

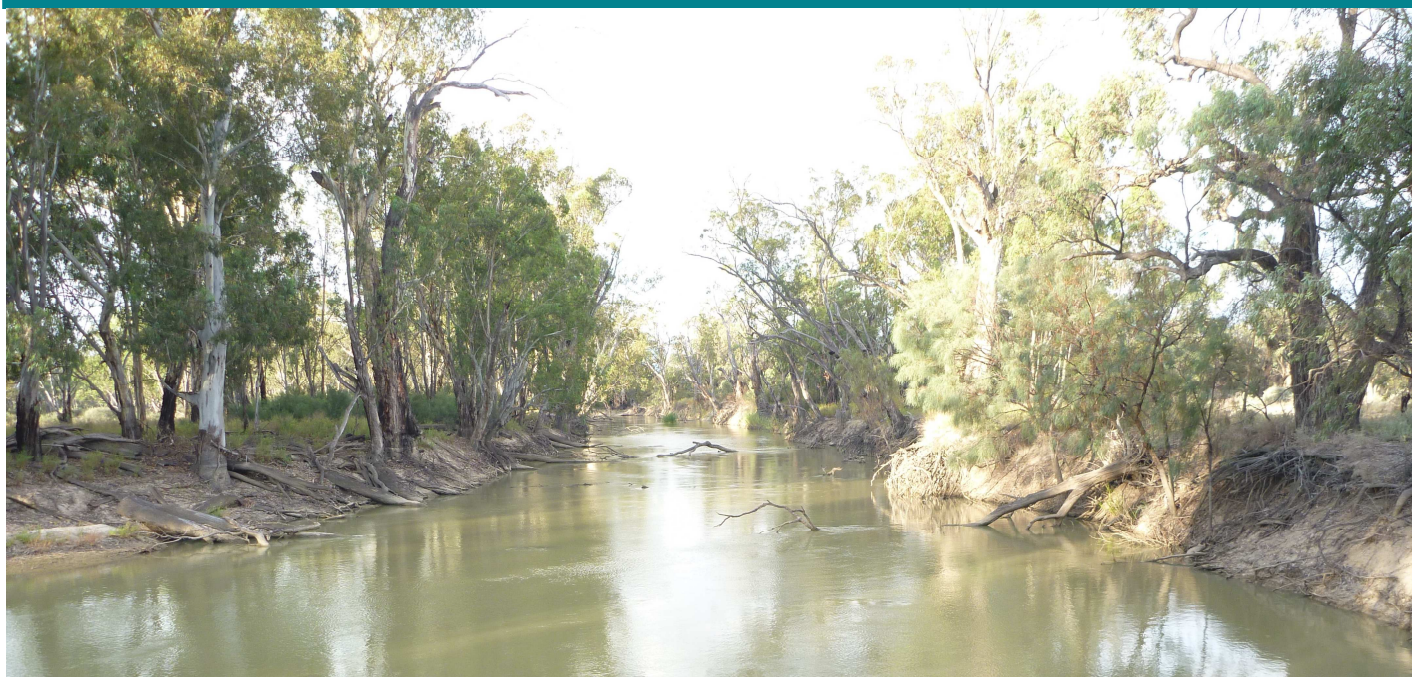
Fish movement through the Lindsay Island anabranch system: 2015 Activity report

Z. Tonkin, J. O'Mahony, S. Raymond and Lyon, J.

November 2015

Arthur Rylah Institute for Environmental Research

Unpublished Client Report for the Mallee Catchment Management Authority



Fish movement through the Lindsay Island anabranch system: 2015 Activity report

Zeb Tonkin, Justin O'Mahony, Scott Raymond and Jarod Lyon

Arthur Rylah Institute for Environmental Research
123 Brown Street, Heidelberg, Victoria 3084

