profiles, distribution, and threats (pp. 259-273). Springer Netherlands

McDowall, R.M. (1996) Freshwater Fishes of South-Eastern Australia, 2nd edn. Sydney: Reed Books, 247 pp.

Mackay, N. 1973. Histological changes in the ovaries of the golden perch, Plectroplites ambiguus, associated with the reproductive cycle. Marine and Freshwater Research, 24, 95–102.

Mallen-Cooper, M. 1996. Fishways and freshwater fish migration in south-eastern Australia. PhD thesis, University of Technology, Sydney.

Mallen-Cooper, M. & Stuart, I. 2003. Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. River Research and Applications, 19, 697–719.

Mallen-Cooper, M., Stuart, I. G., Hides-Pearson, F. & Harris, J. H. 1995. Fish migration in the Murray River and assessment of the Torrumbarry fishway. Final report for the Natural Resources Management Strategy Project N002. New South Wales Fisheries Research Institute: Cronulla and Cooperative Research Centre for Freshwater Ecology: Canberra.

MDBA (Murray–Darling Basin Authority) 2011. Sustainable Rivers Audit 2: the ecological health of rivers in the Murray–Darling Basin at the end of the Millennium Drought (2008–2010). Summary. MDBA: Canberra.

MDBC (Murray–Darling Basin Commission) 2004. Sustainable Rivers Audit: Pilot Audit – Fish Theme technical report. MDBC: Canberra.

MDBC (Murray–Darling Basin Commission) 2008. Murray–Darling Basin rivers: ecosystem health check, 2004–2007. A summary report based on the Independent Sustainable Rivers Audit Group's SRA Report 1: a report on the ecological health of rivers in the Murray–Darling Basin, 2004–2007, submitted to the Murray–Darling Basin Ministerial Council in May 2008. MDBC: Canberra.

Merrick, J. & Midgley, S. 1981. Spawning behaviour of the freshwater catfish *Tandanus tandanus* (Plotosidae). Marine and Freshwater Research, 32, 1003–1006.

Milton, D. & Arthington, A. 1985. Reproductive strategy and growth of the Australian smelt, *Retropinna semoni* (Weber) (Pisces : Retropinnidae), and the olive perchlet, *Ambassis nigripinnis* (De Vis) (Pisces : Ambassidae), in Brisbane, south-eastern Queensland. Marine and Freshwater Research, 36, 329–341.

Neira, F. J., Miskiewicz, A. G., & Trnski, T. (1998). Larvae of temperate Australian fishes: laboratory guide for larval fish identification. University of Western Australia Press: Nedlands.

OEH (Office of Environment and Heritage) 2013. Macquarie Valley: annual environmental watering plan 2013–14. OEH: Sydney.

Page, L. M. & Burr, B. M. 1997. A field guide to freshwater fishes: North America north of Mexico. Houghton Mifflin Harcourt: Boston.

Puckridge, J. T., Sheldon, F., Walker, K. F. & Boulton, A. J. 1998. Flow variability and the ecology of large rivers. Marine and Freshwater Research, 49, 55–72.

Puckridge, J. T. & Walker, K. 1990. Reproductive biology and larval development of a gizzard shad, Nematalosa erebi (Gunther)(Dorosomatinae: Teleostei), in the River Murray, South Australia. Marine and Freshwater Research, 41, 695–712.

Pusey, B., Kennard, M., & Artington, A. (Eds.). (2004). Freshwater fishes of north-eastern Australia. CSIRO publishingRAYNER, T., JENKINS, K., & KINGSFORD, R. 2008. Fish passage in the Macquarie River catchment: enhancing the ecological benefits of environmental flow delivery. University of New South Wales: Sydney.

Rayner, T. S., Jenkins, K. M. & Kingsford, R. T. 2009. Small environmental flows, drought and the role of refugia for freshwater fish in the Macquarie Marshes, arid Australia. Ecohydrology, 2, 440–453.

Rayner, T. S., Kingsford, R. T., Suthers, I. M. & Cruz, D. O. 2015. Regulated recruitment: native and alien fish responses to widespread floodplain inundation in the Macquarie Marshes, arid Australia. Ecohydrology, 8, 148–159.

Reid, H. & Holdway, D. 1995. Early development of the Australian crimson-spotted rainbowfish, *Melanotaenia fluviatilis* (Pisces: Melanotaeniidae). Marine and Freshwater Research, 46, 475–480.

Ren, S. & Kingsford, R. T. 2011. Statistically integrated flow and flood modelling compared to hydrologically integrated quantity and quality model for annual flows in the regulated Macquarie River in arid Australia. Environmental Management, 48, 177–188.

Reynolds, L. F. 1983. Migration patterns of five fish species in the Murray–Darling River system. Marine and Freshwater Research, 34, 857–871.

Robinson, W. 2012. Calculating statistics, metrics, sub-indicators and the SRA Fish Theme Index. Canberra: Murray–Darling Basin Authority: Canberra.

Rolls, R. J., Growns, I. O., Khan, T. A., Wilson, G. G., Ellison, T. L., Prior, A. & Waring, C. C. 2013. Fish recruitment in rivers with modified discharge depends on the interacting effects of flow and thermal regimes. Freshwater Biology, 58, 1804–1819.

Rolls, R. J. & Wilson, G. G. 2010. Spatial and temporal patterns in fish assemblages following an artificially extended floodplain inundation event, northern Murray–Darling Basin, Australia. Environmental Management, 45, 822–833.

Rowland, S. J. 1983a. Spawning of the Australian freshwater fish Murray cod, *Maccullochella peeli* (Mitchell), in earthen ponds. Journal of Fish Biology, 23, 525–534.

Rowland, S. J. 1983b. The hormone-induced ovulation and spawning of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson) (Percichthyidae). Aquaculture, 35, 221–238.

Rowland, S. J. 1984. The hormone-induced spawning of silver perch, *Bidyanus bidyanus* (Mitchell) (Teraponidae). Aquaculture, 42(1), 83–86.

Rowland, S. J. 1996. Development of techniques for the large-scale rearing of the larvae of the Australian freshwater fish golden perch, *Macquaria ambigua* (Richardson, 1845). Marine and Freshwater Research, 47, 233–242.

Rowland, S. J. 1998. Aspects of the reproductive biology of Murray cod, *Maccullochella peelii peelii.* Proceedings of the Linnean Society of New South Wales, 120, 147–162.

Schiller, C. & Harris, J. H. 2001. Native and alien fish. In: YOUNG, W. J. (ed.), Rivers as ecological systems: the Murray–Darling Basin. Murray–Darling Basin Commission: Canberra, pp. 229–258.

Smith, B. B. & Walker, K. F. 2003a. Shrinkage of 0+ carp (*Cyprinus carpio* L.) after preservation in ethanol. Marine and Freshwater Research, 54, 113–116.

Smith, B. B. & Walker, K. F. 2003b. Validation of the ageing of 0+ carp (*Cyprinus carpio* L.). Marine and Freshwater Research, 54, 1005–1008.

Southwell, M., Wilson, G., Ryder, D., Sparks, P. & Thoms, M. 2015. Monitoring the ecological response of Commonwealth environmental water delivered in 2013–14 in the Gwydir River system: a report to the Department of Environment. Commonwealth of Australia: Canberra.

State Water 2015. Burrendong temperature control structure [Online]. State Water: Dubbo. At <http://www.statewater.com.au/current+projects/Environmental+projects/Burrendong+temperature+control+structure>, accessed 6 October 2015.

Steinfeld, C. M. M. & Kingsford, R. T. 2013. Disconnecting the floodplain: earthworks and their ecological effects on a dryland floodplain in the Murray–Darling Basin, Australia. River Research and Applications, 29, 206–218.

Sternberg, D. & Kennard, M. J. 2013. Environmental, spatial and phylogenetic determinants of fish life-history traits and functional composition of Australian rivers. Freshwater Biology, 58, 1767–1778.

Stocks, J., Gray, C. & Taylor, M. 2014. Synchrony and variation across latitudinal gradients: the role of climate and oceanographic processes in the growth of a herbivorous fish. Journal of Sea Research, 90, 23–32.

Todd, C. R., Ryan, T., Nicol, S. J. & Bearlin, A. R. 2005. The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (*Maccullochella peelii peelii*): a case study of the Mitta Mitta River, southeastern Australia. River Research and Applications, 21, 1035–1052.

Tonkin, Z., King, A. J. & Robertson, A. 2008. Validation of daily increment formation and the effects of different temperatures and feeding regimes on short-term otolith growth in Australian smelt *Retropinna semoni*. Ecology of Freshwater Fish, 17, 312–317.

Vilizzi, L. 1998. Age, growth and cohort composition of 0+ carp in the River Murray, Australia. Journal of Fish Biology, 52, 997–1013.

Vilizzi, L. & Walker, K. F. 1999. Age and growth of the common carp, *Cyprinus carpio*, in the River Murray, Australia: validation, consistency of age interpretation, and growth models. Environmental Biology of Fishes, 54, 77–106.

Weber, M. J. & Brown, M. L. 2009. Effects of common carp on aquatic ecosystems 80 years after ‘carp as a dominant’: ecological insights for fisheries management. Reviews in Fisheries Science, 17, 524–537.

Weber, S. & Traunspurger, W. 2014. Top-down control of a meiobenthic community by two juvenile freshwater fish species. Aquatic Ecology, 48, 465–480.

Winfield, I. & Nelson, J. S. 2012. Cyprinid fishes: systematics, biology and exploitation, Springer Science & Business Media: Berlin.

