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Arthur Rylah Institute for Environmental Research

Unpublished Client Report for the Mallee Catchment Management Authority

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Front cover photo: Upper Mullaroo Creek (Scott Raymond).

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Summary

The Murray-Darling Basin Authority (MDBA), Victorian and South Australian state governments and the Mallee Catchment Management Authority (MCMA) have collaborated to construct regulating structures on the upper Mullaroo Creek and Lower Lindsay River with the purpose of restoring natural flows and flooding to the Chowilla-Lindsay-Wallpolla Icon Site. Despite major alterations to the systems flow regime, the system maintains numerous species and communities of conservation significance. Of particular note, is the importance of several anabranch systems in providing critical habitat for native fish due to their unique hydrological regimes and high density of instream habitat. Flow modifications resulting from the operation of the new regulating structures must therefore consider the habitat and migration requirements of important populations of native fish in the system. Subsequently, a research program was established in 2014 to monitor the movements of fish between the Murray River and anabranch systems in response to flows and the operation of floodplain structures over the coming years. The study specifically aims to add to our understanding of migration cues and habitat use by both native and exotic fish species, and provide managers with a set of 'sentinel fish' which can be monitored following floodplain infrastructure construction and operation. This progress report provides an update of the program following the second year of the study. This includes reporting of the number of tagged fish and fish detections in the system as well as a discussion of the impact of the newly constructed regulator and fishway on fish movement.

In March 2014, five data logging stations were installed at strategic locations along the Mullaroo Creek and Lindsay River study site. An additional two logging stations were installed on the upper and lower Potterwalkagee Creek in May 2015; with an eighth logging station installed at Lock 7 in April 2016. This array records individual fish movement and occupancy in 12 distinct zones with the study area containing a variety of both river and anabranch habitats with a range of hydraulic conditions. A total of 227 fish have been tagged with radio transmitters thus far (including 72 fish in April 2016). Of these fish, 163 are still 'active' (detectable) in the system. Specifically, the Mullaroo Creek and Lindsay River reaches contain 94 tagged fish, comprising of 51 Murray cod, 21 golden perch, 20 carp and two catfish. The Murray River (between Lock 7 – 8) currently holds 69 tagged fish, comprising of 21 Murray cod, 19 golden perch, 28 carp and a single catfish.

Between March 2014 – April 2016 we recorded movements of 155 fish tagged in the Lindsay and Mulcra Island regions. This represents all fish tagged prior to April 2016, with 57% of these fish having undertaken movements outside of the zone in which they were initially released. Of these multi zone movements, many encompassed transitions between anabranch and the Murray River main channel. The patterns of fish movements displayed a high degree of spatiotemporal variability, both across and within species.

Our preliminary analysis of fish movement, specifically transition rates between anabranch habitats and the Murray River, indicated carp were the most likely species to transition between habitat types, followed by golden perch, Murray cod and catfish respectively. Fish size also influenced transition probabilities for golden perch and Murray cod, with larger fish more likely to move than smaller individuals. A more detailed analysis of Murray cod transitions also demonstrated significant effects of both discharge and time of year; as well as differences between the two time periods of data collection (2004 – 2007 and; 2014 – 2016). We found a greater proportion of Murray River - anabranch transitions by Murray cod were represented by a shift from the Murray River to the anabranch reaches during the spawning period, particularly the upper Mullaroo Creek, with this transition more likely to occur in the earlier time period (2004-2007) than the more recent study period (2014-2016). The number of daily Murray cod movements between the Murray River and the anabranch has two peaks and two troughs, with the largest peak during October and November; and the smaller peak in April and May. Of most significance to river operations was our finding of a significant positive effect of discharge on Murray cod transition rates between anabranch habitats and

the Murray River which illustrate that more fish are likely to move between habitat types, during periods of higher discharge in the Mullaroo Creek, particularly during the spawning period. For example, just a 100ML increase in daily discharge during October would result in a 26% increase in expected number of Murray cod movements between habitat types. This result has important implications for the operation of the Mullaroo Creek.

All four study species were found to have moved between the Upper Mullaroo Creek and Murray River prior to the recent regulator and associated fishway construction. Murray cod, golden perch and carp all successfully traversed the Mullaroo Creek regulator/fishway pre and post construction, however, the percentage of approaching fish that ascended the structure declined post construction, likely related to comparatively lower flows and disturbance during the construction period. The data collated in the first two years of the study has demonstrated encouraging results, with high fish detection and transition rates between zones throughout the Lindsay Island anabranch system. This provides the basis of determining patterns of fish migration and habitat use within the Icon site. Importantly, the program provides a solid foundation to monitor the response of fish to future operations. Of course this is reliant on the continuation of annual fish tagging (to maintain adequate sample sizes of tagged fish in the system) and annual routine maintenance and data collection. Further years of data collection and analysis is required to confirm and refine the effects of discharge, the new fishway and weir pool manipulation on transition rates for Murray cod, as well as other species in the system.

1 Background

The decline in connectivity of lowland rivers and their floodplain habitats has contributed substantially to the decline of their native fish populations (Natarajan 1989; Saddlier et al. 2007). Regulation of flows has negatively impacted the natural variability of hydrological regimes within the lower Murray River floodplain through alterations to the frequency, duration and size of floodplain inundation and dramatic changes to riverine hydraulics (Maheshwari et al 1995; DSE 2010). The continued regulation of the Murray River poses a threat to the ecological integrity of the region including native fish populations. The Chowilla-Lindsay-Wallpolla Icon Site is one of six icon sites identified under the Murray-Darling Basin Ministerial Council's 'The Living Murray' initiative. The area is situated within Murray Sunset National Park, which covers an area of 15,000 ha of floodplain to the south of the Murray River, between Lock 8 and Lock 6. The waterways, wetlands and floodplain provide refuge and resources for a range of flora and fauna, including threatened fish species. The area also has high social and cultural significance.

River regulation is the key threatening process to the values of the Chowilla-Lindsay-Wallpolla Icon Site, causing a reduction in the frequency, duration and size of floods, reduction in the variability of natural hydrological regimes and, severely altered hydraulic characteristics (such as velocity) of the system. In an effort to mitigate this threat, The Living Murray initiative developed the *Upper Lindsay Watercourse Enhancement Project* with the purpose of restoring aspects of the natural flow regime to the Icon Site (DSE 2010). This project includes lowering the sill in the southern Lindsay River, constructing regulators on the northern and southern Lindsay River inlets and replacing the degraded causeway in the Mullaroo Creek with a new regulator and fishway. A proposed regulator (Mullaroo Stage 2) on the lower Lindsay River outlet (upstream of the Lindsay and Murray Rivers confluence) will further regulate hydrological regimes in the Lindsay River and Mullaroo Creek.

The Mullaroo Creek regulator and fishway, together with the Lindsay River regulators are reported to increase the area and diversity of available aquatic habitat and contribute to the overall viability, abundance and extent of existing fish communities (Mallen-Cooper et al. 2010). However, there is also the potential for these (and future) regulators to restrict fish movement and alter the hydrological and hydraulic characteristics of several key reaches, which historically provide critical habitat to native fish. The upper Mullaroo Creek in particular is an important refuge and breeding ground for a number of native fish species. These species are dependent on the systems unique hydraulic characteristics and high density of instream habitat (structural woody habitat) compared with sites within the lower Mullaroo Creek, Lindsay River and Murray River (Saddlier and O'Mahony 2009). In particular, Murray cod from the Murray and Lindsay rivers showed a preference for the upper Mullaroo Creek during the spawning period (September to November; Saddlier et al. 2007).

The influence of the new regulating structures on fish movement, positive or negative, will be dependent on regulator and fishway operational procedures, movement dynamics and key life-history requirements of individual fish species. Therefore, incorporating ecological data to improve operational procedures will be an important component to facilitate future watering regimes within and through the icon site. In response, this research program was established in 2014 to monitor the movements of fish between the Murray River and anabranch systems in response to flows and the operation of floodplain structures over the coming years. The study specifically aims to add to the understanding of habitat use and migration cues by native species including Murray cod (*Maccullochella peelii*), golden perch (*Macquaria ambigua)*, and freshwater catfish (*Tandanus tandanus*), as well as the exotic carp (*Cyprinus carpio*), and how these are influenced by changes in water management, particularly those induced by infrastructure construction and operation (fishways and regulators). This progress report provides an update of tagged fish, reach occupancy and fish detections following the second year of the study, and incorporates fish movement dynamics pre and post construction/operation of instream structures within the system.

2 Methodology

2.1 Study site and logging towers

With the *Upper Lindsay Watercourse Enhancement Project* well underway, this study is focussed on the Lindsay Island anabranch network of the Chowilla-Lindsay-Wallpolla Icon Site, in north-western Victoria. The primary waterways investigated were the Mullaroo Creek, Lindsay River, Potterwalkagee Creek and Murray River (Lock 6 – Lock 8 reach; Figure 1). The study region was separated into twelve reaches, giving a variety of both river and anabranch habitats and a range of hydraulic conditions, including the moderate water velocities of the upper Mullaroo Creek and semi-lotic weir pools of the Murray River.

In March 2014, five data logging stations were installed at strategic locations along the Mullaroo Creek and Lindsay River (Figure 2). This repeated the array of Saddlier and O'Mahony (2009), with additional logging stations erected at a fork in the Upper Lindsay River, one each on the upper and lower Potterwalkagee Creek (May 2015) and another at Lock 7 on the Murray River (April 2016). The data logging stations receive radio signals (via antennae) from transmitters up to 300 metres away. As the antennas are directional (i.e. an antenna picks up its strongest signal when pointed directly at the transmitter), each antenna receives and records a signal of different strength. The antennas are positioned in either an upstream or downstream direction on the river/creek, and if a tributary exists, a third antenna is directed towards the inflowing tributary. Because signal strength and detection time is recorded for each antenna, the position and direction of movement for each fish within the range of the logger can be determined, thus enabling the exact reach a fish is occupying at any point in time.

As data loggers are subject to theft and vandalism, recording equipment was housed in 8 mm thick steel plate boxes set on 4 m poles secured into the ground with concrete. Ventilation holes and shade cloth were provided to protect the equipment from high summer temperatures. An articulated pole was hinged off the back plate of the logger box for ease of installing and maintaining antennae. Each four-element Yagi antenna (supplied by Advanced Telemetry Systems) was attached by a 1.5 m coaxial cable to a three-way switch box (supplied by Advanced Telemetry Systems). A 40 W solar panel was attached to the roof or the antenna pole and connected to a 12 volt, 100 amp hour lead-acid battery via a regulator. The data logger was connected to the battery to allow continuous, uninterrupted power to the unit.

Data loggers were downloaded three times per year, and given routine maintenance to ensure they were operating appropriately. Tagged fish were also manually tracked twice a year to verify positon and to check if the transmitter was emitting a mortality signal (triggered if the fish has not moved for 168 hours), therefore indicating the fish had either died or rejected the transmitter.

