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Status of fish populations in the lower Goulburn River (2003-2012)

Wayne Koster, David Crook, David Dawson and Paul Moloney

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Arthur Rylah Institute for Environmental Research

Unpublished Client Report for Goulburn Broken Catchment Management Authority

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Front cover photo: Goulburn River at Cemetery Bend (Wayne Koster).

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Summary

Background

This report documents the findings of a nine year study of fish populations in the lower Goulburn River, to provide information on (1) the composition, abundance and population structure of fish species, (2) environmental conditions associated with spawning, and (3) movements of Golden Perch (*Macquaria ambigua*) between the Goulburn and Murray rivers. The study was funded under the Victorian Recreational Fishing Grants program from 2003 to 2006 and by the Goulburn-Broken Catchment Management Authority from 2006 to 2012.

The specific objectives of the project were:

Fish assemblage surveys (electrofishing)

- Assess and benchmark the status of fish stocks in the lower Goulburn River.
- Quantify spatial and temporal patterns in species composition, abundance, and population structure.
- Determine relationships between annual recruitment of juveniles and environmental variables, including flow.

Surveys of eggs and larvae (drift net sampling)

- Detect and determine timing and duration of spawning by key fish species.
- Determine relationships between spawning and environmental variables, including flow.

Movements of Golden Perch (acoustic tracking)

- Determine the level of connectivity between populations of adult Golden Perch within the Goulburn and mid-Murray regions.
- Develop understanding of adult fish movement dynamics and links to spawning and recruitment patterns.

Main findings

Current status of fish assemblages

- Significant populations of native fish occur in the lower Goulburn River, including several species of conservation significance, namely Trout Cod (*Maccullochella macquariensis*), Murray Cod (*Maccullochella peelii*), Silver Perch (*Bidyanus bidyanus*) and Freshwater Catfish (*Tandanus tandanus*).
- There is evidence of increased abundances of Murray Cod and Golden Perch and declines in introduced Redfin Perch (*Perca fluviatilis*) in recent years compared to the 1980s.
- There are signs of a more recent (after 2008) increase in the abundance of Redfin Perch, although they are by no means near their former abundances in the main channel of the lower Goulburn River.
- Despite being previously abundant (i.e. up until around the 1970s), Macquarie Perch (*Macquaria australasica*) now appear to be locally extinct in the main channel of the lower Goulburn River.
- A range of introduced fish species including Redfin Perch, Carp (*Cyprinus carpio*), Oriental Weatherloach (*Misgurnus anguillicaudatus*) and Eastern Gambusia

(*Gambusia holbrooki*) have abundant, self-sustaining populations in the lower Goulburn River.

Fish spawning and recruitment

- Breeding populations of Freshwater Catfish, Trout Cod and Silver Perch still exist within the lower Goulburn River, although adults of these species are very rare compared to their former (e.g. pre 1960s) abundances.
- The lower Goulburn River is a spawning ground for Golden Perch and spawning of this species appears to be associated with increases in discharge, particularly large flows/floods.
- Murray Cod spawning occurred annually in the lower Goulburn River regardless of river discharge. The contribution of artificial stocking to recruitment is currently unclear.
- Large adult populations of Carp exist in the lower Goulburn River, but eggs and larvae of this species were rarely collected. Recruitment sources outside of the Goulburn River (e.g. Murray River) may act as a source of juvenile recruits for the lower Goulburn River.

Movement of Golden Perch

- There is a large amount of connectivity between populations of adult Golden Perch in the lower Goulburn and mid-Murray rivers.
- Movement activity of Golden Perch was greatest during late spring and early summer and the extent of movement was associated with variations in river flow rather than the magnitude of flows.
- Fish tagged in the Goulburn River tended to move into the Murray River during the spawning season, coinciding with the collection of eggs in the mid-Murray River. However, eggs were also collected in the lower Goulburn River in one spawning season (2010/11) when major floods occurred.

Threatening processes

- A range of issues potentially threaten native fish populations in the lower Goulburn River, including drought, floods, blackwater, loss of habitat via removal of woody debris, reductions in water quality and the spread of introduced pest fish species.
- A fish kill below Goulburn Weir in January 2004 impacted fish species diversity and abundance. Subsequent partial recovery of fish species diversity and abundance occurred at Cable Hole following the 2004 fish kill within about a year, but for some species (e.g. Trout Cod) it took many years before they were collected again.
- A blackwater event in December 2010 resulted in fish deaths and impacted the abundance of Murray Cod in the lower reaches of the Goulburn River. Murray Cod have not been collected at Yambuna in the lower reaches since the event. The longer term consequences of the 2010 blackwater event on native fish are currently unknown.
- The results of the acoustic tracking suggest that at least some tagged Golden Perch may have attempted to avoid low dissolved oxygen conditions by moving away from affected areas during the 2010 blackwater event.

The role of river flow

This project has revealed important information about links between environmental factors and fish spawning, recruitment and movement. In particular:

- Golden Perch spawning activity was markedly higher during high flow conditions. The only major spawning event for Golden Perch (i.e. November 2010) in the nine years of the study coincided with the only major high flow event in the spawning period and also followed flooding in September-October.
- Although spawning of Golden perch increased in 2010 during high flows, there was no clear increase in recruitment (i.e. juvenile fish) in the following year. It is possible that the blackwater event in December 2010 impacted on the survival of young fish. Alternatively, the lower Goulburn River may not contain suitable habitat for the recruitment of juvenile Golden Perch.
- The other native species collected in the egg/larval surveys, including Murray Cod, Trout Cod and several small-bodied species spawned under a range of flow conditions and their spawning seems unrelated to flow.
- Abundances of Murray River Rainbowfish (*Melanotaenia fluviatilis*) were higher following years with low spring-summer flows. Low and stable flows may favour egg and juvenile survival of this species (e.g. reduced physical disturbance of eggs attached to vegetation).
- Abundances of Australian Smelt (*Retropinna semoni*) were greatest following higher flow/flood years (i.e. 2010/11, 2011/12). Australian smelt use floodplain environments for spawning and feeding and thus may have benefited from recent high flow conditions and floodplain inundation.
- The study suggests that floods promote recruitment of Carp in the lower Goulburn River. The population of Carp in the lower Goulburn River remained relatively stable during drought conditions which affected the region for about 10 years from around 1997 to 2009. However, following the widespread flooding in 2010, substantial recruitment of juvenile Carp occurred resulting in a considerable expansion in the size of the population.
- Change in flow in the Goulburn River was associated with increased probability of fish moving from the Goulburn River into the Murray River. This result has important implications for the provision of environmental flows designed to promote movement because it suggests that fish responded to variations in flow relative to prevailing conditions, rather than perhaps the absolute magnitude of flow.

Recommendations

- Incorporate new information on spawning ecology of Golden Perch into environmental flow releases, in particular:
    - Timing – the spawning season in the lower Goulburn River stretches from November to January, but peak spawning occurs in November.
    - Cues – rises in water level in spring-summer act as a spawning stimulus. Low levels of spawning can occur under flows ~4500-5000 ML d^{-1}, but spawning was greater under higher flows (e.g. >10,000 ML d^{-1}). High flows in the pre-spawning period may also enhance spawning activity
- Determine the effects of artificial stocking on native fish populations by promoting the ongoing use of methods to allow discrimination of hatchery and wild fish (e.g. chemical marking or genetic techniques).
- Investigate possibilities to extend the distribution and/or increase the abundance of threatened species, particularly Freshwater Catfish and Macquarie Perch, via stocking programs.
- Continue investigations into relationships between flows and movement and spawning dynamics of Golden Perch, particularly regarding responses to environmental flow releases.
- Determine longer term consequences of the 2010 blackwater event on native fish and monitor rate of recovery of fish stocks.
- Continue to monitor status of fish populations via an ongoing survey program.

1 Introduction

Many rivers worldwide have been greatly modified by human development, including through the construction of dams and weirs, water regulation, habitat loss and degradation, and introduction of exotic species. These activities are linked to major changes to the ecology of rivers, including reduced abundance, distribution and diversity of native fish populations (Bain *et al.* 1988; Gehrke *et al.* 1995; Marchetti and Moyle 2001). Dams and weirs in particular have fragmented habitats and obstructed critical movement pathways of fish, whilst natural flow regimes, which are an important cue for movement in many freshwater fish, have also been greatly altered through the storage and diversion of flows (Lucas and Baras 2001).

With growing concern over the impact of human activities on rivers and their biota, various strategies to improve river health have been implemented in regulated rivers throughout the world in recent times. For example, environmental flow requirements for maintaining or restoring important ecological processes (e.g. spawning migrations) have been formulated for fish in many rivers, however, there is often much scientific uncertainty associated with these due to the lack of empirical evidence between flow-movement response relationships for the target species (Cottingham *et al.* 2003; Chee *et al.* 2009). Such information could, for example, greatly inform decision-making regarding the appropriate implementation of environmental flows for fish and also improve predictions of the ecological consequences of flow alterations. Similarly, the provision of fish passage to help restore fish populations has been undertaken across numerous rivers, however, for many freshwater fishes detailed knowledge of movement patterns and behaviours is needed to guide the design of strategies (e.g. fishways) to restore migratory fish pathways (Barrett and Mallen-Cooper 2006; Stuart *et al.* 2008).

In the Goulburn River Basin in northern Victoria, there has been extensive regulation and modification of riverine ecosystems, particularly in the lower reaches of the catchment. Issues that potentially affect native fish in the lower Goulburn River include flow regulation, barriers to movement, loss of habitat via removal of woody debris, reductions in water quality and the spread of introduced pest fish species e.g. Carp (*Cyprinus carpio*) (Pollino *et al.* 2004). Severe drought also affected the region for about 10 years from around 1997 to 2009 following by widespread flooding in late 2010. Major fish kills have also occurred in the lower Goulburn River in recent times including in 1984 (Anderson and Morison 1988), 2004 (Koster *et al.* 2004) and 2010.

Notwithstanding these threats, the lower Goulburn River is recognised as a high value waterway and has been listed as a Heritage River corridor by the Land Conservation Council (1991) due to its high environmental and social values (Cottingham *et al.* 2003; GBCMA 2004). The relatively high diversity of the fish fauna, and the fishing opportunities these fish provide, are key reasons for the river's listing (GBCMA 2004). Conservation of the fish fauna of the lower Goulburn River has been recognised as a high priority by fisheries management and natural resource management agencies (e.g. GERFMP 2002; GBCMA 2004).

In 2003 the Goulburn Valley Association of Angling Clubs commissioned the Arthur Rylah Institute for Environmental Research to examine the status of native fish communities in the lower Goulburn River. The project, funded from 2003 to 2006 under the Victorian Recreational Fishing Grants program, included boat electrofishing surveys and larval fish sampling to provide information on the composition, abundance and population structure of fish species and detect spawning of native species. In 2006 funding to continue the project was provided by the Goulburn-Broken Catchment Management Authority (GBMCA) and has continued through to 2012.

In addition to the electrofishing and drift surveys, GBCMA provided funding for a project to investigate the movements of Golden Perch (*Macquaria ambigua*) in the lower Goulburn and mid-Murray rivers using acoustic telemetry. Results from the electrofishing and drift surveys between 2003 and 2006 indicated a lack of spawning and recruitment of Golden Perch in the lower Goulburn River. The acoustic tracking component was developed to determine whether adult fish in the Goulburn River move into the Murray River during the spawning season and whether the adult population is sourced from recruitment areas outside of the Goulburn River (e.g. the Murray River).

This report documents the results of the research conducted over the life of the project (2003-2012). Our broad aim is to summarise current scientific understanding of the fish assemblages and provide an up-to-date status report to support management and conservation activities for fish in the lower Goulburn River into the future.

Project Objectives

Fish assemblage surveys (electrofishing)

- Assess and benchmark the status of fish stocks in the lower Goulburn River.
- Quantify spatial and temporal patterns in species composition, abundance, and population structure.
- Determine relationships between annual recruitment of juveniles and environmental variables, including flow.

Surveys of eggs and larvae

- Detect and determine timing and duration of spawning by key fish species.
- Determine relationships between spawning and environmental variables, including flow.

Movements of Golden Perch (acoustic tracking)

- Determine the level of connectivity between populations of adult Golden Perch within the Goulburn and mid-Murray regions.
- Develop understanding of adult fish movement dynamics and links to spawning and recruitment patterns.

2 Methodology

2.1 Study area

The Goulburn River has an average annual discharge below Goulburn Weir of 1,340,000 ML and is the largest Victorian tributary of the Murray River (DWR 1989). The study area is situated in northern Victoria and encompasses the lower reaches of the Goulburn River from downstream of Goulburn Weir near Nagambie to the junction of the Murray River, and also the mid-Murray River near Echuca (Figure 1). The catchment in this region consists predominately of cleared agricultural land, although some substantial forest areas remain, with dominant tree species including River Red Gum (*Eucalyptus camaldulensis*), Golden Wattle (*Acacia acinacia*), Dwarf Native Cherry (*Exocarpus stricta*) and Silver Wattle (*Acacia dealbata*). The river below Shepparton flows through the Lower Goulburn National Park. Flow in the lower Goulburn and mid-Murray rivers is highly regulated by several upstream dams and weirs (Cottingham *et al.* 2003).

2.2 Electrofishing surveys

Sampling was conducted at five or six sites during spring and autumn in each year between spring 2003 and autumn 2012 (Table 1, Figure 1, 2). Sampling was conducted at each site using a Smith-Root model 5 GPP boat-mounted electrofishing unit. Electrofishing surveys have been shown to be effective for collecting a range of fish species in lowland rivers in the Murray-Darling Basin (Davies *et al.* 2010), although some species (e.g. Eastern Gambusia *Gambusia holbrooki*) can be difficult to capture using electrofishing so their relative abundance and distribution may be underestimated. Electrofishing was conducted in all habitats within the river channel. At each site the total time during which electrical current was applied to the water was 1800 seconds. Fish collected were identified, counted and measured for length (caudal fork or total length). The weight of large-bodied species was also recorded.

Sampling was also conducted at two sites below Shepparton Weir during spring and autumn in each year since spring 2009. These sites were added to the program for the primary purpose of collecting and tagging fish with PIT (passive integrated transponder) tags to provide information on movement of fish through the recently constructed rock-ramp fish ladder at Shepparton Weir where a PIT tag reader is to be installed. Large-bodied native species (>200 mm in length) collected since 2009/10 at all electrofishing sites were tagged with PIT tags.

2.3 Surveys of eggs and larvae

Fish eggs and larvae were collected at three sites on the lower Goulburn River and one site on the mid-Murray River using a single drift net at each site (Table 1, Figure 1, 3). Sampling was conducted fortnightly between September and February in each year during the 2003/04 to 2011/12 breeding seasons. This frequency of sampling was considered adequate to detect spawning based on the results of other studies of fish spawning in lowland rivers in the Murray-Darling Basin that show spawning of the target species typically occurs over at least several weeks (Humphries *et al.* 1999; Humphries *et al.* 2002; King *et al.* 2003; Humphries 2005; Koehn and Harrington 2006). Drift nets consisted of 500 µm mesh, were 500 mm in diameter and had flow meters fitted to the mouth of the net to measure the volume of water filtered. The nets were attached to 'snags' and set in late afternoon and retrieved the following morning. Drift net surveys have been shown to be effective for collecting eggs and larvae of a range of fish species in lowland rivers in the Murray-Darling Basin (Humphries *et al.* 2002; King *et al.* 2005; King *et al.* 2009b), although drift net surveys may not be effective for collecting some early life stages for some species (e.g. eggs of Carp that are adhesive and attached to vegetation). Egg/larval abundances could also be affected by differing capture efficiencies depending on flows (e.g. under high flows abundances could be greater due to larger water volumes filtered, or lower due to a dilution effect) (Koehn and Harrington 2006).

Drift samples collected were inspected in the field to obtain eggs so that these could be taken to the laboratory for hatching to assist identifications. Remaining samples were preserved in 70% ethanol and sorted in the laboratory under a dissecting microscope, and identified using a guide (Serafini and Humphries 2004).

Table 1. Location details of electrofishing and drift sites (latitude and longitude)

Site	Technique	Latitude	Longitude	Sp ’03	Au ’04	Sp ’04	Au ’05	Sp ’05	Au ’06	Sp ’06	Au ’07	Sp ’07	Au ’08	Sp ’08	Au ’09	Sp ’09	Au ’10	Sp ’10	Au ’11	Sp ’11	Au ’12
Cable Hole, Murchison	Boat electrofishing	S36.68548	E145.22330	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cemetery Bend, Toolamba	Boat electrofishing	S36.51638	E145.32229	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pyke Road, Mooroopna	Boat electrofishing	S36.42758	E145.35757	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Shepparton Causeway	Boat electrofishing	S36.38180	E145.39492	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Downstream of Shepparton Weir #1	Boat electrofishing	S36.36208	E145.36256													✓	✓	✓	✓	✓	✓
Downstream of Shepparton Weir #2	Boat electrofishing	S36.35443	E145.35328													✓	✓	✓	✓	✓	✓
Kotupna	Boat electrofishing	S36.16415	E145.22158							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Yambuna	Boat electrofishing	S36.13129	E145.00308	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cable Hole, Murchison	Drift sampling	S36.68548	E145.22330	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pyke Road, Mooroopna	Drift sampling	S36.42758	E145.35757	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Yambuna	Drift sampling	S36.13129	E145.00308	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Upstream of Echuca	Drift sampling	S36.10383	E144.81612	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✓ - sampled

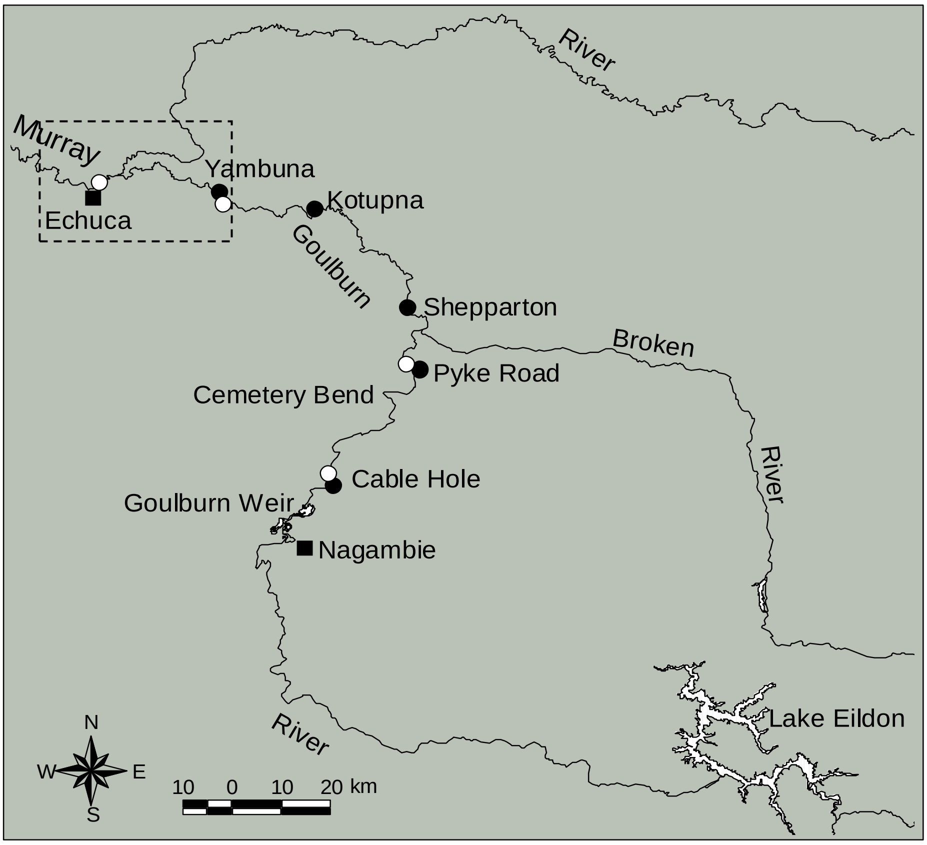

Figure 1. Study area, showing locations of electrofishing (black circles) and drift sampling (white circles) sites. Square with broken line denotes acoustic tracking study area (refer Figure 5).

Figure 2. Collecting fish using the electrofishing boat.

Figure 3. Drift net used to collect drifting fish eggs and larvae.

2.4 Acoustic tracking of Golden Perch

Golden Perch (mean total length [TL] 426 mm, range 315–580 mm) were collected from the lower Goulburn River (about 5 km upstream of the Murray River junction) and the mid-Murray River (about 3–5 km upstream and downstream of the Goulburn River junction) using a boat-mounted electrofishing unit (Figure 4). Golden Perch were tagged in the lower Goulburn (n = 12) and mid-Murray (n = 15) rivers in April 2007. A further 25 fish were tagged in April 2008 (Goulburn: n = 11, Murray: n = 14) and 27 were tagged in April 2009 (Goulburn: n = 14, Murray: n = 13).

Fish were individually anaesthetised using Aqui-S (0.03 ml Aqui-S per litre water). The transmitters (model V13–1L, Vemco, Nova Scotia, Canada; frequency: 69-kHz; dimensions: 36 x 13 mm; weight: 11 g in air; estimated battery life 610–880 d) were implanted into the peritoneal cavity of the fish through an incision of approximately 15 mm, adjacent to the pectoral fin and anterior to the anal vent. Only fish over 300 mm total length were tagged to ensure that the transmitter to fish weight ratios remained below about 2% (Winter 1996). For external identification fish were also tagged with an individually coded 't-bar' tag between the second and third dorsal spines. Following the surgical procedure, each fish was placed into a recovery net positioned in the stream channel. Once the fish were observed to maintain their balance and freely swim throughout the holding net they were released near their point of capture.

Sixteen acoustic listening stations (Model VR2W, Vemco, Nova Scotia, Canada) were deployed in March 2007 in the lower Goulburn (n = 8) and mid-Murray (n = 8) rivers (Figure 5). The listening stations were deployed using a length of plastic-coated stainless steel cable attached to logs as anchor points. The listening stations were set up in pairs to enable movement into or out of different areas to be determined. Range tests showed that the listening stations had detection ranges of approximately 80–200 m depending on the physical attributes of the site (e.g. depth, turbulence). Data was downloaded from the listening stations about every three months throughout the study.

Figure 4. Golden Perch collected by electrofishing.

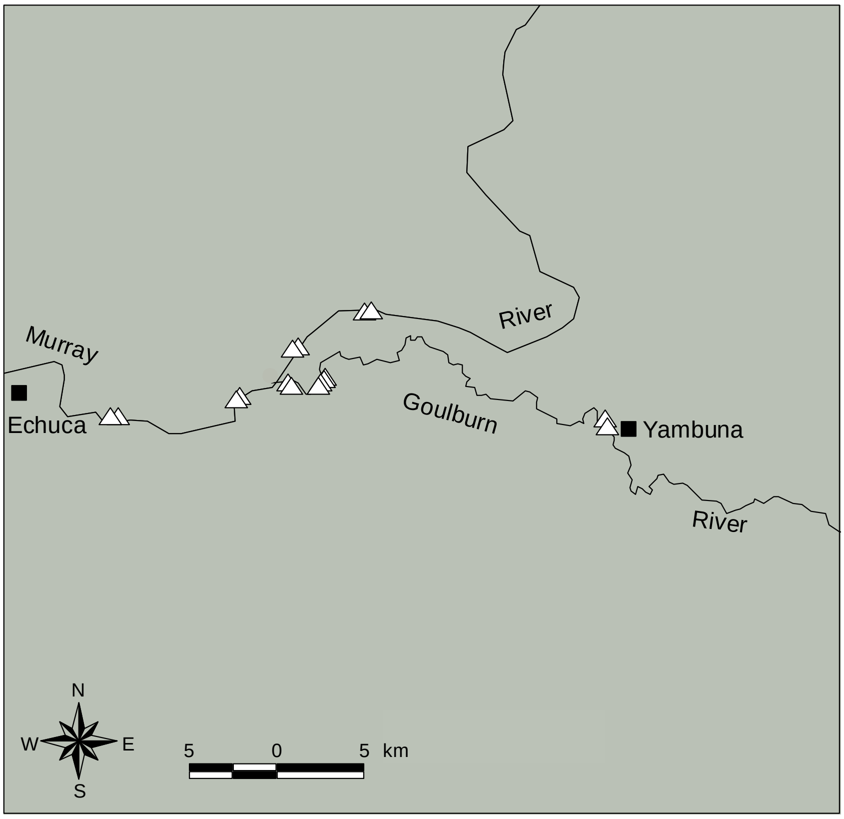

Figure 5. Acoustic tracking study area, showing locations of listening stations (white triangles).

2.5 Data analysis

2.5.1 Electrofishing surveys

Fish assemblage composition

The dataset collected in the regular electrofishing surveys comprises 5–6 sites sampled over 6–9 years. Spatial and temporal patterns in species presence and abundance (i.e. fish assemblage composition) based on the electrofishing data were examined by non-metric multi-dimensional scaling (NMDS) using the Bray–Curtis dissimilarity measure. To examine links between river flow and fish assemblage structure, the average flow in each season prior to each sampling trip was also calculated and categorised as low (<1000 ML d^{-1}), medium (1000-2000 ML d^{-1}) or high (>2000 ML d^{-1}) for NMDS analyses. Multi-dimensional scaling is a variable reduction procedure designed to graphically represent relationships between objects in multi–dimensional space (Quinn and Keogh 2002). The emphasis is on reducing the complexity of the dataset to form a picture of the similarity between samples. Data from the extra sites at Shepparton Weir were excluded because they were not considered representative due to the presence of the weir. Abundance data were log 10 (x+1) transformed to reduce the influence of abundant species (Clarke and Warwick 2001) and the analyses were conducted using Primer 5.0 (Plymouth Marine Laboratory, UK).

Recruitment of fish

Generalised linear mixed models (Zuur *et al.* 2009) were used to examine relationships between the abundance of YOY fish and environmental factors (Table 2). The analysis was restricted to Murray Cod (*Maccullochella peelii*), Murray River Rainbowfish (*Melanotaenia fluviatilis*), Australian Smelt (*Retropinna semoni*) and Carp. Abundances of YOY fish of other species e.g. Golden Perch, Silver Perch (*Bidyanus bidyanus*), were either too low to determine any statistical relationships with environmental variables, or YOY fish e.g. Flat-headed Gudgeon (*Philypnodon grandiceps*) could not be confidently distinguished from older fish based on their lengths. The analysis was also restricted to samples collected in autumn because fish collected in spring could not be confidently designated as YOY fish based only on their lengths. Length-frequency analysis and data from previous studies were used to define YOY fish as ≤ 125 mm for Murray Cod and Carp, ≤ 50 mm for Australian Smelt and ≤ 35 mm for Murray River Rainbowfish (Milton and Arthington 1984; 1985; Gooley 1992; Brumley 1996; Vilizzi and Walker 1999).

Based on an assessment of factors considered likely to influence fish recruitment (see King *et al.* 2009a), a set of variables was selected to model the abundance of YOY in relation to environmental factors (Table 2). The variables that described flow conditions were correlated, as were the set of variables selected to describe water temperature conditions. To reduce the number of correlated variables, a principle components analysis was performed for the set of flow and water temperature variables. The first principle component for the flow variables was dominated by the median flow and high (>80th percentile) flows of both spring and summer, with roughly equal weighting on each. Therefore an aggregate flow measure was created by averaging the four standardised flow measurements. Similarly, the first principle component for the water temperature variables was dominated by the median and high (>80th percentile) temperatures of both spring and summer. Therefore an aggregate temperature measure was created by averaging the four standardised temperature measurements.

To cope with over dispersion of the data, both Poisson and negative binomial models were compared in a Bayesian framework: the negative binomial models were used for all subsequent interpretation as they consistently out-performed the Poisson models. The models were constructed using the package R2OpenBUGS (Sturtz *et al.* 2005). The posterior predictive Bayesian *p*-value (Gelman *et al.* 2004) gives the proportion of times the χ^2 statistic for modelled data is larger than for the observed data. A score close to 0.5 suggests a good model fit, while scores close to 0 or 1 are evidence that the model inadequately describes the phenomenon of concern. Residual plots were examined to test the assumptions of the models.

Table 2. Names and units of environmental variables used to model relationships between the abundance of YOY fish.