Zampatti, B., Wilson, P., Baumgartner, L. J., Koster, W., Livore, J., Mccasker, N. & Thiem, J. 2015. Reproduction and recruitment of golden perch (*Macquaria ambigua ambigua*) in the southern Murray–Darling Basin 2013–2014: an exploration of river-scale response, connectivity and population dynamics. SARDI Research Report Series No. 820. South Australian Research and Development Institute: Adelaide.

Zampatti, B. P. & Leigh, S. J. 2013. Within-channel flows promote spawning and recruitment of golden perch, *Macquaria ambigua ambigua*—implications for environmental flow management in the River Murray, Australia. Marine and Freshwater Research, 64, 618–630.

Zeug, S. & Winemiller, K. 2008. Relationships between hydrology, spatial heterogeneity, and fish recruitment dynamics in a temperate floodplain river. River Research and Applications, 24, 90–102.

Appendices

Appendix 1 – Murray Darling Basin Authority – Sustainable Rivers Audit Protocol for Fish Theme sampling – Implementation Period 8: 2012–13

Introduction

This protocol applies to the sampling of SRA sites as part of the Fish Theme. It was developed by the MDBA's SRA team in consultation with the SRA Joint Venture Committee, Independent Sustainable Rivers Audit Group, the Jurisdictional Managing Agencies (JMAs) and the Fish Taskforce.

Prerequisites

The following prerequisites must be met before applying this protocol:

- a current sampling plan has been received from the Authority office
- the site has been validated in accordance with the Site Validation protocol
- field staff meet the requirements of their respective JMAs and agencies in applying this protocol, and
- field staff must comply with the requirements of the Australian Code of Electrofishing Practice.

Sampling principles

The staff undertaking sampling must adhere to following principles, which are fundamental to the application of this protocol:

- Sampling is to take place between 1 November and 30 April. In the North of the Basin (specifically the Paroo, Warrego and Condamine) the sampling period may extend to the end of May if temperatures earlier in the season are too high to work.
- Sampling is not to take place during periods of high flow, either natural or from impoundment releases. High flows are those which in the judgement of the field operators would pose an occupation health and safety risk or compromise catch efficiency to unacceptable levels.
- The Authority office must be notified as soon as practicable by the sampling agency or the JMA of any change to the application of this protocol or methods deployed at a site during a site visit in the event of equipment malfunction, site abandonment or disruption to a sampling event.
- Each major habitat type present at a site must be sampled at least once and then remaining sampling effort should occur in the most abundant habitat types. Recognised habitat types are pool edges, middle portions of pools, runs and riffles, slow-flowing back waters, emergent vegetation, submerged vegetation, large woody debris and debris dams.
- Sites must be sampled using the most appropriate methods, as listed in Tables A1.1 and A1.2. It is likely that both backpack and boat electrofishing will be used at most sites.
- Data are only to be recorded for fish greater than 15 mm total length.
- All caught fish are released live, except where State noxious or alien fish policies require otherwise or where samples are required as voucher specimens (see Table 5 Voucher specimens).

Deployment of sampling methods

Fish sampling will be conducted by electrofishing (boat and backpack) and by use of bait-traps and opera-house traps. Given the wide variety of site conditions in the Basin (from small upland streams to large lowland rivers) the teams will need to make a site-specific assessment of conditions. This assessment will need to identify the type of habitats present and their relative abundance, after which a decision can be made on the appropriate mix of sampling methods. In particular, the site should be assessed to identify all habitats that can be electrofished by boat, and/or backpack methods, and the proportion suitable for each method should be determined. Guidance on the selection and deployment of fish sampling methods is provided in the following tables.

Table A1.1: Choice of fish sampling method under varying site characteristics.

Site character	Appropriate methods
Large river sites: >15 m wetted channel width (as estimated by sampling teams)	Adopt large boat electrofishing. Include backpack shots as necessary to sample each wadeable habitat type at least once. Deploy 10 bait-traps.
Small river sites: <15 m wetted channel width (as estimated by sampling teams)	Adopt small boat electrofishing Include backpack shots as necessary to sample each wadeable habitat type at least once Deploy 10 bait-traps.
Wadeable habitats	Adopt backpack electrofishing. However, bank-mounted electrofishers can be used instead of backpack electrofishers for sites with electrical conductivity levels between 1500 µS/cm and the detection limits of the bank-mounted unit, provided agencies accept their use. Deploy 10 bait-traps.

Table A1.2: Application of fish sampling methods.

Method name	Application
Boat electrofishing	- Deploy 12 shots. - Note: A shot is 90 seconds of accumulated power-on time. - In portions of streams >15 m wetted channel width (as estimated by sampling teams), adopt alternate shots alongside both banks. - In portions of streams <15 m wetted channel width (as estimated by sampling teams), adopt zigzag coverage of sampled area. - Deploy two mid-channel shots when mid-channel water depth <4 m.
Backpack (and Bank-mount) electrofishing	- Deploy 8 shots. - Note: A shot is 150 seconds of accumulated power-on time. - In portions of streams <10 m wetted channel width (as estimated by sampling teams), adopt zigzag coverage of sampled area. - In streams >10 m wetted channel width (as estimated by sampling teams), adopt alternate shots alongside both banks. - Where electrical conductivity is >1,500 µS/cm and where agencies accept their use, bank-mounted electrofishers can be used in place of backpack electrofishers using the same procedures.
Bait-trap	- Deploy 10 bait-traps for 2 hours (± ½ hour depending on duration of electrofishing effort). - Only deploy at locations with depth <1 m. - Do not use bait or chemical light sticks in the traps. - Set traps in slow-flowing or backwater areas independent of electrofishing sites. - Pool the catch from all traps and record as a single event.

Table A1.3: Number of electrofishing shots required with each type of electrofishing gear.

Method	Proportion of site								
	<1/8	1/8	1/4	3/8	1/2	5/8	3/4	7/8	All
Boat	0	0	4	5	6	8	9	11	12
Backpack	0	1	2	3	4	5	6	8	8

Bait-trap placement

Sampling practices guided by Table A1.2above.

Measurement of individuals and subsampling

Fish smaller than 15 mm may be recorded but should not be reported as core SRA data as they will not be used in the analysis. A subsample of 50 individuals per species captured by each method (ie boat electrofishing, backpack electrofishing and bait-traps) used at each site should be measured for the listed attributes below. The subsample begins with the first individual of each species collected from each method and continues until the 50th individual. During electrofishing operations, in the shot/replicate where the 50th fish is found, all individuals present should be measured and recorded in order to avoid any bias in the size of fish selected for the subsample. For bait-traps the catch is pooled prior to counting and measuring, each fish is identified, and the first 50 of each species are measured. An effort should be made to reduce bias in sub-sampling the pooled catch, e.g. use a small aquarium dip-net to net the pooled catch. (Note: NSW DPI prefers to collect the data for each trap independently and then, using random sampling of the data, generate a compliant pooled data return for MDBA.) If the number of individuals captured by each sampling method is less than 50, all of them should be measured for the attributes listed below.

Data to be recorded for each individual are outlined below.

1) *Length:* Caudal fork length for species with a forked tail and total length for species with round tails are to be measured. Approximate length should be estimated for damaged fish and this will be considered equivalent to a measured length during data analysis. Length should be measured to the nearest mm using a measuring board.
2) *Weight:* If weight is to be recorded for that species (refer to Table A1.4), then each individual fish should be blotted dry and measured on a balance with a suitable range for individual being measured:
    a. for fish >50 g, record weight to nearest gram, or
    b. for fish 50 g or less, record weight to nearest 0.1 g.
3) *Health and condition:* For data requirements see section: ‘Fish health and condition’.
4) *Voucher specimens:* These are to be collected if that species requires a voucher specimen (refer to Table A1.4and section: ‘Voucher specimens’).

Species list

The species list is a combination of those species thought to have occurred in the Basin under reference conditions, those species caught during previous sampling events and those alien species expected to be caught in future sampling.

The list may be updated from time-to-time where new species are identified, taxonomy revised or data collection requirements change. Those species for which voucher specimens should be collected or weight recorded are indicated in this list. Requirements for voucher specimens are detailed below.

When identifying alien species such as carp and goldfish, field teams should be aware that there is the possibility of hybridisation. Jurisdictions may decide whether or not they wish to record the presence of hybrids. However, in doing so they should be aware that when the data are received by the MDBA, any hybrids will be assigned to a single parent taxon (e.g. carp or goldfish) based on which parent stock the body dimensions of the hybrid most resemble. This will therefore require that jurisdiction field teams either record hybrids as a single parent taxa (e.g. carp or goldfish) immediately in the field, OR record in the field as hybrids and take appropriate notes to allow matching to either parent taxa prior to transmission of data to MDBA.

Table A1.4: Murray–Darling Basin SRA fish taxa, including whether they require voucher specimen collection and/or weighing.