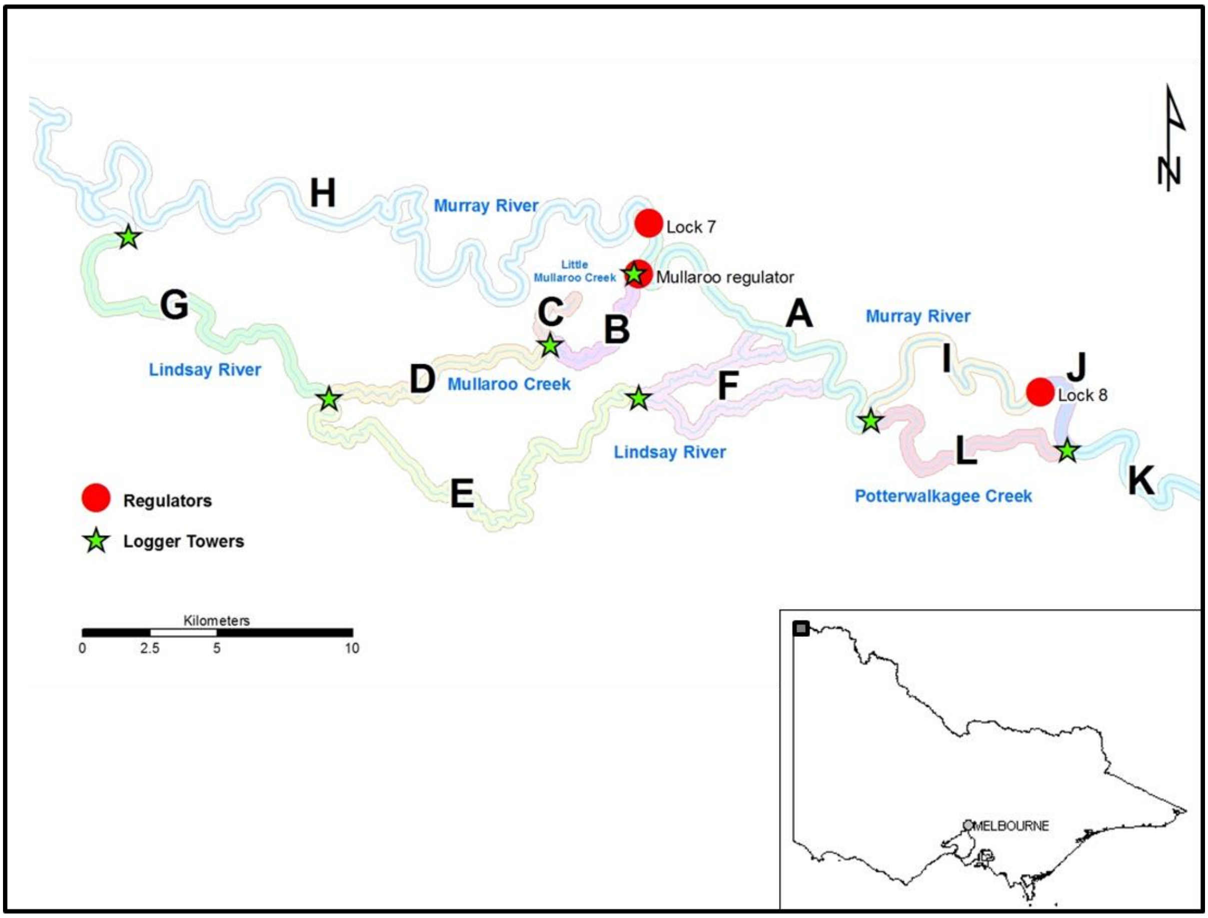


Figure 1. The Lindsay Island anabranch study site. Green stars represent data logging stations and letters represent fish tagging and movement zones.

Figure 2. Upper Mullaroo data logger, showing logger box, solar panel and antennae.

2.2 Fish collection and tagging

This program focuses on movement patterns of the native species, Murray cod, golden perch and freshwater catfish, and exotic carp. A Smith-Root 7.5 GPP boat-mounted electrofisher (settings: 500-1000 volts, 38 Hz, pulse DC) was used to capture fish for radio-transmitter implantation. Angling was also used to capture target fish species (Murray cod, freshwater catfish and carp).

Surgical procedures used to implant fish radio-transmitters follow those outlined in O'Connor et al. (2009). Fish were sedated by immersion in an anaesthetic solution of Aqui-S at a concentration of 1.5 ml per 50 litres of water. After fish were sedated (lack of observed movement) they were placed upside-down on an operating bench. The aforementioned anaesthetic solution was poured directly over the gills to ensure fish remained sedated during surgery. Prior to incision, the underside of the fish was bathed with diluted (0.9% saline solution) Betadine® solution to ensure the area was adequately sterile. A small incision (approximately 2 – 3 cm long) was made through the body wall on the lower left ventral side (parallel with the digestive tract) and the transmitter inserted into the body cavity of the fish. Transmitter size (7, 14, 23 or 56 g; Figure 3) was determined as a proportion (<2%) of total fish body weight (Table 1). Once inserted, the transmitter was positioned so that the external aerial could be passed through the body wall approximately 3 – 7 cm posterior of the incision, depending upon the size of the fish. Once the transmitter was positioned, the incision was again bathed in Betadine® solution before internal sutures were used to close the body wall. External sutures were used to close the outer incision and the entire area bathed with Betadine® solution before the fish was returned to an aerated recovery tank containing a 10 g/L salt solution to limit the possibility of infection. Careful observation of each fish was made to ensure it was able to maintain an upright swimming position prior to release into the same area from which it was captured. Transmitters operated on 150 MHz and were manufactured by Advanced Telemetry Systems.

Each fish was weighed (nearest gram) and measured for total length (mm); Fish were also marked with an external identification tag (T-bar or Dart; Figure 4) adjacent to the dorsal fin, and passive integrated transponder (PIT) tag. External tags display a telephone number for the reporting of fish capture data, which was incorporated into a fish database (Victorian fish tagging database; Arthur Rylah Institute). PIT tags have an individual code which is read as fish pass PIT reading stations. PIT tag readers have been installed on most Locks along the Murray River to record fish movement data.

Whilst not a direct objective of the project, manual tracking of the Mullaroo Creek, Lindsay River and the Murray River upstream of Lock 7 was also conducted during September 2014 and August 2015. Detailed site attributes including water velocity, depth and habitat attributes were also recorded for individual catfish which may be analysed at a later date.

Table 1. Radio transmitter weight, minimum weight of fish and battery life of transmitters.

Transmitter weight (g)	Minimum fish weight-2% (g)	Radio Battery life (days)
7	350	245
14	700	528
23	1150	1142
56	2800	1460

Figure 3. The size range of radio transmitters used in the study.

Figure 4. Golden perch with external identification tag

2.2 Data analysis

For the purpose of activity and progress reporting, we first generated descriptive statistics relating to fish occupancy, detection and movement patterns near and and through the Mullaroo Creek fishway (using signal strengths). We then conducted a more formal investigation of Murray cod transitions between the Murray River and anabranch habitats (Mullaroo Creek; Lindsay River and Potterwalkagee Creek) given the aims of the program. For the latter we used data collected during this study (2014 – 2016), as well as historical data collected during from 2004 - 2006 (Saddlier et al. 2007), which used the same logger locations and tagging protocols, and preceded any regulator interventions.

Given the strong site fidelity typical of the native study species (thus the preponderance of fish staying in the same reach from one day to the next), let alone move between anabranch and the main stem of a system, the analysis focused on two components: how likely is a fish to have ever moved between the Murray River and the anabranch; and how many fish on a given day would move between the Murray River and the anabranch. Logistic regressions were used to analyse the probability that a fish would ever move between the Murray River and the anabranch. That is a fish was given a score of one (1) if it moved either from the anabranch to the Murray River or vice versa and a zero (0) for no movement. Separate models were constructed for each species (carp, catfish, golden Perch and Murray cod). The length of the fish at capture and tagging was used as a potential explanatory variable for all species, while the monitoring period, either 2004 - 2006 (using historical data from Saddlier et al. 2007) or 2014 – 2016, was also used to explain variation for Murray cod. The full model and each nested model was estimated for each species and Akaike information criteria corrected for small samples (AICc) was used to determine the most parsimonious model, the balance between explanatory and predictor variables (Burnham and Anderson, 2010).

Due to the large number of fish that never moved between the Murray River and the anabranch a zero-inflated model was considered suitable. Zero-inflated models try to account for extra (structural) zeros in the data that affect the overall average. The model has two parts, one accounting for the extra zeros, the other accounting for the mean number of fish moving between systems on the day. The day of the year (Julien day), discharge in the Mullaroo Creek, temperature in the Mullaroo Creak as well as if it was spawning season (September – December) were considered as explanatory variables. When Julian day of the year was included, it was included as a smoothed term. Hence the overall model was a general additive model (GAM) using zero-inflated Poisson (ZIP) distribution (Wood et al. 2016). All the analyses were conducted using the statistical program R version 3.3.0 (R Core Team, 2016). The zero-inflated Poisson GAMs were estimated using the package mgcv (Wood, 2011).

3 Results

3.1 2016 Fish tagging and logger array update

In April 2016, an additional logging tower was installed on the weir at Lock 7 (see Figure 1). This ensures fish which were implanted with transmitters in the Murray River downstream of the Lower Potterwalkagee Creek are detected, if they move downstream of the zone which they were tagged in. The existing seven data logging towers were also checked, data downloaded and subject to routine maintenance.

An additional 72 transmitters were implanted into fish during April 2016 to maintain adequate numbers of tagged fish in the system. Specifically, 19 Murray cod (12 juvenile), one catfish, 12 golden perch and six carp were tagged in the Mullaroo Creek; and 10 Murray cod, 12 golden perch and 12 carp were tagged in the Murray River downstream of the Lower Potterwalkagee Creek. Two of the fish were implanted with old transmitters (with significant battery life remaining) which had been returned by recreational anglers who had caught and kept tagged fish during the second year of the study. Three existing transmitter fish (two Murray cod and a golden perch all occupying the Mullaroo Creek) were also recaptured during fish sampling (using electrofishing surveys) with all individuals appearing in good health (surgery wound completely healed and fish lacking any visual sign of disease or ill health). Unfortunately, there was only one catfish captured (and tagged) this year, and it appears numbers may have decreased in the study region.

A total of 227 fish have now been implanted with radio transmitters during the study since 2014, with 163 of these fish still at large in the system (Table 2 and 3; 64 fish have either been kept by anglers or the battery life of the transmitter has elapsed). At the time of monitoring, the Mullaroo / Lindsay anabranch region holds 94 tagged fish, comprising of 51 Murray cod, two catfish, 21 golden perch and 20 carp (Table 2 and 3). The Murray River (between Lock 7 – 8) currently holds 69 tagged fish, comprising of 21 Murray cod, one catfish, 19 golden perch and 28 carp (Table 2b and 3b). See appendix 1 for details of individual tagged fish (e.g. tagging dates, size and condition).

Table 2. Details of fish implanted with radio transmitters in (a) the Mullaroo Creek and Lindsay River in March/April 2014 and May/August 2015, and (b) the Murray River below Lock 8 in May/August 2015. *numbers do not include fish tagged in April 2016.

Species	Length Range (TL: mm)	Weight Range (g)	Total	No. detected	No. Changed zone	No. Active Transmitters
(a) Mullaroo Ck. / Lindsay R.						
Murray cod	519-1210	1908-35000	35	35	24	32
Catfish	348-520	366-1234	21	21	7	1
Golden perch	310-493	402-1508	39	39	25	9
Carp	440-680	1320-5250	16	16	10	14
TOTAL			*111*	*111*	66	*56*
(b) Murray R.						
Murray cod	712-1190	5300-32000	11	11	6	11
Catfish	401-485	535-960	3	3	0	1
Golden perch	320-490	570-1860	13	13	8	7
Carp	380-715	930-6050	17	17	9	16
TOTAL			*44*	*44*	23	*35*
SYSTEM TOTAL			**155**			**91**

Table 3. Details of fish implanted with radio transmitters in April 2016 in (a) the Mullaroo Creek, and (b) the Murray River upstream of Lock 7. TL = total length.