Variable name	Units
Summer flow	Median summer flow (ML d^{-1})
Summer low flow	Number of days when summer flow <20th percentile
Summer high flow	Number of days when summer flow >80th percentile
Summer temperature	Median summer temperature (° C)
Summer low temperature	Number of days when summer temperature <20th percentile
Summer high temperature	Number of days when summer temperature >80th percentile
Spring flow	Median spring flow (ML d^{-1})
Spring low flow	Number of days when spring flow <20th percentile
Spring high flow	Number of days when spring >80th percentile
Spring temperature	Median spring temperature (° C)
Spring low temperature	Number of days when spring temperature <20th percentile
Spring high temperature	Number of days when spring >80th percentile
Murray Cod stocking[1]	Number of Murray Cod fingerlings stocked at each site

2.5.2 Egg and larval surveys

Mixture models were used to examine relationships between the presence and density of eggs and larvae and environmental factors at the approximate time of spawning (Table 3). The analysis was restricted to Murray Cod, Trout Cod (*Maccullochella macquariensis*), Flat-headed Gudgeon, Carp Gudgeon (*Hypseleotris klunzingeri*), Australian Smelt and Carp. Abundances of eggs and/or larvae of other species such as River Blackfish (*Gadopsis marmoratus*) and Freshwater Catfish (*Tandanus tandanus*) were extremely low and were not analysed. For larvae, the approximate time of spawning was based on time to hatching of eggs and estimated age of the larvae at the time of collection (derived from age-development stage relationships) (Milward 1966; Lake 1967b; Milton and Arthington 1985; Humphries 2005; Llewellyn 2007). The date of collection was used as the approximate spawning times of eggs (King *et al.* 2009b).

The number of hours of daylight and mean weekly temperature were highly correlated, as were the difference in flow and the mean weekly flow. Therefore, only one of each pair was considered in the analysis. All four combinations were assessed during the model selection process and the over-fitted model with the lowest Akaike Information Criteria (AICc) was used in subsequent interpretation.

The abundances of eggs and larvae were characterised by a high frequency of zero counts and over dispersion; therefore a zero-altered quasi-Poisson model was used. A zero-altered model is a mixture of two models, one that predicts the chances of detections in an individual sample (using a logistic model with cloglog link), while the other part predicts the mean count per sample, assuming that some are detected (using a quasi-Poisson model to allow for some over dispersion). Each model was fitted using the MCMCglmm package in R (Hadfield 2010; R Development Core Team 2012). The models were tested for convergence using Gelman-Rubin and Geweke

[1] The number of Murray Cod fingerlings stocked was based on the number stocked between December-March immediately prior to each autumn survey (Ewan McLean, DPI unpublished data).

diagnostics (Gelman *et al.* 2004). The Gelman-Rubin statistics should be very close to 1 if the system has converged.

Once the initial models had been completed, the residuals for the hours of daylight and the change in flow had a quadratic pattern. To correct the residuals, quadratic (or squared) terms were also used for the hours of daylight and change in flow variables in the models.

Table 3. Names and units of environmental variables used to model relationships between the presence and densities of eggs and larvae.

Variable name	Units
Daylength	Photoperiod. Time between sunset/sunrise (hours, mins)
Moon phase	Number of days since new moon (days)
Discharge	Mean weekly discharge (ML d^{-1})
Change in discharge	Day 1 – day 7 (ML d^{-1})
Difference in discharge	Max – min discharge in week (ML d^{-1})
Mean temperature	Mean weekly water temperature (° C)
Change in temperature	Day 1 – day 7 (° C)
Difference in temperature	Max – min temperature in week (° C)

2.5.3 Acoustic tracking

State space models were used to examine relationships between the probabilities of fish remaining in or leaving their location and environmental factors. In this model fish have two choices of location - the Goulburn River or Murray River. A state space model was used to determine the probability of a change in each fish's location in weekly time steps given its current location (Johnson *et al.* 2004; Patterson *et al.* 2008). This entailed the use of a logistic Markov transition matrix (Table 4) in which the probability of a fish remaining in the same river or switching rivers is only affected by its current location.

Table 4. Transition matrix for fish movement between Goulburn and Murray Rivers.

		Current location	
		Goulburn River	Murray River
Location next week	Goulburn River	$p_{G,t}$	1- $p_{M,t}$
	Murray River	1-$p_{G,t}$	$p_{M,t}$

pG,t and *pM,t* is the probability that a fish remains in its current location (either the Goulburn River or Murray River respectively) for the next week.

The probabilities of transition between rivers can vary over time with respect to environmental covariates and time factors. The explanatory variables examined were:

- where the fish was captured (its 'home' river)
- whether it was spawning season
- mean weekly flow
- mean weekly water temperature
- percentage change and coefficient of variation for the previous two weeks for both flow and water temperature

Model averaging was conducted using all permutations involving spawning and home river interacting with each covariate (Burnham and Anderson 2010). It was unclear whether a 7- or 14-day averaging process would produce better results, so both were tried independently. In both processes, the 14-day averaging process had marginally lower AICc values and for this reason they were selected for use. Model averaging all the models can be used to determine the relative importance of each predictor. This is achieved through summing the Akaike weights for each model that includes that predictor (Burnham and Anderson 2010).

3 Results

3.1 Electrofishing surveys

3.1.1 Spatial and temporal patterns in species presence and abundance

Over 9800 individuals representing 13 native and five exotic species were collected from the six regular electrofishing sites in the lower Goulburn River (Table 5). Australian Smelt was the most abundant species, comprising 40% of the total abundance for all species. Murray River Rainbowfish was the next most abundant species, comprising 31%, followed by the introduced Carp which comprised 13% (Figure 7, 8). A number of species of conservation significance were collected, namely Murray Cod (5%), Trout Cod, Silver Perch and Freshwater Catfish (all <1%).

Non-metric multidimensional scaling showed that the fish assemblages in the lower Goulburn River varied both spatially and temporally (Figure 9). Samples from the most upstream site (Cable Hole) tended to group out from the other samples, suggesting different assemblages at this site. Cable Hole was the only site where River Blackfish, Freshwater Catfish and Obscure Galaxias (*Galaxias* sp. 1) were collected. Cable Hole was also characterised by large numbers of Australian Smelt, Murray River Rainbowfish and Flat-headed Gudgeon. Samples from Cable Hole tended to show some separation by season (Figure 10). Murray River Rainbowfish, Australian smelt and Flat-headed Gudgeon were typically collected in higher numbers in autumn compared to spring, while Carp were typically collected in higher numbers in spring compared to autumn.

The fish assemblages at Cable Hole were strongly affected by a major fish kill that occurred in January 2004, with abundances of several native species (including the threatened Trout Cod) declining dramatically after the event (Crook and Koster 2006) (Figure 7, 8). In Spring 2003, prior to the fish kill in January 2004, fish assemblages in the Cable Hole region were relatively diverse and abundant (e.g. Golden Perch 14 fish/hr; Trout Cod 2 fish/hr; River Blackfish 14 fish/hr) (Figure 7, 8). In autumn 2004, after the fish kill, abundances of Golden Perch (4 fish/hr) were considerably reduced, whilst River Blackfish and Trout Cod were absent. Trout Cod were not collected again at the site until Autumn 2008, whilst River Blackfish were not collected until Spring 2005 and have only been collected in low abundances (e.g. 2-4 fish/hr). Abundances of Golden Perch remained low (e.g. <6 fish/hr) for many years; only in Spring 2010 did abundances of Golden Perch (12 fish/hr) again approach pre-fish kill levels (Figure 7, 8).

In the mid-reaches of the study area (Cemetery Bend, Pyke Road, Shepparton, Kotupna), samples tended to group near each other (Figure 9). These sites were characterised by large numbers of Murray Cod and Murray River Rainbowfish. Carp Gudgeon (*Hypseleotris* spp.) were also common at these sites, with the exception of Cemetery Bend. Samples from these sites tended to show some separation by season (Figure 10). Murray River Rainbowfish, Australian Smelt and Murray Cod were typically collected in higher numbers in autumn compared to spring. There was a trend for samples collected after the spring 2010 floods to group away from previous samples, in particular at Shepparton and Kotupna. Australian Smelt and Goldfish (*Carassius auratus*) were collected in higher numbers and Murray Cod in lower numbers at these sites following the 2010 floods.

Samples from the most downstream site (Yambuna) tended to group away from the other samples (Figure 9). Yambuna was characterised by large numbers of the introduced Carp and Goldfish and only low numbers of Murray River Rainbowfish. Golden Perch were also less abundant compared to the other sites. Yambuna was one of only three sites where the introduced Oriental Weatherloach (*Misgurnus anguillicaudatus*) was collected. Samples from Yambuna tended to show some separation by season (Figure 10). Australian Smelt, Murray Cod and Carp were typically collected in higher numbers in autumn compared to spring. There was a trend for samples collected after the spring 2010 floods to group away from previous samples. Australian Smelt, Goldfish and Carp were collected in higher numbers while Murray Cod were absent at this site following the 2010 floods.

Samples collected in autumn tended to show some separation according to the previous spring flows (Figure 11). In particular, 'high' and 'low' flow samples tended to group away from each other. Carp were collected in higher numbers in autumn following high spring flows (Figure 11). Samples collected in autumn showed no distinct groupings on the basis of the previous summer flows (Figure 12). Samples collected in spring showed no distinct groupings on the basis of the previous autumn or winter flows (Figure 13, 14). It should be noted, however, that autumn flows were nearly always categorized as low.

Figure 6. Fish species collected during the electrofishing surveys. Australian Smelt (top), Murray Cod (middle) and Silver Perch (bottom).

Table 5. Numbers of individual fish species collected from the Goulburn River in each season in electrofishing surveys from 2003-2012.

Species	Sp 03	Au 04	Sp 04	Au 05	Sp 05	Au 06	Sp 06	Au 07	Sp 07	Au 08	Sp 08	Au 09	Sp 09	Au 10	Sp 10	Au 11	Sp 11	Au 12	Total
Silver Perch *Bidyanus bidyanus*								3	2	4	2	3	9	13	9	8	6	4	63
Goldfish *Carassius auratus*	2		3			1	5	9	7	1	1	13	12	9	2	66	14	7	152
Unspecked Hardyhead *Craterocephalus stercusmuscarum fulvus*										2			3						5
Carp *Cyprinus carpio*	46	40	28	34	38	75	52	30	26	29	27	55	55	45	60	254	335	174	1403
River Blackfish *Gadopsis marmoratus*	7				1			2		2									12
Obscure Galaxias *Galaxias sp. 1*													1						1
Eastern Gambusia *Gambusia holbrooki*						5		3					1	2		11		5	27
Carp Gudgeon *Hypseleotris spp.*	2	7		1		2	4	8	4	6	10	11	2	26	9	3	1	7	103
Trout Cod *Maccullochella macquariensis*	3									4	1		3	3	2	2	1		19
Murray Cod *Maccullochella peelii*	18	36	22	29	16	6	22	26	14	28	21	31	40	125	59	45	47	4	589
Golden Perch *Macquaria ambigua*	18	13	8	9	11	14	13	14	7	14	11	14	26	25	24	25	20	23	289
Murray River Rainbowfish *Melanotaenia fluviatilis*	59	110	31	87	11	177	23	280	50	404	109	350	85	806	171	164	11	36	2964
Oriental Weatherloach *Misgurnus anguillicaudatus*								2		1						1	2		6
Bony Herring *Nematalosa erebi*												1		30					31
Redfin *Perca fluviatilis*				1				1		6	1		4	4	3	9	2		31
Flat-headed Gudgeon *Philypnodon grandiceps*	5	3	1	3	2	26	7	25	6	16	19	41	14	16	3	10	5	7	209
Australian Smelt *Retropinna semoni*	42	140	110	65	92	349	104	118	93	826	206	130	507	359	248	66	99	416	3970
Freshwater Catfish *Tandanus tandanus*										1									1
Total number of individuals	202	349	203	229	171	655	230	521	209	1344	408	649	762	1463	590	664	543	683	9875
Number of sites surveyed	5	5	5	5	5	5	6	6	6	6	6	6	8	8	8	8	8	8	

Sp – spring, Au – autumn.

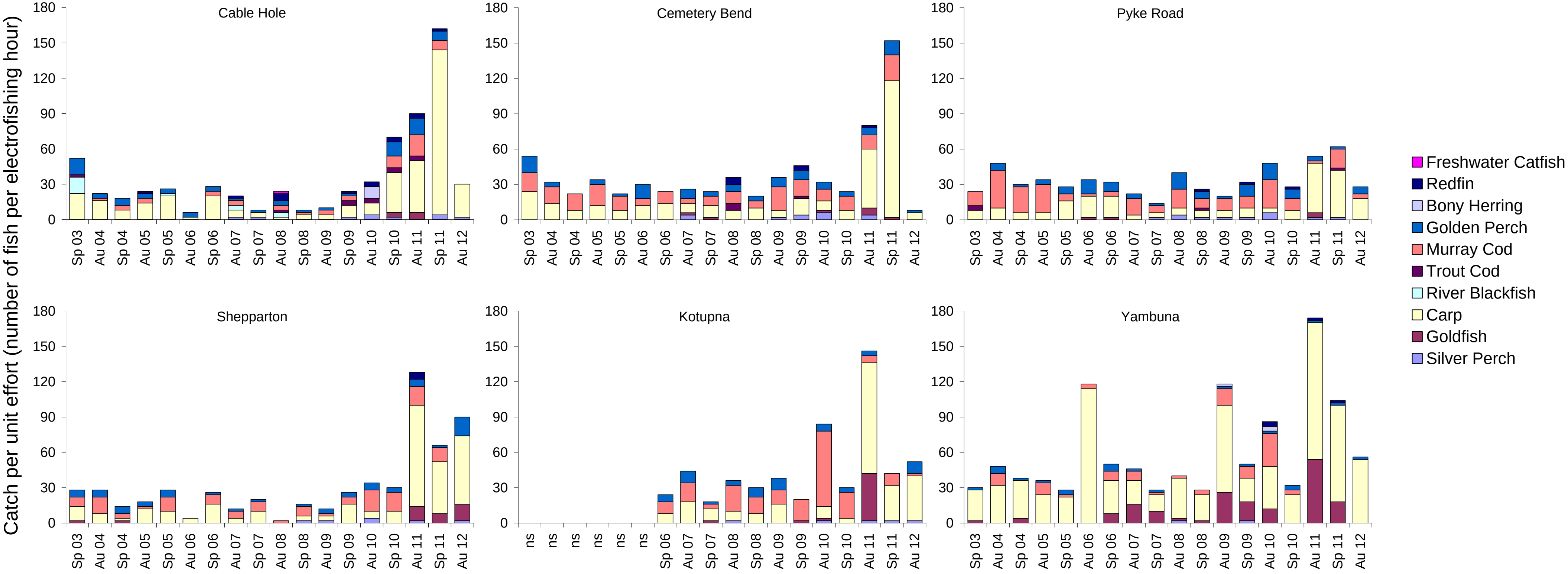

Figure 7. Abundance of large-bodied species collected from the lower Goulburn River in each season at each site by electrofishing. ns = not sampled

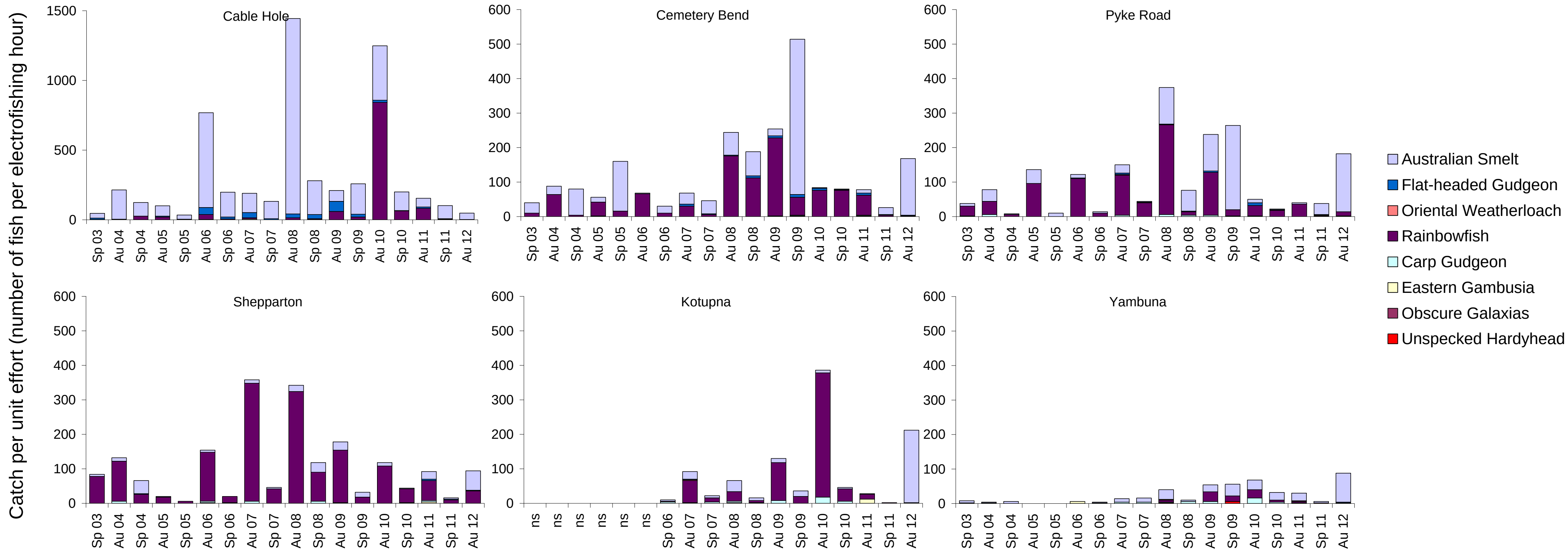

Figure 8. Abundance of small-bodied species collected from the lower Goulburn River in each season at each site by electrofishing. ns = not sampled

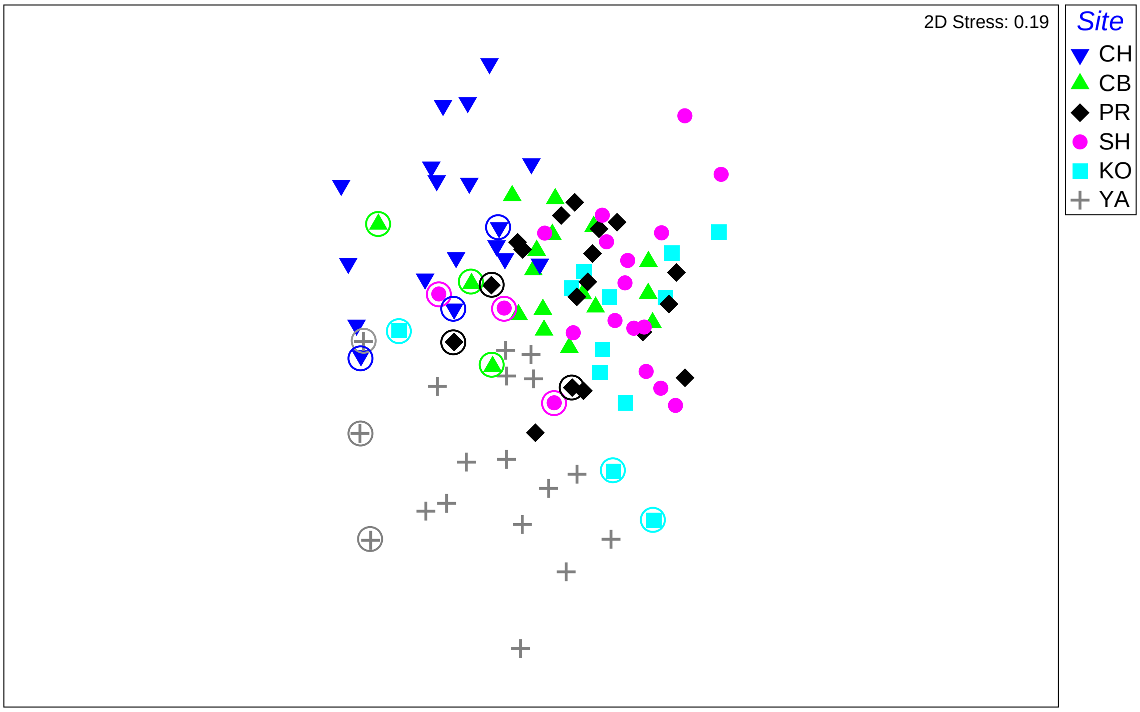

Figure 9. Non-metric multi-dimensional (NMDS) ordination plot showing the data collected during the electrofishing surveys, grouped by site. Encircled symbols indicate samples collected post the 2010 floods. CH – Cable Hole, CB – Cemetery Bend, PR – Pyke Road, SH – Shepparton, KO – Kotupna, YA - Yambuna

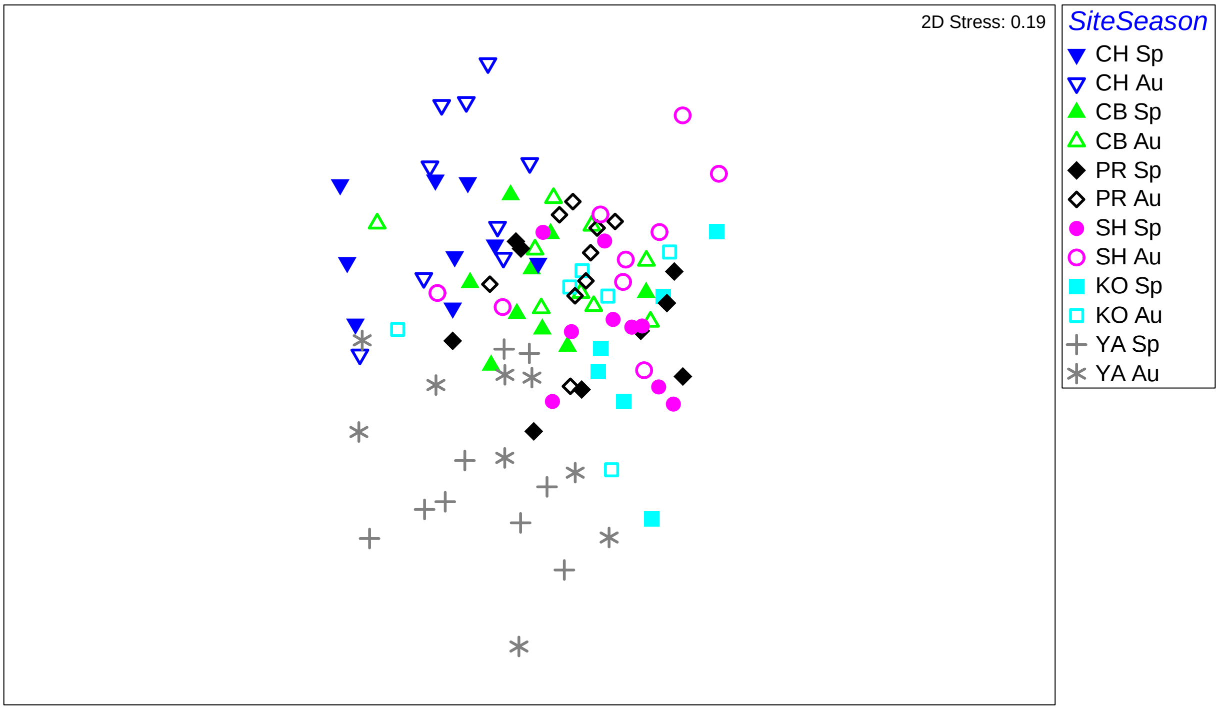

Figure 10. Non-metric multi-dimensional (NMDS) ordination plot showing the data collected during the electrofishing surveys, grouped by site and season. Sp - spring, Au - autumn.

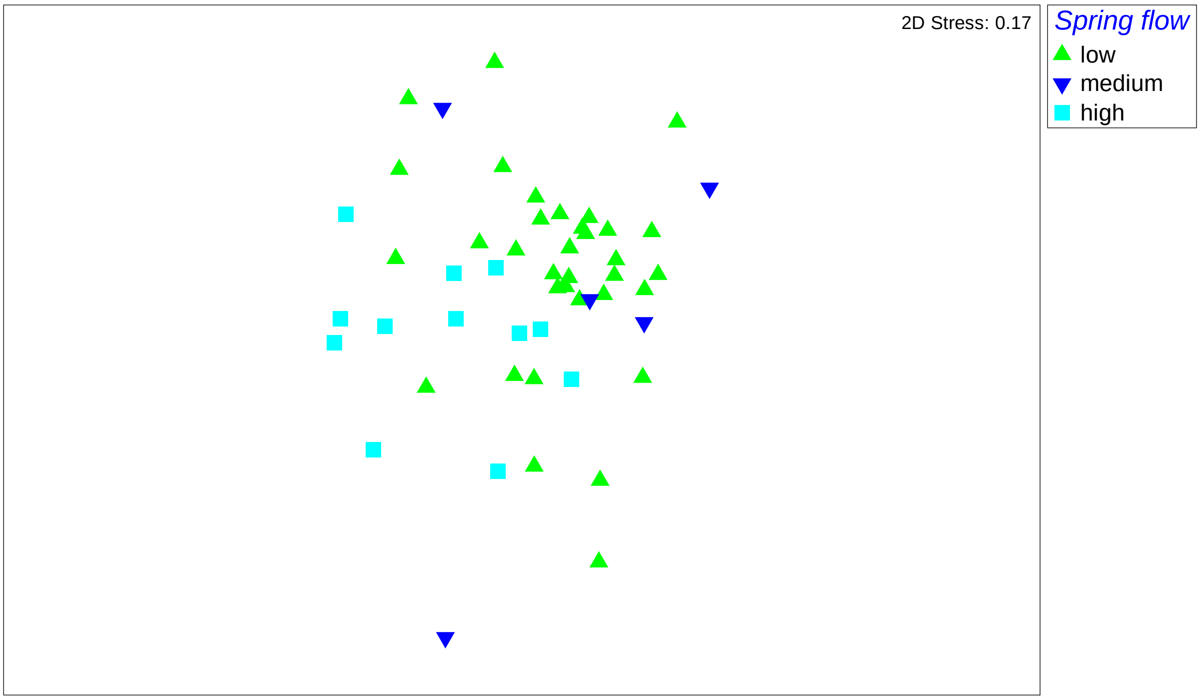

Figure 11. Non-metric multi-dimensional (NMDS) ordination plot showing the autumn site data collected during the electrofishing surveys, grouped by the previous spring flow conditions.

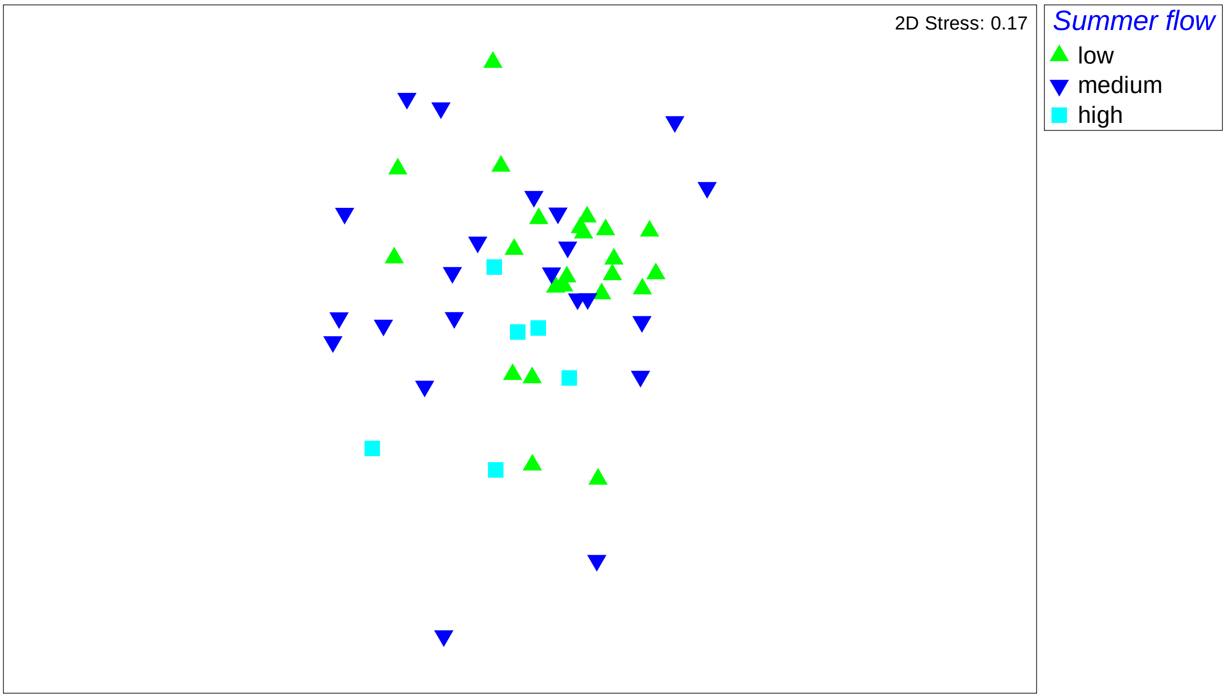

Figure 12. Non-metric multi-dimensional (NMDS) ordination plot showing the spring site data collected during the electrofishing surveys, grouped by the previous summer flow conditions.