Taxa code	Scientific name	Common name	Get voucher specimen	Record weight
ACAFLA	*Acanthogobius flavimanus*	Yellowfin goby	YES	
ACABUT	*Acanthopagrus butcheri*	Black bream		
AFUTAM	*Afurcagobius tamarensis*	Tamar River goby	YES	
ALDFOR	*Aldrichetta forsteri*	Yellow-eyed mullet	YES	
AMBAGA	*Ambassis agassizii*	Olive perchlet	YES photo only	YES
AMOBIF	*Amoya bifrenatus*	Bridled goby	YES	
ANGAUS	*Anguilla australis*	Short-finned eel		
ANGREI	*Anguilla reinhardtii*	Long-finned eel	YES	
ARGHOL	*Argyrosomus hololepidotus*	Mulloway		
ATHMIC	*Atherinosoma microstoma*	Small-mouthed un-specked hardyhead	YES	
BIDBID	*Bidyanus bidyanus*	Silver perch	YES[a]	YES
BIDWEL	*Bidyanus welchi*	Welch's grunter	YES[a]	
CARAUR	*Carassius auratus*	Goldfish		
CARCAR	*Carassius carassius*	Crucian carp	YES	YES
CRAAMN	*Craterocephalus amniculus*	Darling River un-specked hardyhead	YES	YES
CRAFLU	*Craterocephalus fluviatilis*	Murray un-specked hardyhead	YES	YES
CRASTE	*Craterocephalus stercusmuscarum fulvus*	Unspecked un-specked hardyhead	YES	
CYPCAR	*Cyprinus carpio*	Common carp		
GADBIS	*Gadopsis bispinosus*	Two-spined blackfish		
GADMAR	*Gadopsis marmoratus*	River blackfish		
GALBRE	*Galaxias brevipinnis*	Climbing galaxias	YES	YES
GALMAC	*Galaxias maculatus*	Common galaxias	YES	
GALFUS	*Galaxias fuscus*	Barred galaxias	YES	
GALOLI	*Galaxias olidus*	Mountain galaxias	YES	
GALROS	*Galaxias rostratus*	Flat-headed galaxias	YES	YES
GALSP1	*Galaxias* sp1	Obscure galaxias	YES	
GALSP2	*Galaxias* sp2	Riffle galaxias	YES	YES
GALTRU	*Galaxias truttaceus*	Spotted galaxias	YES	YES
GAMHOL	*Gambusia holbrooki*	Gambusia		
GEOAUS	*Geotria australis*	Pouched lamprey	YES	YES

(*continued*)

Table A1.4 (cont'd): Murray–Darling Basin SRA fish taxa, including whether they require voucher specimen collection and/or weighing.

Taxa code	Scientific name	Common name	Get voucher specimen	Record weight
HYPGAL	*Hypseleotris galii*	Firetail gudgeon	YES[b]	
HYPSPP	*Hypseleotris* spp.	Carp gudgeons (lumped)	YES[b]	
LEIUNI	*Leiopotherapon unicolor*	Spangled perch		
LIZARG	*Liza argentea*	Flat-tailed mullet	YES	
MACAMB	*Macquaria ambigua ambigua*	Golden perch		
MACAUS	*Macquaria australasica*	Macquarie perch		
MACCOL	*Macquaria colonorum*	Estuary perch		YES
MACMAC	*Maccullochella macquariensis*	Trout cod / Bluenose cod	YES[c]	
MACPEE	*Maccullochella peelii peelii*	Murray cod	YES[d]	
MELFLU	*Melanotaenia fluviatilis*	Murray–Darling rainbowfish	YES[e]	
MELSPL	*Melanotaenia splendida tatei*	Desert rainbowfish	YES[e]	YES
MISANG	*Misgurnus anguillicaudatus*	Oriental weatherloach	YES	
MOGADS	*Mogurnda adspersa*	Southern purple-spotted gudgeon	YES photo only	
MORMOR	*Mordacia mordax*	Short-headed lamprey	YES	
MUGCEP	*Mugil cephalus*	Sea mullet	YES	
MYXELO	*Myxus elongatus*	Sand mullet	YES	
NANAUS	*Nannoperca australis*	Southern pygmy perch		
NANOBS	*Nannoperca obscura*	Yarra pygmy perch		YES
NEMERE	*Nematalosa erebi*	Bony herring		
NEOHYR	*Neosilurus hyrtlii*	Hyrtl's tandan		
ONCMYK	*Oncorhynchus mykiss*	Rainbow trout	YES[f] <100 mm	
PERFLU	*Perca fluviatilis*	Redfin perch		
PHIGRA	*Philypnodon grandiceps*	Flathead gudgeon	YES	
PHIMAC	*Philypnodon macrostomus*	Dwarf flathead gudgeon	YES	YES
PORREN	*Porochilus rendahli*	Rendahl's tandan		
PSEOLO	*Pseudogobius olorum*	Blue-spot goby		
PSEURV	*Pseudaphritis urvillii*	Congolli		
REDMAC	*Redigobius macrostoma*	Large-mouthed goby	YES	
RETSEM	*Retropinna semoni*	Australian smelt		
RUTRUT	*Rutilus rutilus*	Roach	YES	YES

(*continued*)

Table A1.4 (cont'd): Murray–Darling Basin SRA fish taxa, including whether they require voucher specimen collection and/or weighing.

Taxa code	Scientific name	Common name	Get voucher specimen	Record weight
SALTRU	*Salmo trutta*	Brown trout	YES[f] <100 mm	
TANTAN	*Tandanus tandanus*	Freshwater catfish		
TASLAS	*Tasmanogobius lasti*	Lagoon goby		
TINTIN	*Tinca tinca*	Tench		YES

[a] *Bidyanus bidyanus* and *Bidyanus welchi* may both be in the Paroo and voucher specimens and/or colour images are required for confirmation.

[b] *Hypseleotris* species should be collected in Queensland valleys to determine if *Hypseleotris galii* is present. For all other valleys the genus is lumped.

[c] *Maccullochella macquariensis* to be photographed when individual >120 mm and a voucher specimen collected when <100 mm.

[d] *Maccullochella peelii peelii* to have voucher specimen collected for small fish (<120 mm) in regions where *Maccullochella macquariensis* occurs.

[e] *Melanotaenia fluviatilis* and *Melanotaenia splendida tatei* may both be in the Paroo, Warrego and Middle to Upper Darling and voucher specimens and/or colour images are required for confirmation.

[f] Small trout (<100 mm) should have voucher specimens collected to ensure *Salmo trutta* and *Oncorhynchus mykiss* are distinguished.

Voucher specimens

Voucher specimens are to be collected for rare species, uncertain species and for notable range extensions of any species. Required species are shown in the Get Voucher column of Table A1.4. Note the following recommendations for voucher collections.

- Collect at least three specimens where possible, covering a range of size and colouration.
- Preserve specimens in 90–100% alcohol.
- Label each voucher sample with the following information: SRA site ID, State, river name, date collected and collector's name.
- Use a container of adequate size so that fish are not bent or crammed in, and ensure adequate preservative concentration is maintained.
- Obtain good quality digital images of all live specimens depicting body colouration and fin shape.
- Note: Good quality digital images of live specimens depicting body colouration and fin shape are an acceptable alternative when specimens are too large to be effectively preserved and for those species identified in Table 4 above.

Identification of the specimen is a three-stage process.

1. Return specimens to the sampling team's laboratory and use collective knowledge and identification aids to confirm identification.
2. If uncertainty remains, use a known specialist in that particular taxon to confirm the specimen's identification.

3. If a specialist is not available or any uncertainty remains, send the specimen to the following fish taxonomist, who will confirm identification or, in conjunction with the Authority, determine a process to have the specimen identified.

Tarmo Raadik

Arthur Rylah Institute for Environmental Research

123 Brown Street

Heidelberg Vic 3084

Fish health and condition

The presence of any abnormality sighted on any part of a measured fish should be recorded on the field sheet. At least one side of the fish should be checked completely for abnormalities. Abnormalities are to be assessed only on the measured subsample of each species.

Those fish abnormalities that are considered reportable are listed in Table A1.5. The fact that a handled fish exhibits one or more abnormalities must be indicated by listing the health code against attribute 'HealthCode' in the data return. A 'HealthCode' entry is recorded as a continuous sequence of the codes available in Table A1.5. Examples of valid entries include 'D', 'DWLP' and 'PLWD'. The codes 'yes' or 'true' can be used when an abnormality is observed but the descriptive health code has been misplaced, lost or forgotten. This ensures that the presence of all abnormalities is recorded even if the type of abnormality is lost.

Table A1.5: Reportable abnormalities exhibited by handled fish.

Health code	Abnormality description
D	Deformity (skeleton deformities, blindness, fin deformities, asymmetical, etc)
F	Fin condition poor (broken, eroded fins)
S	Lesions (skin abnormality with raised and/or discoloured scales)
U	Ulcers (skin is broken, crater like, redness)
T	Tumour (localised abnormal growth)
W	Wounds (eg bird strikes, hook wounds)
G	Fungus
L	*Lernaea* spp. (but only where a notable number are present. This is defined as: If fish <100 m total length, report any *Lernaea* sp., If fish >100 mm total length, report if more than 3 Lernaea sp.)
P	Other visible parasites
O	Other: the abnormality must be photographed and described and/or a specimen preserved
Yes No	Either of these codes can be used when an abnormality is observed but the above list has been misplaced, lost or the health code has been forgotten

Appendix 2 – Sample site photographs

Plate A2.1: Bonada (Zone 1), Round 1 sampling event.

Plate A2.2: Boral TSR (Zone 1), Round 1 sampling event.

Plate A2.3: Peach Tree Reserve (Zone 1), Round 1 sampling event.

Plate A2.4: Brilbral (Zone 1), Round 1 sampling event.

Plate A2.5: Dubbo Boat Ramp (Zone 1), Round 1 sampling event.

Plate A2.6: Wambool (Zone 2), Round 1 sampling event.

**Plate A2.7: Gin Gin Bridge (Zone 2),
Round 1 sampling event.**

**Plate A2.8: Mullah (Zone 2),
Round 1 sampling event.**

**Plate A2.9: Ellengerah (Zone 2),
Round 1 sampling event.**

Plate A2.10: DS Gin Gin Weir (Zone 2), Round 1 sampling event.

Plate A2.11: Marebone (Zone 3), Round 1 sampling event.

Plate A2.12: Groggans (Zone 3), Round 1 sampling event.

Plate A2.13: Old Oxley (Zone 3), Round 1 sampling event.

Plate A2.14: Willancorah (Zone 3), Round 1 sampling event.