Species	Length Range (TL: mm)	Weight Range (g)	Total
(a) Mullaroo Ck.			
Murray cod	299-1080	356-21200	19
Catfish	497	1100	1
Golden perch	353-445	573-1168	12
Carp	437-669	1514-5138	6
TOTAL			*38*
(b) Murray R.			
Murray cod	732-1120	5200-24000	10
Golden perch	359-536	618-2170	12
Carp	462-665	1887-5555	12
TOTAL			*34*
SYSTEM TOTAL			**72**

3.2 Fish movements 2014- 2016

Fish movements and recaptures

The first two years of the study detected 155 which represents all fish tagged prior to 2016. Of these fish, 57% have undertaken movements outside of the zone in which they were released (Table 2). Of these multi zone movements, many encompassed transitions between anabranch and the Murray River main channel, further highlighting the importance of these habitats for fish in the region. The patterns of fish movements displayed a high degree of spatiotemporal variability, both across and within species. Figures 5 – 8 provide examples of the variety of movements recorded for each species. These movements include those that appear to be associated with reproductive activity; range shifts and; transitions between anabranches and the Murray River main channel. We investigate the influence of timing, temperature and river flows on Murray cod movements in our analyses below, however, specific patterns of such movements include:

- A high proportion of adult Murray cod movements encompassed the upper Mullaroo Creek (zone B), although some cod moved into the Murray River via the upper Mullaroo Creek, and downstream via the Lindsay River. Some examples of Murray cod movements include:
    - Murray cod **Fish ID 153.49** (712mm, 8500g, tagged in the Murray River downstream of Lock 8 on 18/08/2015) relocated to the upper Mullaroo Creek on the 3/09/2015.
    - Two Murray cod **Fish ID 153.35** (1210mm, 34800g, tagged in the upper Mullaroo Creek on 28/03/2014) and **Fish ID 153.34** (980mm, 15500g, tagged in the lower Mullaroo Creek on 29/03/2014) were detected on data loggers moving downstream into the Murray River via the Lindsay River on 30/10/2014 and 1/11/2014 respectively, and each returned back to their same zones in the Mullaroo Creek on 26/03/2015 via the same route they departed on. They again returned to the Murray River via the Lindsay River both on 28/10/2015, and again returned back to the Mullaroo Creek on 24/03/2016 and 30/03/2016 respectively.
    - Murray cod **Fish ID 153.4a** (720mm, 8000g, 10/05/2015, Murray River downstream of Lock 8) relocated to below Lock 7 on 23/10/2015.
    - Murray cod **Fish ID 173.20** (519mm, 1908g, tagged in the lower Mullaroo Creek on the 29/03/2014) was angled and released in the Murray River 18km's downstream of the Lindsay River junction on 8/07/2015, (now 660mm in total length).

- Golden perch exhibited considerable transition rates throughout the study reach. Of the 39 fish tagged in the Mullaroo Creek, 56% transitioned into the Murray River, either via the Upper Mullaroo Creek (largely for fish tagged in the upper anabranch) or the lower Lindsay River (again, largely for fish tagged in the lower reaches of the Creek). In 2015 13 golden perch were tagged in the Murray River downstream of Lock 8, of which four moved into the Potterwalkagee Creek from late July to early August. These movements were undertaken when the Lock 8 weir pool height was > 24.6 m, and encompassed a range of visitations from daily to extended occupancy.
    - Golden perch **Fish ID 132.16** (395mm, 826g, tagged in the upper Mullaroo Creek on 28/03/2014) was angled and kept in Frenchman's Creek on 5/01/2016. Data loggers recorded it moving into the Murray River thru the Mullaroo Creek fishway on 22/12/2015, and moving upstream past the Lower Potterwalkagee Creek logger on 24/12/2015.
    - Golden perch **Fish ID 234.24** (357mm, 644g, tagged in Mullaroo Creek downstream of the Little Mullaroo on the 2/04/2014) was angled and released at Wentworth Fishway (Lock 10) on 5/2/2015, a movement of approximately 135km's upstream.

    - Golden perch **Fish ID 234.02** (370mm, 670g, tagged in Mullaroo Creek downstream of the Little Mullaroo on the 7/05/2015) was angled and kept 26/6/2015 at Lock 6.

- The majority of the catfish tagged in the Mullaroo Creek and Murray River in 2014/2015 displayed very little movement between zones. Only two fish moved from Mullaroo Creek upstream into the Murray River, whilst another moved downstream into the Lindsay River. Four other catfish moved between zones within the Mullaroo Creek.
- Carp tagged in 2014/2015 displayed a range of different movement patterns. Of the 16 carp tagged in the Mullaroo Creek/Lindsay River, four moved in to the Murray River via the upper Mullaroo Creek and three moved downstream in to the Murray River via the Lindsay River. Six did not move out of their zone in which they were tagged. Seventeen carp were tagged below Lock 8 in the Murray River, with four moving into the Potterwalkagee Creek for varying amounts of time. Some individuals moved upstream thru Lock 8, and a few moved downstream below Lock 7. Eight remained in the same zone in which they were tagged.
    - Carp **Fish ID 132-20** (520mm, 2860g, 10/05/2015, Murray River downstream of Lock 8) moved upstream thru Lock 8 and into the Potterwalkagee Creek on 8/8/2015. Moved back into Murray River on the 19/09/2015 and travelled downstream past Lock 8, and continued downstream below Lock 7. Moved upstream thru Lock 7 on 22/09/2015 and into the Lower Potterwalkagee Creek on 24/09/2015 and moved upstream through the Potterwalkagee Creek and into the Murray river via the Upper Potterwalkagee Creek on 30/09/2015.
    - Carp **Fish ID 153.3a** (585mm, 2835g, 9/05/2015, Murray River downstream of Lock 8) relocated to below Lock 7 on the 30/09/2015.
    - Carp **Fish ID 153.15** (608mm, 3680g, tagged in the Upper Lindsay River on the 3/04/2014) detected on Lock 4 fishway Pit Tag reader 26/11/2014.

Patterns of fish transitions from the upper Mullaroo Creek to the Murray River

An exploration of transmitter signal strength recorded at the Mullaroo Regulator logger tower enabled some exploration of patterns in fish transition from the Upper Mullaroo Creek to the Murray River, both during the period of the old ford structure, and in the first five months of operation of the new regulator / fishway structure. The data indicates that all four species have successfully transitioned into the Murray River under both new and old (except catfish for the latter) structures. Nevertheless, in all, a lower proportion of radio-tagged fish which approached the Mullaroo Creek regulator/fishway made the transition (Table 4). Furthermore, whilst the number of individual fish and total number of approaches were relatively similar, the proportion of accents reduced slightly with the new regulator / fishway. Of course, these data may be only preliminary, with fish needing some time to familiarise themselves to the new structure. Further monitoring over the coming years will help investigate this.

Table 4. Total number of approaches (including multiple approaches by individual fish) and number of fish for each species which approached and ascended the Mullaroo Creek regulator/fishway pre- and post-construction. *numbers do not include fish which approached or ascended during regulator construction.

Species	Total approaches	% Ascended	No. individual fish approached	% individual fish ascended
Pre Regulator/Fishway	(June 2014 – April 2015)			
Murray cod	84	24	17	53
Golden Perch	30	47	7	86
Catfish	16	13	5	40
Carp	3	100	2	100
Post Regulator/Fishway	(July 2015 – April 2016)			
Murray cod	98	11	18	33
Golden Perch	19	37	6	67
Catfish	1	0	1	0
Carp	12	17	7	29

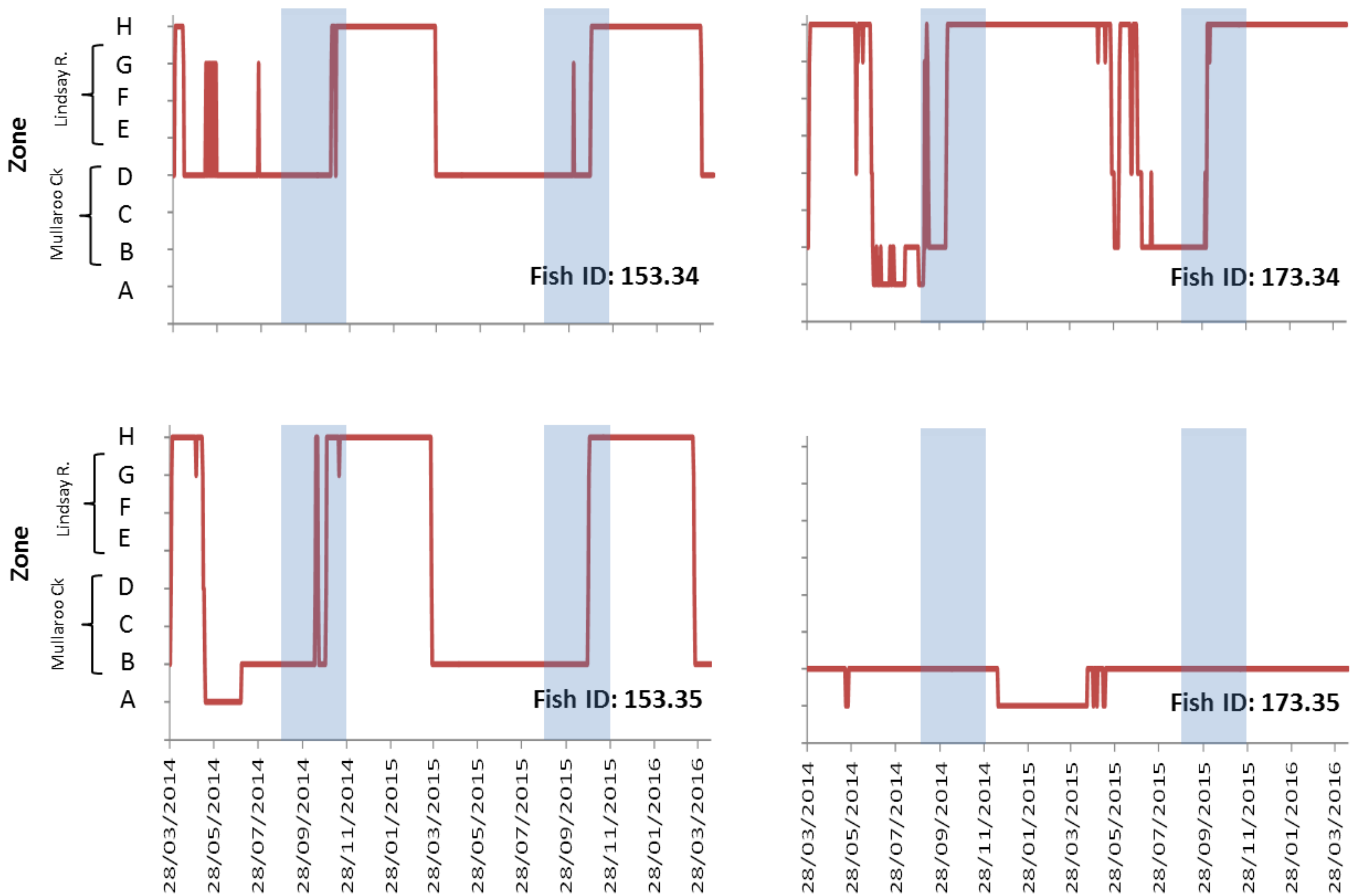


Figure 5. The movement patterns of four individual Murray cod between March 2014 and April 2016. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