November 2015

Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
Heidelberg, Victoria

Report produced by: Arthur Rylah Institute for Environmental Research
Department of Environment, Land, Water and Planning
PO Box 137
Heidelberg, Victoria 3084
Phone (03) 9450 8600
Website: www.delwp.vic.gov.au

Citation: Tonkin, Z., J. O'Mahony, J., Raymond, S. and Lyon, J. (2015). Fish movement through the Lindsay Island anabranch system: 2015 Activity report. Unpublished Client Report for the Mallee Catchment Management Authority. Arthur Rylah Institute for Environmental Research. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

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

© The State of Victoria Department of Environment, Land, Water and Planning 2015



This work is licensed under a Creative Commons Attribution 3.0 Australia licence. You are free to re-use the work under that licence, on the condition that you credit the State of Victoria as author. The licence does not apply to any images, photographs or branding, including the Victorian Coat of Arms, the Victorian Government logo, the Department of Environment, Land, Water and Planning logo and the Arthur Rylah Institute logo. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/3.0/au/deed.en>

Accessibility

If you would like to receive this publication in an alternative format, please telephone the DELWP Customer Service Centre on 136 186, email customer.service@delwp.vic.gov.au or contact us via the National Relay Service on 133 677 or www.relayservice.com.au. This document is also available on the internet at www.delwp.vic.gov.au

Disclaimer

This publication may be of assistance to you but the State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

Contents

Acknowledgements	3
.....	
Summary	4
.....	
1 Background	5
.....	
2 Methodology	6
.....	
2.1 Study site and logging towers	6
2.2 Fish collection and tagging	8
.....	
3 Progress and preliminary results	10
.....	
3.1 Fish tagging and logger array update	10
3.2 Fish movements 2014- 2015	11
.....	
5 Future direction	18
.....	
References	19
.....	
Appendix 1. Size and tag details of individual fish implanted with radio telemetry tags in Lindsay Island anabranh study from March 2014 – August 2015.	20
.....	

Acknowledgements

We thank the Murray Darling Basin Authority (The Living Murray Program) and Mallee Catchment Management Authority for funding and continued interest in this research. In particular, we would like to acknowledge Andrew Greenfield from the Mallee Catchment Management Authority; the staff from Parks Victoria Werrimull office and the local landholders of the Murray Sunset National Park and surrounding region for accommodating our access to study sites. Joanne Kearns (Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning) is thanked for comments on a draft review of this report. This work was carried out under the Victorian Fisheries Research Permit RP827, FFG Research Permit 10007273 and animal ethics approval 14/04.

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 Murrumbidgee 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 region 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 regime and high density of instream habitat. Any flow modifications resulting from the operation of the new regulating structures must therefore consider the habitat and migration requirements of important native fish populations 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 activity report provides an update of tagged fish and fish detections following the first year of the study.

In March 2014, five data logging stations were installed at strategic locations along the Murrumbidgee Creek and Lindsay River study site. An additional two logging stations were installed on the upper and lower Potterwalkagee Creek in May 2015. This array, when used in combination with signal strength and detection time, records individual fish movement and occupancy of 11 distinct zones in a study area containing a variety of both river and anabranch habitats with a range of hydraulic conditions. A total of 135 fish have been tagged with radio transmitters during the study thus far, with 110 of these fish still at large in the system. Specifically, the Murrumbidgee Creek and Lindsay River reaches currently hold 66 tagged fish, comprising of 33 Murray cod, 18 golden perch, 14 carp and a single catfish. The Murray River (between Lock 7 – 8) currently holds 44 tagged fish, comprising of 11 Murray cod, 13 golden perch, 17 carp and three catfish.

Fish movement data collected from March 2014 – August 2015 recorded movements of 108 fish tagged in the Murrumbidgee Creek and Lindsay River region of the study. This represented more than 97% of all fish tagged, with 44% 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. These movements include those that appear to be associated with reproductive activity and range shifts. Also of particular note were records of all four study species moving between the Upper Murrumbidgee Creek and Murray River prior to the recent regulator and associated fishway construction; and several long distance movements, both upstream and downstream of the study site.