Plate A2.15: Pillicawarrina (Zone 3), Round 1 sampling event.

Plate A2.16: Yanda (Zone 4), Round 1 (left) and Round 2 (right) sampling events.

Plate A2.17: Brewon (Zone 4), Round 1 (left) and Round 2 (right) sampling events.

Plate A2.18: Marthaguy Junction (Zone 4), Round 1 (left) and Round 2 (right) sampling events.

Plate A2.19: Binghi (Zone 4), Round 1 (left) and Round 2 (right) sampling events.

Plate A2.20: Glenacre (Zone 4), Round 1 (left) and Round 2 (right) sampling events.

Appendix 3 – Sample site coordinates

Table A3.1. Sites sampled during each sampling round.

Site name	Zone	Latitude	Longitude	Sampled (yes/no)		
				Round 1	Round 2	Round 3
Bonada	1	–32.6264	149.0727	✓	✓	✓
Peach Tree Reserve	1	–32.4462	148.7747	✓	✓	✓
Brilbral	1	–32.4218	148.7282	✓	✓	✓
Dubbo Boat Ramp	1	–32.2472	148.5985	✓	✓	✓
Boral TSR	1	–32.5019	148.9078	✓	✓	✓
Wambool	2	–31.9863	148.2105	✓	✓	✓
DS Gin Gin Weir	2	–31.9295	148.1400	✓	✓	✓
Gin Gin Bridge	2	–31.9101	148.0919	✓	✓	✓
Mullah	2	–31.8893	148.0434	✓	✓	✓
Ellengerah	2	–31.8039	147.9632	✓	✓	✓
Marebone	3	–31.3923	147.6984	✓	✓	✓
Old Oxley	3	–31.1265	147.5788	✓	✓	✓
Pillicawarrina	3	–30.7947	147.5203	✓	✓	✓
Groggans	3	–31.2087	147.6402	✓	✓	✓
Willancorah	3	–30.9003	147.5074	✓	✓	✓
Yanda	4	–30.4187	147.5480	✓	×	✓
Brewon	4	–30.2343	147.5422	✓	×	×
Binghi	4	–30.1801	147.5110	✓	✓	×
Marthaguy Junction	4	–30.2663	147.5790	✓	×	✓
Glenacre	4	–30.1695	147.4764	✓	✓	×

Note: Sites not sampled were dry during the sampling period.

Appendix 4 – Captured species photographs

Plate A4.1: Mature (left) and juvenile (right) eel-tailed catfish sampled from Zone 1 on the Macquarie River.

Plate A4.2: Mature trout cod sampled from Zone 1 on the Macquarie River.

Plate A2.3: Mature (left) and juvenile Murray cod (right) sampled from Zone 1 on the Macquarie River.

Plate A4.4: Mature silver perch sampled from Zone 2 on the Macquarie River.

Plate A4.5: Mature bony bream sampled from Zone 4 on the Macquarie River.

Appendix 5 – Recruitment length cut-offs

Table A5.1: Size limits used to distinguish new recruits for each species.

Species	Estimated size at 1 year old or at sexual maturity (fork or total length)
Native species	
Australian smelt	40 mm (Pusey et al., 2004)
Bony bream	67 mm (Cadwallader, 1977)
Carp-gudgeon	35 mm (Pusey et al., 2004)
Flatheaded gudgeon	58 mm (Pusey et al., 2004; Llewellyn, 2007)
Eel-tailed catfish	83 mm (Davis, 1975)
Golden perch	75 mm (Mallen-Cooper, 2003)
Murray cod	222 mm (Gavin Butler, unpublished data)
Murray–Darling rainbowfish	45 mm (Pusey et al. 2004: for *M. duboulayi*)
Silver perch	75 mm (Mallen-Cooper, 2003)
Spangled perch	68 mm (Leggett and Merrick, 1987)
Trout cod	150 mm
Un-specked hardyhead	38 mm (Pusey et al., 2004)
Exotic species	
Common carp	155 mm (Vilizzi and Walker, 1999)
Eastern gambusia	20 mm (McDowall, 1996)
Goldfish	127 mm (Lorenzoni et al., 2007)
Redfin perch	60 mm (maximum reported by Heibo and Magnhagen, 2005)

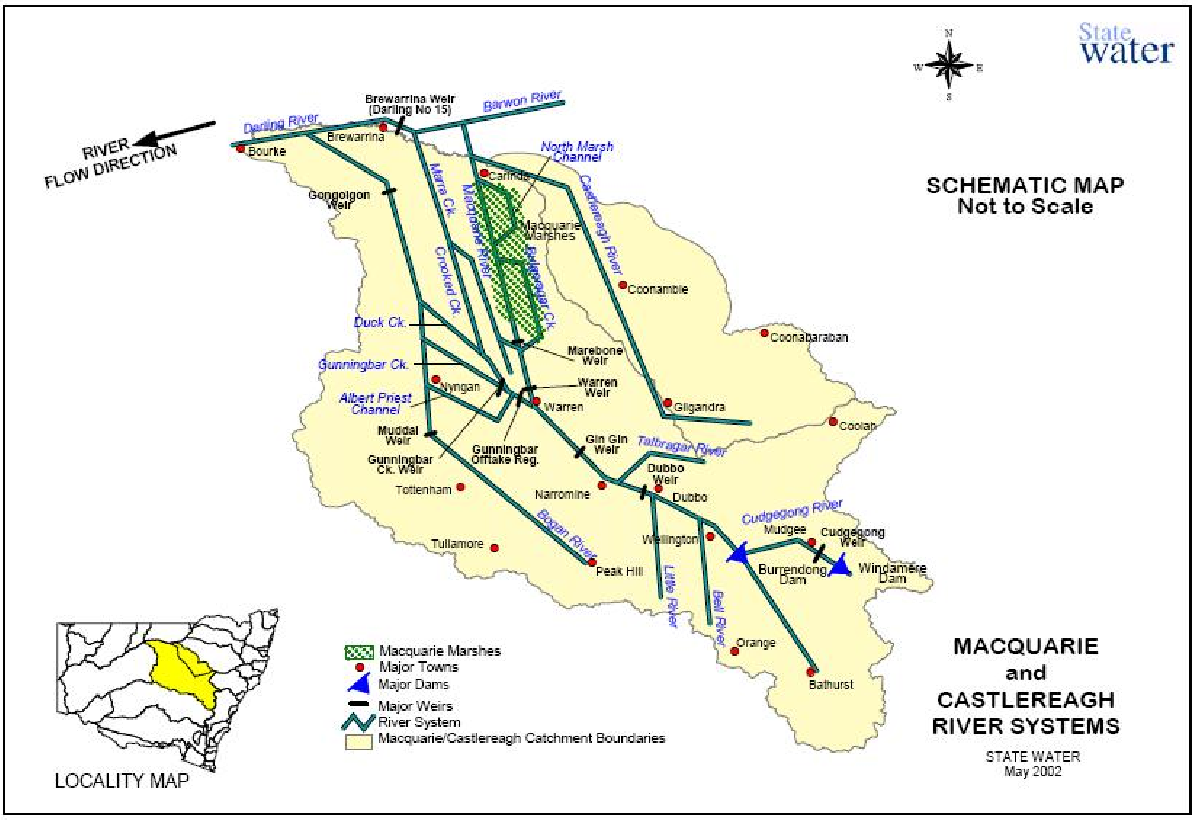
Note: Values represent the length at 1 year of age for longer-lived species or the age at sexual maturity for species that reach maturity within 1 year.

Appendix 6 – Historic fish community monitoring data for the Macquarie River

NSW Department of Primary Industries (DPI) and partnerships have pre-existing data from approximately 65 riverine sites within the Macquarie River and Macquarie Marshes channel system collected from 13 programs operating between 1976 and 2012. Of these, 26 sites have been sampled ≥1 time/s during the years of 2006, 2009 and 2012 as part of the Sustainable Rivers Audit/Monitoring Evaluating and Reporting (SRA/MER). In 2000/2001, eight sites were sampled as part of the 'Integrated monitoring of environmental flow' (Growns and Gehrke, 2005). In 1998, four sites were sampled by Astles et al. (2003) during the non-irrigation (June) and irrigation (October) seasons, examining the effects of cold water pollution below Burrendong Dam. Finally, between 2007 and 2012, five sites were sampled annually on the Macquarie River as control sites for the Lachlan Carp Demo Project. The remaining sites have been sampled inconsistently, with little replication or non-standardised techniques between 1976 and 2012.

Appendix 7 – Water diversion schematic for the Macquarie System

Figure A7.1: Water diversion schematic for the Macquarie River system.