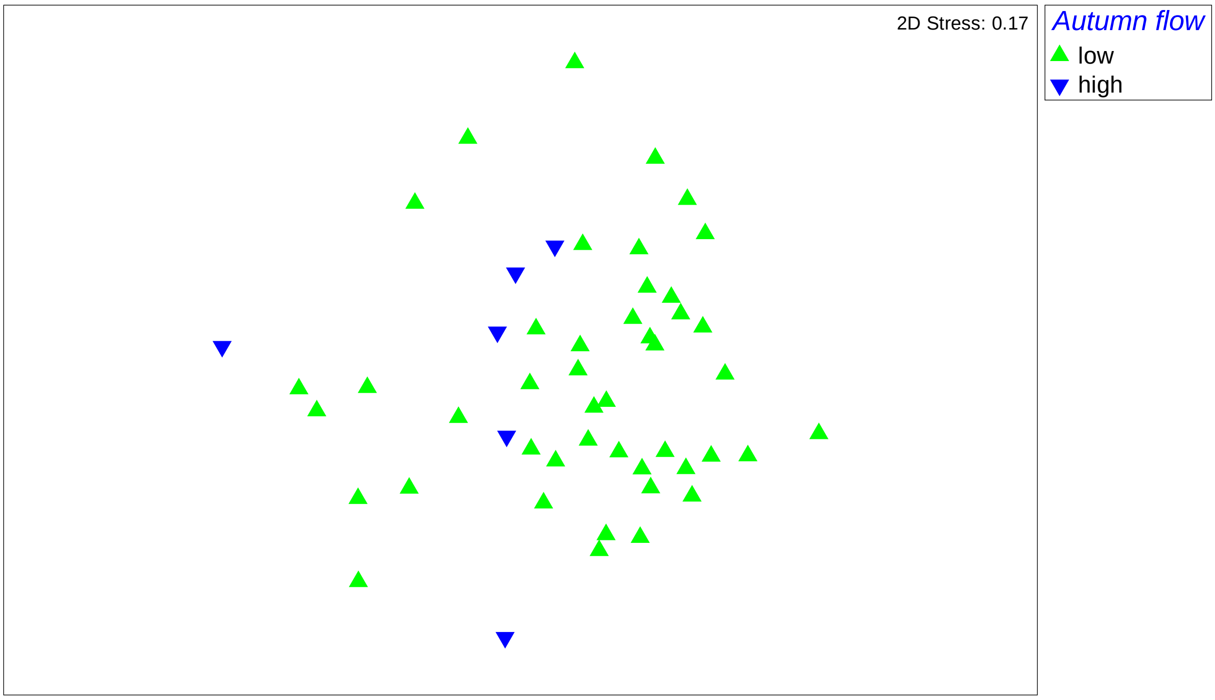

Figure 13. Non-metric multi-dimensional (NMDS) ordination plot showing the spring site data collected during the electrofishing surveys, grouped by autumn flow.

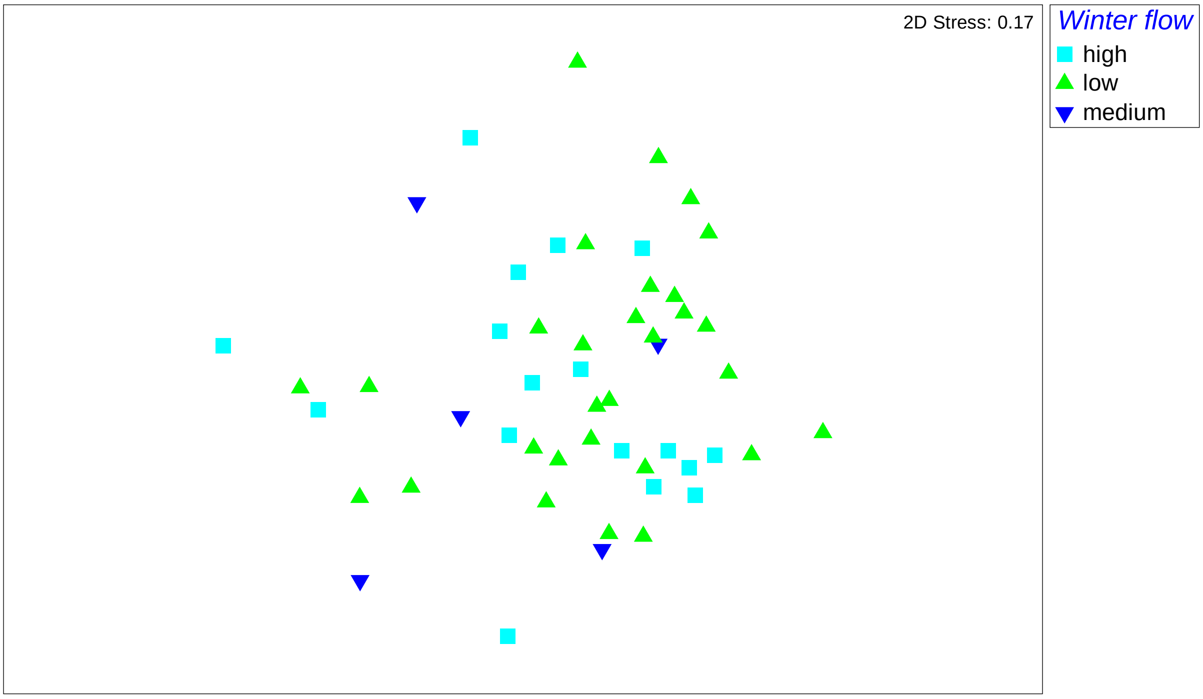

Figure 14. Non-metric multi-dimensional (NMDS) ordination plot showing the spring site data collected during the electrofishing surveys, grouped by winter flow.

3.1.2 Size structure

Length frequency histograms are presented for the most abundant large and small-bodied species.

Murray Cod

The vast majority of the population were smaller than the minimum legal size (MLS) of 600 mm (Figure 15). Since the increase in the MLS of Murray Cod from 500 mm to 600 mm in early 2009, CPUE of fish > 500 mm has remained similar (CPUE mean 1.5 fish/hour, range 0.3-3.7 fish/hour) to levels recorded prior to the change in MLS (CPUE mean 1.3 fish/hour, range 0.0-4.3 fish/hour).Young-of-year (YOY) Murray Cod were collected in most years, but were most abundant in autumn 2004, 2007 and 2010 (Figure 15). Abundance of YOY Murray Cod in autumn 2010 was double that of any other year sampled.

Golden Perch

In contrast to Murray Cod, the Golden Perch population in the lower Goulburn River consisted of larger, older fish, with few individuals below the MLS of 300 mm (8% of total numbers collected) (Figure 16). There was a slight increase, however, in the number of smaller fish (i.e. 150-250 mm TL) collected in recent years. Natural recruitment of Golden Perch in the lower Goulburn River appears to have been negligible over the nine years of the study, with only a single YOY fish (47 mm TL) collected at Pyke Road in Autumn 2007.

Carp

The population of Carp in the lower Goulburn River consists of predominantly large fish (400–600 mm FL), although YOY fish occasionally comprised a large proportion of the population following high flows and floods (e.g. autumn 2006, 2009, and 2011) (Figure 17). A large number of YOY carp were captured in autumn 2011 after the floods during the previous breeding season.

Australian Smelt

The majority of Australian Smelt collected in the lower Goulburn River were approximately 30–60 mm in length (Figure 18). These fish likely represent 0+ year old individuals in the autumn samples, whilst in the spring samples these fish would be approaching 1 year in age. Some larger fish (>60 mm in length) were also occasionally present in the samples, which are likely to be 1–2 years old. Australian smelt are a short-lived species (e.g. 1-2 years) and only one or two size classes would be expected in the population.

Murray River Rainbowfish

The majority of Murray River Rainbowfish collected were approximately 20–60 mm in length (Figure 19). A range of sizes of fish, including YOY (approximately <35 mm in length), indicating recruitment, was collected each year in the Goulburn River.

Other species

Trout Cod and Silver Perch were recorded only in low numbers. There was evidence of patchy recruitment of these species, with YOY fish collected occasionally (e.g. Trout Cod: autumn 2004 and 2008, Silver Perch: autumn 2010 and 2011).

For Murray Cod, Murray River Rainbowfish and Carp, the posterior predictive Bayesian *p*-values for the YOY recruitment models were 0.007, 0.853, and 0.033, which is evidence for a lack of fit for the models (values close to 0.5 support the model). As a consequence, no further interpretation was attempted for these species. For Australian Smelt, however, the posterior predictive Bayesian *p*-value was estimated as 0.52, which suggests a reasonable model fit. Results of the modelling indicate that Australian Smelt YOY CPUE increased over time, while above average aggregate flow and above average aggregate temperature decreased the expected YOY CPUE (Table 6).

Table 6. Influence of environmental variables on YOY Australian smelt catch-per-unit effort (CPUE). Lwr – lower 95% high density interval; Upr – upper 95% high density interval. Relationship non-significant if 95% HDI includes zero.

Model	Explanatory Variable	Mean	Lwr	Upr
CPUE	Intercept	1.479	0.436	2.404
	Year	0.343	0.225	0.478
	Flow	-0.783	-1.178	-0.320
	Temp	-0.456	-0.856	-0.078

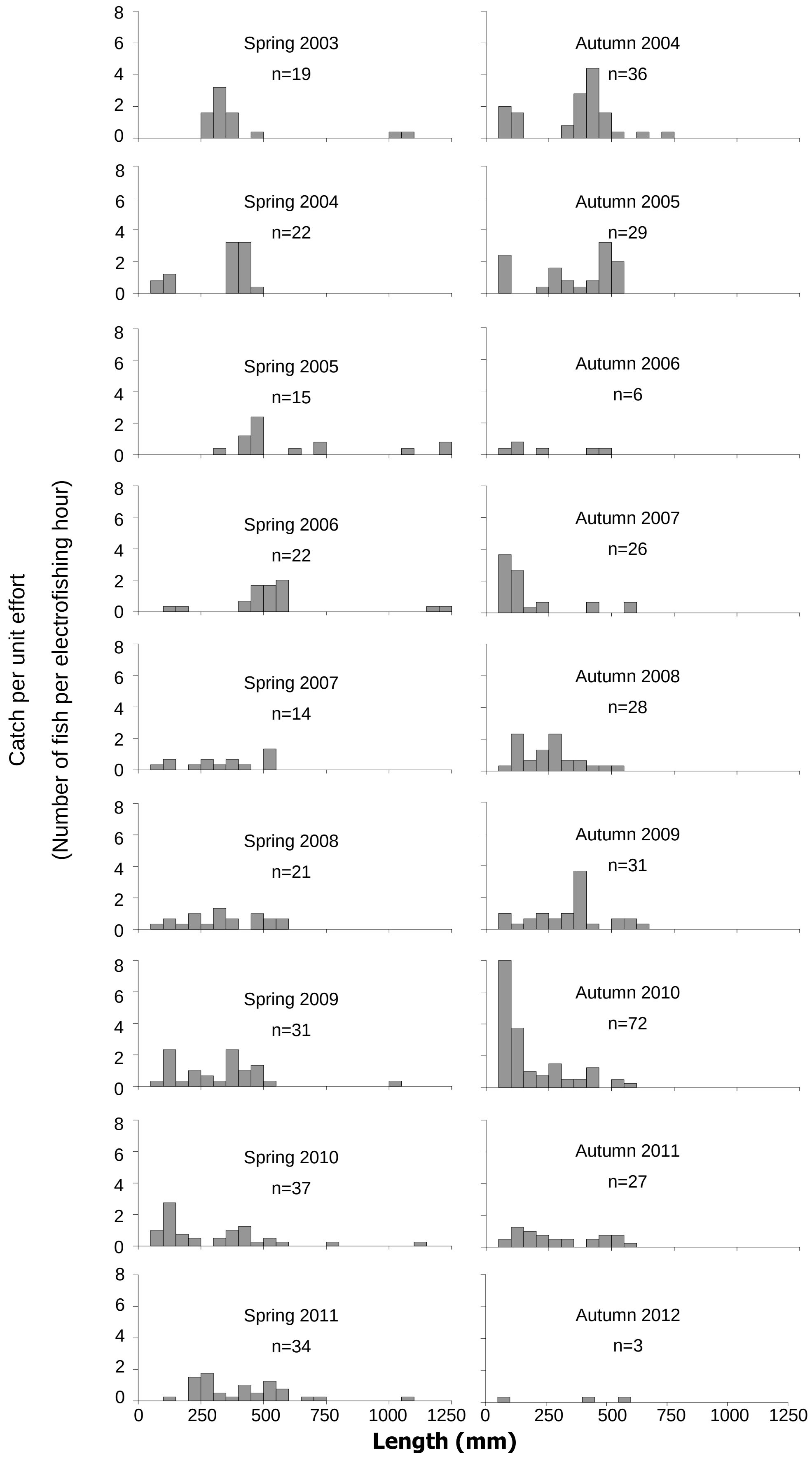

Figure 15. Length frequency of Murray Cod in the Goulburn River.

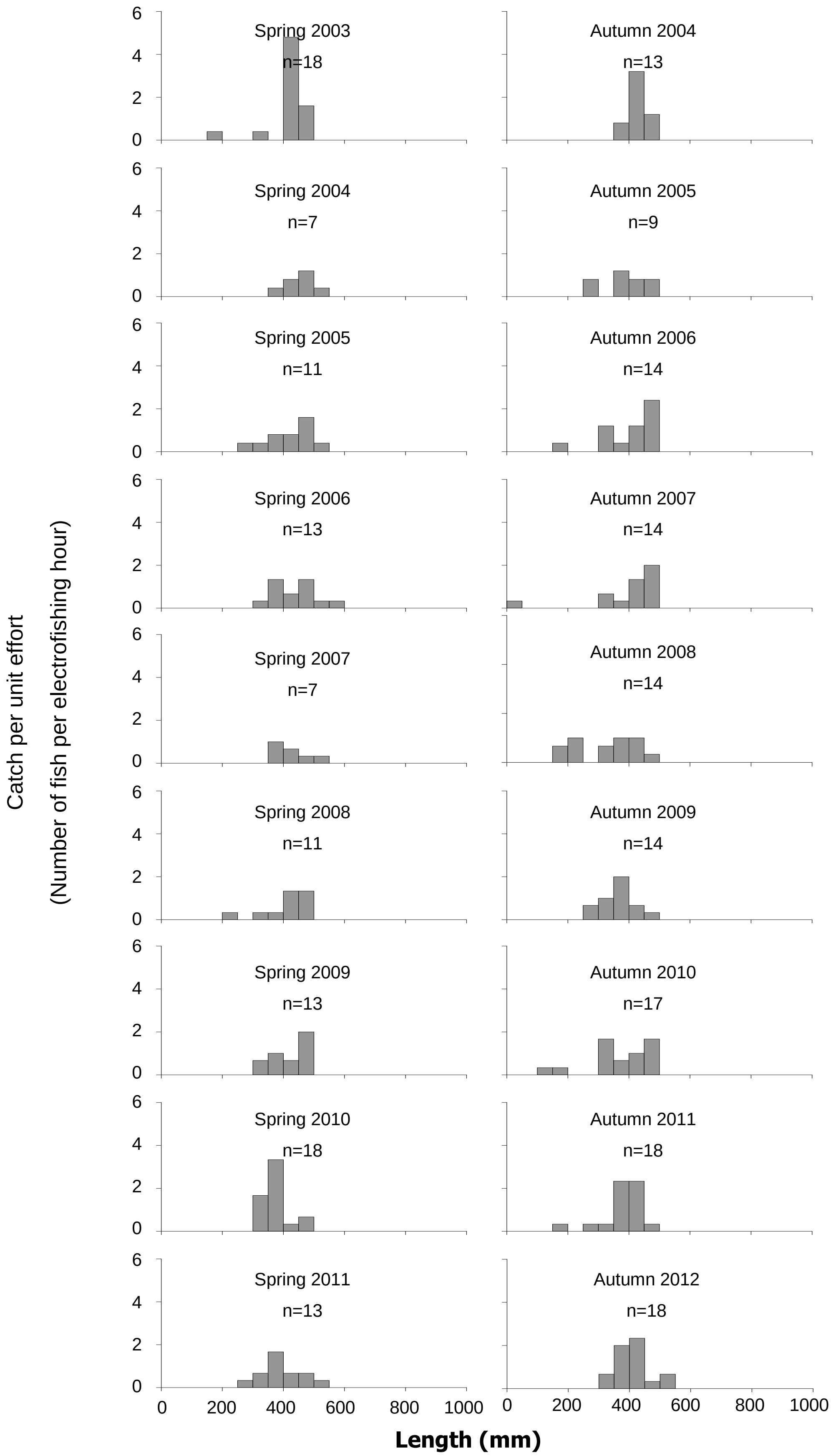

Figure 16. Length frequency of Golden Perch in the Goulburn River.

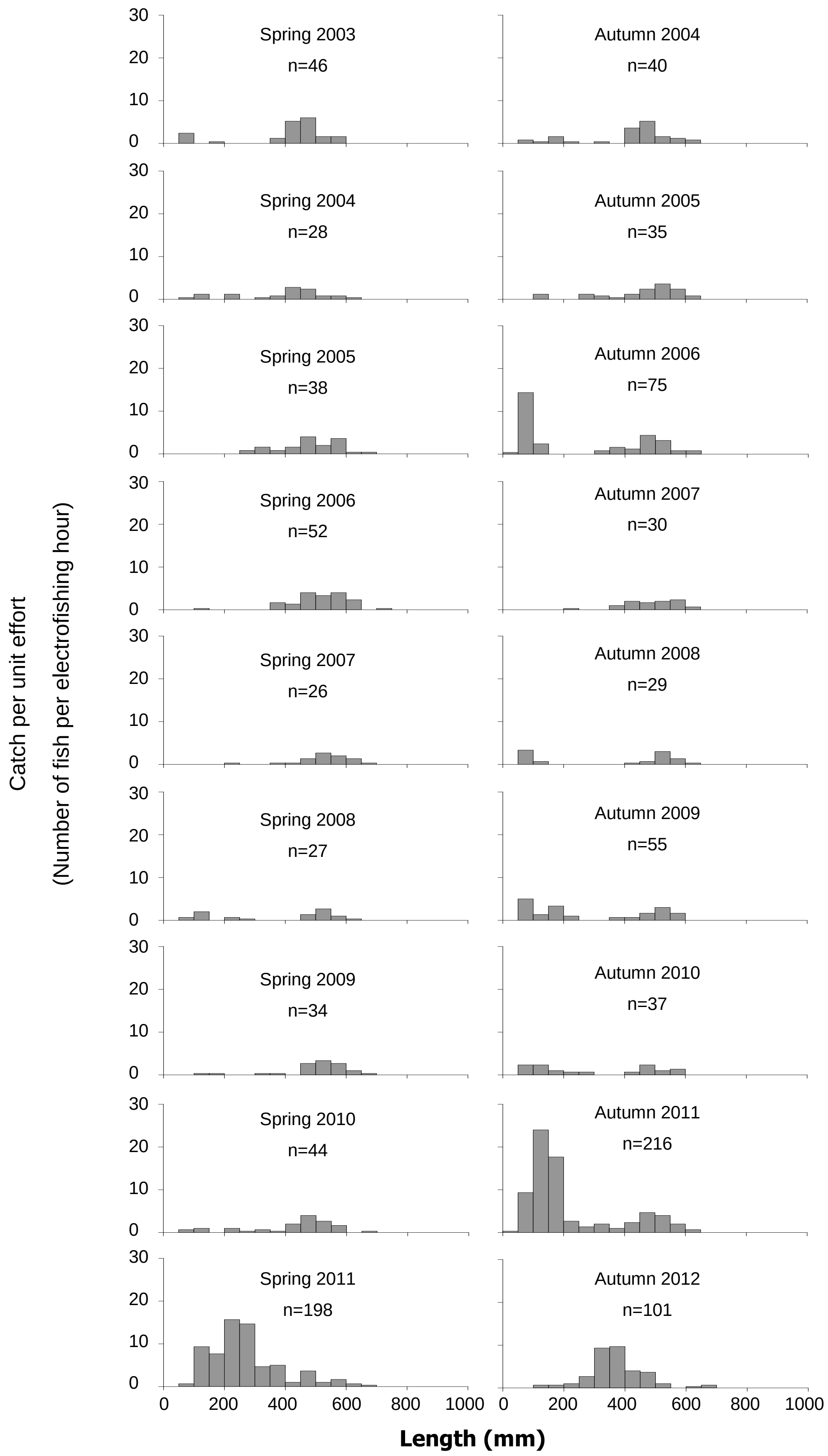

Figure 17. Length frequency of Carp in the Goulburn River.

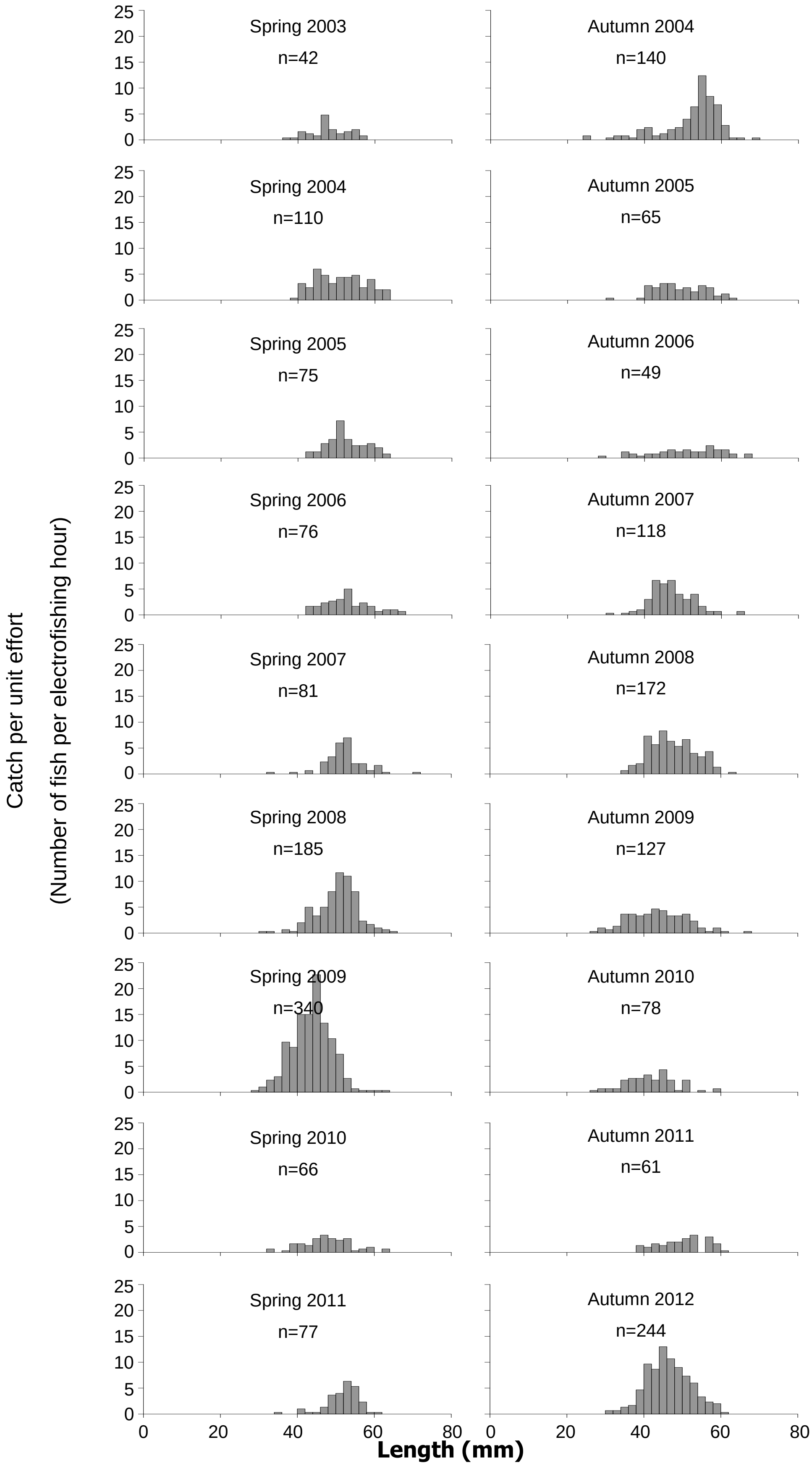

Figure 18. Length frequency of Australian Smelt in the Goulburn River.

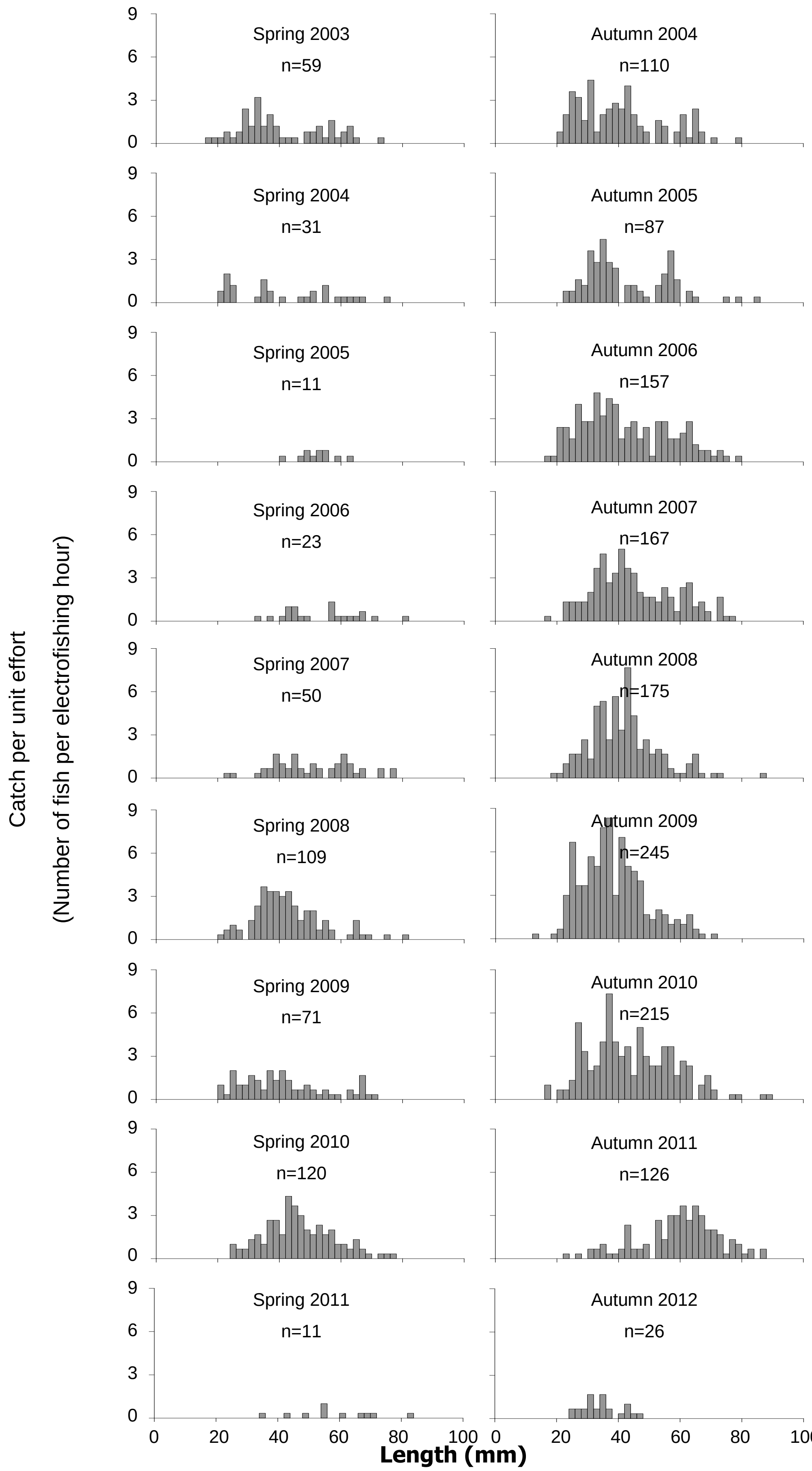

Figure 19. Length frequency of Murray River Rainbowfish in the Goulburn River.