The data collated in the first year of the study has demonstrated encouraging results, with high detection and transition rates between zones throughout the Lindsay Island anabranch system. This will provide the basis of assessing the current migration and habitat use of fish within the Icon site, a deliverable for the program in June 2016. Importantly, the program provides a solid foundation to monitor future operations, but is reliant on the continuation of annual fish tagging (to maintain adequate sample sizes of tagged fish in the system) and biannual routine maintenance and data downloading.

1 Background

Regulation of the Murray River 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 (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, as well as important waterbird breeding habitat during flood events. 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 natural flows and flooding 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. In particular, the upper Mullaroo Creek is an important refuge and breeding ground for a number of native fish species, which are dependent on the systems unique hydraulic characteristics and high density of instream habitat (structural woody habitat) compared to sites within the lower Mullaroo Creek, Lindsay River and Murray River (Saddler and O'Mahony 2009). In particular, Murray cod from surrounding reaches including fish from both the Murray and Lindsay rivers showed a preference for the Mullaroo Creek during the spawning period (September to November; Saddler et al. 2008).

The influence of the new regulating structures on fish, positive or negative, will be dependent on regulator 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 Mullaroo Creek/Lindsay River system. In response, 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 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 this is influenced by changes in water management, particularly those induced by infrastructure construction and operation (fishways and regulators). This activity report provides an update of tagged fish, reach occupancy and fish detections following the first year of the study, and prior to any major infrastructure and operational changes in the system.

2 Methodology

2.1 Study site and logging towers

With the aforementioned *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 eleven 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 Saddler and O'Mahony (2009), with an additional logging station erected at a fork in the Upper Lindsay River. 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 are 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.