Appendix 8 – Native fish stocking within the Macquarie River

Table A8.1: Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
20/01/2011	Golden perch	5,000	Murray Darling Fisheries	Macquarie River	'Raby Irrigation'	Warren	–31.613051	147.778969
20/01/2011	Golden perch	5,000	Murray Darling Fisheries	Macquarie River	Bryan Egan Weir	Warren	–31.684722	147.835785
20/01/2011	Golden perch	5,000	Murray Darling Fisheries	Macquarie River	Oxley Park fronting Coonamble Road	Warren	–31.696928	147.839032
20/01/2011	Golden perch	5,000	Murray Darling Fisheries	Macquarie River	Warren 'Top Weir'	Warren	–31.734697	147.866298
20/01/2011	Murray cod	4,225	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
20/01/2011	Murray cod	4,225	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
1/03/2011	Murray cod	1,574	Uarah Fish Hatchery	Macquarie River	Terramungamine Reserve	Terramungamine	–32.169494	148.585074
1/03/2011	Murray cod	1,574	Uarah Fish Hatchery	Macquarie River	Whylandra Crossing Reserve	Whylandra	–32.190047	148.494510
1/03/2011	Murray cod	1,574	Uarah Fish Hatchery	Macquarie River	Minore Falls Reserve	Dubbo	–32.192231	148.396239
1/03/2011	Murray cod	1,574	Uarah Fish Hatchery	Macquarie River	Brumagen Creek Reserve	Narromine	–32.233601	148.364787
1/03/2011	Murray cod	1,574	Uarah Fish Hatchery	Macquarie River	Scabbing Flat Reserve	Geurie	–32.430641	148.810245

(*continued*)

Table A8.1 (cont'd): Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
1/03/2011	Murray cod	1,574	Uarah Fish Hatchery	Macquarie River	Peach Tree Reserve	Ponto	–32.446781	148.777073
1/03/2011	Murray cod	1,575	Uarah Fish Hatchery	Macquarie River	Ponto Falls Reserve	Ponto	–32.465147	148.818204
16/01/2012	Golden perch	4,546	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
16/01/2012	Golden perch	4,546	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
16/01/2012	Murray cod	2,273	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
16/01/2012	Murray cod	2,273	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
16/01/2012	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	'Raby Irrigation'	Warren	–31.613051	147.778969
16/01/2012	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	Bryan Egan Weir	Warren	–31.684722	147.835785
16/01/2012	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	Oxley Park fronting Coonamble Road	Warren	–31.696928	147.839032
16/01/2012	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	Warren 'Top Weir'	Warren	–31.734697	147.866298
2/04/2012	Golden perch	1,137	Murray Darling Fisheries	Macquarie River	Minore Falls Reserve	Dubbo	–32.192230	148.396240
2/04/2012	Golden perch	1,138	Murray Darling Fisheries	Macquarie River	Butlers Falls Reserve	Dubbo	–32.315866	148.621385
2/04/2012	Murray cod	757	Murray Darling Fisheries	Macquarie River	Minore Falls Reserve	Dubbo	–32.192230	148.396240

(*continued*)

Table A8.1 (cont'd): Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
2/04/2012	Murray cod	758	Murray Darling Fisheries	Macquarie River	Butlers Falls Reserve	Dubbo	–32.315866	148.621385
13/01/2013	Golden perch	1,298	Murray Darling Fisheries	Macquarie River	Terramungamine Reserve	Dubbo	–32.169495	148.585074
13/01/2013	Golden perch	1,298	Murray Darling Fisheries	Macquarie River	Whylandra Crossing Reserve	Dubbo	–32.190047	148.494510
13/01/2013	Golden perch	1,298	Murray Darling Fisheries	Macquarie River	Minore Falls Reserve	Dubbo	–32.192230	148.396240
13/01/2013	Golden perch	1,298	Murray Darling Fisheries	Macquarie River	Brumagen Creek Reserve	Narromine	–32.233601	148.364787
13/01/2013	Golden perch	1,298	Murray Darling Fisheries	Macquarie River	Scabbing Flat Reserve	Geurie	–32.430641	148.810245
13/01/2013	Golden perch	1,298	Murray Darling Fisheries	Macquarie River	Peach Tree Reserve	Geurie	–32.446781	148.777073
13/01/2013	Golden perch	1,303	Murray Darling Fisheries	Macquarie River	Ponto Falls Reserve	Geurie	–32.465147	148.818204
13/01/2013	Murray cod	865	Murray Darling Fisheries	Macquarie River	Terramungamine Reserve	Dubbo	–32.169495	148.585074
13/01/2013	Murray cod	865	Murray Darling Fisheries	Macquarie River	Whylandra Crossing Reserve	Dubbo	–32.190047	148.494510
13/01/2013	Murray cod	865	Murray Darling Fisheries	Macquarie River	Minore Falls Reserve	Dubbo	–32.192230	148.396240
13/01/2013	Murray cod	865	Murray Darling Fisheries	Macquarie River	Brumagen Creek Reserve	Narromine	–32.233601	148.364787
13/01/2013	Murray cod	865	Murray Darling Fisheries	Macquarie River	Scabbing Flat Reserve	Geurie	–32.430641	148.810245

(*continued*)

Table A8.1 (cont'd): Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
13/01/2013	Murray cod	865	Murray Darling Fisheries	Macquarie River	Peach Tree Reserve	Geurie	–32.446781	148.777073
13/01/2013	Murray cod	871	Murray Darling Fisheries	Macquarie River	Ponto Falls Reserve	Geurie	–32.465147	148.818204
24/01/2013	Golden perch	3,409	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
24/01/2013	Golden perch	3,409	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
24/01/2013	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	'Raby Irrigation'	Warren	–31.613051	147.778969
24/01/2013	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	Bryan Egan Weir	Warren	–31.684722	147.835785
24/01/2013	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	Oxley Park fronting Coonamble Road	Warren	–31.696928	147.839032
24/01/2013	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	Warren 'Top Weir'	Warren	–31.734697	147.866298
24/01/2013	Murray cod	2,280	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
24/01/2013	Murray cod	2,280	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
18/01/2014	Golden perch	3,785	Murray Darling Fisheries	Macquarie River	Gin Gin Bridge	Gin Gin	–31.915770	148.083448
18/01/2014	Golden perch	757	Murray Darling Fisheries	Macquarie River	Turkey Farm Reserve	Narromine	–32.142028	148.234459
18/01/2014	Golden perch	757	Murray Darling Fisheries	Macquarie River	Rotary Park, Narromine	Narromine	–32.225730	148.245399

(*continued*)

Table A8.1 (cont'd): Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
18/01/2014	Golden perch	1,514	Murray Darling Fisheries	Macquarie River	Lions Park West	Dubbo	–32.245484	148.598802
18/01/2014	Golden perch	757	Murray Darling Fisheries	Macquarie River	Sand Beach Dubbo	Dubbo	–32.254978	148.592877
18/01/2014	Golden perch	1,514	Murray Darling Fisheries	Macquarie River	Bril Bral Reserve	Geurie	–32.414511	148.724246
18/01/2014	Golden perch	1,523	Murray Darling Fisheries	Macquarie River	Scabbing Flat Reserve	Geurie	–32.430641	148.810245
18/01/2014	Golden perch	1,514	Murray Darling Fisheries	Macquarie River	Peach Tree Reserve	Geurie	–32.446781	148.777073
18/01/2014	Murray cod	2,021	Murray Darling Fisheries	Macquarie River	Gin Gin Bridge	Gin Gin	–31.915770	148.083448
18/01/2014	Murray cod	2,020	Murray Darling Fisheries	Macquarie River	Terramungamine Reserve	Dubbo	–32.169495	148.585074
18/01/2014	Murray cod	2,020	Murray Darling Fisheries	Macquarie River	Dundullimal Reserve	Dubbo	–32.282718	148.602318
18/01/2014	Murray cod	2,020	Murray Darling Fisheries	Macquarie River	Pilchers Reserve	Dubbo	–32.298760	148.622601
18/01/2014	Murray cod	2,020	Murray Darling Fisheries	Macquarie River	Butlers Falls Reserve	Dubbo	–32.315866	148.621385
18/01/2014	Murray cod	2,020	Murray Darling Fisheries	Macquarie River	Bril Bral Reserve	Geurie	–32.414511	148.724246
23/01/2014	Golden perch	3,409	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
23/01/2014	Golden perch	3,409	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
23/01/2014	Murray cod	2,273	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076

Table A8.1 (cont'd): Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
23/01/2014	Murray cod	2,272	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
23/01/2014	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	'Raby Irrigation'	Warren	–31.613051	147.778969
23/01/2014	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	Bryan Egan Weir	Warren	–31.684722	147.835785
23/01/2014	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	Oxley Park fronting Coonamble Road	Warren	–31.696928	147.839032
23/01/2014	Murray cod	2,500	Murray Darling Fisheries	Macquarie River	Warren 'Top Weir'	Warren	–31.734697	147.866298
31/01/2014	Murray cod	2,525	Uarah Fish Hatchery	Macquarie River	Brummagen Reserve	Narromine	–32.227029	148.353422
1/02/2014	Murray cod	2,525	Uarah Fish Hatchery	Macquarie River	Timbrebongie Falls Reserve	Timbrebong	–32.130191	148.247750
1/02/2014	Murray cod	2,525	Uarah Fish Hatchery	Macquarie River	Rotary Park, Narromine	Narromine	–32.225730	148.245399
22/01/2015	Golden perch	3,409	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
22/01/2015	Golden perch	3,409	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399
22/01/2015	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	'Raby Irrigation'	Warren	–31.613051	147.778969
22/01/2015	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	Bryan Egan Weir	Warren	–31.684722	147.835785
22/01/2015	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	Oxley Park fronting Coonamble Road	Warren	–31.696928	147.839032

Table A8.1 (cont'd): Murray cod and golden perch stocking in the Macquarie River downstream of Burrendong Dam, January 2001 – February 2005.

Date	Species	Number	Hatchery	River	Site	Nearest town	Latitude	Longitude
22/01/2015	Golden perch	3,750	Murray Darling Fisheries	Macquarie River	Warren 'Top Weir'	Warren	–31.734697	147.866298
22/01/2015	Murray cod	2,272	Murray Darling Fisheries	Macquarie River	Trangie Ski Hole	Trangie	–31.950525	148.152076
22/01/2015	Murray cod	2,272	Murray Darling Fisheries	Macquarie River	Narromine boat ramp	Narromine	–32.225730	148.245399

Other titles in this series

No. 1 Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G., 1998. Changes after 20 years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. Final Report to Fisheries Research and Development Corporation. Project no. 96/139.