3.2 Drift net sampling

3.2.1 Goulburn River

Over 15 000 individuals representing ten native and two introduced species were collected in the lower Goulburn River from 2003-12 (Table 7). Flat-headed Gudgeon was the most abundant species, comprising 90% of the total abundance for all species. Australian Smelt and Murray Cod were the next most abundant species each comprising 4% of the total abundance. Collection of eggs and/or larvae confirmed breeding by a number of species of conservation significance, including Murray Cod, Trout Cod, Silver Perch and Freshwater Catfish. Based on the results of the egg and larval surveys, a spawning calendar which summarises the main spawning periods for fish in the lower Goulburn River has been developed and presented below (Figure 20).

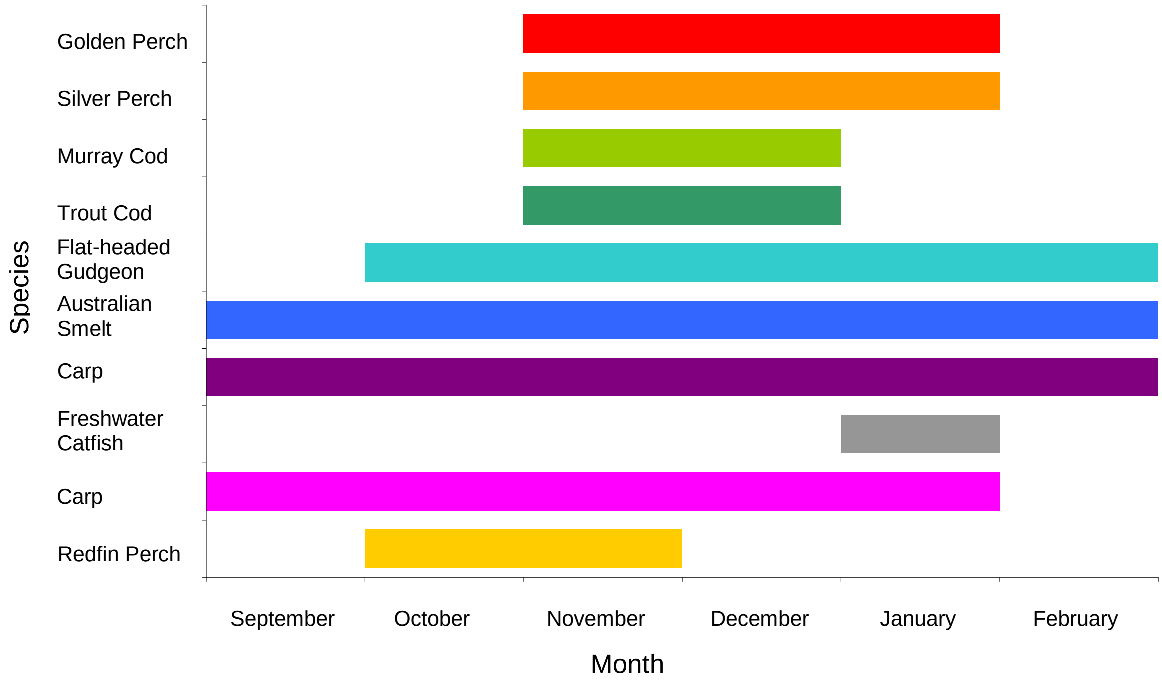

Figure 20. Estimates of spawning periods from collections of eggs and larvae for fish in the lower Goulburn River.

Murray Cod

Murray Cod larvae were collected in all years under a range of flow conditions at temperatures ranging from 18–26° C (Table 7, Figure 21). Larvae were collected from mid November to mid December. Around these times flow in the lower Goulburn River was typically low and stable, but not always (e.g. 2010-11, 2011-12). Densities were highest in 2007-08, 2008-09 and 2009-10: years characterised by low and stable flows during the spawning season.

The probability of detecting Murray Cod larvae was influenced by daylength (linear and squared terms) (*p*-values <0.001) (Table 8). The probability of detecting larvae was highest when daylength was about 13.76 hours per day. The expected CPUE was influenced by change in temperature and daylength (squared) (*p*-values 0.017 and 0.014, respectively). The maximum expected CPUE occurs at about 13.64 hours of daylight. The posterior predictive Bayesian *p*-value was estimated as 0.586, which suggests a reasonable model fit.

Trout Cod

Trout Cod larvae were patchy over time (i.e. 2003-04, 2007-08, 2008-09) and were largely restricted to the Cable Hole site (Table 7, Figure 22). Trout Cod larvae were collected slightly earlier and over a shorter period than Murray Cod from mid November to early December. Around these times flow in the lower Goulburn River was low and stable, while water temperatures were around 22–24° C (Figure X). Densities were highest in 2007-08 (Figure X), which was characterised by low and stable flows during the spawning season. Low occurrences of larvae prevented convergence of the models for Trout Cod.

Golden Perch

Golden Perch eggs and/or larvae were collected in low numbers in 2005-06, 2006-07 and 2011-12, and large numbers in 2010-11 (Table 7, Figure 23). Golden Perch eggs/larvae were collected in November and mid January in water temperatures ranging from 18–24° C. Around these times flow in the lower Goulburn River typically increased (e.g. from 1121 to 4157 ML d^{-1} in mid November 2005, 3546 to 13342 ML d^{-1} in early November 2010, and 684 to 4767 ML d^{-1} in mid November 2011). The flow event in November 2011 was a ‘spring fresh’ environmental flow release (up to about 5353 ML d^{-1}). Densities were substantially higher in 2010-11. This year was characterised by flooding prior to the spawning season and considerably higher flows during the spawning season. Low occurrences of eggs and larvae prevented convergence of the models for Golden Perch.

Silver Perch

Silver Perch eggs were collected in low numbers only in 2010-11 and 2011-12 (Table 7). Silver Perch eggs collected in mid January 2011 and mid November 2011. Around these times flow in the lower Goulburn River increased (e.g. from 2429 to 11977 ML d^{-1} in mid January 2011 and 684 to 4767 ML d^{-1} in mid November 2011), while water temperatures were around 22–25° C. Low occurrences of eggs prevented convergence of the models for Silver Perch.

Australian Smelt

Australian Smelt eggs and/or larvae were collected in all years under a range of flow conditions at water temperatures ranging from 12–27° C (Table 7, Figure 24). Australian Smelt eggs/larvae were collected from September to February. Densities were substantially higher in 2008-09. This year was characterised by low and stable flows during the spawning season.

The posterior predictive Bayesian *p*-value was estimated as 0.865 and the model failed to converge, which is evidence for a lack of fit for the model. This may have occurred because the variability in the data was too great for any patterns to be detected or because variables not accounted for in the models were highly influential.

Flat-headed Gudgeon

Flat-headed Gudgeon larvae were collected in all years under a range of flow conditions at water temperatures ranging from 15–30° C (Table 7, Figure 25). Flat-headed Gudgeon larvae were collected from October to February. Densities were substantially higher in 2008-09 which was characterised by low and stable flows during the spawning season.

The probability of detecting Flat-headed Gudgeon larvae was influenced by moon phase, daylength (squared), mean weekly flow and to a lesser extent change in flow (*p*-values: <0.003; <0.001; <0.001; and <0.03 respectively) (Table 8). The probability of detecting larvae was highest when daylength was about 13.16 hours per day. The expected CPUE was influenced by daylength (linear and squared terms) (*p*-values <0.001) and to a lesser extent change in temperature (*p*-value <0.03). The maximum expected CPUE occurs at about 14.20 hours of daylight. The posterior predictive Bayesian *p*-value was estimated as 0.134, which suggests only a moderate-poor model fit.

Carp Gudgeon

Carp Gudgeon larvae were collected in low numbers in most years under a range of flow conditions at water temperatures ranging from 13–28° C (Table 7). Carp Gudgeon larvae were collected from September to February.

The probability of detecting Carp Gudgeon larvae was influenced by daylength (linear and squared terms) and difference in temperature (p-values <0.001, 0.025 and 0.035 respectively) (Table 8). The probability of detecting larvae was highest when daylength was about 14.2 hours per day. None of the predictors influenced expected CPUE. The posterior predictive Bayesian p-value was estimated as 0.692, which suggests a reasonable model fit.

Carp

Carp larvae were collected in low numbers in 2003-04, 2004-05, 2008-09, 2009-10 and 2010-11 under a range of flow conditions at water temperatures ranging from 15 to 27 ° C (Table 7, Figure 26). Carp larvae were collected from September to January. Low occurrences of larvae prevented convergence of the models for Carp.

Table 7. Numbers of eggs and larvae of fish species in drift samples collected from the Goulburn River between 2003–04 and 2011–12.

		03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11	11–12	Total
Golden Perch	Eggs								134	3	137
	Larvae			3	1				2		6
Silver Perch	Eggs								2	3	5
Murray Cod	Larvae	8	14	31	58	158	156	108	12	12	557
Trout Cod	Larvae	31				60	1				92
River Blackfish	Larvae				1						1
Australian Smelt	Eggs	27	29	15	10	34	32	49	14	24	234
	Larvae	33	4	7	2	32	301	24	32	3	438
Flat-headed Gudgeon	Eggs	3									3
	Larvae	92	1267	343	1061	736	7902	1884	249	87	13621
Carp Gudgeon	Larvae		14	38		4	19	17	15	3	110
Carp	Larvae	1	1				10	9	6		27
Freshwater Catfish	Larvae					1					1
Redfin	Larvae					1		3	3		7
	Total	195	1329	437	1133	1026	8421	2094	469	135	15239

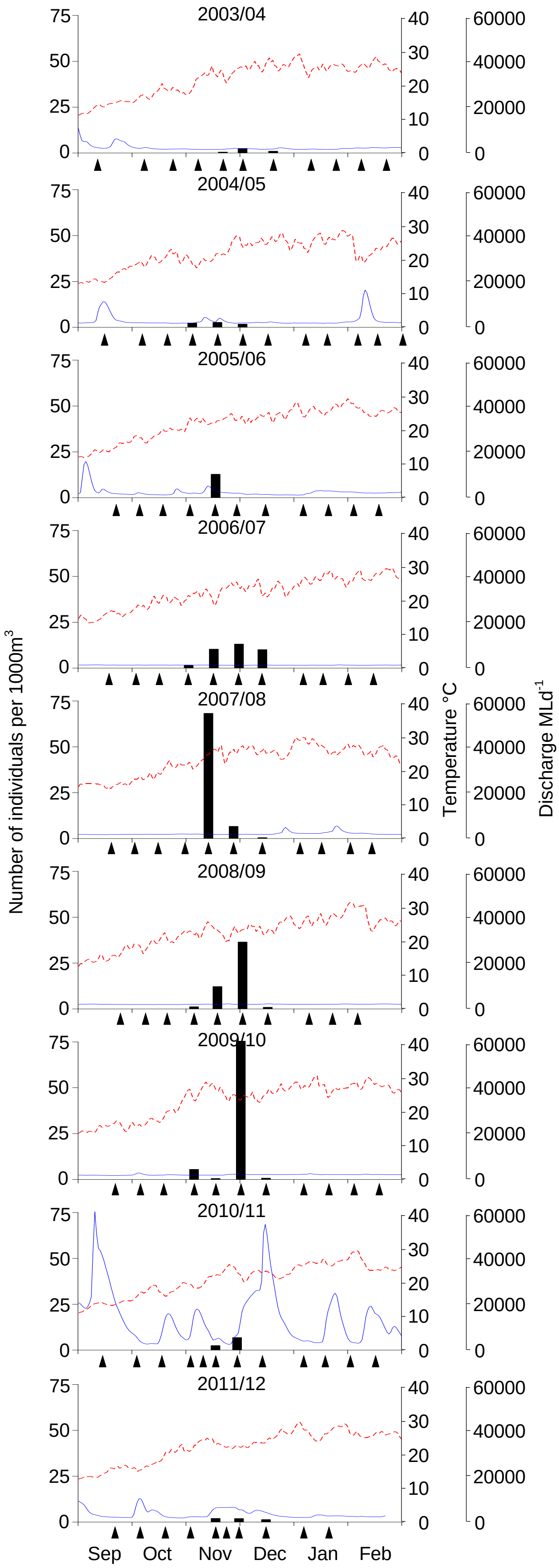

Figure 21. Adjusted total density of Murray Cod larvae per 1000m^3 collected at the three collection sites combined in the Goulburn River. Red dashed line represents water temperature and the blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

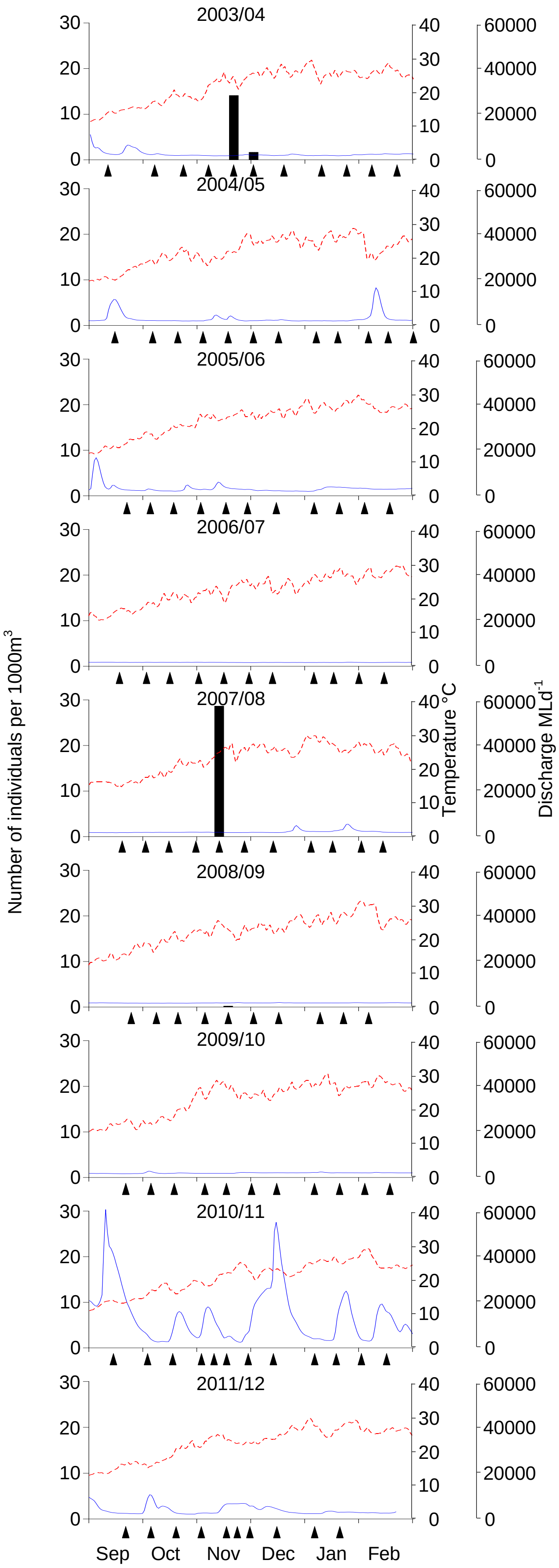

Figure 22. Adjusted total density of Trout Cod larvae per 1000m^3 collected at the three collection sites combined in the Goulburn River. Red dashed line represents water temperature and the blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

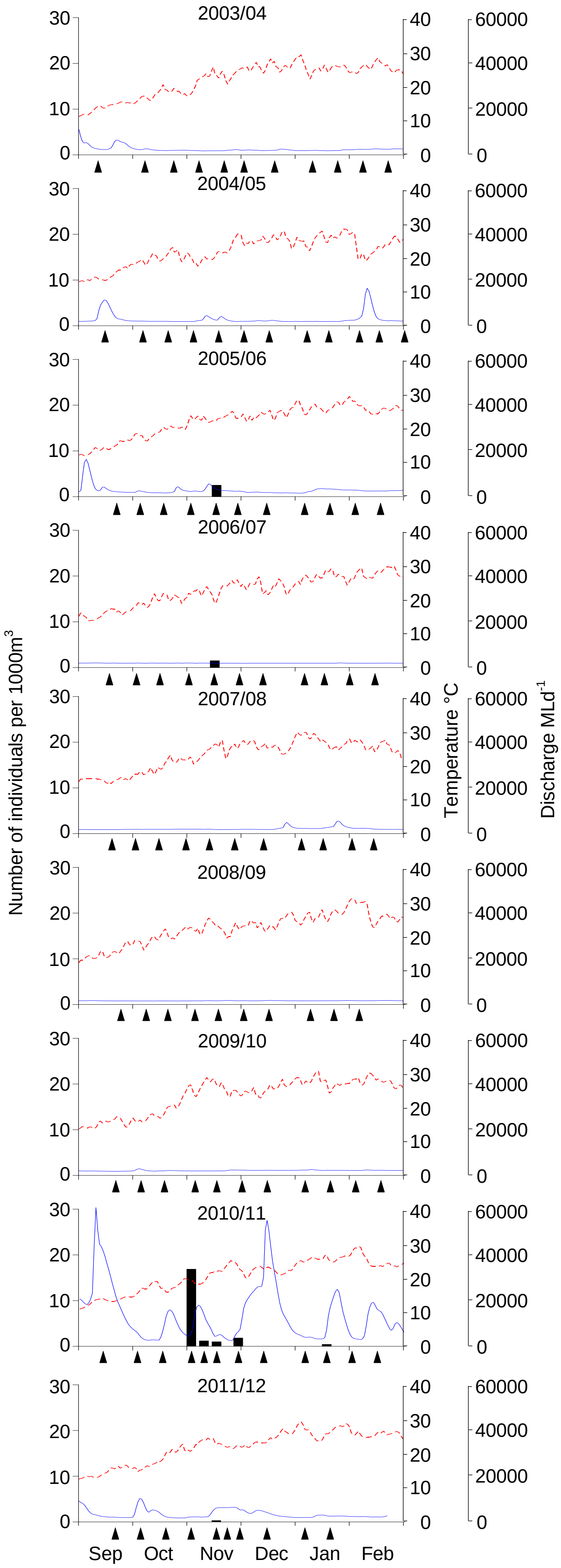

Figure 23. Adjusted total density of Golden Perch eggs/larvae per 1000m^3 collected at the three collection sites combined in the Goulburn River. Red dashed line represents water temperature and the blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

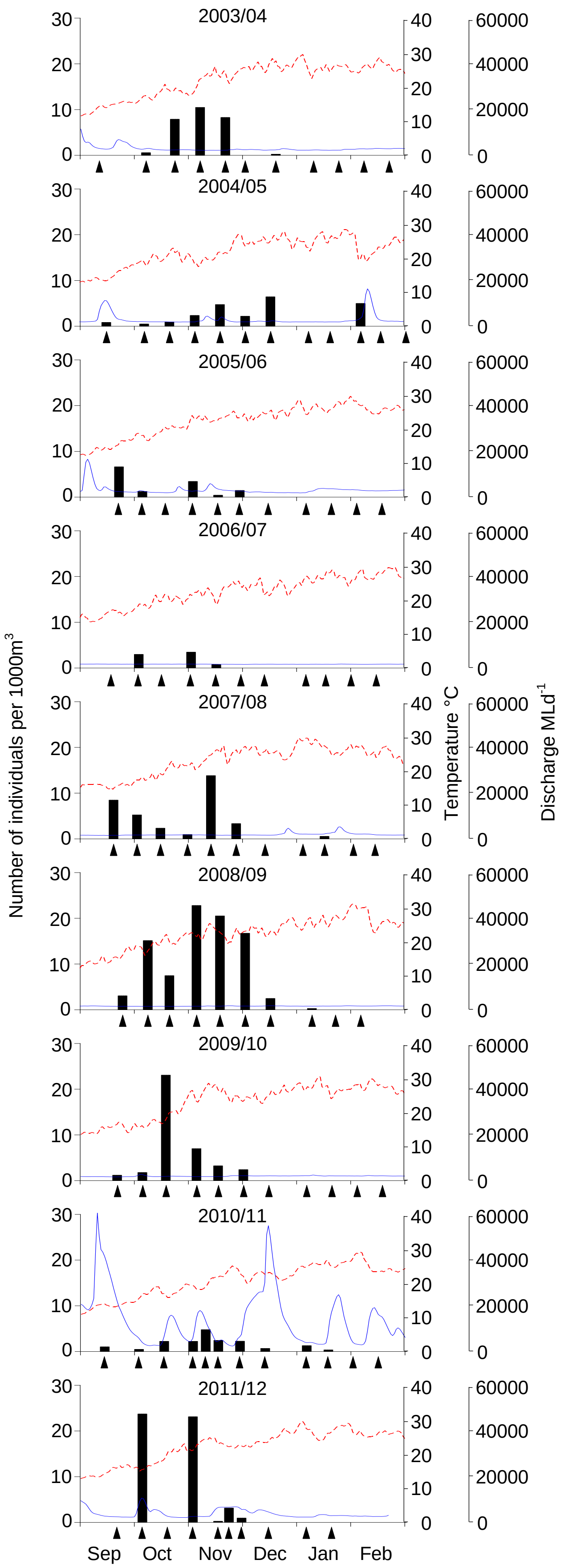

Figure 24. Adjusted total density of Australian smelt eggs/larvae per 1000m^3 collected at the three collection sites combined in the Goulburn River. Red dashed line represents water temperature and the blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

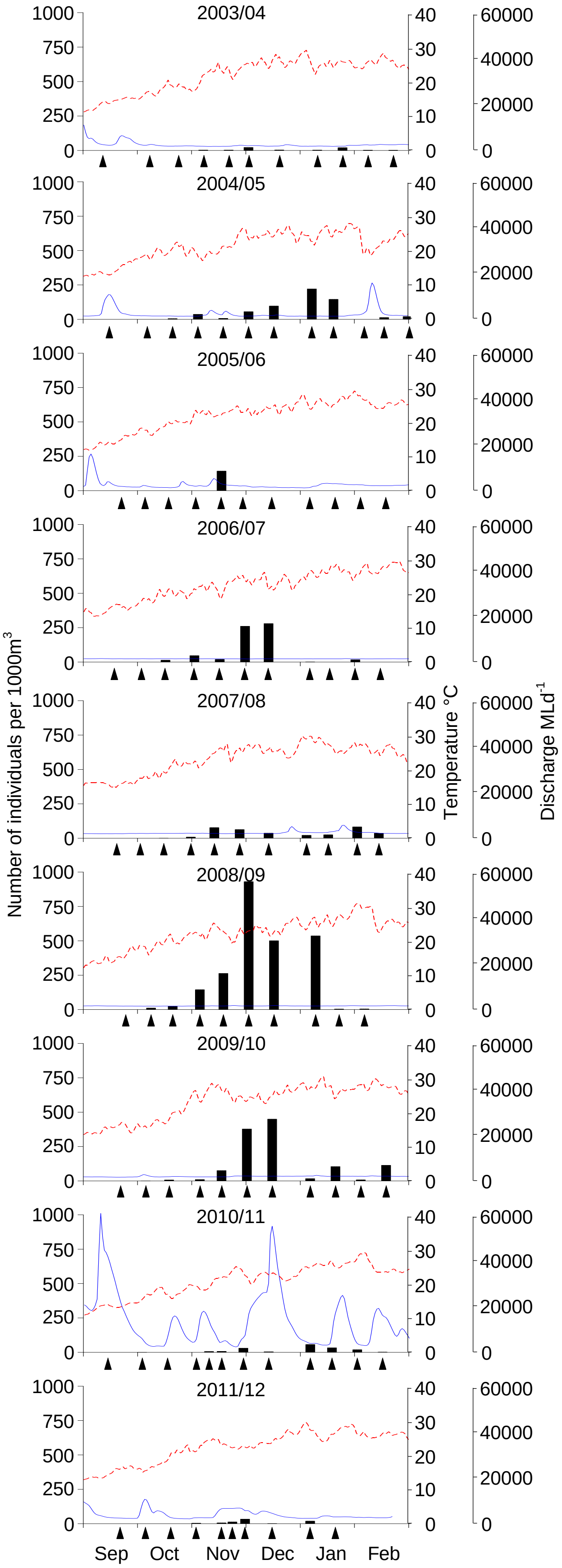

Figure 25. Adjusted total density of Flat-headed Gudgeon larvae per 1000m^3 collected at the three collection sites combined in the Goulburn River. Red dashed line represents water temperature and the blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

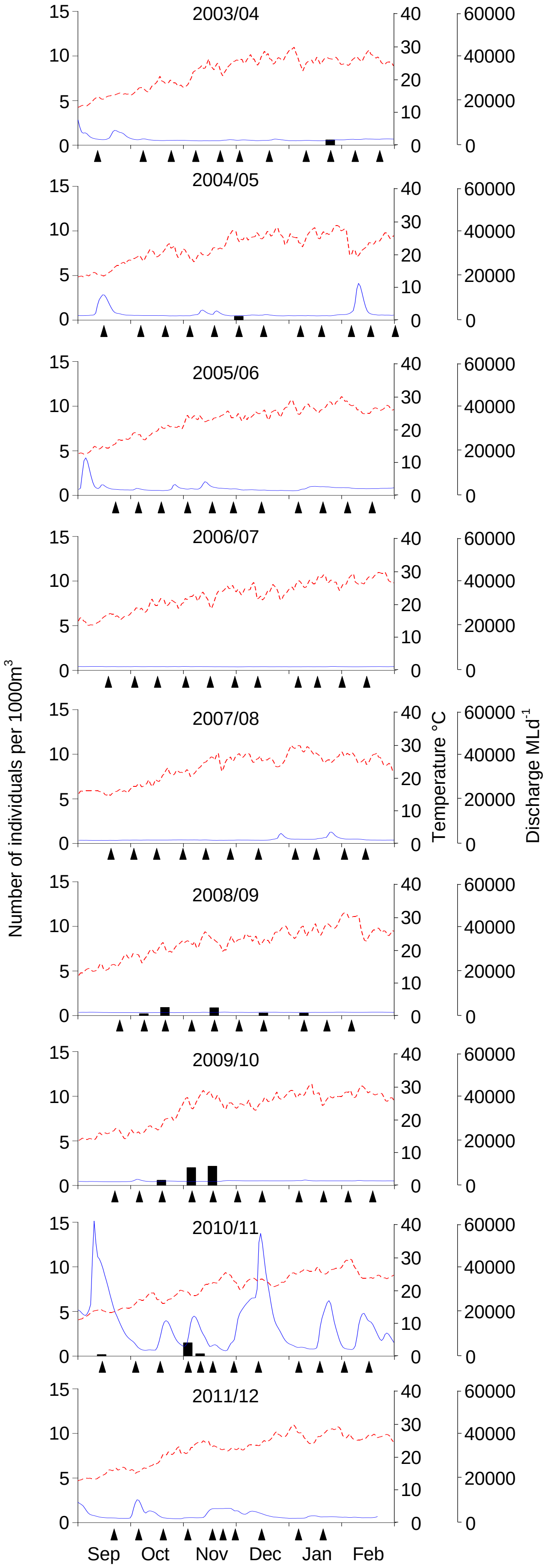

Figure 26. Adjusted total density of Carp larvae per 1000m^3 collected at the three collection sites combined in the Goulburn River. Red dashed line represents water temperature and the blue line represents daily mean discharge in the Goulburn River at McCoy's Bridge.

Table 8. Influence of environmental variables on probability of detection and catch-per-unit effort (CPUE) on early life history stages of native fish species. Lwr – lower 95% high density interval; Upr – upper 95% high density interval. Relationship non-significant if 95% HDI includes zero. Highlighted cells have a 95% high density interval that does not include zero. Results shown only for species models with a posterior predictive Bayesian *p*-value close to 0.5.