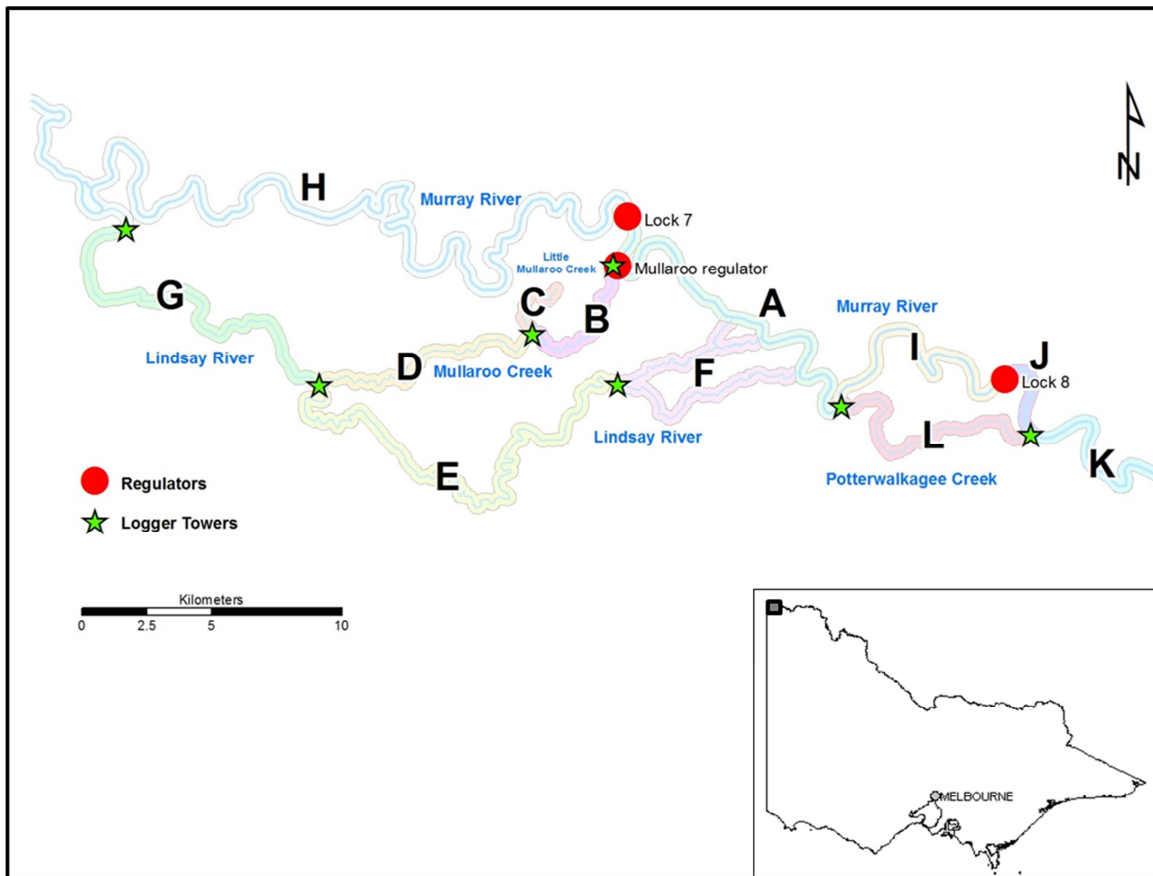


Figure 1. The Lindsay Island anabranch study site. Green stars represent data logging stations and letters represent fish tagging and movement zones.



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 (carp and freshwater catfish).

Surgical procedures used to implant fish radio-transmitters follow those outlined in O'Connor et al. (2009). Fish were sedated with Aqui-S at a concentration of 1.5 ml per 50 litres of water in which they were immersed. After fish were sedated (lack of observed movement) they were placed upside-down on an operating bench. 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 prevent 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 also marked with an external identification tag (T-bar or Dart) adjacent to the dorsal fin, and PIT (passive integrated transponder) tag. External tags display a telephone number for the reporting of fish capture data, which is 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.

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.

3 Progress and preliminary results

3.1 Fish tagging and logger array update

In May 2015, two additional logging towers were installed on the upper and lower Potterwalkagee Creek, respectively (see Figure 1). This enabled the detection of fish use of this anabranch following regulator construction and weir pool manipulation. The existing five data logging towers were also checked, data downloaded and subject to routine maintenance.

An additional 63 transmitters were transplanted into fish during May 2015 to maintain adequate numbers of tagged fish in the system. Specifically, one Murray cod, one catfish, 17 golden perch and 10 carp were tagged in the Mullaroo Creek; and six Murray cod, three catfish, 13 golden perch and 12 carp were tagged in the Murray River upstream of the Lower Potterwalkagee Creek. Three of the tagged 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 first year of the study. Six existing transmitter fish (all Murray cod occupying the Mullaroo Creek) were also recaptured during fish collections (using electrofishing surveys) with all individuals appearing in good health (two individuals had increased in length by 10 cm). Unfortunately, there were very few catfish captured (and tagged) this year, either due to inactivity (thus detection), or movement out of the study region.

A total of 155 fish have now been tagged with radio transmitters during the study thus far, with 110 of these fish still at large in the system (Table 2; 45 fish have either been captured or the battery life of the transmitter has elapsed). Specifically, the Mullaroo / Lindsay anabranch region currently holds 66 tagged fish, comprising of 33 Murray cod, one catfish, 18 golden perch and 14 carp (Table 2a). The Murray River (between Lock 7 – 8) currently holds 44 tagged fish, comprising of 11 Murray cod, three catfish, 13 golden perch and 17 carp (Table 2b). See appendix 1 for details of individual tagged fish.

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.