No. 2 Virgona, J.L., Deguara, K.L., Sullings, D.J., Halliday, I. and Kelly, K., 1998. Assessment of the stocks of sea mullet in New South Wales and Queensland waters.

No. 3 Stewart, J., Ferrell, D.J. and Andrew, N.L., 1998. Ageing Yellowtail (*Trachurus novaezelandiae*) and Blue Mackerel (*Scomber australasicus*) in New South Wales.

No. 4 Pethebridge, R., Lugg, A. and Harris, J., 1998. Obstructions to fish passage in New South Wales South Coast streams. 70pp.

No. 5 Kennelly, S.J. and Broadhurst, M.K., 1998. Development of by-catch reducing prawn-trawls and fishing practices in NSW's prawn-trawl fisheries (and incorporating an assessment of the effect of increasing mesh size in fish trawl gear). 18pp + appendices.

No. 6 Allan, G.L. and Rowland, S.J., 1998. Fish meal replacement in aquaculture feeds for silver perch. 237pp + appendices.

No. 7 Allan, G.L., 1998. Fish meal replacement in aquaculture feeds: subprogram administration. 54pp + appendices.

No. 8 Heasman, M.P., O'Connor, W.A. and O'Connor, S.J., 1998. Enhancement and farming of scallops in NSW using hatchery produced seedstock. 146pp.

No. 9 Nell, J.A., McMahon, G.A. and Hand, R.E., 1998. Tetraploidy induction in Sydney rock oysters. 25pp.

No. 10 Nell, J.A. and Maguire, G.B., 1998. Commercialisation of triploid Sydney rock and Pacific oysters. Part 1: Sydney rock oysters. 122pp.

No. 11 Watford, F.A. and Williams, R.J., 1998. Inventory of estuarine vegetation in Botany Bay, with special reference to changes in the distribution of seagrass. 51pp.

No. 12 Andrew, N.L., Worthington D.G., Brett, P.A. and Bentley N., 1998. Interactions between the abalone fishery and sea urchins in New South Wales.

No. 13 Jackson, K.L. and Ogburn, D.M., 1999. Review of depuration and its role in shellfish quality assurance. 77pp.

No. 14 Fielder, D.S., Bardsley, W.J. and Allan, G.L., 1999. Enhancement of Mulloway (*Argyrosomus japonicus*) in intermittently opening lagoons. 50pp + appendices.

No. 15 Otway, N.M. and Macbeth, W.G., 1999. The physical effects of hauling on seagrass beds. 86pp.

No. 16 Gibbs, P., McVea, T. and Louden, B., 1999. Utilisation of restored wetlands by fish and invertebrates. 142pp.

No. 17 Ogburn, D. and Ruello, N., 1999. Waterproof labelling and identification systems suitable for shellfish and other seafood and aquaculture products. Whose oyster is that? 50pp.

No. 18 Gray, C.A., Pease, B.C., Stringfellow, S.L., Raines, L.P. and Walford, T.R., 2000. Sampling estuarine fish species for stock assessment. Includes appendices by D.J. Ferrell, B.C. Pease, T.R. Walford, G.N.G. Gordon, C.A. Gray and G.W. Liggins. 194pp.

No. 19 Otway, N.M. and Parker, P.C., 2000. The biology, ecology, distribution, abundance and identification of marine protected areas for the conservation of threatened Grey Nurse Sharks in south east Australian waters. 101pp.

No. 20 Allan, G.L. and Rowland, S.J., 2000. Consumer sensory evaluation of silver perch cultured in ponds on meat meal based diets. 21pp + appendices.

No. 21 Kennelly, S.J. and Scandol, J. P., 2000. Relative abundances of spanner crabs and the development of a population model for managing the NSW spanner crab fishery. 43pp + appendices.

No. 22 Williams, R.J., Watford, F.A. and Balashov, V., 2000. Kooragang Wetland Rehabilitation Project: History of changes to estuarine wetlands of the lower Hunter River. 82pp.

No. 23 Survey Development Working Group, 2000. Development of the National Recreational and Indigenous Fishing Survey. Final Report to Fisheries Research and Development Corporation. (Volume 1 – 36pp + Volume 2 – attachments).

No.24 Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally *Pseudocaranx dentex* off New South Wales. 69pp.

No. 25 Allan, G.L., Jantrarotai, W., Rowland, S., Kosuturak, P. and Booth, M., 2000. Replacing fishmeal in aquaculture diets. 13pp.

No. 26 Gehrke, P.C., Gilligan, D.M. and Barwick, M., 2001. Fish communities and migration in the Shoalhaven River – Before construction of a fishway. 126pp.

No. 27 Rowling, K.R. and Makin, D.L., 2001. Monitoring of the fishery for Gemfish *Rexea solandri*, 1996 to 2000. 44pp.

No. 28 Otway, N.M., 1999. Identification of candidate sites for declaration of aquatic reserves for the conservation of rocky intertidal communities in the Hawkesbury Shelf and Batemans Shelf Bioregions. 88pp.

No. 29 Heasman, M.P., Goard, L., Diemar, J. and Callinan, R., 2000. Improved Early Survival of Molluscs: Sydney Rock Oyster (*Saccostrea glomerata*). 63pp.

No. 30 Allan, G.L., Dignam, A and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 1. R&D Plan.

No. 31 Allan, G.L., Banens, B. and Fielder, S., 2001. Developing Commercial Inland Saline Aquaculture in Australia: Part 2. Resource Inventory and Assessment. 33pp.

No. 32 Bruce, A., Growns, I. and Gehrke, P., 2001. Woronora River Macquarie Perch Survey. 116pp.

No. 33 Morris, S.A., Pollard, D.A., Gehrke, P.C. and Pogonoski, J.J., 2001. Threatened and Potentially Threatened Freshwater Fishes of Coastal New South Wales and the Murray-Darling Basin. 177pp.

No. 34 Heasman, M.P., Sushames, T.M., Diemar, J.A., O'Connor, W.A. and Foulkes, L.A., 2001. Production of Micro-algal Concentrates for Aquaculture Part 2: Development and Evaluation of Harvesting, Preservation, Storage and Feeding Technology. 150pp + appendices.

No. 35 Stewart, J. and Ferrell, D.J., 2001. Mesh selectivity in the NSW demersal trap fishery. 86pp.

No. 36 Stewart, J., Ferrell, D.J., van der Walt, B., Johnson, D. and Lowry, M., 2001. Assessment of length and age composition of commercial kingfish landings. 49pp.

No. 37 Gray, C.A. and Kennelly, S.J., 2001. Development of discard-reducing gears and practices in the estuarine prawn and fish haul fisheries of NSW. 151pp.

No. 38 Murphy, J.J., Lowry, M.B., Henry, G.W. and Chapman, D., 2002. The Gamefish Tournament Monitoring Program – 1993 to 2000. 93pp.

No. 39 Kennelly, S.J. and McVea, T.A. (Ed), 2002. Scientific reports on the recovery of the Richmond and Macleay Rivers following fish kills in February and March 2001. 325pp.

No. 40 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port of Botany Bay Introduced Marine Pest Species Survey. 69pp.

No. 41 Pollard, D.A. and Pethebridge, R.L., 2002. Report on Port Kembla Introduced Marine Pest Species Survey. 72pp.

No. 42 O'Connor, W.A, Lawler, N.F. and Heasman, M.P., 2003. Trial farming the akoya pearl oyster, *Pinctada imbricata*, in Port Stephens, NSW. 170pp.

No. 43 Fielder, D.S. and Allan, G.L., 2003. Improving fingerling production and evaluating inland saline water culture of snapper, *Pagrus auratus*. 62pp.

No. 44 Astles, K.L., Winstanley, R.K., Harris, J.H. and Gehrke, P.C., 2003. Experimental study of the effects of cold water pollution on native fish. 55pp.

No. 45 Gilligan, D.M., Harris, J.H. and Mallen-Cooper, M., 2003. Monitoring changes in the Crawford River fish community following replacement of an effective fishway with a vertical-slot fishway design: Results of an eight year monitoring program. 80pp.

No. 46 Pollard, D.A. and Rankin, B.K., 2003. Port of Eden Introduced Marine Pest Species Survey. 67pp.

No. 47 Otway, N.M., Burke, A.L., Morrison, NS. and Parker, P.C., 2003. Monitoring and identification of NSW Critical Habitat Sites for conservation of Grey Nurse Sharks. 62pp.

No. 48 Henry, G.W. and Lyle, J.M. (Ed), 2003. The National Recreational and Indigenous Fishing Survey. 188 pp.

No. 49 Nell, J.A., 2003. Selective breeding for disease resistance and fast growth in Sydney rock oysters. 44pp. (Also available – a CD-Rom published in March 2004 containing a collection of selected manuscripts published over the last decade in peer-reviewed journals).

No. 50 Gilligan, D. and Schiller, S., 2003. Downstream transport of larval and juvenile fish. 66pp.

No. 51 Liggins, G.W., Scandol, J.P. and Kennelly, S.J., 2003. Recruitment of Population Dynamacist. 44pp.

No. 52 Steffe, A.S. and Chapman, J.P., 2003. A survey of daytime recreational fishing during the annual period, March 1999 to February 2000, in Lake Macquarie, New South Wales. 124pp.

No. 53 Barker, D. and Otway, N., 2003. Environmental assessment of zinc coated wire mesh sea cages in Botany Bay NSW. 36pp.

No. 54 Growns, I., Astles, A. and Gehrke, P., 2003. Spatial and temporal variation in composition of riverine fish communities. 24pp.

No. 55 Gray, C. A., Johnson, D.D., Young, D.J. and Broadhurst, M. K., 2003. Bycatch assessment of the Estuarine Commercial Gill Net Fishery in NSW. 58pp.