		Murray Cod larvae			Flat-headed Gudgeon larvae			Carp Gudgeon larvae		
Model	Explanatory Variable	Mean	Lwr	Upr	Mean	Lwr	Upr	Mean	Lwr	Upr
Detection	Intercept	1.235	-0.700	3.236	2.079	-0.351	4.752	-1.326	-3.238	0.443
	Lunar Phase	-0.002	-0.101	0.096	0.171	0.045	0.312	-0.003	-0.073	0.065
	Daylight Hours	5.169	2.181	8.340	0.847	-0.266	1.998	1.576	0.503	2.681
	Daylight hours Squared	-4.995	-7.960	-2.308	-3.030	-4.792	-1.415	-1.391	-2.764	-0.052
	Mean Weekly Flow	1.121	-2.105	4.125	2.842	0.585	5.725	0.552	-0.325	1.439
	Change in Flow	-0.595	-2.469	1.134	1.176	0.033	2.371	0.273	-0.604	1.149
	Change in Flow Squared	-0.390	-1.055	0.171	-0.223	-0.717	0.265	-0.285	-0.636	0.038
	Change in Temperature	-0.216	-1.006	0.551	0.406	-0.445	1.226	0.284	-0.388	0.987
	Difference in Temperature	0.781	-0.419	2.006	0.705	-0.434	1.898	-0.931	-1.874	-0.053
CPUE	Intercept	0.908	-0.514	2.272	3.283	1.449	5.186	0.011	-2.321	2.242
	Lunar Phase	0.049	-0.017	0.114	0.002	-0.044	0.047	0.041	-0.065	0.147
	Daylight Hours	2.266	-0.391	4.824	1.355	0.787	1.944	-0.575	-2.059	0.869
	Daylight hours Squared	-2.949	-5.183	-0.657	-1.099	-1.921	-0.279	-0.040	-2.327	2.232
	Mean Weekly Flow	0.985	-1.077	3.181	-0.024	-0.598	0.521	0.027	-1.859	1.901
	Change in Flow	0.459	-2.808	3.647	0.370	-0.109	0.859	0.167	-0.965	1.300
	Change in Flow Squared	-0.234	-1.257	0.786	-0.099	-0.276	0.086	-0.112	-0.860	0.636
	Change in Temperature	0.790	0.134	1.469	0.392	0.048	0.746	-0.363	-1.277	0.518
	Difference in Temperature	0.322	-0.531	1.106	-0.038	-0.476	0.410	0.382	-0.561	1.262

3.2.2 Murray River

The composition of catches in the Murray River was very different to that in the Goulburn River (Table 9). Over 2700 individuals representing seven native and one introduced species were collected from the Murray River between 2003-04 and 2011-12 (Table 9). Silver Perch was the most abundant species, comprising 40% of the total abundance. Golden Perch was the next most abundant species, comprising 36% of the total abundance, followed by Australian Smelt, comprising 14% of the total abundance. Two species of conservation significance were collected, namely Murray Cod and Silver Perch.

The two most abundant species in the Murray River, Silver Perch and Golden Perch, were collected only in low numbers in the Goulburn River, with the exception of Golden Perch in one spawning season (2010-11). Unspecked Hardyhead (*Craterocephalus stercusmuscarum fulvus*), collected in low numbers in the Murray River, were absent from the Goulburn River. Trout Cod was collected in the Goulburn River but not the Murray River. River Blackfish, Freshwater Catfish and Redfin (*Perca fluviatilis*), collected in low numbers in the Goulburn River, were also absent from the Murray River. For a more detailed assessment of fish spawning in the mid-Murray River region, see King *et al.* (2009b; 2011).

Table 9. Numbers of eggs and larvae of fish species in drift samples collected from the Murray River between 2003–04 and 2011–12.

		03–04	04–05	05–06	06–07	07–08	08–09	09-10	10-11	11-12	Total
Golden Perch	Eggs	47	428	432	1		37		37	3	985
	Larvae		9								9
Silver Perch	Eggs	72	37	25	41	60	262	382	27	192	1098
	Larvae		10				2	2		1	15
Murray Cod	Larvae	1	17				4	4			26
Australian Smelt	Eggs		4		3		4	13	1		25
	Larvae	45	9		13	179	100	3		2	351
Flat-headed Gudgeon	Larvae	2	8	2	3	3	17	12	2	1	50
Carp Gudgeon	Larvae		1			3	6			1	11
Carp	Eggs	3	2			2	4				11
	Larvae	9	5	87	3	4	5	1	13	28	155
Unspecked Hardyhead	Eggs					3					3
	Total	179	530	546	64	254	441	417	80	228	2739

3.3 Acoustic tracking of Golden Perch

3.3.1 Goulburn River tagged fish

Of the 37 Golden Perch tagged in the Goulburn River across three years, 29 were detected by the listening stations. Three of these fish were reported by anglers as caught and kept. About half (20 out of 37) of the tagged fish were detected moving into the Murray River (Figure 27, 28).

Movement of fish into the Murray River occurred in all seasons but was most common during spring and summer (Figure 27, 28). In particular, between December 2007 and January 2008 during which time about 42% (5 out of 12) of fish tagged in the Goulburn River entered the Murray River. Movement of fish from the Goulburn River into the Murray River was also concentrated around November 2008, September-November 2009 and August-September 2010. During these periods, about 33% (7 out of 21), 30% (7 out of 23) and 36% (5 out of 14) of fish tagged in the Goulburn River entered the Murray River, respectively.

Of the fish that entered the Murray River, nine fish visited the Murray River once and 11 fish visited on multiple occasions (Figure 27). Of the visits to the Murray River, about one third (33%) halted near the junction (i.e. < 2 km upstream or downstream) (Figure 27). Most (40%) extended a short distance (i.e. 2–10 km) upstream or downstream into the Murray River, and about one quarter (27%) extended further (i.e. > 10 km upstream or downstream) into the Murray River. The time spent by fish in the Murray River per visit ranged from one day to over 20 months. Most (61%) visits to the Murray River lasted for short periods (i.e. < 3 weeks) followed by a return to the Goulburn River. Four of the fish did not return to the Goulburn River.

Most (81%) of the visits to the Murray River occurred during or shortly after (i.e. within 7 days) a change in flow greater than 100 ML magnitude in the Goulburn River. Of these visits, about two thirds (76%) occurred on a rising limb and the remainder (24%) on a falling limb of the hydrograph. About half (52%) and one third (38%) of the total visits occurred during or shortly after a change in flow greater than 400 ML and 1000 ML magnitude, respectively.

Times when fish were detected moving into the Murray River coincided with a broad range of water temperatures in the Goulburn River (range 9.6–24.4° C, median 19.1° C). Most (76%) of the visits to the Murray River occurred during or shortly after a change in temperature greater than 2° C in the Goulburn River. Of these visits, most (75%) were associated with a decrease in water temperature.

In 2010, Goulburn River fish were also detected moving between the Murray and Goulburn rivers coinciding with dissolved oxygen (DO) depletion and blackwater events. For example, in mid November 2011, the number of Goulburn River fish detected in the Murray River decreased from 6 to 3 (43 to 21%), coinciding with a severe blackwater event and low DO (<4 mg/L) in the Murray River (Figure 28). Shortly afterwards in early December 2010, the number of Goulburn River fish detected in the Murray River then increased from 3 to 5 (21 to 36%), coinciding with a severe blackwater event and low DO (<4 mg/L) in the Goulburn River (Figure 28). These fish, however, immediately returned to the Goulburn River. The Murray and Goulburn rivers were both highly anoxic at the time. These results suggest that tagged Golden Perch may have been attempting to avoid low dissolved oxygen conditions by moving away from affected areas.

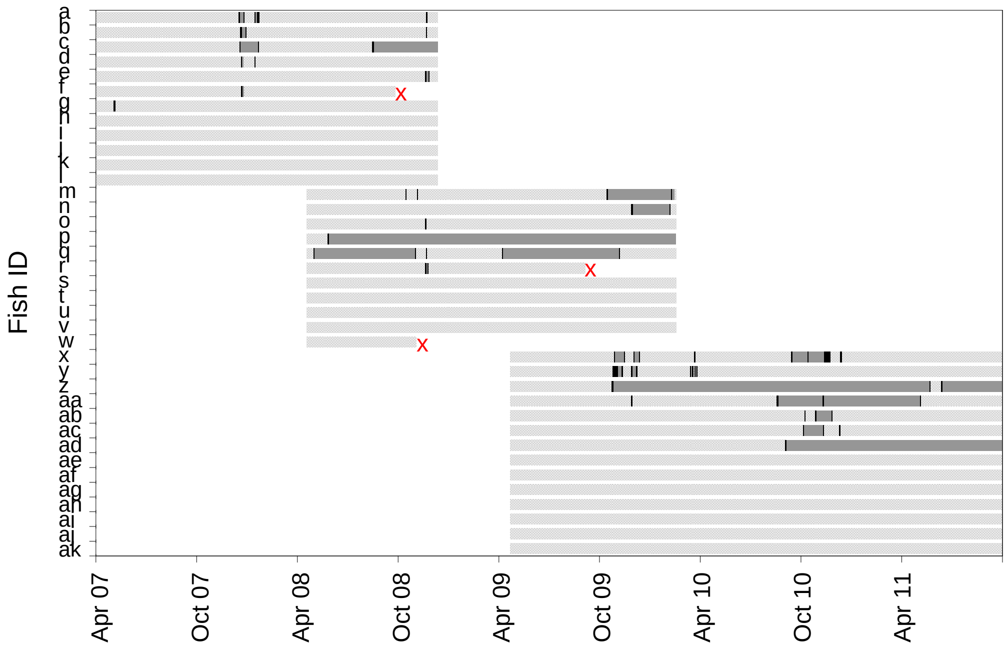

Figure 27. Times (bars) during which fish tagged in the Goulburn River were detected in the Goulburn River (■), Murray River within 2 km of junction (■) and Murray River >2km from junction (■). Red 'x' indicates fish reported as caught and kept by angler. Letters refer to individual tagged fish. Fish were tagged on three separate occasions (a-l April 2007; m-w April 2008, x-ak April 2009).

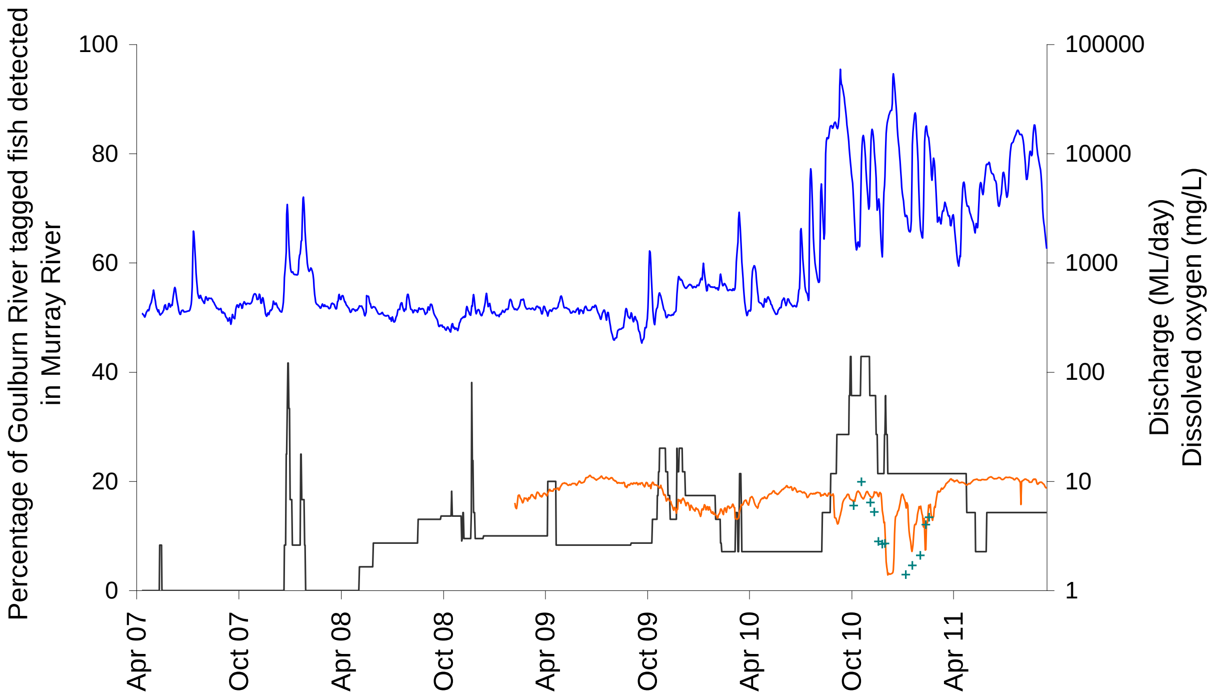

Figure 28. Percentage of Goulburn River tagged fish (grey line) detected in the Murray River. Blue line represents daily mean discharge and orange line daily mean dissolved oxygen in the Goulburn River at McCoy's Bridge. Green crosses indicate spot measurements of dissolved oxygen in the Murray River at Echuca.

3.3.2 Murray River tagged fish

Of the 42 Golden Perch tagged in the Murray River across three years, 39 were detected by the listening stations. About one quarter (11 out of 42) of the tagged fish were detected moving into the Goulburn River (Figure 29).

Movement of fish into the Goulburn River occurred in all seasons and was not concentrated during any one particular period (Figure 29). Of the fish that entered the Goulburn River, five fish visited the Goulburn River once and six fish visited on multiple occasions (Figure 29). The time spent by fish in the Goulburn River per visit ranged from one day to over 24 months. Most (68%) visits to the Goulburn River lasted for short periods (i.e. < 2 weeks) followed by a return to the Murray River. Three fish did not return to the Murray River.

Most (80%) of the visits to the Goulburn River occurred during or shortly after (i.e. within 7 days) a change in flow greater than 500 ML magnitude in the Murray River. Of these visits, half (50%) occurred on a rising limb and half (50%) on a falling limb of the hydrograph. About half (53%) and one quarter (27%) of the total visits occurred during or shortly after a change in flow greater than 1000 ML and 3000 ML magnitude in the Murray River, respectively.

Most (57%) of the visits to the Goulburn River coincided with changes in flow greater than 500 ML in the Murray River coupled with changes in flow greater than 100 ML magnitude in the Goulburn River. About one third (30%) of the visits coincided with changes in flow greater than 500 ML in the Murray River coupled with changes in flow less than 100 ML magnitude in the Goulburn River.

Times when fish were detected moving into the Goulburn River coincided with a broad range of water temperatures in the Murray River (range 9.0–25.8° C, median 17.3° C) and Goulburn River (range 8.5–28.6° C, median 17.1° C). Half (50%) of the visits to the Goulburn River occurred during or shortly after a change in temperature greater than 2° C in the Murray River. Of these visits, most (60%) occurred on an increase in temperature.

About 48% (20 out of 42) of the tagged fish were detected near the junction (i.e. < 2 km upstream or downstream) (Figure 29). Movement of fish to the junction was concentrated during spring and summer, during which time about 33% (28 out of 84) of fish tagged in the Murray River were detected near the junction. Of the fish that visited the junction, two fish visited once and 18 fish visited on multiple occasions. Most (93%) visits to the junction lasted for short periods (i.e. < 1 week) followed by a return to nearby in the Murray River (i.e. 2–10 km upstream or downstream of the junction).

Similar to Goulburn River fish, Murray River tagged fish were detected moving between the Goulburn and Murray rivers coinciding with dissolved oxygen (DO) depletion and blackwater events in 2010. For example, in mid November 2011, the number of Murray River fish detected in the Goulburn River increased from 2 to 4 (15 to 31%), coinciding with a severe blackwater event and low DO (<4 mg/L) in the Murray River (Figure 30).

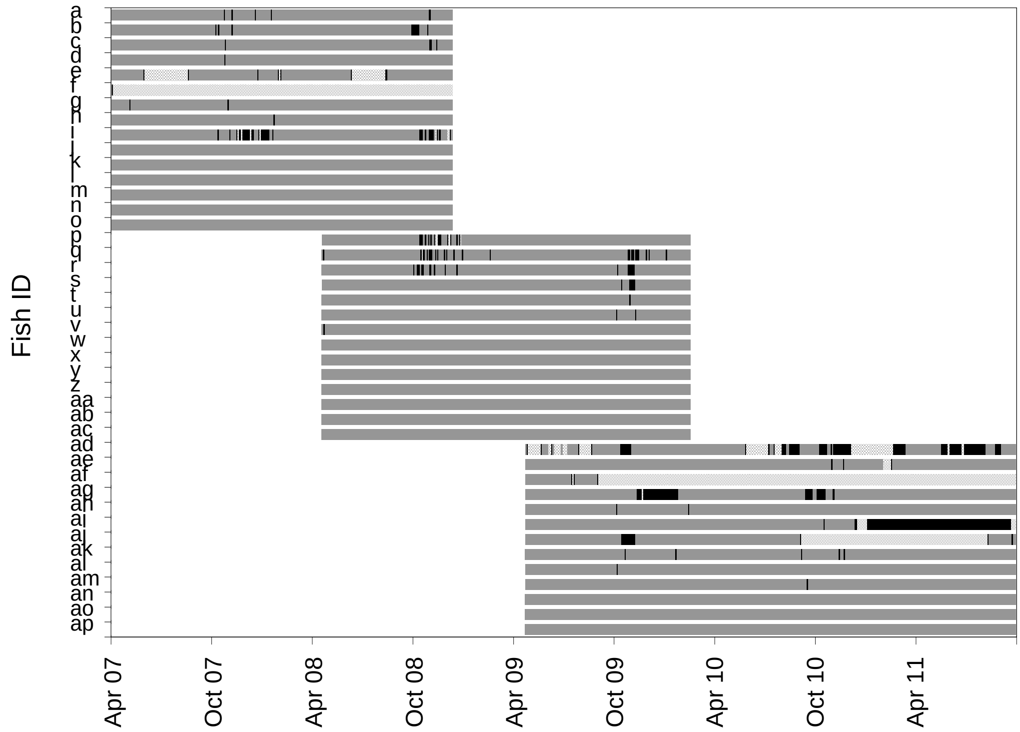

Figure 29. Times (coloured bars) during which fish tagged in the Murray River were detected in the Murray River >2km from junction (■), Murray River within 2 km of junction (■), and Goulburn River (■). Letters refer to individual tagged fish. Fish were tagged on three separate occasions (a-o April 2007; p-ac April 2008, ad-ap April 2009).

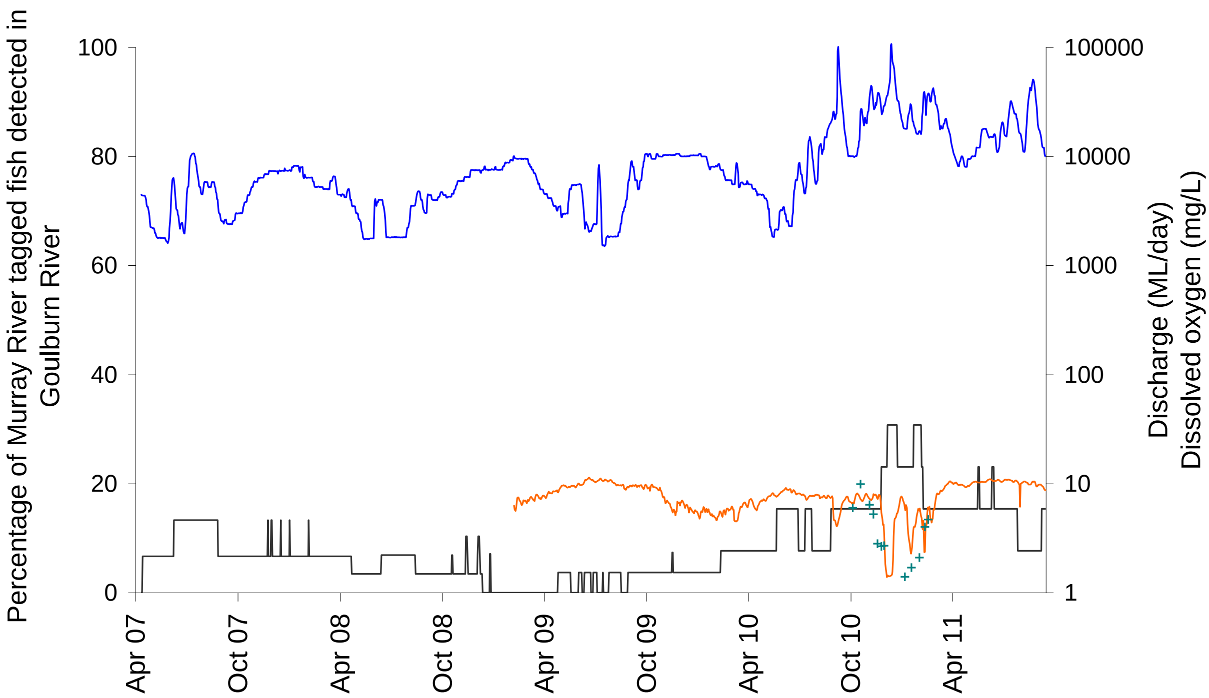

Figure 30. Percentage of Murray River tagged fish (grey line) detected in the Goulburn River. Blue line represents daily mean discharge in the Murray River at Yarrawonga. Green crosses indicate spot measurements of dissolved oxygen in the Murray River at Echuca. Orange line represents daily mean dissolved oxygen in the Goulburn River at McCoy's Bridge.

3.3.3 Probability of movement

Overall, tagged fish were more likely to remain in the river in which they were tagged or move back to it if they leave. The onset of spawning season influenced movement patterns in both rivers, but in different ways. During the spawning season, fish in the Murray River were more likely to stay in that river, although this effect was reduced when mean weekly temperatures were above average. In the Goulburn River, flows above average during the spawning season increased the likelihood of the fish staying in the river for the next week. However, a change in flow (at all times, including spawning season) more strongly influenced fish movement, with the greater the change in flow the more likely fish were to leave.

Goulburn to Murray

The Goulburn to Murray section of the model ($p_{G,t}$) deals with probability of fish in the Goulburn River staying in the Goulburn River for the next weekly time step. The predictors with the greatest relative importance were: where the fish was originally tagged, whether it was spawning season, the percentage change in weekly flow, and the mean weekly flow. However, if the model is averaged over models with the most evidence (ΔAICc < 4, see Table 10) then the non-zero coefficients were related to: where the fish was caught; the percentage change in weekly flow, and the interaction between spawning season and mean weekly flow. In summary:

- In general fish prefer to stay in the Goulburn River. The large intercept suggests on an average week 99% of fish with the Goulburn River as their ‘home’ river will stay in the Goulburn River.
- The odds of fish with the Murray River as home remaining in the Goulburn River for the next week were 83% less than fish with Goulburn River as home.
- A change in flow decreases the odds of fish staying in the Goulburn River. As an example, a 10% increase in mean weekly flow reduces the odds of fish remaining in the Goulburn River for the next week by 16%.
- Flows above average[2] during the spawning season increased the likelihood of fish staying in the Goulburn River. As an example, during the spawning season, a mean weekly flow of 100 ML above average in the Goulburn River increases the odds of the fish staying by 1%.

[2] Averages refer to values observed through the study period, not long term averages.

Table 10. Model averages for the models with ΔAICc < 4.

Predictor variable	Estimate	Lower CI	Upper CI
(Intercept)	4.5165	3.4205	5.6126
Goulburn mean weekly flow	0.0000	-0.0001	0.0001
Goulburn mean weekly flow when Murray River is home	0.0001	-0.0001	0.0002
Goulburn mean weekly flow when Murray River is home and spawning season	0.0001	-0.0001	0.0004
Goulburn mean weekly flow during spawning season	0.0001	0.0000	0.0003
Goulburn mean weekly flow CV	-0.0014	-0.0061	0.0033
Goulburn mean weekly flow CV when Murray River is home	0.0030	-0.0017	0.0076
Goulburn mean weekly flow CV when Murray River is home and spawning season	0.0021	-0.0075	0.0117
Goulburn mean weekly flow CV during spawning season	-0.0036	-0.0105	0.0033
Goulburn mean weekly flow percentage change	-1.7602	-3.0609	-0.4595
Goulburn mean weekly flow percentage change when Murray River is home	1.2484	-0.7168	3.2137
Goulburn mean weekly flow percentage change when Murray River is home and spawning season	2.1932	-2.9271	7.3135
Goulburn mean weekly flow percentage change during spawning season	0.9884	-1.3058	3.2825
Goulburn mean weekly temperature	-0.0182	-0.0765	0.0401
Goulburn mean weekly temperature when Murray River is home	0.0108	-0.1054	0.1270
Goulburn mean weekly temperature when Murray River is home and spawning season	-0.2090	-0.4468	0.0288
Goulburn mean weekly temperature during spawning season	-0.0513	-0.1472	0.0446
Goulburn mean weekly temperature CV	6.7495	-6.9487	20.4476
Goulburn mean weekly temperature CV when Murray River is home	-17.7972	-39.2437	3.6494
Goulburn mean weekly temperature CV during spawning season	9.2493	-11.8499	30.3485
Goulburn mean weekly temperature percentage change	-4.9888	-21.9896	12.0119
Goulburn mean weekly temperature percentage change when Murray River is home	-14.1295	-36.6452	8.3863
Goulburn mean weekly temperature percentage change when Murray River is home and spawning season	-17.9178	-61.4903	25.6546
Goulburn mean weekly temperature percentage change during spawning season	18.9588	-1.5539	39.4715
Murray River is home	-1.7470	-3.2369	-0.2572
Murray River is home and it is spawning season	1.3979	-2.3196	5.1153
Spawning season	-0.7716	-2.4056	0.8623

Shaded cells are those whose values are different from zero in that their 95% confidence interval does not include zero.

Murray to Goulburn

The Murray to Goulburn section of the model ($p_{M,t}$) deals with probability of fish currently in the Murray River staying in the Murray River for the next week. The predictors with the greatest relative importance were: where the fish was originally tagged, whether it was spawning season, the mean weekly water temperature, the mean weekly water temperature during spawning season, and to a lesser degree the mean weekly flow. However, if the model is averaged over models with the most evidence (ΔAICc < 4, see Table 11) then the non-zero coefficients were related to: where the fish was caught; whether it is spawning season, and the interaction between spawning season and mean weekly water temperature. In summary:

- In general fish prefer to stay in the Murray River. The large intercept suggests on an average week 99% of fish with the Murray River as their home will stay in the Murray River.
- The odds of fish with the Goulburn River as home remaining in the Murray River for the next week were 88% less than fish with Murray River as home.
- During the spawning season, the odds of fish staying in the Murray River for the next week increase by a factor of over 17.
- Higher water temperatures during the spawning season increased the likelihood of fish leaving the Murray River. As an example, during the spawning season a week where the weekly mean water temperature is 1ºC above average in the Murray River decreases the odds of the fish staying by nearly 17% compared to an average week during the spawning season.

Table 11. Model averages for the models with ΔAICc < 4.

Predictor Variable	Estimate	Lower CI	Upper CI
Intercept	1.8232	0.4201	3.2264
Murray River is home	2.9833	1.8063	4.1603
Murray mean weekly flow when Murray River is home	0.0000	-0.0001	0.0000
Murray mean weekly flow CV when Murray River is home	-0.0007	-0.0025	0.0011
Murray mean weekly flow percentage change when Murray River is home	0.7635	-5.0526	6.5797
Murray mean weekly temperature when Murray River is home	0.0442	-0.0495	0.1379
Murray mean weekly temperature when Murray River is home and spawning season	-0.1229	-0.3663	0.1205
Murray mean weekly temperature CV when Murray River is home	-4.0046	-24.3235	16.3144
Murray mean weekly temperature percentage change when Murray River is home	-3.3183	-22.8978	16.2612
Murray River is home and it is spawning season	0.1737	-1.3181	1.6655
Murray mean weekly flow	0.0000	0.0000	0.0001
Murray mean weekly flow during spawning season	0.0000	-0.0001	0.0000
Murray mean weekly flow CV	-0.0003	-0.0015	0.0009
Murray mean weekly flow CV during spawning season	0.0006	-0.0026	0.0037
Murray mean weekly flow percentage change	-1.6685	-5.0712	1.7341
Murray mean weekly flow percentage change during spawning season	3.0913	-2.8064	8.9889
Murray mean weekly temperature	0.0405	-0.0409	0.1220
Murray mean weekly temperature during spawning season	-0.1897	-0.3020	-0.0774
Murray mean weekly temperature CV	-10.0179	-22.0643	2.0284
Murray mean weekly temperature CV during spawning season	11.3274	-12.7419	35.3968
Murray mean weekly temperature percentage change	9.4279	-5.2439	24.0996
Murray mean weekly temperature percentage change during spawning season	-12.0243	-35.0409	10.9923
Spawning season	2.8650	0.6558	5.0742

Shaded cells are those whose values are different from zero in that their 95% confidence interval does not include zero.