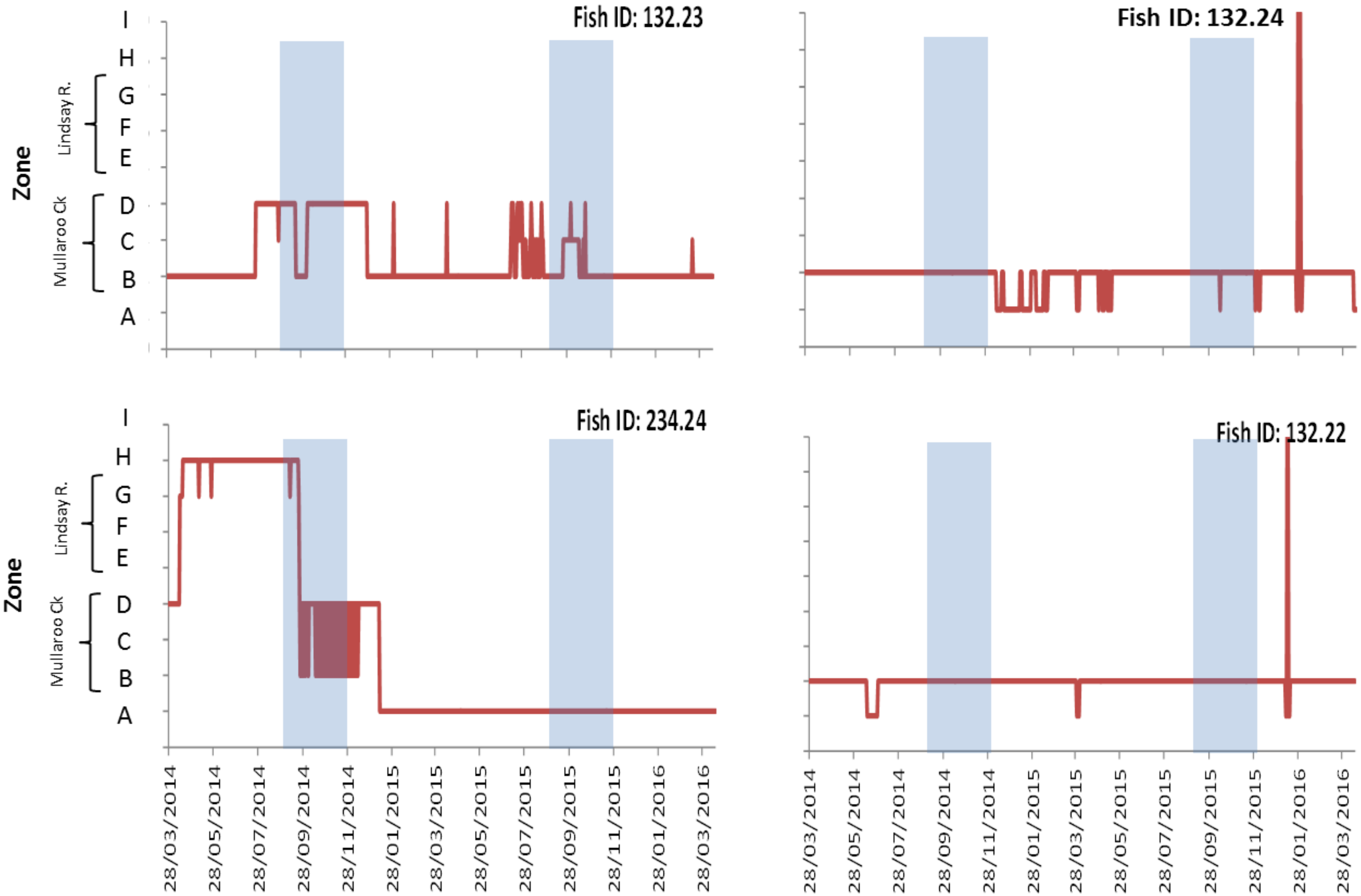


Figure 6. The movement patterns of four individual golden perch between March 2014 and August 2016. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

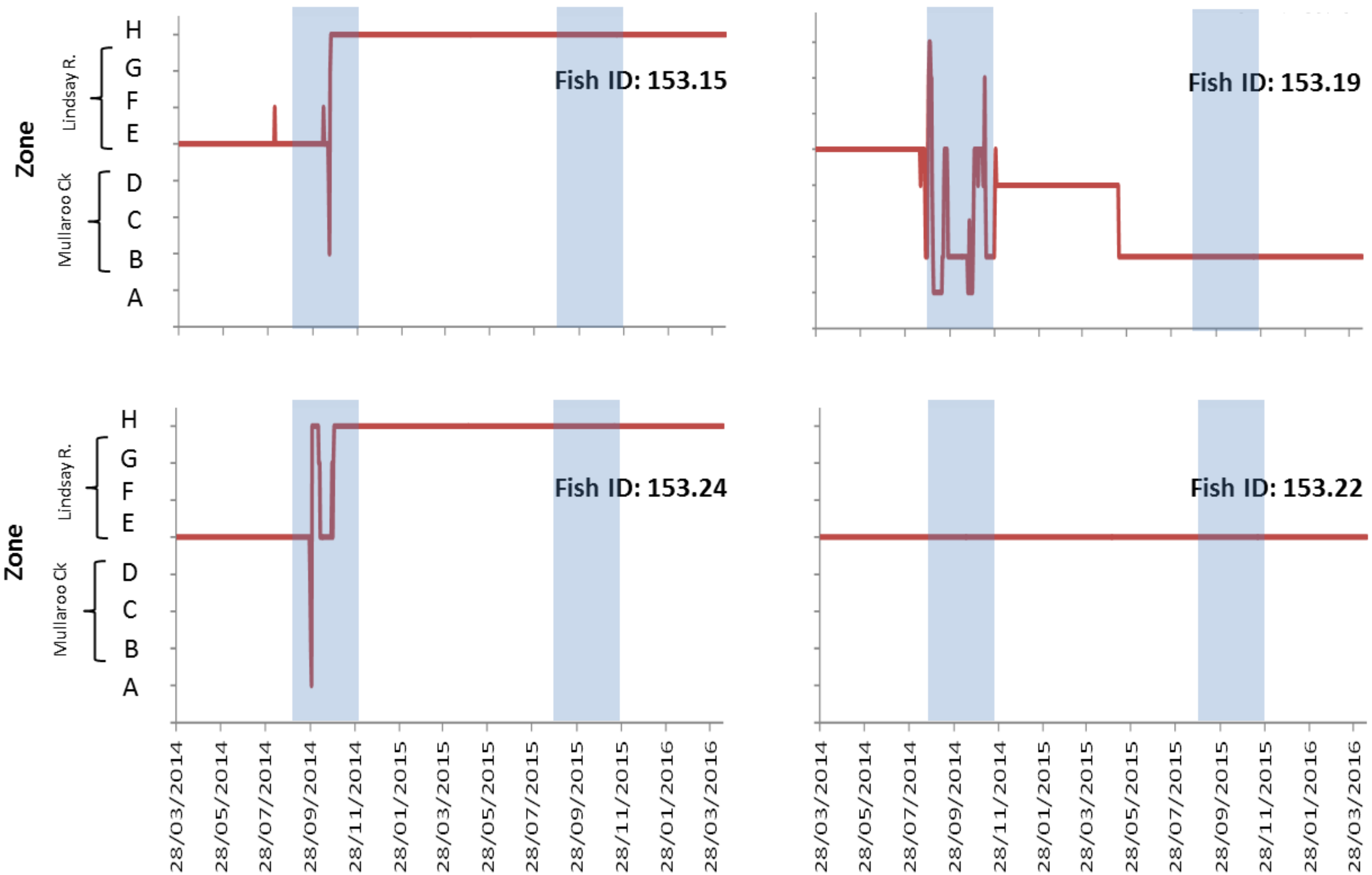


Figure 7. The movement patterns of four individual carp between March 2014 and August 2016 Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

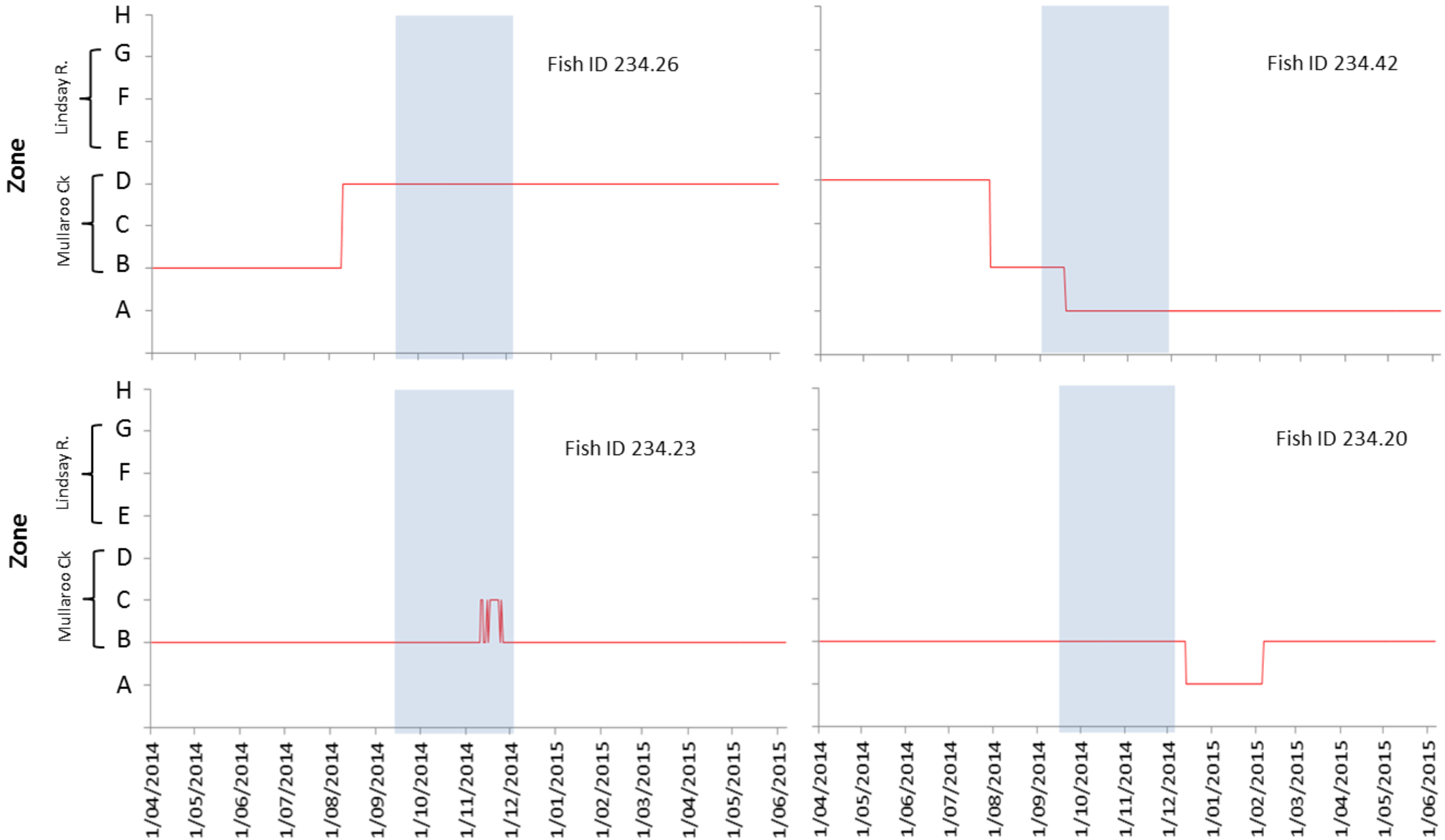
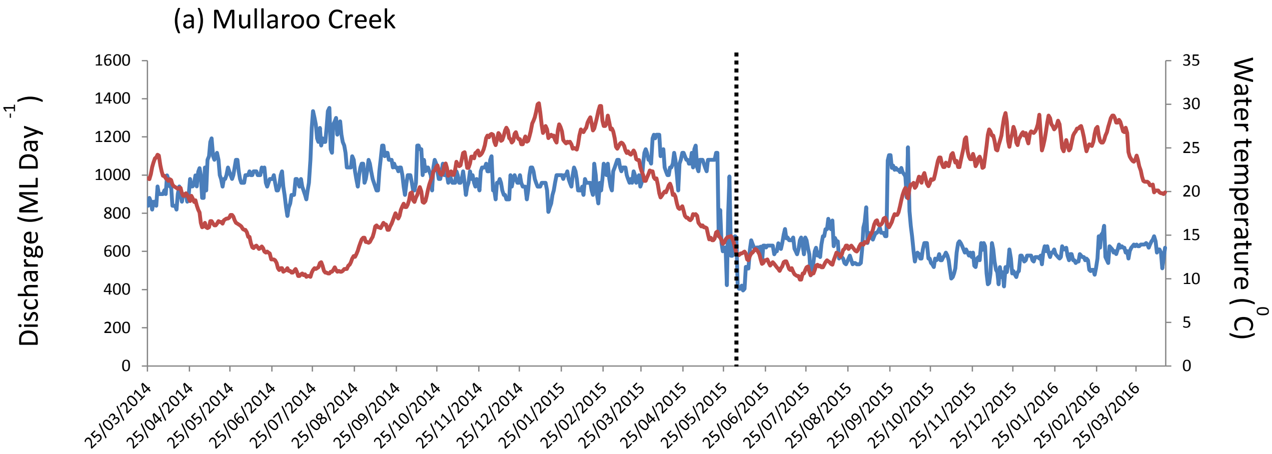