No. 56 Worthington, D.G. and Blount, C., 2003. Research to develop and manage the sea urchin fisheries of NSW and eastern Victoria. 182pp.

No. 57 Baumgartner, L.J., 2003. Fish passage through a Deelder lock on the Murrumbidgee River, Australia. 34pp.

No. 58 Allan, G.L., Booth, M.A., David A.J. Stone, D.A.J. and Anderson, A.J., 2004. Aquaculture Diet Development Subprogram: Ingredient Evaluation. 171pp.

No. 59 Smith, D.M., Allan, G.L. and Booth, M.A., 2004. Aquaculture Diet Development Subprogram: Nutrient Requirements of Aquaculture Species. 220pp.

No. 60 Barlow, C.G., Allan, G.L., Williams, K.C., Rowland, S.J. and Smith, D.M., 2004. Aquaculture Diet Development Subprogram: Diet Validation and Feeding Strategies. 197pp.

No. 61 Heasman, M.H., 2004. Sydney Rock Oyster Hatchery Workshop 8 – 9 August 2002, Port Stephens, NSW. 115pp.

No. 62 Heasman, M., Chick, R., Savva, N., Worthington, D., Brand, C., Gibson, P. and Diemar, J., 2004. Enhancement of populations of abalone in NSW using hatchery-produced seed. 269pp.

No. 63 Otway, N.M. and Burke, A.L., 2004. Mark-recapture population estimate and movements of Grey Nurse Sharks. 53pp.

No. 64 Creese, R.G., Davis, A.R. and Glasby, T.M., 2004. Eradicating and preventing the spread of the invasive alga *Caulerpa taxifolia* in NSW. 110pp.

No. 65 Baumgartner, L.J., 2004. The effects of Balranald Weir on spatial and temporal distributions of lower Murrumbidgee River fish assemblages. 30pp.

No. 66 Heasman, M., Diggles, B.K., Hurwood, D., Mather, P., Pirozzi, I. and Dworjanyn, S., 2004. Paving the way for continued rapid development of the flat (angasi) oyster (*Ostrea angasi*) farming in New South Wales. 40pp.

ISSN 1449-9967 (NSW Department of Primary Industries – Fisheries Final Report Series)

No. 67 Kroon, F.J., Bruce, A.M., Housefield, G.P. and Creese, R.G., 2004. Coastal floodplain management in eastern Australia: barriers to fish and invertebrate recruitment in acid sulphate soil catchments. 212pp.

No. 68 Walsh, S., Copeland, C. and Westlake, M., 2004. Major fish kills in the northern rivers of NSW in 2001: Causes, Impacts & Responses. 55pp.

No. 69 Pease, B.C. (Ed), 2004. Description of the biology and an assessment of the fishery for adult longfinned eels in NSW. 168pp.

No. 70 West, G., Williams, R.J. and Laird, R., 2004. Distribution of estuarine vegetation in the Parramatta River and Sydney Harbour, 2000. 37pp.

No. 71 Broadhurst, M.K., Macbeth, W.G. and Wooden, M.E.L., 2005. Reducing the discarding of small prawns in NSW's commercial and recreational prawn fisheries. 202pp.

No. 72. Graham, K.J., Lowry, M.B. and Walford, T.R., 2005. Carp in NSW: Assessment of distribution, fishery and fishing methods. 88pp.

No. 73 Stewart, J., Hughes, J.M., Gray, C.A. and Walsh, C., 2005. Life history, reproductive biology, habitat use and fishery status of eastern sea garfish (*Hyporhamphus australis*) and river garfish (*H. regularis ardelio*) in NSW waters. 180pp.

No. 74 Growns, I. and Gehrke, P., 2005. Integrated Monitoring of Environmental Flows: Assessment of predictive modelling for river flows and fish. 33pp.

No. 75 Gilligan, D., 2005. Fish communities of the Murrumbidgee catchment: Status and trends. 138pp.

No. 76 Ferrell, D.J., 2005. Biological information for appropriate management of endemic fish species at Lord Howe Island. 18 pp.

No. 77 Gilligan, D., Gehrke, P. and Schiller, C., 2005. Testing methods and ecological consequences of large-scale removal of common carp. 46pp.

No. 78 Boys, C.A., Esslemont, G. and Thoms, M.C., 2005. Fish habitat and protection in the Barwon-Darling and Paroo Rivers. 118pp.

No. 79 Steffe, A.S., Murphy, J.J., Chapman, D.J. and Gray, C.C., 2005. An assessment of changes in the daytime recreational fishery of Lake Macquarie following the establishment of a 'Recreational Fishing Haven'. 103pp.

No. 80 Gannassin, C. and Gibbs, P., 2005. Broad-Scale Interactions Between Fishing and Mammals, Reptiles and Birds in NSW Marine Waters. 171pp.

No. 81 Steffe, A.S., Murphy, J.J., Chapman, D.J., Barrett, G.P. and Gray, C.A., 2005. An assessment of changes in the daytime, boat-based, recreational fishery of the Tuross Lake estuary following the establishment of a 'Recreational Fishing Haven'. 70pp.

No. 82 Silberschnieder, V. and Gray, C.A., 2005. Arresting the decline of the commercial and recreational fisheries for mulloway (*Argyrosomus japonicus*). 71pp.

No. 83 Gilligan, D., 2005. Fish communities of the Lower Murray-Darling catchment: Status and trends. 106pp.

No. 84 Baumgartner, L.J., Reynoldson, N., Cameron, L. and Stanger, J., 2006. Assessment of a Dual-frequency Identification Sonar (DIDSON) for application in fish migration studies. 33pp.

No. 85 Park, T., 2006. FishCare Volunteer Program Angling Survey: Summary of data collected and recommendations. 41pp.

No. 86 Baumgartner, T., 2006. A preliminary assessment of fish passage through a Denil fishway on the Edward River, Australia. 23pp.

No. 87 Stewart, J., 2007. Observer study in the Estuary General sea garfish haul net fishery in NSW. 23pp.

No. 88 Faragher, R.A., Pogonoski, J.J., Cameron, L., Baumgartner, L. and van der Walt, B., 2007. Assessment of a stocking program: Findings and recommendations for the Snowy Lakes Trout Strategy. 46pp.

No. 89 Gilligan, D., Rolls, R., Merrick, J., Lintermans, M., Duncan, P. and Kohen, J., 2007. Scoping knowledge requirements for Murray crayfish (*Euastacus armatus*). Final report to the Murray Darling Basin Commission for Project No. 05/1066 NSW 103pp.

No. 90 Kelleway, J., Williams. R.J. and Allen, C.B., 2007. An assessment of the saltmarsh of the Parramatta River and Sydney Harbour. 100pp.

No. 91 Williams, R.J. and Thiebaud, I., 2007. An analysis of changes to aquatic habitats and adjacent land-use in the downstream portion of the Hawkesbury Nepean River over the past sixty years. 97pp.

No. 92 Baumgartner, L., Reynoldson, N., Cameron, L. and Stanger, J. The effects of selected irrigation practices on fish of the Murray-Darling Basin. 90pp.

No. 93 Rowland, S.J., Landos, M., Callinan, R.B., Allan, G.L., Read, P., Mifsud, C., Nixon, M., Boyd, P. and Tally, P., 2007. Development of a health management strategy for the Silver Perch Aquaculture Industry. 219pp.

No. 94 Park, T., 2007. NSW Gamefish Tournament Monitoring – Angling Research Monitoring Program. Final report to the NSW Recreational Fishing Trust. 142pp.

No. 95 Heasman, M.P., Liu, W., Goodsell, P.J., Hurwood D.A. and Allan, G.L., 2007. Development and delivery of technology for production, enhancement and aquaculture of blacklip abalone (*Haliotis rubra*) in New South Wales. 226pp.

No. 96 Ganassin, C. and Gibbs, P.J., 2007. A review of seagrass planting as a means of habitat compensation following loss of seagrass meadow. 41pp.

No. 97 Stewart, J. and Hughes, J., 2008. Determining appropriate harvest size at harvest for species shared by the commercial trap and recreational fisheries in New South Wales. 282pp.

No. 98 West, G. and Williams, R.J., 2008. A preliminary assessment of the historical, current and future cover of seagrass in the estuary of the Parramatta River. 61pp.

No. 99 Williams, D.L. and Scandol, J.P., 2008. Review of NSW recreational fishing tournament-based monitoring methods and datasets. 83pp.

No. 100 Allan, G.L., Heasman, H. and Bennison, S., 2008. Development of industrial-scale inland saline aquaculture: Coordination and communication of R&D in Australia. 245pp.

No. 101 Gray, C.A and Barnes, L.M., 2008. Reproduction and growth of dusky flathead (*Platycephalus fuscus*) in NSW estuaries. 26pp.

No. 102 Graham, K.J., 2008. The Sydney inshore trawl-whiting fishery: codend selectivity and fishery characteristics. 153pp.

No. 103 Macbeth, W.G., Johnson, D.D. and Gray, C.A., 2008. Assessment of a 35-mm square-mesh codend and composite square-mesh panel configuration in the ocean prawn-trawl fishery of northern New South Wales. 104pp.

No. 104 O'Connor, W.A., Dove, M. and Finn, B., 2008. Sydney rock oysters: Overcoming constraints to commercial scale hatchery and nursery production. 119pp.

No. 105 Glasby, T.M. and Lobb, K., 2008. Assessing the likelihoods of marine pest introductions in Sydney estuaries: A transport vector approach. 84pp.

No. 106 Rotherham, D., Gray, C.A., Underwood, A.J., Chapman, M.G. and Johnson, D.D., 2008. Developing fishery-independent surveys for the adaptive management of NSW's estuarine fisheries. 135pp.