4 Discussion

4.1 Historical perspective on the status of fish assemblages

Like most lowland rivers in the Murray-Darling Basin, the native fish assemblage of the lower Goulburn River has changed dramatically since European settlement. Although scientific data of the type collected in the current study are not available to track these changes over time, Trueman (2007) compiled extensive anecdotal accounts to build up an excellent picture of historical fish assemblages in the mid-Murray/Goulburn River region. With regards to the pre-European fish fauna of the lower Goulburn River:

"The historical account suggests that downstream from Seymour/Traawool that Murray Cod, Macquarie Perch, Golden Perch, Silver Perch, Catfish and River Blackfish were abundant in the Goulburn River and its tributaries. Trout Cod were regularly taken in relatively low numbers and Bony Bream were present at least upstream to the Shepparton area. Adjacent billabongs are reported to have contained large numbers of Catfish, Macquarie Perch and Blackfish with the other species also present" (Trueman 2007).

Noticeable declines of some native fish species in the Goulburn River began in the 1890's following the construction of Goulburn Weir at Nagambie, and Golden and Silver Perch had essentially disappeared upstream of the weir by the 1930s (Trueman 2007). Large fish kills, possibly due to disease outbreaks, were also reported in the Goulburn catchment in the early 1930s.

Following an extensive survey of the Murray River from 1949-50, Langtry reported declines in fish populations in the Echuca and Barmah regions of the Murray River: "Fishing is very poor, with few professional fishermen, if any, operating in the area. Departmental Inspector G. Clarke states that local fishing has declined severely" (Cadwallader 1977). Langtry attributed the declines in the area to overfishing and suggested that the effects of newly constructed dams and weirs on the river (longer periods of stable flows and clear water) had exacerbated the situation by making Murray Cod and other native species more vulnerable to overfishing. Langtry also found that the introduced Redfin Perch, Tench (*Tinca tinca*), Goldfish and Carp were common and widespread in the mid-Murray region at this time.

Electrofishing surveys conducted by the Arthur Rylah Institute in the early 1980s (Brumley *et al.* 1987) later found that Redfin Perch, Carp and Goldfish dominated the fish assemblages of the lower Goulburn River, whilst Tench had largely disappeared. Although Redfin Perch and Carp had been present in the mid-Murray region, the distribution and abundance of Carp, in particular, increased massively during the 1970s following extensive flooding in the Murray River. Native species including Murray Cod, Golden Perch and Macquarie Perch comprised only 4% of fish collected in the 1980s surveys and the formerly abundant Freshwater Catfish was not collected at all.

4.2 Current status of fish assemblages

The surveys conducted during the current study show that the fish assemblages of the lower Goulburn River have continued to change since the 1980s. Comparisons of the boat electrofishing survey data collected in 1982-83 and 2003-04 demonstrated a dramatic decline in the abundance of Redfin Perch, as well as a recovery in the abundance of several native species, including Murray Cod and Golden Perch (Crook and Koster 2006). It has been suggested that the decline in Redfin Perch numbers may have been caused by an outbreak of epizootic haematopoietic necrosus (EHNV) that occurred in 1986 (Koehn *et al.* 1995; CSIRO 2002; Crook and Koster 2006). In our more recent surveys (after 2008), the abundance of Redfin Perch showed some signs of increasing once again, although they are by no means near their former abundances in the main channel of the lower Goulburn River. Redfin Perch remain a dominant species in the various impoundments and irrigation channels of the Goulburn River catchment however.

Reasons for the improvement in Murray Cod and Golden Perch abundances in recent times are likely to be multi-faceted and complex, and may include a wide range of interacting environmental and biological factors. One partial explanation may be the commencement of large-scale stocking of hatchery-reared fingerlings that began in the mid-1980s. A recent study conducted in southern New South Wales of chemically marked Golden Perch fingerlings found a >5-fold increase in the abundance of Golden Perch following stocking, with stocked fish comprising up to 100% of year classes (Crook et al. in review). As most fingerlings stocked into the Goulburn River region during the study were not marked, and examination of otoliths was outside the scope of the study, we were unable to distinguish between wild and stocked fish in our surveys. However, we collected several externally tagged Murray Cod released as yearlings by Fisheries Victoria. Whilst it appears likely that artificially stocked fish make a significant contribution to the fish assemblages sampled in the recent surveys, further research is required to determine the proportion of stocked fish within the populations.

Another important finding of the recent surveys was the confirmation that breeding populations of Freshwater Catfish, Trout Cod and Silver Perch still exist within the lower Goulburn River. Records of freshwater Catfish have been very rare in the lower Goulburn River since the 1950s (Cottingham et al. 2003). The collection of a single larva and a young-of-year fish is significant because it demonstrates that the lower Goulburn has retained the potential to support spawning and recruitment of Freshwater Catfish. Research on the habitat/movement requirements of Freshwater Catfish has been undertaken recently at Tahbilk lagoon (Koster *et al.* 2010) and is shedding further light on the status of the species, and actions required to increase its abundance, in the lower Goulburn River. In particular, the results demonstrate a strong association between Freshwater Catfish and macrophytes. The results also suggest that smaller-scale features such as woody debris (i.e. "snags") play an important role as habitat for Freshwater Catfish.

Adult Trout Cod were occasionally collected in low numbers in the recent surveys and larvae were collected in reasonably high abundances on a few occasions. Evidence of spawning by Trout Cod was restricted largely to the Cable Hole site and was very patchy between years. Trout Cod were not collected in the electrofishing surveys and drift sampling for several years following the fish kill in the lower Goulburn River in January 2004, but there is evidence of a recovery in recent years, with juvenile and adult fish collected regularly in low numbers since 2008 and spawning detected in 2007/08 and 2008/09.

Adult Silver Perch were occasionally collected in low numbers and were patchy in time and space. There was evidence of limited spawning by Silver Perch in 2010/11 and 2011/12 coinciding with two of the largest spring/summer flow rises during the study. As Silver Perch are a highly mobile species (Mallen-Cooper *et al.* 1996), the patchy nature of their occurrence in the lower Goulburn River may suggest that they make occasional forays into the system from the Murray River, as was observed also for Golden Perch.

Another significant, but less positive, finding of the recent surveys was the failure to collect any Macquarie Perch below Lake Nagambie. As mentioned, Macquarie Perch were once highly abundant in the lower Goulburn River and the river used to be renowned for its Macquarie Perch fishery. The lack of Macquarie Perch in the lower reaches over many decades now, combined with the fragmented distribution of the species across the wider Goulburn catchment, highlights the urgent need for action to halt further declines of this species. Significant funding and effort has already been invested in recent years to secure populations in the upper catchment during the recent drought and bushfires (Kearns *et al.* 2012a; Kearns *et al.* 2012b). If these actions can secure the existing populations, it may then be possible to attempt to extend the distribution within the catchment to reduce the risk that events like drought and bushfire will result in extirpation of the species. This will require further research to identify the underlying reasons for the initial decline and any constraints that may limit the ability of the lower Goulburn in its present state to sustain populations of Macquarie Perch.

Several small bodied native species were highly abundant and widespread, including Australian Smelt, Carp Gudgeon, Murray River Rainbowfish and Flat-headed Gudgeon. It has been suggested that several of these species are advantaged by changes to flow regimes due to river regulation (Humphries *et al.* 2002; Humphries *et al.* 2012). For example, Humphries *et al.* (2012) found that survival of Australian Smelt larvae spawned early in the season was lower than those spawned later in the year when conditions were better for survival. From this Humphries *et al.* (2012) concluded that species with a protracted spawning period are likely to advantaged in regulated rivers because they are more likely to encounter "windows of opportunity" in which there are good conditions for spawning. Flat-headed Gudgeon also has a protracted spawning period and was particularly abundant at Cable Hole, which is possibly the most flow-altered site in the survey.

4.3 Fish spawning and recruitment

Golden Perch

A summary of flow/spawning relationships for Golden Perch in the lower Goulburn River is provided below (Table 12). Despite large adult populations of Golden Perch in the lower Goulburn River, eggs and larvae or juveniles of this species were only rarely collected. Although this precluded statistical analysis of the larval drift data for this species, some inference can be drawn by examining the flow conditions under which spawning was recorded. The only major spawning event for Golden Perch in the nine years of the study (i.e. November 2010) coincided with the only major high flow event in the spawning period and also followed flooding in September-October (Table 12). Golden Perch spawning was detected in some of the other years, typically coinciding with much smaller flow events including a 'spring fresh' environmental flow release in November 2011, but levels of spawning activity were substantially lower.

These findings support previous suggestions that spawning of Golden Perch can be flexible and occur during high flow and within-channel flows (Mallen-Cooper and Stuart 2003; Ebner *et al.* 2009; King *et al.* 2009b), but levels of spawning are enhanced during high flow and/or flood conditions (King *et al.* 2009b). The results also confirm that Golden Perch can spawn at different water temperatures and that an increase in water temperature to around 23° C (Lake 1967a) is not crucial to spawning in this species (see also Ebner *et al.* 2009). While Golden Perch spawning was enhanced during the 2010 high flow conditions, electrofishing surveys indicated a lack of subsequent recruitment of juvenile fish into the population. It is possible that the blackwater event in December 2010 impacted on the survival of young fish or that recruitment of Golden Perch in the Goulburn River is limited by other factors. An increase in the abundance of YOY Golden Perch was found following a flood event in 2005 in the mid-Murray River, though low capture rates made it difficult to determine the strength of the recruitment (King *et al.* 2009b). Whilst our results show evidence of a spawning response by Golden Perch to high flow events, further investigation of spawning and recruitment is needed to better understand how Golden Perch respond to flow in the lower Goulburn River. Electrofishing sampling during the night can be more effective for collecting smaller individuals of some species such as Golden Perch compared to sampling during the day, especially when abundances are low (Tonkin, unpublished data), and could be useful as part of future monitoring to detect recruitment.

Table 12. Summary of flow/spawning relationships for Golden Perch in the lower Goulburn River.

	Goulburn River flow events		
Year	Pre-spawning period (Sep-Oct)	Main spawning period (Nov-Jan)	Spawning response
2003/04	High flow ~ 10000 ML d^{-1}	Low flow	None
2004/05	High flow ~ 9900 ML d^{-1}	Several freshes ~ 2600-3000 ML d^{-1}	None
2005/06	High flow ~ 16000 ML d^{-1}	Several freshes ~ 3300-4300 ML d^{-1}	Yes - 3 larvae
2006/07	Low flow	Low flow	Yes - 1 larva
2007/08	Low flow	Several freshes ~ 3400-4000 ML d^{-1}	None
2008/09	Low flow	Low flow	None
2009/10	Low flow	Fresh ~ 1300 ML d^{-1}	None
2010/11	Flooding/overbank flows	Several high flows ~ 14000-16000 ML d^{-1}	Yes - 134 eggs & 2 larvae
2011/12	High flow ~ 9000 ML d^{-1}	High flow/fresh ~ 5500 ML d^{-1}	Yes - 3 eggs

Murray Cod

Murray Cod spawned each year in the lower Goulburn River under a wide range of flow conditions. The timing of spawning was consistent across years and always occurred between late November and early December. This finding is consistent with those of previous studies of Murray Cod spawning in the Broken and Murray Rivers (Humphries 2005; Koehn and Harrington 2006; King *et al.* 2009b). Although the timing of spawning was consistent, the abundance of Murray Cod larvae varied considerably between years. Abundance was greatest during the lowest flow years (i.e. 2006/07-2009/10), but there was no statistically significant relationship between river flow and spawning intensity. Spawning intensity was, however, associated with daylength and change in temperature. Koehn and Harrington (2006) similarly found that densities of Murray Cod larvae were correlated with daylength in the mid-Murray and Ovens rivers. Given that daylength is a consistent inter-annual variable and there were large inter-annual differences in spawning intensity, other unaccounted factors (e.g. stock size of reproductive adults) might be important in explaining levels of spawning in this species.

While Murray Cod spawning was highest during the 2006/07-2009/10 low flow years, electrofishing surveys revealed a subsequent strong year class of juvenile fish in the population only in two (i.e. 2006/07, 2009/10) out of these four years. Flow conditions after the spawning period (i.e. summer-autumn) in 2006/07 and 2009/10 were low and stable though similar flow conditions occurred after the spawning period in 2007/08 and 2008/09. Abundances of YOY Murray Cod in the mid-Murray River were shown to be higher following major flooding though assessment of recruitment strength in more years with variable flow conditions was needed to confirm the role of flows in recruitment success (King *et al.* 2009b). In the current study, the abundance of YOY Murray Cod did not noticeably increase following the 2010 floods. The blackwater event in December 2010, however, might have impacted on the survival of young fish.

It is also important to consider the potential impacts of stocking of hatchery reared Murray Cod on populations in the lower Goulburn River. For example, in 2006/07, most YOY fish were collected at Pyke Road. Murray Cod were stocked at Pyke Road in January 2007, but they were also stocked at other study sites (e.g. Shepparton Causeway) that were not characterised by a strong year class of YOY fish. In 2009/10, most of the YOY fish were collected at Kotupna, Pyke Road and Shepparton Causeway. Murray Cod were stocked at Shepparton Causeway in December 2009, but not at Kotupna or Pyke Road. Thus, these results indicate strong year classes of YOY Murray Cod in the absence of stocking at these sites. It is possible that YOY Murray Cod stocked at other sites might have migrated into these particular sites. However, we could not distinguish stocked fish from natural recruits.

Australian Smelt

Australian Smelt spawned each year in the lower Goulburn River under a range of flow conditions. Spawning occurred over an extended period (September to February). These findings are consistent with those of previous studies of Australian Smelt spawning (Milton and Arthington 1985; Humphries *et al.* 2002). Spawning of Australian Smelt is reported to occur when water temperatures exceed 15° C (Milton and Arthington 1985), although eggs and larvae were collected when temperatures were as low as 12° C in the current study. Spawning of Australian Smelt seems unrelated to flow (Humphries *et al.* 1999). It has been suggested that low flows favour larval Smelt in terms of prey abundance and reduced physical disturbance (Milton and Arthington 1985). Australian Smelt larval abundance was greatest during a low flow year (i.e. 2008/09), but there was no statistically significant relationship between river flow and spawning intensity. It has also been suggested that high summer flows may damage Australian Smelt eggs and flush eggs and larvae downstream (Pusey *et al.* 2004), and lead to a reduction in the abundance of Australian Smelt (Webb *et al.* 2010). The results of the modelling, which suggest that abundances of YOY Australian Smelt were lower following years with above aggregate flows, also provide support for the suspected link between flows and recruitment.

Flat-headed Gudgeon

Flat-headed Gudgeon larvae were collected in all years under a range of flow conditions, although the probability of detecting larvae was significantly higher during stable, low flows. Similar to a study of fish spawning in the Campaspe River (Humphries *et al.* 2002), Flat-headed Gudgeon dominated the larval fish fauna in the Goulburn River. The timing of spawning was associated with moon phase and mean weekly flow. Llewellyn (2007) found that Flat-headed Gudgeon spawned in the absence of rises in water level, albeit in ponds and aquaria. These results could suggest that the flow or water level, rather than water level change, influences spawning of Flat-headed Gudgeon. Spawning intensity was associated with daylength. Given that daylength is a consistent inter-annual variable and there were large inter-annual differences in spawning intensity, other unaccounted factors (e.g. stock size of reproductive adults) might be important in explaining levels of spawning in this species.

Carp Gudgeon

Carp Gudgeon larvae were collected in low numbers in most years under a range of flow conditions. Spawning occurred over an extended period (September to February). It has been suggested that temperature is the main factor stimulating spawning in this species (Lake 1967a). The timing of spawning was associated with daylength and difference in temperature. Spawning of Carp Gudgeon is reported to occur when water temperatures are around 22° C, although larvae were collected when temperatures were as low as 13° C in the current study. Similar to Flat-headed Gudgeon, other unaccounted factors (e.g. stock size of reproductive adults) might be important in explaining levels of spawning in this species.

Carp

Despite large adult populations of Carp in the lower Goulburn River, eggs and larvae of this species were rarely collected. The lack of evidence of spawning by Carp could indicate that recruitment sources outside of the Goulburn River act as a source of juvenile recruits for the lower Goulburn River. A study of recruitment sources of Carp using otolith chemistry methods indicated that the Barmah-Millewa forest floodplain was a major recruitment source for YOY Carp in the lower Goulburn River (Macdonald and Crook 2006). The relative importance of recruitment areas for Carp, however, is likely to vary over time, particularly in relation to flow variability

(Crook and Gillanders 2006). Consequently, further work to identify the origins of Carp in the lower Goulburn River under differing hydrology would be valuable for the management of this pest species.

4.4 Movement of Golden Perch

Movement and connectivity between rivers

The present study shows that adult Golden Perch typically remained in the river they were collected. This result is consistent with previous studies that indicate strong site fidelity in this species (Crook 2004a; O'Connor *et al.* 2005). However, the present study also provides evidence for connectivity between populations of adult Golden Perch in the lower Goulburn and mid-Murray rivers; about one quarter of fish tagged in the Murray River moved into the Goulburn River, and about one third of fish tagged in the Goulburn River moved into the Murray River. Although most (24 out of 31) individuals returned to the river where they were originally collected, seven fish (9% of total fish tagged) did not return to their original capture river and thus appear to have undergone a shift in the location of their home range (sensu Crook 2004a; Crook 2004b).

Some fish could have shifted between rivers around the time of capture and been mistakenly categorised as either ‘Murray’ fish or ‘Goulburn’ fish, and thus the estimate of fish leaving the original capture river could be an overestimate. However, Golden Perch that emigrate from a home range location and explore alternative residence areas have been shown to return to the original home range or settle into new home ranges within 90 days (Crook 2004b). Most of the fish in the current study that shifted and did not return to the original capture river spent a large amount of time (i.e. 128–491 days) in the capture river before shifting, which would suggest that the river they were collected in represented their home range area at the time of collection.

The finding that the Murray River acts as a source of adult emigrants to the Goulburn River, and vice versa, has important implications for conservation of Golden Perch and management of fisheries for the species. In particular, the findings demonstrate the potential for stocks to be replenished by movement of adults between rivers from nearby areas. Such movements could represent an important mechanism to assist recovery or colonisation following disturbance events, such as from the recent blackwater events experienced in the lower Goulburn and mid-Murray regions (King *et al.* 2012). The findings also highlight the potential for management regulations such as fishing size and bag limits in one area to influence populations in another area.

Whether movement by adult Golden Perch from the Murray River has made a major contribution to maintaining stocks in the Goulburn River is unclear. It has been suggested that the adult Golden Perch population in the Goulburn River could be sourced from areas outside of the system (e.g. Murray River), based on a lack of spawning by the species within the Goulburn River in recent times (King *et al.* 2005). Given the longevity of Golden Perch (up to at least 26 years) (Mallen-Cooper and Stuart 2003), it is also possible that the population in the Goulburn River can persist for long periods without spawning or input of fish from other sources, although under this scenario the Goulburn River population could be vulnerable to a population crash if spawning and recruitment continues to be low. Use of techniques such as otolith chemical signatures could help to estimate recruitment sources of Golden Perch.

This study examined the movements of Golden Perch over relatively small spatial scales (i.e. the lower reaches of the Goulburn River and mid-Murray River). Although Golden Perch typically exhibit restricted movements (home range <3 km) and strong site fidelity (Crook 2004b; O'Connor *et al.* 2005), the species is also capable of moving long (e.g. 10s-100s of km) distances at times (Reynolds 1983; O'Connor *et al.* 2005). Whether there is widespread movement of fish within the Goulburn River is unclear but has important implications for the spatial scale at which management and conservation actions should be applied. Within this context, additional listening stations were deployed between Cable Hole and McCoys Bridge in spring 2010, and additional Golden Perch were tagged in spring 2010 and autumn 2011 and 2012 at sites further upstream in the Goulburn River, to provide information on fish movement and responses to flows throughout the length of the lower Goulburn River. A brief summary of the results to date of this component is provided in the annual summary for 2011/12. The transmitters in many of these fish will continue to transmit for the next 1-2 years. Data from these fish will then be collated and analysed.

This study examined the movements of adult Golden Perch only. Movements of earlier life history stages (e.g. eggs, juveniles) of this species also have the potential to facilitate movement amongst populations. For example, Golden Perch lay buoyant eggs that drift downstream on river currents (Reynolds 1983). Large numbers of juvenile Golden Perch have also been observed migrating upstream through a fishway on the mid-Murray River, possibly representing an upstream colonisation to compensate for the downstream drift of eggs (Mallen-Cooper *et al.* 1996; Mallen-Cooper 1999). Determining patterns of movement of different life history stages of Golden Perch represents an important area for future research.

Movement and links to reproduction

The results of this study indicate that movement activity of Golden Perch was greatest during late spring and early summer. In particular, there was a trend during this time for fish from the Goulburn River to move into the Murray River shortly followed by a return to the Goulburn River. The timing of these movements coincides with the spawning season of Golden Perch in the study area (King *et al.* 2005; King *et al.* 2009b) and could be related to reproduction and be ecologically important with respect to population connectivity by facilitating successful exchange of gametes among populations (i.e. genetic exchange). Eggs of Golden Perch were collected from the mid-Murray River in October-November 2008 and 2010 as part of a related study (King *et al.* 2009b; Koster unpublished data), coinciding with the appearance of tagged fish from the Goulburn River in the Murray River. No Golden Perch eggs were collected in the 2007/08 or 2009/10 spawning seasons (King *et al.* 2009b; Koster unpublished data) however, despite movement of fish into the Murray River. It is possible that unfavourable environmental conditions (e.g. low flows) in the 2007/08 and 2009/10 spawning seasons may have limited spawning by Golden Perch in the mid-Murray River. Golden Perch are known to resorb gonads and may limit spawning or not spawn at all in the absence of appropriate environmental conditions (e.g. flow rises) (Lake 1967a; Mackay 1973).

While the results of this study show that fish tagged in the Goulburn River moved into the Murray River during the spawning season, coinciding with the collection of eggs in the mid-Murray River, eggs of Golden Perch were also collected in the lower Goulburn River in one of these spawning seasons (2010/11) (Koster unpublished data). The 2010/11 spawning season was characterized by flooding and high flows in the Goulburn and Murray rivers. On the basis of these results, it appears that during the spawning season, increased movement activity of Golden Perch may result in some individuals from the lower reaches of the Goulburn River entering the Murray River, but such movements are apparently not obligatory to spawning. However, the ability to move into the Murray River may become important to spawning during times (e.g. drought) when the Goulburn River lacks appropriate conditions for spawning. Although the flow regime in both the Goulburn and Murray rivers is highly regulated, the Goulburn River typically has a much lower discharge compared to the Murray River which could impact on spawning opportunities.

Environmental factors influencing movement

The results of this study suggest that movement between rivers is influenced by hydrological events. In particular, the percentage change in flow in the Goulburn River was associated with increased probability of fish moving from the lower reaches of the Goulburn River into the Murray River. This result has important implications for the provision of environmental flows designed to promote movement between the rivers because it suggests that fish responded to variations in flow relative to prevailing conditions, rather than the absolute magnitude of flow. Thus, even under low flow conditions, providing there is sufficient variation in flow or ‘freshes’, the probability of movement might be expected to increase. Change or variation in flow (or water level), rather than a particular flow threshold, is often cited as triggering the movement of fish (Baran 2006).

The mean weekly flow in the Goulburn River also influenced movement between rivers during the spawning season, but was associated with decreased probability of fish moving from the lower reaches of the Goulburn River into the Murray River. Under high flows conditions, fish might remain in the Goulburn River and spawn, whereas under lower flow conditions fish might seek better spawning opportunities elsewhere (e.g. Murray River).

4.5 Issues affecting fish populations

Flow regulation

Flow patterns have been drastically altered in the lower Goulburn River. A large proportion of annual flow is diverted for irrigation at Lake Nagambie. This diversion of flow has reduced both the frequency and duration of ecologically important flows, including baseflows, freshes and overbank flows (see Cottingham *et al.* 2003). Severe drought conditions also affected the region for about 10 years from around 1997 to 2009. The results of the current study suggest that flow regulation impacts on the spawning of species such as Golden Perch which appear to be reliant on flows cues (e.g. spring/summer high flows/freshes) for spawning. In contrast, other species such as Flat-headed Gudgeon do not appear to be as heavily impacted by flow regulation. It has been suggested that these species can better cope with alterations to the flow regime because of their extended spawning period, which increases the probability of encountering good conditions for spawning and recruitment (Humphries *et al.* 2012).

Fish kills and blackwater

Fish kills have occurred in recent years in the lower Goulburn River, with a large kill occurring in 1984 (Anderson and Morison 1988), and more recent kills occurring in 2004 and 2010. Twenty-one reports of fish kill events are recorded for the Goulburn-Broken catchment between 1998 and 2004 (Ecos 2004). The results of this study show differences in fish assemblage composition in the Goulburn River following the fish kill below Goulburn Weir in January 2004. One of the main differences after the 2004 fish kill was an absence of some species (e.g. Trout Cod) and a decrease in the abundance of other species (e.g. Golden Perch) at Cable Hole immediately after the fish kill. Differences in fish assemblage composition were also observed after the blackwater event below Shepparton in December 2010. One of the main differences was a decrease in the abundance of Murray Cod in the lower reaches of the Goulburn River. Electrofishing surveys in the Goulburn River just upstream of the Murray River junction also revealed a decrease in the abundance of Murray Cod following the 2010 blackwater event (King *et al.* 2012). Although subsequent partial recovery of fish species diversity and abundance occurred at Cable Hole following the 2004 fish kill within about a year, it should be noted that for some species (e.g. Trout Cod) it took many years before they were collected again. In the case of the 2010 blackwater event, Murray Cod have not been collected at one of the sites, Yambuna, since.

Introduced pest fish

A range of introduced pest fish species such as Carp, Eastern Gambusia and Oriental Weatherloach are present in the lower Goulburn River. Since at least the 1980s, Carp have dominated large-bodied fish abundance and biomass in the lower Goulburn River and continue to do so (Brumley *et al.* 1987; Crook and Koster 2006). The population of Carp in the lower Goulburn River appeared to remain relatively stable during drought conditions which affected the region for about 10 years from around 1997 to 2009. However, following the widespread flooding throughout the Murray-Darling Basin in 2010, substantial recruitment of juvenile Carp occurred resulting in a considerable expansion in the size of the population. In light of this, consideration should be given to targeted Carp reduction work at key locations, such as Tahbilk Lagoon which supports one of the few remaining remnant populations of the threatened Freshwater Catfish in Victoria.

The recent surveys also showed that Eastern Gambusia is both widespread and abundant in the lower Goulburn. This introduced species is a highly successful invader of aquatic environments, with the capacity to detrimentally impact native fishes directly (e.g. competition, predation, agonistic interactions) and indirectly (e.g. triggering trophic cascades) (Macdonald *et al.* 2012). Eastern Gambusia is difficult to sample using electrofishing gear, so its relative abundance is underestimated in the survey data. However, it is clear from observations made during the survey that Eastern Gambusia are a dominant small-bodied species in the system and that they are likely to be having effects upon native fishes (Macdonald *et al.* 2012).

The recent surveys also confirmed the presence of Oriental Weatherloach in the lower Goulburn River. This species was reported from drains and irrigation channels near Shepparton in the early 2000's (Koster *et al.* 2002) and has subsequently been collected at several sites in the lower reaches (Yambuna, Kotupna, Pyke Road) of the Goulburn River in the last 5-6 years. Potential impacts of Oriental Weatherloach include competition for spawning sites, disturbance or predation of eggs, competition for food and shelter, and alteration of habitat (Koster *et al.* 2002). Although Oriental Weatherloach has been collected only in low numbers and appears to be restricted to the lower reaches, this species is difficult to capture in turbid waters using electrofishing so its relative abundance and distribution may be underestimated.

Barriers to movement

About 243 artificial barriers to fish movement have been documented throughout the Goulburn River Basin (Lintermans 2007). A major barrier to fish passage is the Goulburn Weir on the lower Goulburn River near Nagambie which blocks movement pathways of migratory fish such as Golden Perch and Silver Perch. Goulburn Weir was listed as a high priority site for installation of a fishway, although issues associated with cold water releases from Lake Eildon and altered flow regimes would also need to be addressed (McGuckin and Bennett 1999; Cottingham *et al.* 2003). A rockramp fishway was recently constructed at Shepparton Weir on the lower Goulburn River. The ability of fish to migrate through the fishway is unknown. A PIT tag reader has been proposed to be installed on the fishway to detect fish moving through the fishway and provide information on the ability of fish to migrate through the fishway. Large-bodied native fish collected in the electrofishing surveys have also been tagged with PIT tags. The information collected could be used to determine whether fish are able to successfully migrate through the fishway.

4.6 Influence of environmental factors and management intervention

Flows

Environmental flow recommendations have been developed for fish in the Goulburn River (Cottingham *et al.* 2003). As part of the Victorian Environmental Flows Monitoring and Assessment Program, conceptual models have also been developed for the Goulburn River which summarise current scientific understanding between flows and ecological responses (Chee *et al.* 2009). New knowledge or support for flow-ecology relationships based on the results of the current study are summarised below (Table 13).