Figure 8. The movement patterns of four individual catfish between March 2014 and August 2015. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).



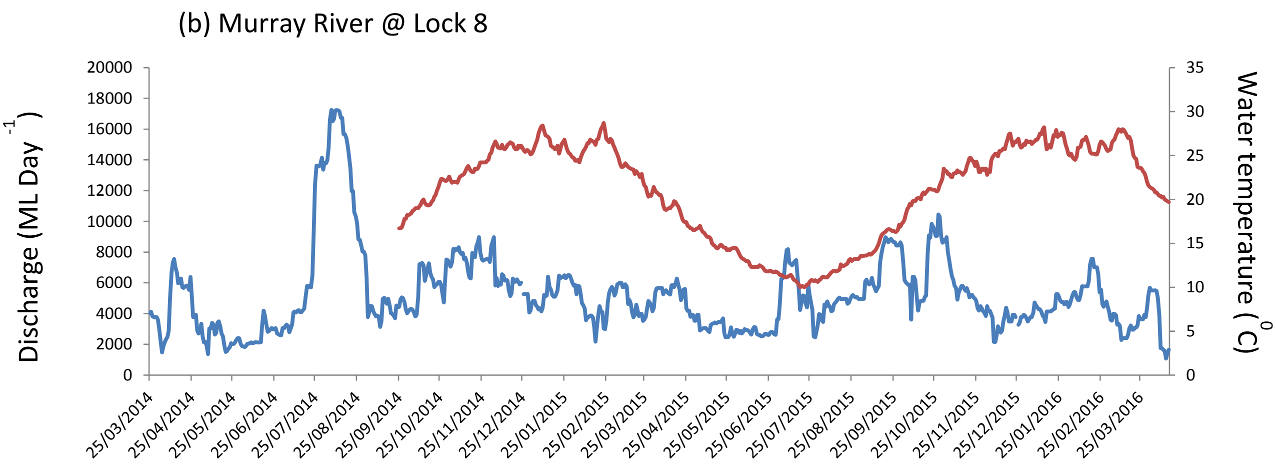


Figure 9. Average daily discharge (blue) and water temperature (red) in (a) Mullaroo Creek and; (b) the Murray River at Lock 8 during the monitoring period. Dotted vertical line illustrates approximate commencement of Mullaroo Creek regulator construction and operation.

Transitions between the Murray River and anabranch habitats

The likelihood that a monitored fish ever moved from the Murray River and the anabranch system (Mullaroo Creek or Lindsey River) or vice versa was different for the four species of interest. The likelihood of a Murray cod moving was dependent on the length of the fish and when the monitoring was conducted (2004 to 2006 or, 2014 to 2016). The model with that parameterisation had the smallest AICc (Appendix 2). The greater the length of an individual, the greater the likelihood it moved between the Murray and the anabranch (Figure 10). For instance, a 400 mm Murray cod (tagged in 2014) had an expected probability of moving between systems of 14.4% (with 95% confidence interval from 6% to 30%), while a 1200mm Murray cod (in 2014) has a 43.8% (25% to 65%) chance. In the earlier monitoring period (2004 to 2006) the likelihood of a Murray cod moving was 2.8 (1.2 to 6.4) times larger than the same sized Murray cod in the later (2014 to 2016) monitoring period (Figure 10).

The probability of carp and catfish transitioning between systems was independent of length. The null model had the smallest AICc for each species (Appendix 2). The fraction of carp that moved between the Murray River and the anabranch was the highest amongst the four species monitored at ~70% (50% to 82%; Figure 11). The fraction of catfish that transitioned between the Murray River and the anabranch was the lowest, at ~20% (10% to 42%, Figure 11). The likelihood of a golden perch moving was dependent on the length of the fish, the model with that parameterisation had the smallest AICc (Appendix 2d). The greater the length of the golden perch, the greater the likelihood it moved between the Murray and the anabranch (Figure 12). For instance, a 300 mm Golden Perch (in 2014) has an expected probability of moving between systems of 22.1% (6% to 56%), while a 500 mm golden perch (in 2014) has an 84.3% (54% to 96%) chance.

Of the four species monitored, at this point in the study, only Murray cod had enough movements between the Murray River and the anabranch habitats to warrant further analysis to investigate the influence of discharge, temperature and time of year. The other species had less than 5% of days where movement between the systems occurred. Whilst we did not have enough data to include the direction of this transition in the analysis, on average, just 10.6% of Murray cod in the study occupied the Murray River on any given day during the spawning season. The percentage of all movements recorded between anabranches and Murray River are 58% (from anabranches to Murray River) and 42% (from Murray River to anabranches). Therefore, in consideration of the reduced number of fish occupying the Murray River, just ~11% of movements between the habitat types are represented as moves from the anabranch to Murray River. Conversely, this data suggests Murray cod are more likely to move to the anabranch system during the spawning season than the Murray River.

The model with the most support for effecting the number of Murray cod that move between the Murray River and anabranches on a day was whether it was spawning season (September – December); the time of year and average daily discharge within the anabranch (Appendix 2). There were more days when Murray cod will move during spawning season compared to non-spawning season, at 36% to 12% respectively (Figure 13; Appendix 2). Greater discharge within the anabranch was associated with greater numbers of Murray cod movements between the Murray River and the anabranch (Figure 14; Appendix 2). A 100ML increase in discharge would result in a 26% (16% to 36%) increase in expected Murray cod movements between systems. The number of daily Murray cod transitions between Murray River and the anabranch has two peaks and two troughs (Figure 15). The largest peak is during October and November, with the smaller peak in April and May. The depths of the troughs are in February and August.

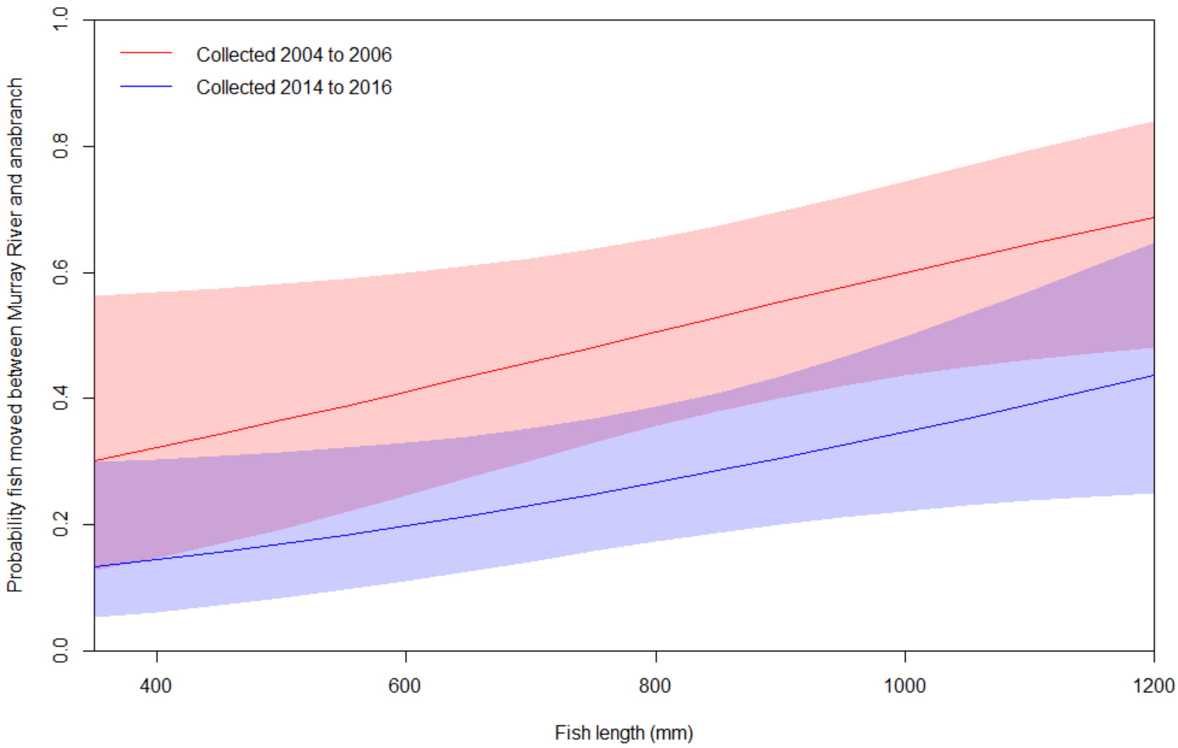


Figure 10. The probability (± 95% CI) of Murray cod transition between the Murray River and anabranch habitats in relation to fish length during the two periods of data collection.