Species	Length Range (TL: mm)	Weight Range (g)	Total	No. detected	No. Changed zone	No. Active Transmitters
(a) Mullaroo / Lindsay						
Murray cod	519-1210	1908-35000	35	33	21	33
Catfish	348-520	366-1234	21	21	7	1
Golden perch	310-493	402-1508	39	38	17	18
Carp	440-680	1320-5250	16	16	4	14
TOTAL			111	108	49	66
(b) Murray R.						
Murray cod	712-1190	5300-32000	11	-	-	11
Catfish	401-485	535-960	3	-	-	3
Golden perch	320-490	570-1860	13	-	-	13
Carp	380-715	930-6050	17	-	-	17
TOTAL			44	-	-	44
SYSTEM TOTAL			155			110

3.2 Fish movements 2014- 2015

The first year of the study detected 108 of the 111 fish tagged in the Mullaroo creek / Lindsay River region of the study. This represented more than 97% of all fish tagged, with 44% of these fish having 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. Typical of fish movement studies, the patterns of fish movements displayed a high degree of spatiotemporal variability, both across and within species. Figures 4 – 7 provide examples of the variety of movements recorded for each of the study 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.

The most obvious pattern of movements was (unsurprisingly) the increasing likelihood of multiple zone movements to occur within spring and early summer, most likely associated with reproductive period of all four study species. Such movements associated with reproductive period appear to be largely triggered by increasing water temperatures and/or day length (Figure 8) however, further drivers of fish movement associated with hydrology and hydraulic characteristics of each zone will be investigated in 2016.

Other interesting and important observations for the first year of movement data include:

- The majority of adult Murray cod movements during the spawning period encompassed the upper Mullaroo Creek (zone A), which has previously been suggested as being important spawning reach for the species due to its favourable hydraulic and woody habitat characteristics (Saddler and O'Mahony 2009).
- Nine Murray cod, six golden perch, two catfish and two carp moved out of the upper Mullaroo Creek and into the Murray River before the regulator and associated fishway was constructed on the upper Mullaroo Creek. This indicates all four study species were able to use the previous infrastructure to complete what is obviously an important migratory pathway. Future investigation of this movement following the infrastructure installation will prove insightful into the effectiveness of the fishway.
- Several relatively large moves by tagged fish in the first year of the study include:
 - o 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.
 - o 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.
 - o 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.
 - o Murray cod **Fish ID 153.04** (720mm, 8000g, tagged downstream of Lock 8 on the 10/05/2015) detected on downstream antenna of Lock 7 fishway pit reader on most days between 23/10/2015 to 8/11/2015.
 - o 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).
- Several fish captured have previously been tagged prior to the 2011 blackwater event, thus indicating many fish survived this period of low dissolved oxygen. For example:

- o Murray cod **Fish ID 153.34** (980mm, 15500g, tagged in the lower Murrumbidgee Creek on the 29/3/2014) was a recapture and was first tagged on 11/11/2003 below Lock 2 @ 826mm);
- o Murray cod **Fish ID153.33** (980mm, 17000g, tagged in the upper Murrumbidgee Creek 27/03/2014) was a recapture from 1/8/2004 tagged in Murrumbidgee Creek (726mm, 5198g);
- o Murray cod **Fish ID 153.48** (1080mm, 24000g, tagged downstream of Lock 8 on the 18/8/2015) was a recapture from 24/08/2005 tagged below Lock 8 (432mm).
- Whilst not a direct objective of the project, manual tracking of the Murrumbidgee Creek, Lindsay River and the Murrumbidgee River upstream of Lock 7 during September 2014 and August 2015 was also conducted, whereby detailed site attributes including water velocity, depth and habitat attributes were recorded for individual catfish which may be analysed at a later date.