No. 107 Broadhurst, M., 2008. Maximising the survival of bycatch discarded from commercial estuarine fishing gears in NSW. 192pp.

No. 108 Gilligan, D., McLean, A. and Lugg, A., 2009. Murray Wetlands and Water Recovery Initiatives: Rapid assessment of fisheries values of wetlands prioritised for water recovery. 69pp.

No. 109 Williams, R.J. and Thiebaud, I., 2009. Occurrence of freshwater macrophytes in the catchments of the Parramatta River, Lane Cove River and Middle Harbour Creek, 2007 – 2008. 75pp.

No. 110 Gilligan, D., Vey, A. and Asmus, M., 2009. Identifying drought refuges in the Wakool system and assessing status of fish populations and water quality before, during and after the provision of environmental, stock and domestic flows. 56pp.

ISSN 1837-2112 (Industry & Investment NSW – Fisheries Final Report Series)

No. 111 Gray, C.A., Scandol. J.P., Steffe, A.S. and Ferrell, D.J., 2009. Australian Society for Fish Biology Annual Conference & Workshop 2008: Assessing Recreational Fisheries; Current and Future Challenges. 54pp.

No. 112 Otway, N.M. Storrie, M.T., Louden, B.M. and Gilligan, J.J., 2009. Documentation of depth-related migratory movements, localised movements at critical habitat sites and the effects of scuba diving for the east coast grey nurse shark population. 90pp.

No. 113 Creese, R.G., Glasby, T.M., West, G. and Gallen, C., 2009. Mapping the habitats of NSW estuaries. 95pp.

No. 114 Macbeth, W.G., Geraghty, P.T., Peddemors, V.M. and Gray, C.A., 2009. Observer-based study of targeted commercial fishing for large shark species in waters off northern New South Wales. 82pp.

No. 115 Scandol, J.P., Ives, M.C. and Lockett, M.M., 2009. Development of national guidelines to improve the application of risk-based methods in the scope, implementation and interpretation of stock assessments for data-poor species. 186pp.

No. 116 Baumgartner, L., Bettanin, M., McPherson, J., Jones, M., Zampatti, B. and Kathleen Beyer., 2009. Assessment of an infrared fish counter (Vaki Riverwatcher) to quantify fish migrations in the Murray-Darling Basin. 47pp.

No. 117 Astles, K., West, G., and Creese, R.G., 2010. Estuarine habitat mapping and geomorphic characterisation of the Lower Hawkesbury river and Pittwater estuaries. 229pp.

No. 118 Gilligan, D., Jess, L., McLean, G., Asmus, M., Wooden, I., Hartwell, D., McGregor, C., Stuart, I., Vey, A., Jefferies, M., Lewis, B. and Bell, K., 2010. Identifying and implementing targeted carp control options for the Lower Lachlan Catchment. 126pp.

No. 119 Montgomery, S.S., Walsh, C.T., Kesby, C.L and Johnson, D.D., 2010. Studies on the growth and mortality of school prawns. 90pp.

No. 120 Liggins, G.W. and Upston, J., 2010. Investigating and managing the *Perkinsus*-related mortality of blacklip abalone in NSW. 182pp.

No. 121 Knight, J., 2010. The feasibility of excluding alien redfin perch from Macquarie perch habitat in the Hawkesbury-Nepean Catchment. 53pp.

No. 122 Ghosn, D., Steffe, A., Murphy, J., 2010. An assessment of the effort and catch of shore and boat-based recreational fishers in the Sydney Harbour estuary over the 2007/08 summer period. 60pp.

No. 123 Rourke, M. and Gilligan, D., 2010. Population genetic structure of freshwater catfish (*Tandanus tandanus*) in the Murray-Darling Basin and coastal catchments of New South Wales: Implications for future re-stocking programs. 74pp.

No. 124 Tynan, R., Bunter, K. and O'Connor, W., 2010. Industry Management and Commercialisation of the Sydney Rock Oyster Breeding Program. 21pp.

No. 125 Lowry, M., Folpp, H., Gregson, M. and McKenzie, R., 2010. Assessment of artificial reefs in Lake Macquarie NSW. 47pp.

No. 126 Howell, T. and Creese, R., 2010. Freshwater fish communities of the Hunter, Manning, Karuah and Macquarie-Tuggerah catchments: a 2004 status report. 93pp.

No. 127 Gilligan, D., Rodgers, M., McGarry, T., Asmus, M. and Pearce, L., 2010. The distribution and abundance of two endangered fish species in the NSW Upper Murray Catchment. 34pp.

No. 128 Gilligan, D., McGarry, T. and Carter, S., 2010. A scientific approach to developing habitat rehabilitation strategies in aquatic environments: A case study on the endangered Macquarie perch (*Macquaria australasica*) in the Lachlan catchment. 61pp.

No. 129 Stewart, J., Hughes, J., McAllister, J., Lyle, J. and MacDonald, M., 2011. Australian salmon (*Arripis trutta*): Population structure, reproduction, diet and composition of commercial and recreational catches. 257 pp.

ISSN 1837-2112 (Fisheries Final Report Series)

No. 130 Boys, C., Glasby, T., Kroon, F., Baumgartner, L., Wilkinson, K., Reilly, G. and Fowler, T., 2011. Case studies in restoring connectivity of coastal aquatic habitats: floodgates, box culvert and rock-ramp fishway. 75pp.

No. 131 Steffe, A.S. and Murphy, J.J., 2011. Recreational fishing surveys in the Greater Sydney Region. 122pp.

No. 132 Robbins, W.D., Peddemors, V.M. and Kennelly, S.J., 2012. Assessment of shark sighting rates by aerial beach patrols. 38pp.

No. 133 Boys, C.A. and Williams, R.J., 2012. Fish and decapod assemblages in Kooragang Wetlands: the impact of tidal restriction and responses to culvert removal. 80pp.

No. 134 Boys, C.A, Baumgartner,L., Rampano, B., Alexander, T., Reilly, G., Roswell, M., Fowler, T and Lowry. M. 2012. Development of fish screening criteria for water diversions in the Murray-Darling Basin. 62pp.

No. 135 Boys, C.A, Southwell, M., Thoms, M., Fowler, T, Thiebaud, I., Alexander, T. and Reilly, G. 2012. Evaluation of aquatic rehabilitation in the Bourke to Brewarrina Demonstration Reach, Barwon-Darling River, Australia. 133pp

No. 136 Baumgartner, L., McPherson, B., Doyle, J., Cory, J., Cinotti, N. and Hutchison, J. 2013. Quantifying and mitigating the impacts of weirs on downstream passage of native fish in the Murray-Darling Basin. 79pp.

No. 137 Boys, C.A, Baumgartner, B., Miller, B., Deng, Z., Brown, R. and Pflugrath, B. 2013. Protecting downstream migrating fish at mini hydropower and other river infrastructure. 93pp.

No. 138 Hughes, J.M. and Stewart, J. 2013. Assessment of barotrauma and its mitigation measures on the behaviour and survival of snapper and mulloway. 152pp.

No. 139 Ochwada-Doyle, F.A., McLeod, J., Barrett, G., Clarke, G. and Gray, C.A., 2014. Assessment of recreational fishing in three recreational fishing havens in New South Wales. 29pp.

No. 140 Walsh, C. T., Rodgers, M. P., Thorne, N. J. and Robinson, W. A., 2013. Thermoshock Fish Mortality Investigation. 32pp.

No. 141 Boys, C.A., Navarro, A., Robinson, W., Fowler, T., Chilcott, S., Miller, B., Pflugrath, B., Baumgartner, L.J., McPherson, J., Brown, R. and Deng, Z., 2014. Downstream fish passage criteria for hydropower and irrigation infrastructure in the Murray-Darling Basin. 119pp.

No. 142 Cameron, L., Baumgartner, L. and Miners, B., 2012. Assessment of Australian bass restocking in the upper Snowy River. 102pp.

No. 143 Walsh, C., Rodgers, M., Robinson, W. and Gilligan, D., 2014. Evaluation of the effectiveness of the Tallowa Dam Fishway. 89pp.

ISSN 2204-8669 (NSW Trade & Investment – Fisheries Final Report Series)

No. 144 Ghosn, D.L., Collins, D.P. and Gould, A., 2015. The NSW Game Fish Tournament Monitoring Program 1994 to 2013: A summary of data and assessment of the role and design. 200pp.

No. 145 Boys, C., 2015. Changes in fish and crustacean assemblages in tidal creeks of Hexham Swamp following the staged opening of Ironbark Creek floodgates. 47pp.

No. 146 Jordan, A., and Creese, R. 2015. Ecological Background to the Assesment of Shore-Based Recreational fishing on Ocean Beaches and Rocky Headlands in Sanctuary Zones in mainland NSW Marine Parks. 114pp.

No. 147 Glasby, T.M. and West, G., 2015. Estimating losses ofPosidonia australisdue to boat moorings in Lake Macquarie, Port Stephens and Wallis Lake. 30pp.

No. 148 Macbeth, W.G. and Gray, C.A., 2016. Observer-based study of commercial line fishing in waters off New South Wales. 151p.

No. 149 West, L.D., Stark, K.E., Murphy, J.J., Lyle, J.M. and Ochwada-Doyle, F.A., 2016. Survey of Recreational Fishing in New South Wales and the ACT, 2013/14. 150p.

No. 150 Stocks, J.R., Scott, K.F., Rodgers, M.P., Walsh, C.T., van der Meulen, D.E. and Gilligan, D., 2016. Short-term intervention monitoring of a fish community response to an environmental flow in the mid and lower Macquarie River: 2014/2015 watering year. 109p.