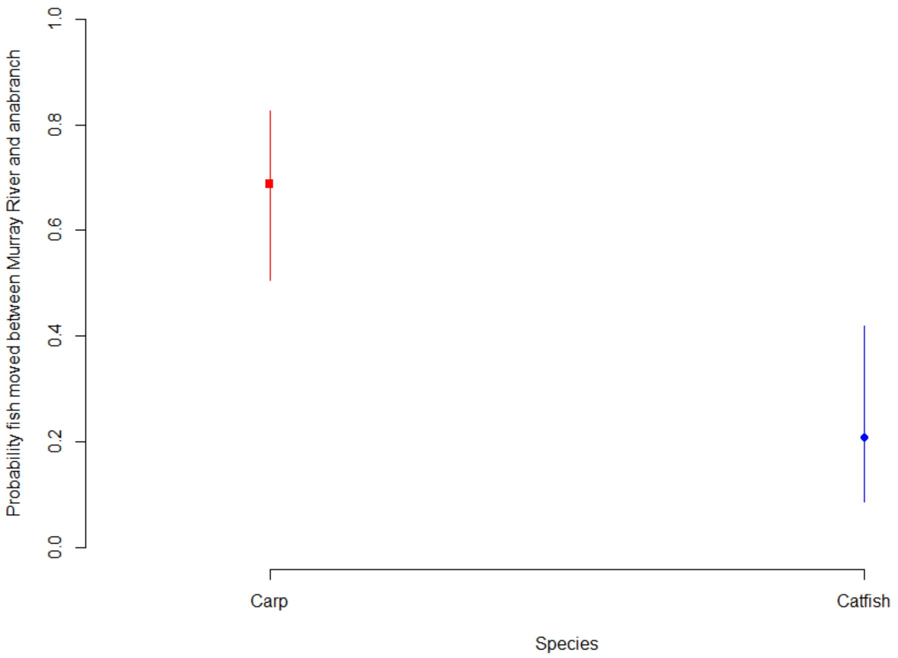


Figure 11. The probability of carp or catfish transition between the Murray River and anabranch habitats monitored in the study. Shaded region represents 95% confidence intervals.

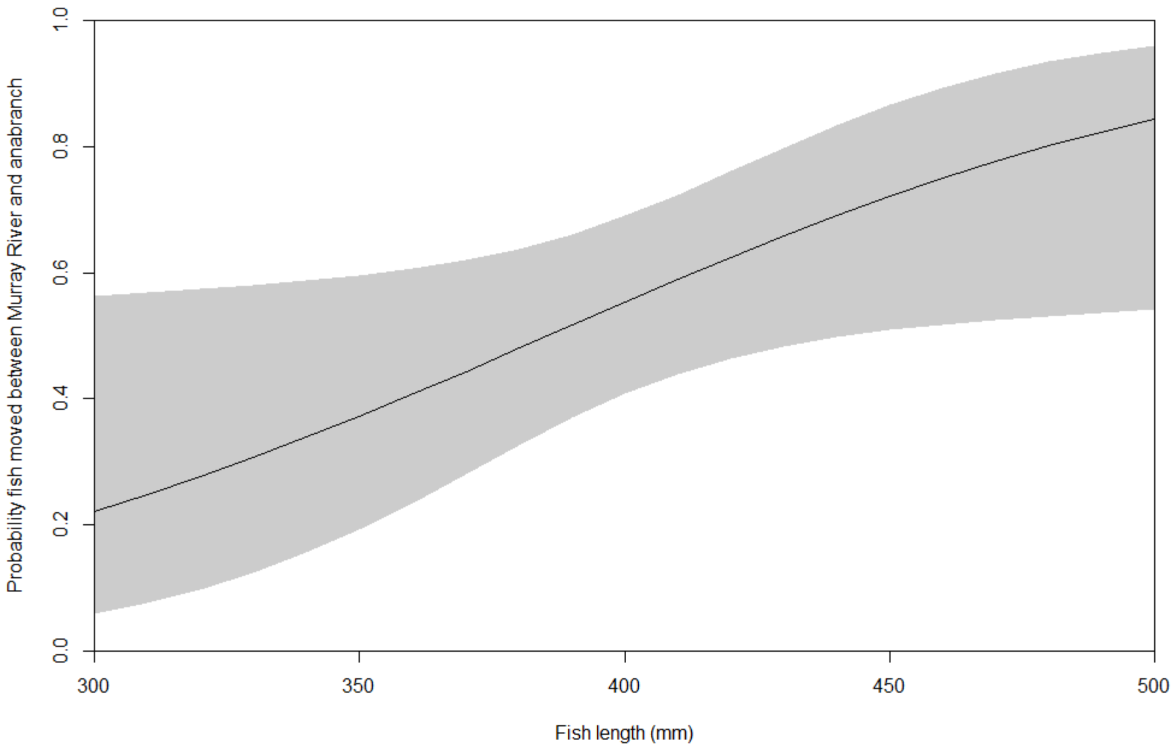


Figure 12. The probability (± 95% CI) of Golden Perch transition between the Murray River and anabranch habitats monitored in the study.

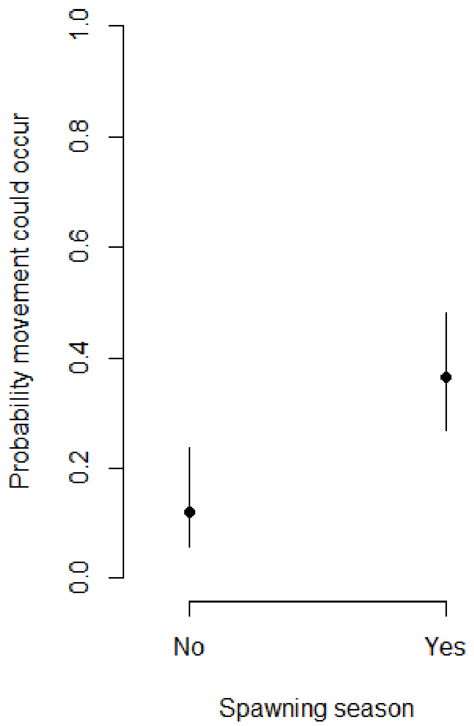


Figure 13. The probability of Murray cod transition between the Murray River and anabranch habitats on a given day during (September – December) and outside the spawning period. Shaded region represents 95% confidence intervals.

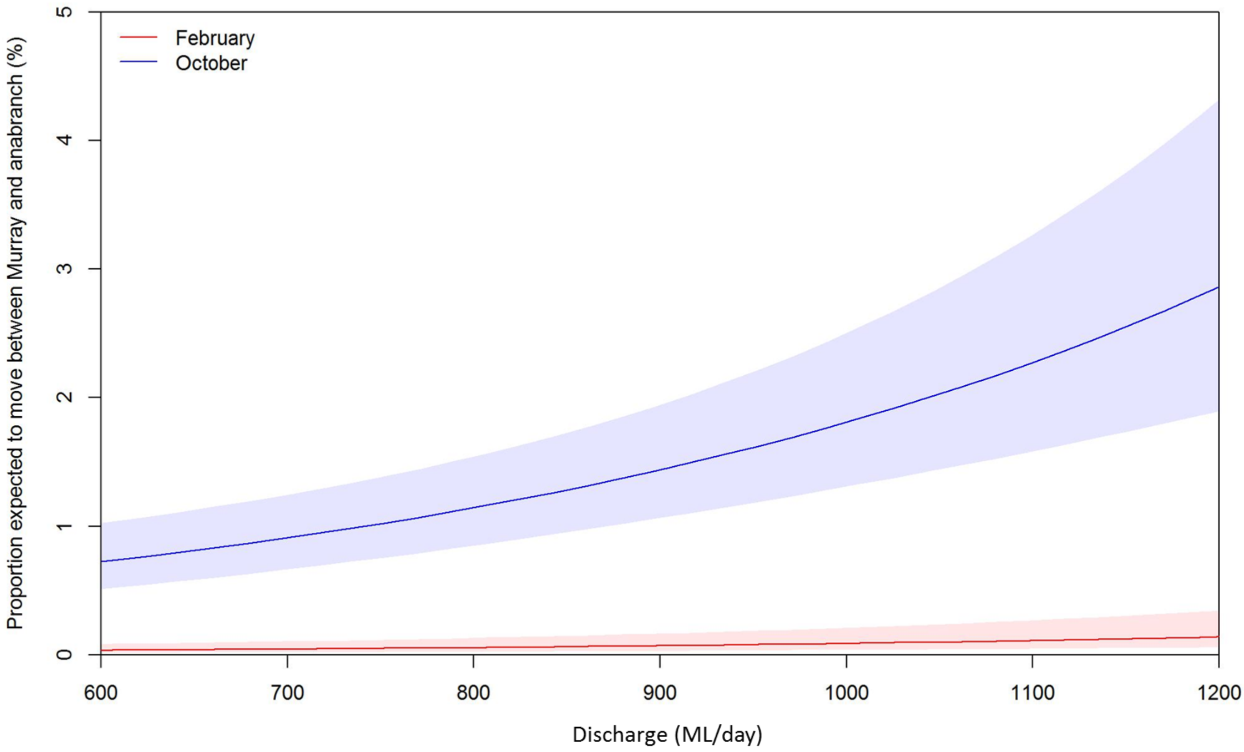


Figure 14. Proportion of Murray cod expected to transition between the Murray River and anabranch habitats relative to average daily discharge in the Mullaroo Creek on any day in February and October. Shaded region represents 95% confidence intervals.

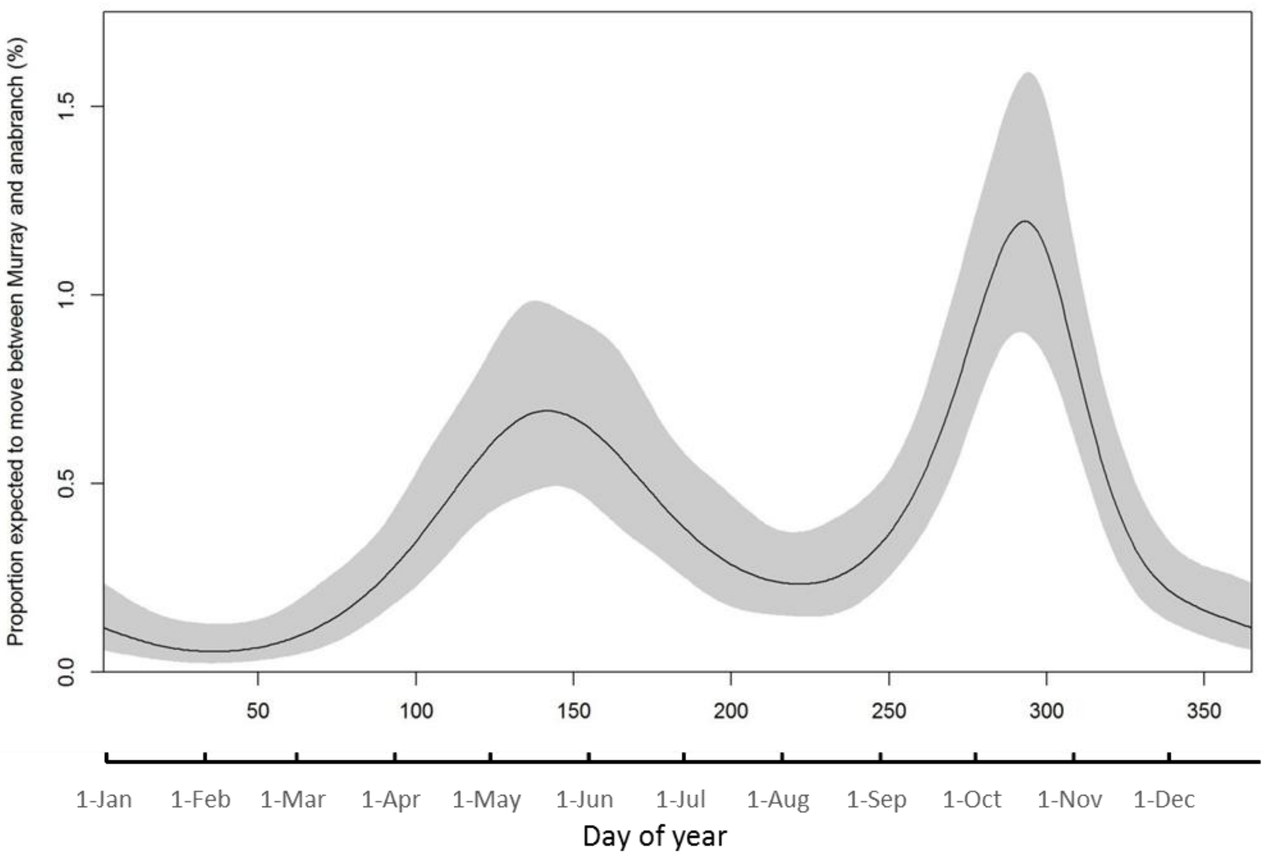


Figure 15. Proportion of Murray cod expected to move on a day given average discharge. Shaded region represents 95% confidence intervals.