Fish movement through the Lindsay Island anabranch system

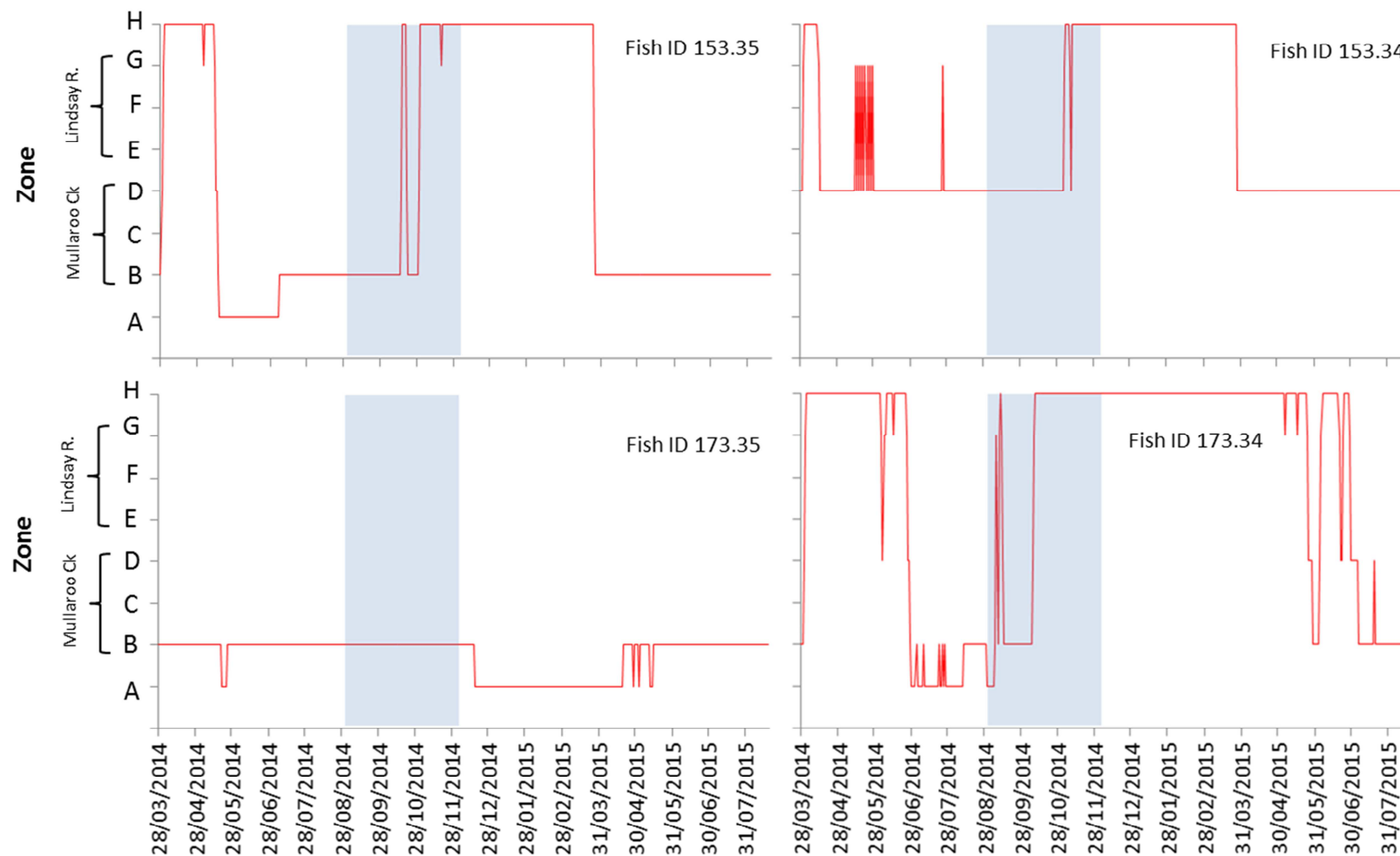


Figure 4. The movement patterns of four individual Murray cod between March 2014 and August 2015. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