For native fish, a key hypothesis relates to spring-summer bankfull and overbank flows as a trigger for spawning of fish such as Golden Perch and Silver Perch (Chee *et al.* 2009). Higher flows over the winter-spring period are also postulated to improve the pre-spawning condition of these fish resulting in increased spawning activity (Chee *et al.* 2009). Based on the results of the current study, there is evidence to support these links in the lower Goulburn River. In particular, in 2010 the lower Goulburn River experienced flooding in September for the first time in about 17 years, followed by another increase in flow in October; the only large Golden Perch spawning event (100+ eggs) in this nine year study occurred shortly afterwards.

Another key hypothesis relates to low flow conditions providing favourable spawning conditions for fish such as Murray River Rainbowfish (Chee *et al.* 2009). Based on the results of the current study, there is some evidence to support this link; abundances of Murray River Rainbowfish were higher following years with low spring-summer flows. Murray River Rainbowfish spawns amongst aquatic vegetation during periods of low flow (Milton and Arthington 1985; Humphries *et al.* 1999). The eggs remain attached to aquatic vegetation for about 6-7 days while the juveniles hang on to plants for about 2 days and it has thus been suggested that eggs and juvenile fish might be susceptible to fluctuating water levels (Milton 1984). The probability of egg and juvenile survival might therefore be favoured during years with low and stable flows.

Low flow conditions are also postulated to influence Carp spawning; namely low flows can expose banks and beds leading to the drying of Carp eggs (Chee *et al.* 2009). Abundances of Carp were lower in years following low spring-summer flows. Spawning by Carp in the lower Goulburn River was extremely limited, nonetheless, in all years. As mentioned previously, outside areas (e.g. Murray River) likely act as a key source of recruitment of Carp into the Goulburn River (Crook and Gillanders 2006). During low flow years recruitment of Carp into the Goulburn River would therefore be expected to be lower.

Low flow conditions are also speculated to provide favourable conditions for spawning and recruitment of Australian Smelt (Chee *et al.* 2009). Australian Smelt larval abundance was greatest during a low flow year (i.e. 2008/09), but there was no statistically significant relationship between river flow and spawning intensity. Abundances of YOY Australian Smelt, however, were lower following years with above aggregate flows. As previously mentioned, high summer flows may damage Australian Smelt eggs and flush eggs and larvae downstream (Pusey *et al.* 2004), and lead to a reduction in the abundance of Australian Smelt (Webb *et al.* 2010).

Managed flow releases

The current study also adds to existing knowledge on the effects of water management on fish spawning and recruitment which can be used to develop and refine understanding of flow-ecology relationships. In particular, in November 2011 a ‘spring fresh’ environmental flow (maximum discharge ~ 5500 ML d^{-1}) was released into the lower Goulburn River, which aimed to trigger spawning of Golden Perch. This managed flow release was successful in that Golden Perch spawning did occur coinciding with the release, although only low levels of spawning were detected. Nevertheless, the result suggests that strategies to reinstate appropriate flow conditions (i.e. spring-summer freshes) are likely to be important in conserving populations of Golden Perch in the lower Goulburn River by providing spawning opportunities for this species. The result also provides a scientifically defensible analysis upon which to base future decisions related to the provision of environmental flows for this species.

In October-December 2005, an environmental water allocation (513 GL) was also used in the Murray River to extend the duration of floodplain inundation of a spring flood event (King *et al.* 2009b). Whilst Golden Perch and Silver Perch increased their spawning activity in the Murray River during this event (King *et al.* 2009b), there was a considerable increase in the abundance of juvenile Carp the following autumn (2006) in the lower Goulburn River. It is possible that improved conditions for Carp spawning led to increased recruitment into the lower Goulburn River.

Table 13. Revised hypothesised flow/environmental relationships for fish in the lower Goulburn River.

Life cycle stage	Hypothesised relationship	Goulburn River study insights to date
Adult	Higher flows in winter-spring improve adult body condition and reproductive potential (Chee *et al*. 2009)	Golden Perch collected on inundated floodplain during 2010 floods and exhibited excellent body condition. The largest Golden Perch spawning event in the study occurred shortly afterwards
	Higher flows in spring trigger movement of adult Golden Perch to spawning grounds (Reynolds 1983; O'Connor et al. 2005)	Increased movement activity of Golden Perch during spawning season coinciding with changes in flow in Goulburn River
	High flows may facilitate downstream dispersal of Australian Smelt (Milton and Arthington 1985)	Abundance of Australian Smelt increased at sites in the lower reaches following higher flow/flood years (i.e. 2010/11, 2011/12)
Egg	Minimum temperature (e.g.<23° C) cues spawning of Golden Perch (Lake 1967a)	Spawning can occur <23° C. Spawning occurred at temperatures 18-24° C. Large spawning event occurred in 2010 when temperature was 18° C
	Flow rises/floods cue spawning of Golden Perch (Lake 1967a, King et al. 2009b)	Large spawning event of Golden Perch coincided with high flow/flooding in 2010. Golden Perch spawning was detected coinciding with smaller flow events, but levels of spawning activity were substantially lower.
	Flow rises/floods cue spawning of Silver Perch (Lake 1967a)	Spawning event of Silver Perch coincided with high flow/flooding in 2010.
	Minimum temperature (e.g.<23° C) cues spawning of Silver Perch (Lake 1967a)	Spawning occurred at similar temperatures (22-25° C).
	'Low flow spawning' - Murray Cod, Trout Cod, Gudgeons spawn under a range of flow conditions including low flows (Humphries 2005, Humphries *et al.* 1999, Koehn and Harrington 2006, King *et al*. 2009b)	Confirmed. Murray Cod, Trout Cod, Gudgeons spawned under a wide range of flow conditions including low flows
Larvae and juveniles	Low flow conditions favour larval Smelt in terms of prey abundance and reduced physical disturbance (Milton and Arthington 1985)	Australian Smelt larval abundance was greatest during a low flow year (i.e. 2008/09)
	High summer flows may damage Australian Smelt eggs and flush eggs and larvae downstream, leading to reduced recruitment (Pusey *et al*. 2004)	Recruitment was lower in years following above aggregate flows.
	Floodplain inundation enhances Carp recruitment (Stuart and Jones 2006)	Substantial recruitment of juvenile Carp occurred following flooding in 2010
	Low flows conditions may provide favourable spawning and recruitment conditions for Murray River Rainbowfish (Milton and Arthington 1985; Chee *et al*. 2009)	Abundances of Murray River Rainbowfish were higher following years with low spring-summer flows

Fish kills – responses and recovery

Fish kills have become a serious problem in the Goulburn River, as well as other neighbouring streams (e.g. Murray River, Broken Creek) in recent years. A decline in abundance of Murray Cod post-blackwater was found in the lower Goulburn River both in the short (3 months) and medium term (1 year post blackwater). The length of time required for populations to return to pre-blackwater abundances is unknown.

There is also an urgent need to improve understanding of the responses of native fish to blackwater events and reductions in water quality (e.g. dissolved oxygen depletion). For example, at what point does it become critical to implement measures (e.g. environmental flows) to manage low dissolved oxygen for fish? Such information if collected would provide a scientifically defensible analysis upon which to base future decisions related to the provision of environmental flows aimed at minimizing the risks of reduced water quality for native fish.

Fish stocking

Murray Cod and Golden Perch have been stocked into the lower Goulburn River over many years. As a consequence, distinguishing the extent to which natural recruits and stocked fish contribute to the population has been difficult. Since 2011 and 2012, Golden Perch and Murray Cod, respectively, stocked into the lower Goulburn River by DPI have been marked with calcein, a chemical marker used to mark and identify fish from hatcheries. The marking of stocked fish represents an important step towards understanding the efficacy of stocking as a fisheries management tool as well as the influence of environmental variables on levels of recruitment of wild fish.

Fish monitoring

Fish monitoring in the lower Goulburn River is also conducted as part of other programs such as the Sustainable Rivers Audit (SRA) and the Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP). In general, the results of these other programs are similar to some of the results of the current study. For example, in VEFMAP and SRA surveys in the lower Goulburn River, Australian Smelt was the most abundant species collected, while the exotic Carp was the most abundant large-bodied fish (MDBC 2008; URS 2012; Lieschke unpublished data). Similar to the current study, most of the Golden Perch collected in the VEFMAP surveys were larger fish with none below the MLS of 300 mm (URS 2012). There are some differences, however, between the results of these other studies and the current study. For instance, various fish species (e.g. Freshwater Catfish, Bony Herring, Unspecked Hardyhead) collected in the current study were not caught in the lower Goulburn River in the other studies. Although these species were collected only occasionally in the current study, this difference demonstrates the value of a long-term monitoring program to describe fish assemblage composition accurately.

5 Recommendations

Management Intervention

Environmental flows

- Aside from Golden Perch, most species did not exhibit a strong spawning response to increased flows.
- Rises in water level in spring-summer were associated with spawning by Golden Perch. Low levels of spawning occurred at ~4500-5000 ML d^{-1}, but spawning was greater under higher flows (e.g. >10,000 ML d^{-1}). High flows in the pre-spawning period may also enhance spawning activity. Given the lack of high flow events throughout this study, further assessment of spawning in more years with higher flow conditions is needed to better understand the role of flows in spawning success.
- Provide flow variability to promote local movement of Golden Perch between the lower Goulburn and Murray rivers. In low flow years, flow variability during the spawning season may encourage movement of fish into the Murray River, which could be important during times (e.g. drought) when the Goulburn River lacks appropriate conditions for spawning.
- Provide high flows/freshes (e.g. >10,000 ML d^{-1}) around September to promote pre-spawning condition of Golden Perch. Conduct follow-up research to assess the minimum magnitude of flows required to promote pre-spawning condition of Golden Perch.
- Provide high flows/freshes (e.g. >5,500 ML d^{-1}) around October-November to promote Golden Perch spawning. Conduct follow-up research to assess the minimum magnitude of flows to promote Golden Perch spawning.
- It is possible that large flows/floods during the spawning and rearing period of Murray Cod (October-December) may displace eggs and larvae and increase mortality. Large flow releases earlier in spring may be more desirable than later in spring/early summer.

Pest species

- Carp show a clear spawning and recruitment response to high flow events. Further research is required to determine whether it is possible to deliver spring/summer environmental flows for native fish in such a way that Carp spawning and recruitment is not enhanced.
- Consider Carp reduction work at key locations, particularly Tahbilk Lagoon which supports one of the few remaining remnant populations of Freshwater Catfish in Victoria.

Threatened species

- Investigate possibilities to extend the distribution and/or increase the abundance of threatened species, particularly Freshwater Catfish and Macquarie Perch, via stocking programs.

Monitoring

- Continue investigations into relationships between flows and movement and spawning dynamics of Golden Perch, particularly regarding responses to environmental flow releases. In the case of the drift net surveys, targeted sampling during environmental flow releases would be valuable to better understand the links between spawning and flows.
- Determine longer term consequences of the 2010/11 blackwater event on native fish and monitor rate of recovery of fish stocks.

- Determine the effects of artificial stocking on native fish populations by promoting the ongoing use of methods to allow discrimination of hatchery and wild fish (e.g. chemical marking or genetic techniques).
- Examine detailed relationships between river flow and Carp reproduction to determine whether environmental flow releases can be delivered without enhancing carp spawning and recruitment.
- Continue to monitor status of fish populations via an ongoing survey program.

6 Conclusion

This study has documented the composition, abundance and population structure of fish species, and environmental conditions associated with fish spawning, in the lower Goulburn River, and movements of Golden Perch between the Goulburn and Murray rivers.

Significant populations of native fish occur in the lower Goulburn River, including several species of conservation significance (Trout Cod, Silver Perch, Murray Cod, Freshwater Catfish). Possibilities to extend the distribution and/or increase the abundance of threatened species, particularly Freshwater Catfish and Macquarie Perch should be investigated.

There is evidence of increased abundances of Murray Cod and Golden Perch in recent years. Artificially stocked fish may make a significant contribution to the fish assemblages, but further research is required to determine the proportion of stocked fish within the populations.

The lower Goulburn River is a spawning ground for Golden Perch and spawning of this species appears to be associated with increases in flow. Given that there were relatively few high flow events throughout this study, further assessment of spawning in more years with higher flow conditions is needed to better understand the role of flows in spawning success of this species. There is a large amount of connectivity between populations of adult Golden Perch in the lower Goulburn and mid-Murray rivers. Further investigations into relationships between flows and movement and spawning dynamics of Golden Perch, particularly regarding responses to environmental flow releases, are needed.

Floods appear to promote recruitment of Carp in the lower Goulburn River. Further work to identify the origins of Carp in the lower Goulburn River under differing hydrology would be valuable for the management of this pest species.

Fish kills in recent years in the lower Goulburn River have impacted fish species diversity and abundance. Monitoring the status of fish populations via an ongoing survey program would allow for determination of the longer term consequences of the 2010/11 blackwater event on native fish and monitoring the rate of recovery of fish stocks.

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Appendix Selected outputs from the project

Ecological Management and Restoration, 2005

NOTES & ABSTRACTS

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RIPARIAN & STREAM ECOLOGY

8.10

Comparison of larval fish drift in the Lower Goulburn and mid-Murray Rivers. Alison J. King, David A. Crook, Wayne M. Koster, John Mahoney and Zeb Tonkin. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, PO Box 137, Heidelberg, Victoria 3084, Australia.
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Key words: *recruitment, river regulation, spawning.*

Introduction. The early life of fishes is an important stage of the life cycle, with extremely high levels of natural mortality that strongly influence future year-class strength. The collection of eggs and fish larvae not only provides evidence of which species have spawned, but also when, where and under what environmental conditions. In rivers, a number of studies have demonstrated a relationship between environmental conditions, particularly flow regimes, and the occurrence and density of young fishes (eg. Scheidegger & Bain 1995; Humphries *et al.* 2002). Thus, fish larvae have been suggested as a useful tool to monitor the effects of river regulation and restoration (Humphries & Lake 2000).

Eggs, larvae and juveniles of many riverine fish species undergo a downstream displacement or drifting dispersal phase. In the Murray–Darling Basin, south-eastern Australia, recent studies have established that a number of fish species have drifting early life stages (see Humphries & King 2004). These include several native species of recreational and/or conservation significance, such as Murray Cod (*Maccullochella peelii peelii*), Trout Cod (*Maccullochella macquariensis*), Golden Perch (*Macquaria ambigua*), and Silver Perch (*Bidyanus bidyanus*).

This paper reports significant findings from larval drift sampling during spring/summer 2003–2004 in the heavily flow-regulated lower Goulburn and mid-Murray Rivers. The work is part of two concurrent longer-term projects that aim to determine the spawning and recruitment patterns of native and introduced fish in these systems.

Methods. Fish eggs and larvae were collected at three sites in the lower Goulburn River below the Goulburn Weir (Cable Hole, 36°68.699, 145°22.150; Pyke Rd, 36°42.819, 145°35.720; and Yambuna Bridge, 36°13.104, 145°00.300), and four sites in the Murray River in the Barmah–Millewa Forest region (Ladgroves Beach, 35°51.677, 145°20.773; Barmah Choke, 35°54.947, 144°57.267; Morning Glory, 36°04.765, 144°57.553; and Looker Road 36°42.498, 145°49.740). Sampling was conducted overnight using drift nets once in mid-September 2003, and fortnightly thereafter to the end of February 2004; a total of 11 sampling trips. All nets were set on dusk and retrieved as early as possible the following morning, generally before 11.00 hours.

Drift nets were 1.5 m long, with a 0.5 m diameter mouth opening and were constructed of 500-μm mesh, which tapered to a removable collection jar. A General Oceanics Inc. (Florida, USA) flow meter was fixed in the mouth of each drift net to determine the volume of water filtered, therefore, enabling raw catch data to be adjusted to a standard volume of filtered water (1000 m^3). At the Goulburn River sites and the Echuca site on the Murray River, one drift net at each site was attached to a snag in relatively high velocity flow, therefore, sampling the top layer of the water column. At the other Murray River sites, two drift nets were attached to the top and bottom of a long pole to sample surface and bottom of the water column (overall depths 3–5 m). However, to enable comparisons between all sites, only the collections from the surface nets were analysed here. In the field, eggs were removed alive from the samples and returned to the laboratory to hatch, enabling correct identification. Remaining samples were preserved in 95% ethanol in the field and returned to the laboratory. Fish were removed from the samples using a dissecting microscope. Identifications were made by experienced staff using available keys (eg. Serafini & Humphries 2004), and by collating a reference collection of successive larval stages.

Results. Both the Murray and Goulburn Rivers had similar temperature and flow regimes (Figure 1), however the Murray had a higher average discharge throughout the study period. The Murray River contained a higher species diversity of drifting eggs and/or larvae (11 species) compared to the Goulburn River (five species; Table 1). All five species collected in the Goulburn River were found at one site, Cable Hole, with only two species found at the two downstream sites. Trout Cod larvae were only collected at the Cable Hole site on the Goulburn River. Larval Murray Cod were only collected at Cable Hole, but were collected at a number of sites in the Murray River (also found in benthic set nets at Murray sites; A J King, unpub. data, 2003/2004). A greater number of Murray Cod larvae were collected per volume of water in the Murray than the Goulburn River (Figure 1), although the larvae were collected over the same time period in both rivers, from mid-November to the end of December. Australian Smelt (*Retropinna semoni*), Carp Gudgeons (*Hypseleotris* spp.), Flathead Gudgeons (*Philypnodon grandiceps*), and Murray Cod were collected in both rivers.

Both reaches contain adult populations of Golden Perch and Silver Perch (Stuart & Jones 2002; Koster *et al.* 2004), but no eggs or larvae of either species were collected at any site in the Goulburn River, while both species were collected at all sites

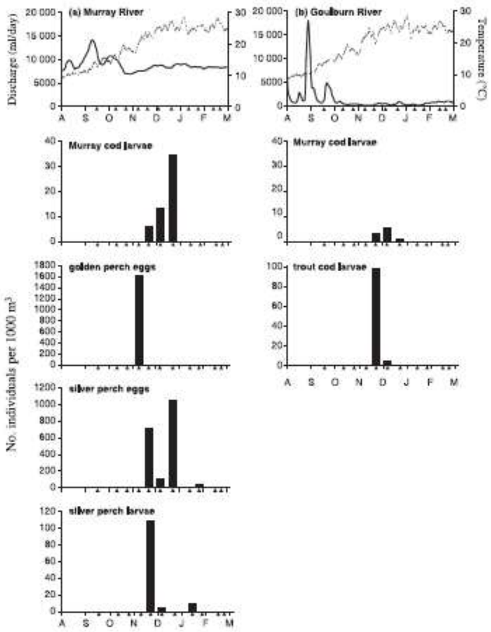

Figure 1. Mean daily discharge (solid line), water temperature (dashed line), and adjusted abundance of fish eggs and larvae (number of individuals per 1000 m^3) of selected species in the (a) Murray River and (b) Goulburn River collected from drift nets in 2003/2004. Discharge and temperature data from Barmah gauge on Murray River and McCoys Bridge at Wyuna on the Goulburn River. Adjusted abundance data is presented to allow for realistic comparisons with other data sets. Note scale of *y*-axis varies, solid triangles on *x*-axis indicates sampling event.

in the Murray River. Golden Perch eggs were collected in the Murray River on only one occasion in early November, while Silver Perch eggs and larvae were collected from mid November to early January (Figure 1).

The majority of individuals of all three introduced species were collected in the Murray River (Table 1). Carp larvae were collected in the highest numbers at the two sites below Barmah–Millewa Forest. Whilst these densities were substantially lower than previous collections during extended flood periods (Stuart & Jones 2002), it does further support that the Forest is a significant carp recruitment area.

Discussion. Although this study was of a relatively short duration, it has shed light on some important aspects of the ecology of fish with drifting life stages. The collection of Trout Cod larvae from the Cable Hole site on the Goulburn River confirms unequivocally that a breeding population of this critically endangered species had become established since artificial stocking in the River between 1993 and 1998, and represents one of only a few confirmed breeding populations known to exist for the species. However, in January 2004, a major fish kill occurred in the Goulburn River below the Goulburn Weir, resulting in the deaths of hundreds of fish, including Murray Cod, Trout Cod, Golden Perch and Redfin (*Perca fluviatilus*), and has resulted in a large reduction in total fish numbers at the Cable Hole site (Koster *et al.* 2004). Species that were commonly collected before the fish kill, such as Trout Cod, Golden Perch and River Blackfish, were either not collected at all or were in very low numbers after the fish kill (Koster *et al.* 2004). The loss of large numbers of adult Trout Cod from one of its only known breeding populations is of great concern, and highlights the urgent need for a greater understanding of the factors contributing to fish kills and for environmentally sensitive management, restoration and protection of the lower Goulburn River.

Contrary to previous studies that have suggested that Golden and Silver Perch require floods or in-channel rises to initiate spawning (Lake 1967; Mallen-Cooper & Stuart 2003), this study found that both species were able to spawn during fairly stable, bankfull, summer irrigation flows in the Murray River (see also Gilligan & Schiller 2004). While these results confirm spawning for these two species, as larvae of later developmental stages were not collected in either drift nets or in other larval sampling methods (A J King, unpub. data, 2003/2004), the success of subsequent recruitment remains unclear. These findings also support the suggestion that these two species are able to spawn and recruit during within channel flows (Mallen-Cooper & Stuart 2003). However, longer-term studies on the strength of spawning events and larval and juvenile abundance relative to various flow events are required to fully understand this relationship.

Evidence of spawning was not detected for either Golden or Silver Perch at any site within the Goulburn River system, despite significant adult populations of both species in the River (Koster *et al.* 2004), and no barriers to movement between the Murray and lower Goulburn River. Whilst future sampling is required to confirm the absence of spawning, it is possible that spawning and recruitment did not naturally occur at high levels in the lower Goulburn River, and that the adult population was naturally sourced entirely from recruitment areas outside of the system. Under this scenario, restoration efforts should perhaps be more driven towards facilitating fish movement and dispersal, and restoring juvenile and adult habitats in the River. Understanding the wider spatial context of a populations' persistence, and implementing management strategies at scales appropriate for the life history strategies of the species, is an important challenge in riverine science and management (Fausch *et al.* 2002). Commonly, environmental flow recommendations are targeted at increasing the spawning and recruitment success of native fish species, including those formulated for the lower Goulburn River (Cottingham *et al.* 2003). Therefore, it is critical that we improve our understanding of the factors that limit spawning and recruitment strength, relative to various managed flow components. This knowledge should also assist in maximising the ecological benefits of environmental flows.

NOTES & ABSTRACTS

Table 1. Species and total number of eggs, larval and juvenile fish collected using drift nets at each site throughout the duration of the study

		Murray River					Goulburn River			
		Ladgroves Beach	Barmah Choke	Morning Glory	Looker Road	Total	Cable Hole	Pykes Road	Yambuna Bridge	Total
Australian Smelt (*Retropinna semoni*)	Eggs	22	1			23	25	7	1	33
	Larvae	2	1	10	48	61	8	18	1	27
Carp gudgeons (*Hypseleotris* sp.)	Larvae	8	3	1		12				0
Flathead Gudgeon (*Philypnodon grandiceps*)	Eggs					0		3		3
	Larvae	6		2	2	10	56	35	1	92
	Juveniles	4				4	1			1
Murray Cod (*Maccullochella peelii peelii*)	Larvae	4			1	5		8		8
Trout Cod (*Maccullochella macquariensis*)	Larvae					0	31			31
Golden Perch (*Macquaria ambigua*)	Eggs	19	37	126	47	229				0
Silver Perch (*Bidyanus bidyanus*)	Eggs	87	93	52	72	304				0
	Larvae	19	7	1		27				0
Oriental Weatherloach* (*Misgurnus anguillicaudatus*)	Larvae		1			1				0
Unidentified cyprinid* (Cyprinidae)	Eggs			7	3	10				0
Common Carp* (*Cyprinus carpio*)	Larvae	2		38	12	52	1			1
Goldfish* (*Carassius auratus*)	Larvae			1		1				0
	TOTAL	173	143	238	185	739	129	63	3	195

*Introduced species.

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Comment

Temporal change in fish assemblages in the lower Goulburn River, south-eastern Australia: comment on Pollino *et al.* (2004)

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Abstract. A recent analysis of fish assemblages in the Goulburn River, south-eastern Australia, used fish survey data collected between 1970 and 2002 to examine spatial patterns in the compositions and relative abundances of fish assemblages in the catchment. Based on this analysis, it was concluded that the native fish fauna of the Goulburn River is in a stressed condition and that introduced species dominate the fish assemblages. Fish survey data collected in 1982–1983 are compared with data collected in 2003–2004 to examine whether fish assemblages in the lower Goulburn River were stable at the temporal scale at which the data were aggregated in the previous analysis. The results show significant differences in fish assemblage composition between the two surveys, suggesting that fish assemblage structure in the lower Goulburn River did not remain stable between 1982–1983 and 2003–2004. The aggregation of data collected over several decades has the potential to confound analysis of spatial variations in fish assemblages and is unlikely to provide a reliable means of assessing their current condition.

Extra keywords: fish communities, flow regulation, Murray–Darling Basin, temporal stability.

Introduction

Growing recognition of the degraded state of many rivers around the world has led to increased efforts to restore natural ecological processes, including the provision of 'environmental flows', physical habitat rehabilitation, removal of barriers to the dispersal of aquatic fauna, and supplementation of fish populations via stocking. If such restoration initiatives are to continue to receive political and community support, their effectiveness needs to be determined and any economic or social costs justified (Downes *et al.* 2002; Whitelaw and Macmullan 2002). The development and implementation of reliable methods for assessing the condition of flora and fauna, therefore, has a key role in the effective management and restoration of aquatic ecosystems (see Block *et al.* 2001; Downes *et al.* 2002). Pollino *et al.* (2004) conducted an assessment of the condition of fish assemblages in the Goulburn River, south-eastern Australia. The Goulburn River has a highly modified flow regime that is regulated primarily to provide water for irrigation and is also affected by land clearing and associated catchment erosion, introduced flora and fauna, riparian zone degradation and hypolimnic releases of cold water from the Eildon dam (see Cottingham *et al.* 2003). Pollino *et al.* (2004) analysed aggregated data collected during irregular fish surveys conducted between 1970 and 2002 using a variety of sampling gears. Based on this analysis, it was concluded that the native fish fauna of the Goulburn River is in a stressed condition owing to human disturbances, particularly alterations to the natural flow regime, and that introduced species currently dominate Goulburn River fish communities.

The use of fish survey data aggregated over three decades raises issues regarding the temporal dynamics of fish populations in regulated rivers, and whether such an approach provides a reliable method for assessing the current condition of fish assemblages. Lengthy and complex debate has occurred in the scientific literature regarding the temporal stability of riverine fish assemblages: assemblage structure has been found to be stable over long periods in some instances, and is highly variable over a range of temporal scales in others (see reviews by Grossman *et al.* 1990; Matthews 1998). The lack of a generally applicable paradigm regarding the temporal stability of riverine fish assemblages emphasises the importance of understanding the temporal scales at which fish assemblages exhibit variability in any given river system (Matthews 1998). The premise of the approach employed by Pollino *et al.* (2004) was that the fish assemblages in the Goulburn River were stable at the temporal scale at which the data were aggregated (i.e. over 32 years between 1970 and 2002); however, no data were presented to support this assertion. Here, we investigate the stability of fish assemblages in the

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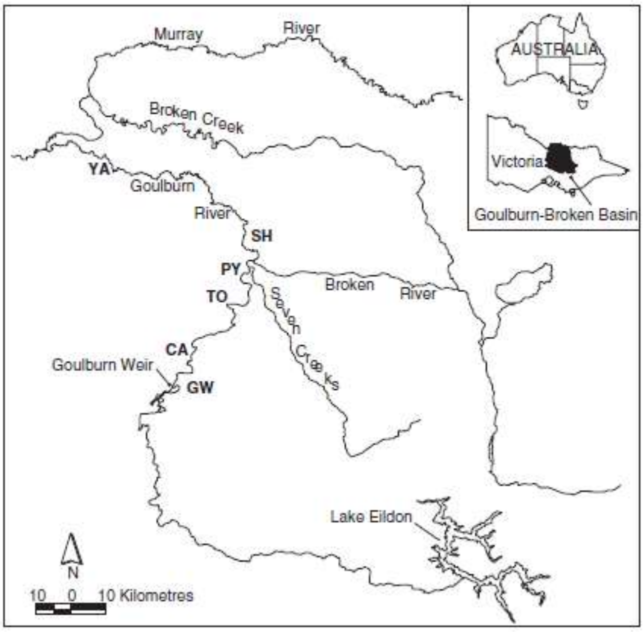

Fig. 1. Map showing locations of survey regions. CA, Cable Hole; GW, Below Goulburn Weir; PY, Pyke Road; SH, Shepparton; TO, Toolamba; YA, Yambuna.

lower reaches of the Goulburn River by comparing fish survey data collected in the early 1980s with recently collected data.