4 Discussion

A key factor influencing population dynamics of any taxa is connectivity. The degree of connection that occurs within populations of animals, or indeed between populations of animals, drives processes that govern, in essence, the fate of species (Levin 1992; Lyon et al. 2014). This study is collating valuable information on the use and cues to accessing main river channel and anabranch habitats. Importantly, our data has generated a series of 'sentinel behaviours' (and fish) for comparisons with fish movement data collections following floodplain infrastructure construction and operation.

Data collected since March 2014 have high detection (100% of tagged fish) and transition rates (57% of tagged fish) between zones throughout the lower Murray River and Lindsay and Mulcra Island anabranch systems for all four study species. The multitude of fish movements between anabranches and the Murray River main channel further highlights the importance of access between these habitat types for fish in the region. Typical of fish movement studies, the patterns of fish movements displayed a high degree of spatiotemporal variability, both across and within species, with our preliminary analysis showing some interesting patterns of fish movement in response to fish size, timing and discharge.

Riverine fishes have been shown to use dispersal corridors between habitat types to fulfil a variety of life-history requirements, including spawning, foraging, refuge, and permanent migration to new habitats (Schlosser 1991; Crook 2004; Walther et al. 2011; Lyon et al. 2014). The data collected thus far already shows such patterns, with all four study species recorded transitioning between the Murray River and anabranch habitats. Our preliminary analysis demonstrated these transitions to vary between species, with carp having the highest probability of these moves, followed by golden perch, Murray cod and catfish respectively. Indeed, previous studies have demonstrated catfish to show extremely strong site fidelity (Koster et al. 2015). For golden perch and Murray codthe likelihood of transition increased with increasing fish length, a pattern previously recognised for Murray cod in the Mullaroo Creek (Saddlier et al. 2007).

Our analysis of Murray cod movement, specifically transition rates between anabranch habitats and the Murray River, which included previous data collections from 2004 – 2006 (Saddlier et al. 2007) also provides information on specific drivers and timing of these transitions. Firstly, a high proportion of adult Murray cod movements encompassed the upper Mullaroo Creek (zone B), with a greater proportion of Murray River - anabranch transitions representing a shift from the Murray River to the anabranch reaches during the spawning period, particularly the upper Mullaroo Creek. This highlights the previously suggested importance of this reach as a spawning area for the species due to its favourable hydraulic and woody habitat characteristics (Saddlier and O'Mahony 2009).

In addition to the influence of fish size, our analysis of Murray cod transition rates between anabranch habitats and the Murray River also highlights the significant effects of both discharge and time of year; as well as differences between the two time periods of data collection. Our models predict that on average, there are more days when Murray cod will move during spawning season compared to non-spawning season (36% to 12% respectively). Furthermore, the number of daily Murray cod movements between Murray River and the anabranch has two peaks and two troughs, with the largest peak occurring during October and November; and the smaller peak occurring in April and May. The depths of the troughs are in February and August. Similarly, Koehn and Harrington (2006) and Saddlier et al. (2007) observed adult Murray cod exhibiting seasonal movement patterns, with large-scale movements more commonly observed in the period from August to January. The most typically observed movement pattern comprised a sedentary period with limited movements and high site fidelity around a home site, a late winter/early spring upstream migration to a second home site, followed by a rapid downstream migration, where the individual often returned to its original location (Koehn and Harrington 2006). Thus, in addition to the peak in movement during the spawning period, the peak in April and May could be indicative of fish returning to home sites as described by Koehn and Harrington (2006).

The significant positive effect of discharge on Murray cod transition rates between anabranch habitats and the Murray River illustrate that more fish are likely to move between habitat types during periods of higher discharge in the Mullaroo Creek, particularly during the spawning period. For example, just a 100 ML increase in daily discharge during October would result in a 26% increase in expected number of Murray cod movements between systems. This result has important implications for the operation of the Mullaroo Creek regulator.

The effect of regulator construction and early operation perhaps explain why our analysis indicate significantly greater proportions of Murray cod were transitioning between habitat types during the first period of data collection (prior to regulator construction), as compared to the recent period of data collection. Alternatively, this pattern may be indicative of reduced fish passage following the construction of the recent Mullaroo Creek regulator (and fishway). Our exploration of signal strength recorded at the Mullaroo regulator logger tower enabled some exploration of patterns in fish transition from the Upper Mullaroo Creek to the Murray River, both during the period of the old ford structure, and in the first five months of operation of the new regulator (and fishway). The data indicates that whilst all four species were recorded to have successfully transitioned into the Murray River under both new and old (except catfish for the latter) structures, in all, a lower proportion of tagged fish which approached the Mullaroo Creek regulator made the transition. Furthermore, whilst the number of fish and approaches were relatively similar (pre and post construction), the proportion of accents reduced slightly with the new regulator / fishway. Although Murray cod (and golden perch) can successfully ascend the fishway, repeated approaches to the regulator may indicate upstream movements are delayed. Optimising the regulator gates/flow to attract fish to the fishway entrance may also help to increase fish ascents. Of course, these observations are preliminary, with fish needing some time to adjust to the new structure. Continued monitoring is required to confirm and refine the effects of discharge and the new fishway on transition rates for Murray cod, as well as other species in the system.

5 Future direction

The collection of additional data in coming years which encompass a variety of flow conditions will enable further refinement of the models and expanding the analysis to the other species. Importantly, this will enable an assessment of how fish migratory patterns may be influenced by the operation of the new infrastructures, and responses to environmental water delivery.

It is imperative to continue annual fish tagging and maintenance routine as has been undertaken thus far. Limitations associated with battery life of transmitters (eight months to four years) dictate that an annual tagging trip is undertaken to ensure sufficient replicates for each fish species are present for effective monitoring and data analysis of a range of flow and operational conditions. Secondly, biannual maintenance of data loggers and data downloading is necessary in late winter and summer. The late winter download will ensure that the loggers are able to maintain sufficient memory preceding the the core reproductive period when large volumes of data will be recorded. The summer download will ensure sufficient memory is available to record fish movement over the following six month period. In conjunction with the logger downloads, battery and logger integrity shall be maintained. These bi-annual trips will also provide opportunities for manual tracking of fish to determine within zone habitat selection and identify post spawning mortality (if any). We also recommend future automation of priority loggers to allow remote data acquisition and prevent data loss due to storage limitations. Automation will also alert researchers of any logger issues immediately (such as loss of battery power and/or component malfunctions), thus reducing the risk of loggers being off-line for extended periods of time.

Specific topics of key interest following operation of the floodplain regulators include:

- Continued monitoring of fish transitions between the Murray River and upper Mullaroo Creek under a range operational scenarios including:
    - Simulated flooding;
    - Increased spring discharge at levels above 600 ML/day; For example, a gradual increase to 1000 ML/day from October – December.
    - different regulator operational scenarios, particularly under different gate and weir pool height scenarios;
- Habitat use (using targeted point measures of tagged fish) and possible expansion of preferred habitat availability under new floodplain operations (for both native and exotic species). Some of this data has already been collected from freshwater catfish during the first year of the study.

We also suggest incorporating specific information on weir pool levels and regulator gate configurations into any future data analysis on fish movement. There is also scope for incorporation of Murray cod movement data collected in the Chowilla anabranch region of the Icon site (Brenton Zampatti unpublished data) into future analyses following regulator operations. This will improve the analytical power and test the transferability of results across the Murray Darling Basin.

The short and long term influences of hydrological and hydraulic alterations following artificial floodplain inundation (and subsequent organic carbon input) on key components of life-history, population structure and movement of both native and exotic fish in Australian temperate floodplain ecosystems is unknown, but vital to the long-term sustainability of the fish community. Collection and incorporation of ecological data and scientific representation into regulator operational procedures will be an important component in the management of future watering regimes within the Icon site.

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Appendix 1. Size and tag details of individual fish implanted with radio telemetry tags in the Lindsay Island anabranch study from March 2014 – April 2016.

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Murray cod	a	890	10500	132.1	Tag active
Murray cod	b	919	12600	132.2	Tag active
Murray cod	a	957	13500	132.3	Tag active
Murray cod	a	1050	22000	132.4	Tag active
Murray cod	a	1120	24000	132.5	Tag active
Murray cod	a	832	9239	132.6	Tag active
Murray cod	a	931	12300	132.8	Tag active
Murray cod	a	848	8650	132.9	Tag active
Murray cod	a	840	9000	132.27	Tag active
Murray cod	a	732	5200	132.28	Tag active
Murray cod	b	713	5191	132.32	Tag active
Murray cod	i	880	11000	153.1b	Tag active
Murray cod	i	920	12000	153.2b	Tag active
Murray cod	i	1140	25000	153.3b	Tag active
Murray cod	i	720	8000	153.4a	Tag active
Murray cod	i	718	5300	153.4b	Tag active
Murray cod	i	965	14000	153.5b	Tag active
Murray cod	b	760	8200	153.11	Tag active
Murray cod	d	720	5976	153.12	Tag active
Murray cod	d	815	10400	153.13	Tag active
Murray cod	b	885	14000	153.14	Tag active
Murray cod	d	955	16400	153.16	Tag active
Murray cod	b	1140	24000	153.18	Tag active
Murray cod	b	579	2826	153.21	Tag active
Murray cod	d	870	14200	153.23	Tag active
Murray cod	b	1060	21000	153.27	Re-used tag
Murray cod	b	990	18500	153.32	Tag active
Murray cod	b	980	17000	153.33	Tag active
Murray cod	d	980	15500	153.34	Tag active
Murray cod	b	1210	34800	153.35	Tag active