Fish movement through the Lindsay Island anabranch system

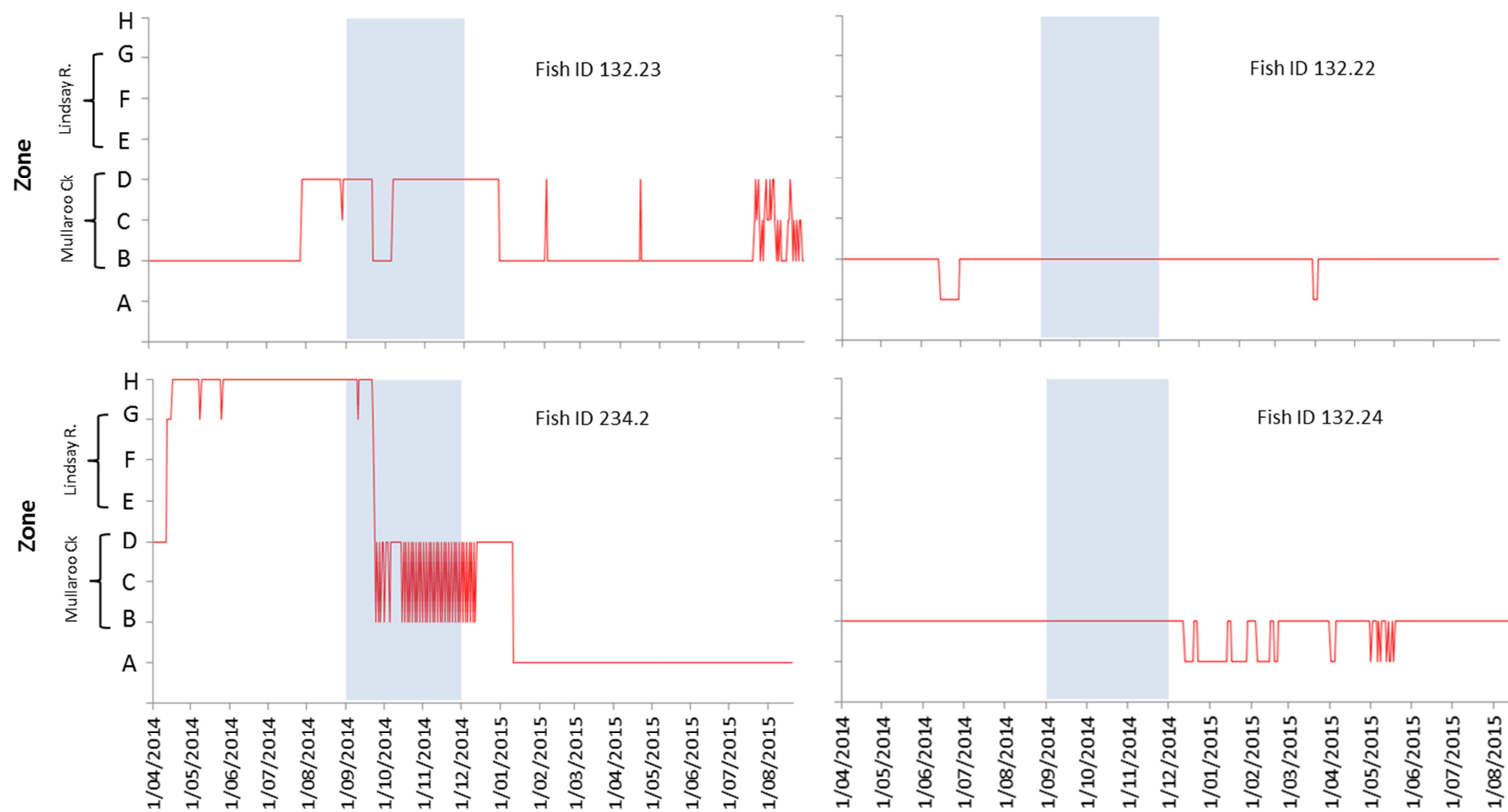


Figure 5. The movement patterns of four individual golden perch between March 2014 and August 2015. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