Materials and methods

Study sites and fish sampling

The results of boat electrofishing surveys conducted in the lower Goulburn River in 1982–1983 (Brumley *et al.* 1987) and 2003–2004 (Koster *et al.* 2004) were analysed. In each survey, five regions of the river were sampled between Goulburn Weir and the Murray River junction (Fig. 1). The Cable Hole, Toolamba, Shepparton and Yambuna regions were sampled in both surveys. The region below Goulburn Weir was sampled only in the 1982–1983 survey and the Pyke Road region was sampled only in the 2003–2004 survey. In the 1982–1983 surveys, several other sampling methods (mesh nets, fyke nets, backpack electrofishing, angling) were employed in addition to boat electrofishing. However, because the data collected using these methods are not directly comparable to the boat electrofishing data collected in the 2003–2004 surveys, they are not included in the analysis. In both surveys, fish were sampled by single-pass boat electrofishing in all navigable habitats within the river channel. The 1982–1983 survey used an electrofishing unit powered by a 6.5 KVA generator operated at either 350 or 600 V (A. Morison, Victorian Department of Primary Industries, personal communication). A Smith-Root model 5 GPP boat-mounted electrofishing unit operated at 500–1000 V was used in the 2003–2004 survey (Koster *et al.* 2004). The total time spent electrofishing at each site on each sampling occasion was recorded and ranged from 1 to 3 h in the 1982–1983 survey (total sampling time 14 h) and 1 to 1.5 h in the 2003–2004 survey (total sampling time 25 h).

In the 1982–1983 survey, sampling was conducted at the Shepparton site on three occasions (August 1982, October 1982, January 1983) and at all other sites on one occasion each (Below Goulburn Weir, September 1982; Cable Hole region, July 1983; Toolamba region, December 1982; Yambuna region, November 1982). All five sites in 2003–2004 were surveyed in September 2003 and February, May and July 2004. Collected fish were identified, weighed, measured and then released at the site of capture. Small-bodied species (Australian smelt *Retropinna semoni*, Murray River rainbowfish *Melanotaenia fluviatilis*, carp gudgeon *Hypseleotris* sp., flatheaded gudgeon *Philypnodon grandiceps*) were excluded from the analysis because the mesh size of the dip net used in the 1982–1983 surveys was too large to collect

Table 1. Total number of individuals, catch per hour and species composition (%) of large-bodied fish species collected during boat electrofishing surveys in 1982–1983 and 2003–2004

Survey	Murray cod	Golden perch	River blackfish	Trout cod	Silver perch	Macquarie perch	Common carp[A]	Redfin perch[A]	Goldfish[A]	Brown trout[A]	Tench[A]
Total											
1982–1983	2	0	6	0	0	2	84	109	24	1	1
2003–2004	98	39	8	4	3	0	143	1	3	0	0
Catch per hour											
1982–1983	0.14	0	0.43	0	0	0.14	6.00	7.79	1.71	0.07	0.07
2003–2004	3.92	1.56	0.32	0.16	0.12	0	5.72	0.04	0.12	0	0
% Composition											
1982–1983	<1	0	3	0	0	<1	37	48	10	<1	<1
2003–2004	33	13	3	1	1	0	47	<1	1	0	0

[A]Introduced species.

small individuals of these species effectively (A. Morison, personal communication). To examine whether the five sites sampled in the 2003–2004 surveys provided an adequate spatial representation of the fish assemblages in the lower Goulburn River at the time of sampling, we also surveyed five additional sites in May 2004. These surveys showed that the length–frequency distributions and relative abundances of species were very similar for the regular and additional survey sites, suggesting that sampling of the regular sites provided a reliable representation of the fish assemblage structure (Koster *et al*. 2004).

Data analysis

The abundance data for each species were adjusted to catch per hour by dividing the number of fish collected by the total electrofishing time at each site on each survey occasion. Patterns in fish assemblage composition were examined by non-metric multidimensional scaling (nMDS) on $\log_{10}(x+1)$ transformed data using the Bray–Curtis similarity measure (Primer 5.0, Plymouth Marine Laboratory, UK). To determine whether there were differences between the 1982–1983 and 2003–2004 surveys and between seasons, a nested analysis of similarities (ANOSIM) was conducted, with the season of the survey (autumn, winter, spring, summer) nested within survey (1982–1983, 2003–2004). Probability values were estimated using up to 1000 random permutations. Similarity percentage (SIMPER) analysis was used to determine the degree to which the various species contributed to the dissimilarity between the 1982–1983 and 2003–2004 surveys.

Results

The relative abundances of Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*) were higher in the 2003–2004 survey than the 1982–1983 survey, whereas the opposite was the case for the introduced redfin perch (*Perca fluviatilis*), and to a lesser extent, for the introduced goldfish (*Carassius auratus*) (Table 1). The introduced common carp (*Cyprinus carpio*) made up a higher percentage of the catch in the 2003–2004 survey, although the hourly catch rates were slightly lower than in the 1982–1983 survey. Trout cod (*Maccullochella macquariensis*) and silver perch (*Bidyanus bidyanus*) were collected in low numbers in 2003–2004, whereas they had been absent from the 1982–1983 survey. Conversely, Macquarie perch (*Macquaria australasica*) and the introduced brown trout (*Salmo trutta*) and tench (*Tinca tinca*) were recorded in very low numbers in the 1982–1983 survey but were not collected in 2003–2004. River blackfish (*Gadopsis marmoratus*) were collected in similar numbers in both surveys. Although golden perch and trout cod were not collected in the 1982–1983 boat electrofishing surveys, they were collected in small numbers using other methods (Brumley *et al*. 1987). There was distinct separation between the 1982–1983 and 2003–2004 surveys in the nMDS ordination (Fig. 2*a*; ANOSIM: $R = 0.852$, $P < 0.05$). Murray cod, carp, golden perch, redfin perch and goldfish contributed most to the dissimilarities between the surveys (Table 2). Fish assemblages were not significantly different between seasons (Fig. 2*b*; ANOSIM: $R = -0.059$, $P = 0.853$).

In January 2004, a major fish kill occurred from Goulburn Weir to ~6–10 km downstream. The fish kill resulted in the deaths of thousands of fish, including Murray cod, golden perch, trout cod, carp, redfin perch and Australian smelt (EPA 2004; Koster *et al*. 2004). Although the cause of the fish kill was not determined, the event had a severe impact on the Cable Hole survey site, with a large reduction in the abundance of large-bodied fish species recorded. The nMDS ordination (Fig. 2*b*) shows that in Spring 2003, before the fish kill in January 2004, fish assemblages in the Cable Hole region were relatively diverse and abundant (golden perch 5.6/h; trout cod 0.8/h; river blackfish 5.6/h; carp 8.8/h) and were distinct from those recorded in 1983 (redfin perch 3.0/h; carp 1.0/h). Following the fish kill, the Summer 2004 sample from the Cable Hole site (golden perch 0.8/h; carp 1.6/h) more closely resembled the depauperate fish fauna recorded in 1983 from Cable Hole. In the Autumn and Winter 2004 samples, the Cable Hole region appeared

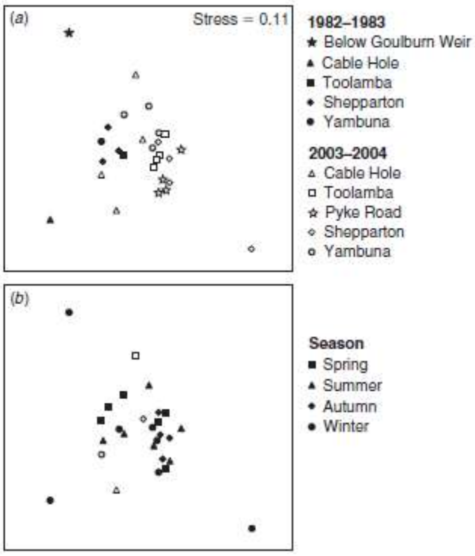

Fig. 2. Two dimensional non-metric multidimensional scaling (nMDS) ordination plot presented to show the groupings of (*a*) the 1982–1983 and 2003–2004 surveys and (*b*) different seasons within the surveys. The open symbols in (*b*) show the results for the Cable Hole region, which was affected by a major fish kill in January 2004.

Table 2. Results of SIMPER analysis showing major species contributing to the dissimilarities between the 1982–1983 and 2003–2004 surveys
Mean dissimilarity = 57.5

Species	%	Cumulative %
Murray cod	29.06	29.06
Common carp	18.83	47.89
Golden perch	16.20	64.09
Redfin perch	15.20	79.29
Goldfish	9.47	88.76

to be showing limited signs of recovery, with some of the species collected before the fish kill being once again collected (Autumn: golden perch 1.6/h; carp 6.4/h; Murray cod 0.8/h; Winter: carp 3.7/h; river blackfish 0.7/h) (Fig. 2).

Discussion

A major conclusion reached by Pollino *et al*. (2004) was that fish communities in the Goulburn River are in poor condition and are dominated by introduced species, including redfin perch, carp and goldfish. Our analysis shows that although carp were a dominant species in the 2003–2004 surveys, the fish assemblage structure differed significantly between 1982–1983 and 2003–2004, with introduced species comprising 49% of the catch in 2003–2004, compared with 96% of the catch in 1982–1983. One of the major differences was a dramatic decline in the abundance of redfin perch between 1982–1983 and 2003–2004. There have been accounts of declines in redfin perch populations since the 1970s in mainland Australia (e.g. Koehn *et al*. 1995), and this may be owing to the spread of carp or epizootic haematopoietic necrosis virus (EHNV): a major outbreak of EHNV among redfin perch was recorded in the Goulburn River in 1986 (CSIRO 2002). There was also a slight reduction in the catch rates of carp and goldfish in the recent surveys compared with the surveys conducted in the 1980s. Although carp abundance increased dramatically in many rivers in the Murray–Darling Basin during the 1970s and 1980s (Koehn *et al*. 2000), slight decreases in catch rates of carp in more recent years have also been reported in the Murray River between Yarrawonga and Tocumwal (Nicol *et al*. 2004).

The relative abundance of native Murray cod and golden perch increased between the two surveys. It is possible that this, at least in part, is due to artificial stocking aimed at improving the recreational fishery. Murray cod fingerlings have been released into the lower Goulburn River on an annual basis since 1997 and yearling Murray cod marked with dart tags have been released since 2001(Victorian Department of Primary Industries, unpublished data). Three of these tagged yearlings were collected in the 2003–2004 surveys. Although there are no recent official records of golden perch stocking in the lower Goulburn River, this species has been regularly stocked in the Broken River, a tributary of the lower Goulburn River (Department of Primary Industries, unpublished data). Trout cod were also stocked in the lower Goulburn River for conservation purposes in the mid-1990s and, at least before the recent fish kill, a breeding population was established (King *et al*. 2005). Another possible reason for the increase in the relative abundance of native species is the improvement in fish passage following the installation and upgrading of fish ladders in the Murray River in recent years. In particular, the Torrumbarry fish ladder ~50 km downstream of the junction of the Goulburn and Murray rivers (fully operational since 1991) is likely to have had an impact on the upstream abundance of species that display migratory behaviours, including Murray cod, golden perch and silver perch (Mallen-Cooper *et al*. 1995).

Although our findings suggest that the abundances of Murray cod and golden perch have recovered to some extent in recent years, significant components of the former native fish fauna are still absent. In particular, Macquarie perch and freshwater catfish (*Tandanus tandanus*), once both common in the lower Goulburn River (Cadwallader 1981; Clunie and Koehn 2001), were not collected in the recent surveys and are now either very rare or extinct in the main channel of the lower Goulburn River. The major fish kill below Goulburn Weir in January 2004 and previous fish kills that have occurred periodically in the lower Goulburn River are a significant concern for the management of native fish in the system (Koehn 2005). The fish kill also serves to show how rapidly changes in fish assemblage structure can occur, as demonstrated by the decline and subsequent partial recovery of fish species diversity in the Cable Hole region within a single year.

In the current analysis, we attempted to reduce the potential for bias owing to variation in sampling methods, effort and efficiency by limiting the analysis to data collected using boat electrofishing within the same general study regions and by removing data relating to small-bodied fish species. Despite this, however, direct quantitative comparisons between different surveys still need to be treated with some caution. For example, there is likely to be variation in the efficiencies of the two electrofishing boats used in the 1982–1983 and 2003–2004 surveys due to, for example, differences in the power sources and configuration of anodes. The rationale for conducting a particular survey is also likely to influence the data collected. For example, the aim of the 1982–1983 surveys was to determine the conservation status of several large-bodied species – the relative abundance of small-bodied species was not assessed in a systematic manner (A. Morison, personal communication) and only very low numbers of small-bodied species were recorded (Brumley *et al.* 1987). In their analysis of Goulburn River fish assemblages (which included data from the 1982–1983 surveys), Pollino *et al.* (2004) acknowledged potential sampling biases and used relative (rather than absolute) abundance data summed across all gear types in an attempt to minimise bias. Although this may have reduced sampling bias to some degree, substantial bias is still likely given that the previous surveys were sporadic both spatially and temporally, used a wide variety of non-comparable sampling methods (including rotenone, angling, set lines, fyke nets, drum nets, gill-nets, fish traps, backpack electrofishing, boat electrofishing), and did not necessarily aim to report on the relative abundance of all species present.

Although there is potential for some sampling bias between the 1982–1983 and 2003–2004 survey data analysed here, the magnitude of differences between the surveys suggests that the fish assemblage structure in the lower Goulburn River did not remain stable between 1982–1983 and 2003–2004. We suggest that aggregation of data at the temporal scale of decades as described by Pollino *et al.* (2004), therefore, has the potential to confound analysis of spatial variations in fish assemblages and appears unlikely to provide a reliable means of assessing their current condition. Although our results are limited to the lower reaches of the Goulburn River, they raise the possibility that temporal changes in fish assemblages may have also occurred in other regions of the Goulburn River catchment. It should be recognised that the two surveys used in our analysis represent only brief snapshots, and that it is not at all clear whether the populations at the time of sampling had reached a stable equilibrium or were on a trajectory of change. The potential for temporal variation in fish assemblages demonstrated here, even in the absence of major changes to managed flow regimes, needs to be taken into account in the design of studies that aim to assess the condition of riverine fish assemblages. On this basis, we suggest that temporal variability should be explicitly recognised in study design and that ongoing assessments of fish assemblage condition using standardised sampling techniques are required to measure change over time.

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Fisheries Revenue Allocation Committee, 2006

NOTES FRAC

Fisheries Revenue Allocation Committee

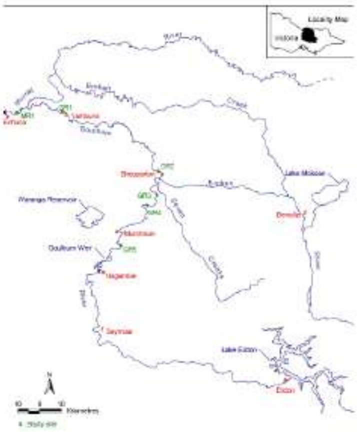
Your fishing licence fees at work

No. 1, March 2006 ISSN 1833 - 7066

Status of Murray cod and golden perch in the lower Goulburn River.

Murray cod and golden perch, native species that are popular with recreational anglers, are widespread in the lower Goulburn River, according to the results of a three year study.

The lower Goulburn River (from below the Goulburn weir to its junction at the Murray River) (see map) is listed as a Heritage River, partly because of the fishing opportunities provided by a diverse fish community.



Anglers in this stretch of river target two native species, Murray cod and golden perch, along with the introduced common carp.

Development within the catchment has modified the lower Goulburn River. The flow of this river is highly regulated. Water is diverted at Lake Nagambie to irrigation areas, which has altered the river's natural flows. Such changes in flow regimes can adversely affect the distribution and abundance of native fish as can

- the spread of introduced fish species,
- the imposition of barriers to fish movement such as weirs,
- the removal of woody debris and the loss of other river habitats and
- a decrease in water quality.

The Goulburn Valley Association of Angling Clubs (GVAAC) identified a need to better understand how fish species targeted by anglers are using the lower Goulburn River.

Funded by Recreational Fishing Licence revenue, GVAAC joined forces with fish scientists from the Arthur Rylah Institute to survey the fish communities of lower Goulburn River in spring and autumn each year for three years.

Survey sites were established at five locations between Lake Nagambie and the Murray River junction. Each spring and autumn the researchers used boat mounted electro-fishing gear to capture fish in the river . All fish collected were identified, counted, measured and weighed.

Over the three year study researchers caught 1797 fish, which represented eight native and four introduced species. Native fish comprised 85% of the catch.

Australian smelt (798 individuals) and Murray River rainbowfish (475) were the most abundant native species. Common carp (249) was the most abundant introduced species. Small numbers of goldfish (6), eastern Gambusia (5) and redfin (1) were also found.

Of the species of interest to anglers, Murray cod (127) was the most abundant. Golden perch (73) was also common throughout the lower Goulburn River.

Victoria The Place To Be

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Fisheries Revenue Allocation Committee

Your fishing licence fees at work

Table showing proportion of angler species along the lower Goulburn River across the three years of the survey

Location	Total # fish			Murray Cod (% catch)			Golden perch (%catch)			Common Carp (%catch)		
	03/04	04/05	05/06	03/04	04/05	05/06	03/04	04/05	05/06	03/04	04/05	05/06
GR1	45	40	64	11	13	5	9	5	3	64	70	88
GR2	136	59	96	8	5	6	4	8	3	7	12	7
GR3	95	104	97	25	22	4	3	3	9	9	6	18
GR4	106	96	140	13	17	6	8	2	5	18	10	7
GR5	168	133	417	<1	2	-	5	4	1	11	8	3
TOTAL	**550**	**432**	**815**	**10**	**12**	**3**	**6**	**4**	**3**	**16**	**14**	**13**

The abundance of Murray cod was similar in the first two years of the survey (around 12%) but declined (to 3%) in the final year. This decline was most noticeable in the mid-sections of the river.

Golden perch were also common throughout the lower Goulburn River though their numbers varied from year to year and from site to site.

Most of the Murray cod caught were small, with only 12% above the legal minimum limit (LML) of 500 mm (see photo). In contrast 95% of the golden perch were above the LML of 300 mm.

Murray cod collected from the lower Goulburn River (photo David Crook).

However, there are large fish of both species present in the lower Goulburn River. Researchers collected and tagged four Murray cod weighing over 22 kg and measuring just over a metre in length. The largest golden perch recorded was 2.5 kg.

While common carp were found throughout the lower Goulburn River they were most abundant in the lower reaches. Most of the carp collected were 400-600mm in length, however smaller fish (<200 mm in length) were present at most sites and in most surveys.

Researchers also wanted to determine whether these species were spawning in the lower Goulburn River. To do this, in the spawning season (spring) they established drift nets at three sites to catch fish eggs and larvae. A site was also established on the Murray River below the Goulburn junction for comparison.

Murray cod larvae were collected from the Goulburn River in all three years of the survey, though not consistently at any one location. This is encouraging news as it suggests that natural spawning and recruitment of the Murray Cod is occurring in the lower Goulburn River.

In contrast golden perch larvae were only detected in the Goulburn River on one occasion and then only in low numbers. In contrast, large numbers of golden perch eggs and larvae were collected in the nearby Murray River site. These results suggest that spawning of this species is currently limited in the lower Goulburn River. If this is the case then the population of golden perch in the lower Goulburn might be moving into the river from some other area, most likely the Murray River.

The results of this study will be used by GVAAC, Fisheries Victoria and the Goulburn-Broken CMA to assist in the development of strategies to manage the recreational fishery.

For further information about this project please contact Wayne Koster or David Crook, at the Arthur Rylah Institute for Environmental Research on (03) 9450 8600

Contact the FRAC Secretariat during business hours on 9658 4369.

FRAC Notes are available on the web at the following address: www.fcc.vic.gov.au Follow the prompts to *****************

Victoria The Place To Be

Shepparton News, 2006

Fish not flipping out

By Rebecca Tampion
September 10 2007
Country News

The fish are biting in the lower Goulburn River.

Results from a study on fish populations in the river are sure to put a smile on recreational fishers and anglers, with research indicating that native fish populations, particularly Murray cod and golden perch, are thriving.

The study, which was conducted by scientists from DSE's Arthur Rylah Institute for Environmental Research in cooperation with anglers from the Goulburn Valley Association of Angling Clubs, aimed to establish an estimate of fish numbers in the lower Goulburn River.

Wayne Koster from ARI said previous studies had been conducted on an "ad hoc" basis, however unclear status regarding the current status of fish in the river was the motivation for the study.

The survey was conducted between Lake Nagambie and the Murray River with five boat-mounted electrofishing sites established along this stretch of river.

Fish were caught, identified, measured and weighed before being released and the figures were compared to similar surveys conducted in the lower Goulburn River in the early 1980s.

Recreational fisherman Callan Trew fishes along the lower Goulburn River frequently throughout the summer months and believes the fish populations have been increasing steadily over the past 10 years.

"About three years ago I really started noticing it," Mr Trew said.

"From my experience the stocking program has worked well."

Mr Koster said it was possible the fish stocking program had contributed to the increased populations.

Fish-e-fax, 2007

DEPARTMENT OF PRIMARY INDUSTRIES

Fish-e-Fax

A fortnightly round-up of recreational fishery management issues

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Angling for more native fish in the lower Goulburn

A three-year Victorian Government study of fish stocks has found both Murray cod and golden perch – two native species popular with recreational fishers – are widespread in the lower Goulburn River.

The results of the study, which ran from 2003/04 to 2005/06, suggested there are good numbers of young Murray cod entering the fishery, probably as a combined result of natural spawning when environmental conditions are favourable and Fisheries Victoria's native fish stocking program.

Researchers are hopeful that a large proportion of the undersize cod have now grown to legal size. They should complement the abundant golden perch population and make for excellent fishing over coming summer seasons.

The study was undertaken by scientists from the Department of Sustainability and Environment's Arthur Rylah Institute for Environmental Research (ARI) in cooperation with anglers from the Goulburn Valley Association of Angling Clubs.

Survey sites were established at five locations between Lake Nagambie and the Murray River junction. Adult fish population surveys at each site using boat-mounted electro-fishing gear found that of 1797 fish were caught, identified, measured and weighed, eighty-five per cent were native fish.

Of the species of interest to anglers, Murray cod (127) were the most abundant while golden perch (73) were also common throughout the lower Goulburn River. Carp, an introduced species, was the most abundant fish found with 249 specimens.

Large Murray cod and golden perch were present in the lower Goulburn River. Four Murray cod that weighed over 22 kg and measured over a metre were caught and released, while the largest golden perch captured was 2.5 kg.

Most of the Murray cod caught were small with only 12 per cent above the legal minimum limit (LML) of 50 cm. In contrast, 95 per cent of the golden perch were above the LML of 30 cm.

Surveys were also conducted to identify fish spawning events in the lower Goulburn using larval drift nets.

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The study was funded by Recreational Fishing Licence revenue and the surveys have continued in 2007 through funding from the Goulburn-Broken Catchment Management Authority.

Measure your snapper to estimate its weight

Fishcare has released a free 'Weigh Your Catch' ruler which allows recreational anglers to estimate the weight and age of a snapper based purely on its length.

By lying snapper down on the ruler an angler can quickly get a weight estimate of the fish without suspending it on scales. While good handling is not as important for fish that are going to be retained for the table, it is critical for released fish, whether they be undersize or in excess of anglers' personal needs.

The ruler also contains useful information about snapper and their habits, colour pictures of adult and juvenile snapper for identification purposes and a list of tips about good fish handling practises.

Given the phenomenal snapper seasons we have experienced over the last two seasons, particularly in Port Phillip Bay, this stick-on ruler should be very popular amongst keen saltwater anglers.

The rulers were produced care of a $22,100 grant from Round 4 of the Commonwealth Recreational Community Grants Program.

The 'Weigh Your Catch' snapper rulers will be available free of charge from selected fishing tackle stores in September, just in time for the spring snapper season.

Fishcare has also produced free 'Weigh Your Catch' ruler for other species such as black bream and mulloway. To obtain them or for more information about Fishcare's range of community programs and products visit www.fishcare.org.au.

Fishcare is a statewide community based organisation that promotes responsible and sustainable attitudes and practices amongst recreational anglers and the wider community.

Fisheries Victoria listens to all recreational concerns

Fisheries Victoria is working closely with recreational fishing bodies during the current review of fishing consultative arrangements.

The current review is about strengthening the consultative structures and processes that underpin fisheries co-management in Victoria.

Co-management is recognised as an integral feature of contemporary fisheries management. The review was initiated at the request of the former Premier in response to persistent concerns being expressed from a range of stakeholders about the governance, effectiveness and efficiency of current fisheries stakeholder consultative arrangements.

The objectives of the review are to ensure that the consultative framework is delivering the best possible fisheries management decisions within current budgetary and property right constraints, and to provide government with options for ensuring an effective stakeholder engagement framework.

"It is possible that the population increase is attributable, at least in part, to artificial stocking aimed at improving the recreational fishery," Mr Koster said.

However, he said improved fish passage through the installation and upgrade of fish ladders in the Murray River, particularly the Torrumbarry fish ladder, was also likely to have played a part in the increase in numbers of native fish populations.

Goulburn Valley Sports Fishing Club secretary Ross Reddrop said he believed drought conditions had made it hard to tell whether there had been an increase in fish, however, he believed a good season was in store.

"With no run-off from the rain and no bugs and insects going into the water, the fish are dormant," Mr Reddrop said.

"Once we get rain and it gets a bit warmer it should be a good season."

The Goulburn Valley Sports Fishing Club is looking for new members. For more information phone Ross Reddrop on 0412 606 341.

rebecca.tampion@sheppnews.com.au

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Fish go into food frenzy

Native fish in the Goulburn River have gone into a feeding frenzy, gorging themselves on new food sources available as a result of the recent floods.

Researchers from the Department of Sustainability and Environment's Arthur Rylah Institute jumped into their boats to take advantage of the rare opportunity to study the response of Victorian freshwater fish to floods in the Goulburn River.

"Last month's flood was the first major flood event in the Goulburn River for over 15 years and so we seized the chance to find out what our native fish do — and what they do is eat," ARI scientist fish ecology Wayne Koster said.

"We collected a range of native fish species including a Murray cod weighing about 30 kg.

"Our monitoring has shown the fish moved straight out onto the flood plains, which are normally dry land, and gorged themselves on everything from worms to insects and anything else they can find.

"The results of the monitoring confirm the importance of flood events for our native fish by showing that they will move from their normal sites to take advantage of the extra sources of food which become available."

Surveys will also be conducted over the coming months to investigate the benefits of better river flows for native fish spawning.

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Seymour Telegraph, 2010

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Flooding helps fish

The recent floods in the Goulburn River appear to have prompted the local golden perch (*macquaria ambigua*) to start breeding en-masse for the first time in at least eight years.

Researchers from the Department of Sustainability and Environment's Arthur Rylah Institute have spent the past few months monitoring the response of Victorian freshwater fish to the strongest water flows the Goulburn River has seen in years.

"The floods in September were the first major flood event in the Goulburn River for over 15 years and so we seized the chance to get into our boats and find out what our native fish do," Arthur Rylah Institute fish ecology scientist Wayne Koster said.

"Our research has shown their initial response to the floods was to move out onto the floodplains, that are normally dry land, and gorge themselves on food that would otherwise be inaccessible.

"Now we've found that they have followed that up with a significant breeding event.

"We've been monitoring golden perch in the lower Goulburn River for eight years and last month was the first time we have detected a spawning event of any size," Dr Koster said.

"The spawning event is likely attributable to the extra food that was available to the fish immediately after the September flood, ensuring fish were in excellent condition to breed, as well as the follow-up high flows that occurred in October.

"This is crucial information showing the links between increased flows and golden perch spawning in the Goulburn River.

"An important step now is to continue monitoring the river to assess whether increased spawning results in improved adult fish populations."

The Goulburn Broken Catchment Management Authority has funded this work for more than five years.

www.dse.vic.gov.au/ari