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Murray cod	b	885	12500	153.36	Tag active
Murray cod	i	1150	26000	153.45	Tag active
Murray cod	i	1190	32000	153.46	Tag active
Murray cod	i	1010	18000	153.47	Tag active
Murray cod	i	1080	24000	153.48	Tag active
Murray cod	i	712	8500	153.49	Tag active
Murray cod	b	360	462	153.54	Tag active
Murray cod	b	379	630	153.57	Tag active
Murray cod	b	377	606	153.58	Tag active
Murray cod	b	395	732	153.61	Tag active
Murray cod	d	303	359	153.63	Tag active
Murray cod	b	384	709	153.64	Tag active
Murray cod	b	1150	29000	173.5	Tag active
Murray cod	b	588	3130	173.11	Angled
Murray cod	d	680	5150	173.12	Tag active
Murray cod	d	660	5190	173.13	Tag active
Murray cod	d	890	12900	173.14	Tag active
Murray cod	b	835	11000	173.15	Tag active
Murray cod	b	527	2100	173.16	Tag active
Murray cod	b	855	9900	173.17	Tag active
Murray cod	b	637	3940	173.18	Tag active
Murray cod	b	625	3542	173.19	Tag active
Murray cod	d	519	1908	173.2	Tag active
Murray cod	b	550	2700	173.21	Tag active
Murray cod	b	640	4256	173.22	Tag active
Murray cod	b	611	3408	173.23	Angled
Murray cod	b	835	10000	173.24	Tag active
Murray cod	b	900	13400	173.26	Mortality
Murray cod	b	825	9000	173.32	Tag active
Murray cod	b	1100	26900	173.33	Tag active
Murray cod	b	1080	25400	173.34	Tag active
Murray cod	b	1160	35000	173.35	Tag active
Murray cod	b	640	4100	173.36	Tag active
Murray cod	b	392	726	173.52	Tag active
Murray cod	b	366	565	173.54	Tag active
Murray cod	d	299	356	173.55	Tag active

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Murray cod	b	383	633	173.57	Tag active
Murray cod	b	381	669	173.58	Tag active
Murray cod	b	354	488	173.59	Tag active
Murray cod	a	860	9700	234.3	Tag active
Murray cod	d	1080	21200	234.31	Tag active
Murray cod	d	855	10150	234.32	Tag active
Murray cod	d	960	14000	234.33	Tag active
Murray cod	b	712	5315	234.44	Tag active
Murray cod	b	740	6200	234.45	Tag active
Golden perch	d	404	948	132.11	Tag expired
Golden perch	b	374	740	132.12	Tag expired
Golden perch	d	402	974	132.15	Tag expired
Golden perch	b	395	826	132.16	Angled
Golden perch	b	376	802	132.17	Tag expired
Golden perch	d	397	894	132.18	Tag expired
Golden perch	b	493	1242	132.19	Tag expired
Golden perch	b	359	750	132.2	Angled
Golden perch	b	436	1202	132.22	Tag expired
Golden perch	b	413	1038	132.23	Tag expired
Golden perch	b	376	784	132.24	Tag expired
Golden perch	b	402	940	132.26	Tag expired
Golden perch	a	536	2170	132.35	Tag active
Golden perch	b	395	980	132.37	Tag active
Golden perch	b	430	1024	132.38	Tag active
Golden perch	i	402	900	132.4	Tag active
Golden perch	d	421	985	132.41	Tag active
Golden perch	i	428	1385	132.42	Tag active
Golden perch	d	418	970	132.43	Tag active
Golden perch	b	433	1210	132.44	Tag active
Golden perch	b	415	1035	132.45	Tag active
Golden perch	b	400	952	132.46	Tag active
Golden perch	d	478	1508	153.2	Tag active
Golden perch	i	475	1820	153.28	Tag active
Golden perch	b	386	846	153.5	Tag active

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Golden perch	b	420	1130	153.51	Tag active
Golden perch	b	359	635	153.52	Tag active
Golden perch	b	421	1057	153.53	Tag active
Golden perch	a	447	1118	153.55	Tag active
Golden perch	a	405	819	153.56	Tag active
Golden perch	a	359	618	153.59	Tag active
Golden perch	a	438	1077	153.6	Tag active
Golden perch	d	353	573	153.62	Tag active
Golden perch	i	451	1450	173.4	Tag active
Golden perch	i	480	1690	173.6	Mortality
Golden perch	a	435	1160	173.3	Tag active
Golden perch	a	443	1237	173.31	Tag active
Golden perch	b	425	1100	173.38	Angled
Golden perch	i	380	940	173.39	Tag active
Golden perch	d	460	1135	173.4	Tag active
Golden perch	i	465	1250	173.41	Tag active
Golden perch	i	490	1860	173.42	Angled
Golden perch	i	440	1080	173.43	Tag active
Golden perch	b	360	860	173.45	Mortality
Golden perch	a	398	983	173.47	Tag active
Golden perch	a	408	988	173.48	Tag active
Golden perch	d	445	1168	173.5	Tag active
Golden perch	d	396	750	173.51	Tag active
Golden perch	a	387	858	173.53	Tag active
Golden perch	d	412	778	173.56	Tag active
Golden perch	d	398	627	173.6	Tag active
Golden perch	b	402	937	173.61	Tag active
Golden perch	d	423	1159	173.62	Tag active
Golden perch	a	453	1055	173.63	Tag active
Golden perch	d	404	908	173.64	Tag active
Golden perch	d	375	700	234.1	Tag expired
Golden perch	d	370	670	234.2	Angled
Golden perch	b	446	1340	234.2	Re-used tag
Golden perch	i	320	570	234.3	Tag expired

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Golden perch	i	430	1148	234.4	Tag expired
Golden perch	i	456	1140	234.5	Tag expired
Golden perch	d	405	940	234.6	Tag expired
Golden perch	d	386	720	234.8	Tag expired
Golden perch	d	353	630	234.9	Tag expired
Golden perch	d	340	570	234.12	Tag expired
Golden perch	i	374	790	234.13	Tag expired
Golden perch	d	423	1080	234.16	Tag expired
Golden perch	b	375	718	234.17	Tag expired
Golden perch	d	357	644	234.24	Tag expired
Golden perch	a	466	1695	234.29	Tag active
Golden perch	b	360	666	234.34	Tag expired
Golden perch	d	335	532	234.36	Tag expired
Golden perch	b	350	522	234.39	Tag expired
Golden perch	b	310	402	234.59	Tag expired
Golden perch	d	403	660	234.6	Tag expired
Golden perch	b	310	430	234.65	Tag expired
Catfish	b	470	902	132.13	Tag expired
Catfish	b	457	894	132.14	Tag expired
Catfish	b	520	1234	132.21	Tag expired
Catfish	b	497	1100	173.29	Tag active
Catfish	b	490	1150	234.11	Tag active
Catfish	i	485	960	234.14	Tag expired
Catfish	i	401	535	234.15	Tag expired
Catfish	b	458	900	234.18	Tag expired
Catfish	d	348	366	234.19	Tag expired
Catfish	b	426	610	234.2	Tag expired
Catfish	d	465	682	234.21	Tag expired
Catfish	b	430	714	234.22	Tag expired
Catfish	b	465	902	234.23	Tag expired
Catfish	b	398	516	234.26	Tag expired
Catfish	b	407	624	234.35	Tag expired
Catfish	b	380	438	234.38	Tag expired
Catfish	b	432	622	234.4	Tag expired

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Catfish	d	450	806	234.41	Tag expired
Catfish	d	435	696	234.42	Tag expired
Catfish	b	398	550	234.58	Tag expired
Catfish	b	438	824	234.62	Tag expired
Catfish	d	450	728	234.63	Tag expired
Catfish	d	361	372	234.64	Tag expired
Catfish	b	405	640	234.66	Tag expired
Catfish	i	445	650	234.75	Tag expired
Carp	i	520	2860	132.2	Re-used tag
Carp	b	600	3398	132.29	Tag active
Carp	b	578	3468	132.3	Tag active
Carp	a	618	3750	132.31	Tag active
Carp	b	547	2199	132.33	Tag active
Carp	a	630	4320	132.34	Tag active
Carp	b	610	4367	132.36	Tag active
Carp	i	380	940	132.39	Tag active
Carp	a	575	3090	132.47	Tag active
Carp	a	632	4310	132.48	Tag active
Carp	i	515	1670	153.1a	Tag active
Carp	d	545	2222	153.2a	Tag active
Carp	i	585	2830	153.3a	Tag active
Carp	i	590	3515	153.5a	Tag active
Carp	b	635	4230	153.6	Tag active
Carp	i	640	4530	153.8	Tag active
Carp	i	550	2950	153.9	Tag active
Carp	e	608	3680	153.15	Tag active
Carp	b	640	2896	153.17	Tag active
Carp	e	640	3444	153.19	Tag active
Carp	e	603	3290	153.22	Tag active
Carp	e	440	1320	153.24	Tag active
Carp	b	502	1772	153.26	Angled
Carp	i	690	5550	153.26	Re-used tag
Carp	b	640	3470	153.27	Angled
Carp	i	695	5950	153.4	Tag active

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Carp	i	480	1936	153.41	Tag active
Carp	i	605	3934	153.42	Tag active
Carp	i	470	1506	153.43	Tag active
Carp	i	715	6050	153.44	Tag active
Carp	b	590	3040	173.1	Tag active
Carp	b	680	4840	173.2	Tag active
Carp	b	680	5250	173.3	Tag active
Carp	b	504	1920	173.8	Tag active
Carp	b	645	3050	173.9	Tag active
Carp	i	580	3250	173.23	Re-used tag
Carp	b	555	2590	173.27	Tag active
Carp	b	565	2720	173.28	Tag active
Carp	i	386	1180	173.37	Tag active
Carp	d	669	5138	173.38	Re-used tag
Carp	d	437	1514	173.44	Re-used tag
Carp	i	390	930	173.44	Angled
Carp	i	490	1890	173.46	Tag active
Carp	a	488	1935	234.27	Tag active
Carp	a	665	5555	234.28	Tag active
Carp	a	462	1887	234.43	Tag active
Carp	a	594	3435	234.46	Tag active
Carp	a	592	3328	234.47	Tag active
Carp	a	628	3350	234.48	Tag active
Carp	a	626	4300	234.49	Tag active
Carp	a	616	4280	234.5	Tag active

Appendix 2. Model selection parameters for the anabranch – Murray River transition analysis.

Table 1a: Comparison between potential models for Murray cod moving between Murray River and anabranch systems.

Model	AICc	ΔAICc	Evidence Ratio
Length + Period	146.0		
Length * Period	148.2	2.1	2.9
Period	148.8	2.7	3.9
Length	150.4	4.4	9.1
Null	155.0	9.0	88.9

Table 4a: Parameter estimates for Murray cod moving between Murray River and Anabranch model. Estimates are in logit (log-odds) scale and zLength is the standardised lengths of the fish.

Parameter	Estimate	Standard Error	*p*-value
Constant	-1.00	0.28	0.0003
zLength	0.47	0.22	0.0325
Period is 2004 to 2006	1.04	0.41	0.0114

Table 5a: Comparison between potential models for Carp moving between Murray River and anabranch systems.

Model	AICc	ΔAICc	Evidence Ratio
Null	41.9		
Length	43.6	1.7	2.4

Table 6a: Comparison between potential models for Catfish moving between Murray River and anabranch systems.

Model	AICc	ΔAICc	Evidence Ratio
Null	26.7		
Length	29.1	2.3	3.2

Table 7a: Comparison between potential models for Golden Perch ever moving between Murray River and anabranch systems.

Model	AICc	ΔAICc	Evidence Ratio
Length	70.6		
Null	73.5	2.8	4.1

Table 8a: Parameter estimates for the Golden Perch ever move between Murray River and Anabranch model. Estimates are in logit (log-odds) scale and zLength is the standardised lengths of the fish.

Parameter	Estimate	Standard Error	*p*-value
Constant	0.26	0.29	0.3834
Length	0.67	0.32	0.0354