Fish movement through the Lindsay Island anabranch system

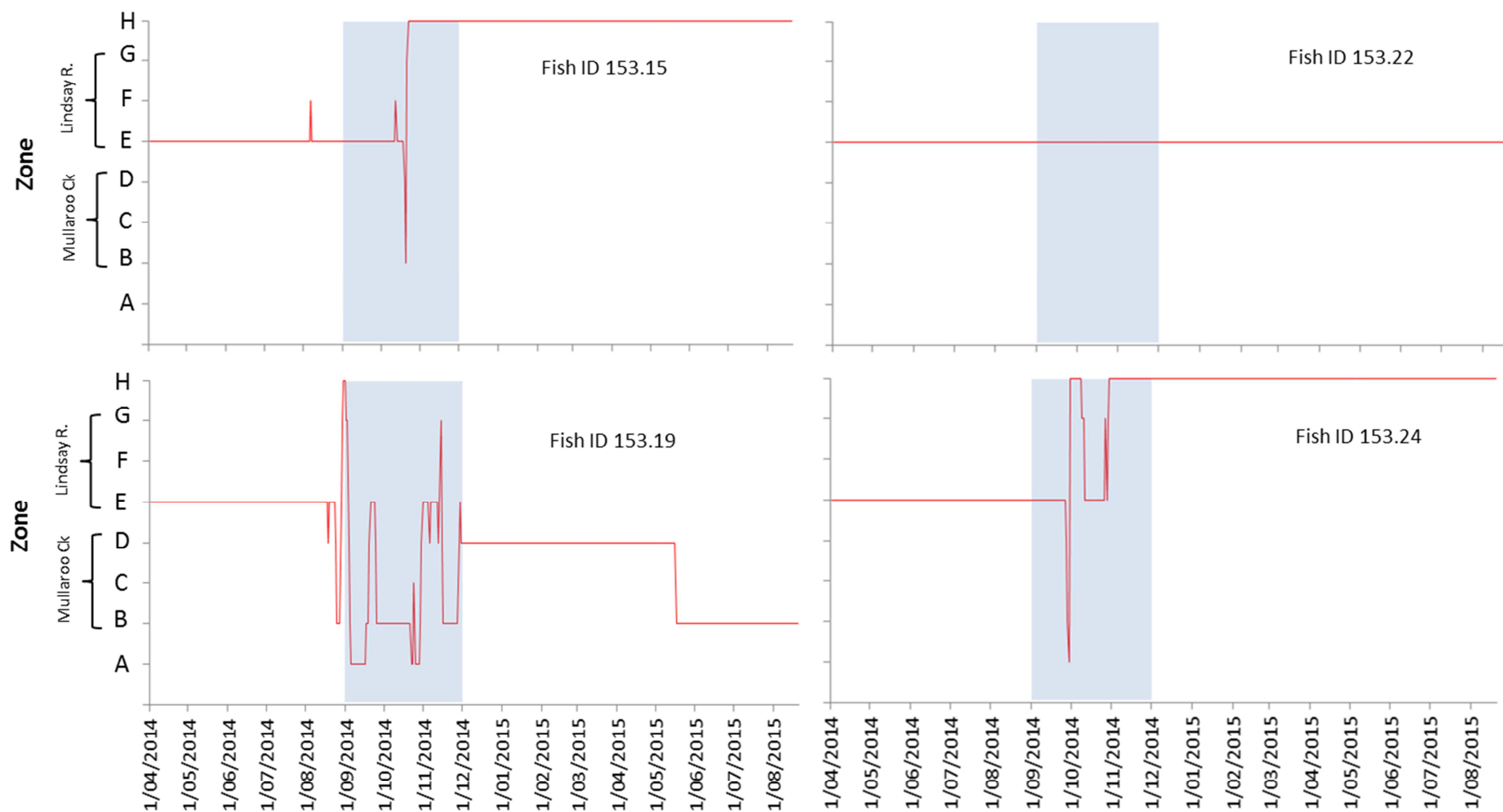


Figure 6. The movement patterns of four individual carp between March 2014 and August 2015. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

Fish movement through the Lindsay Island anabranch system

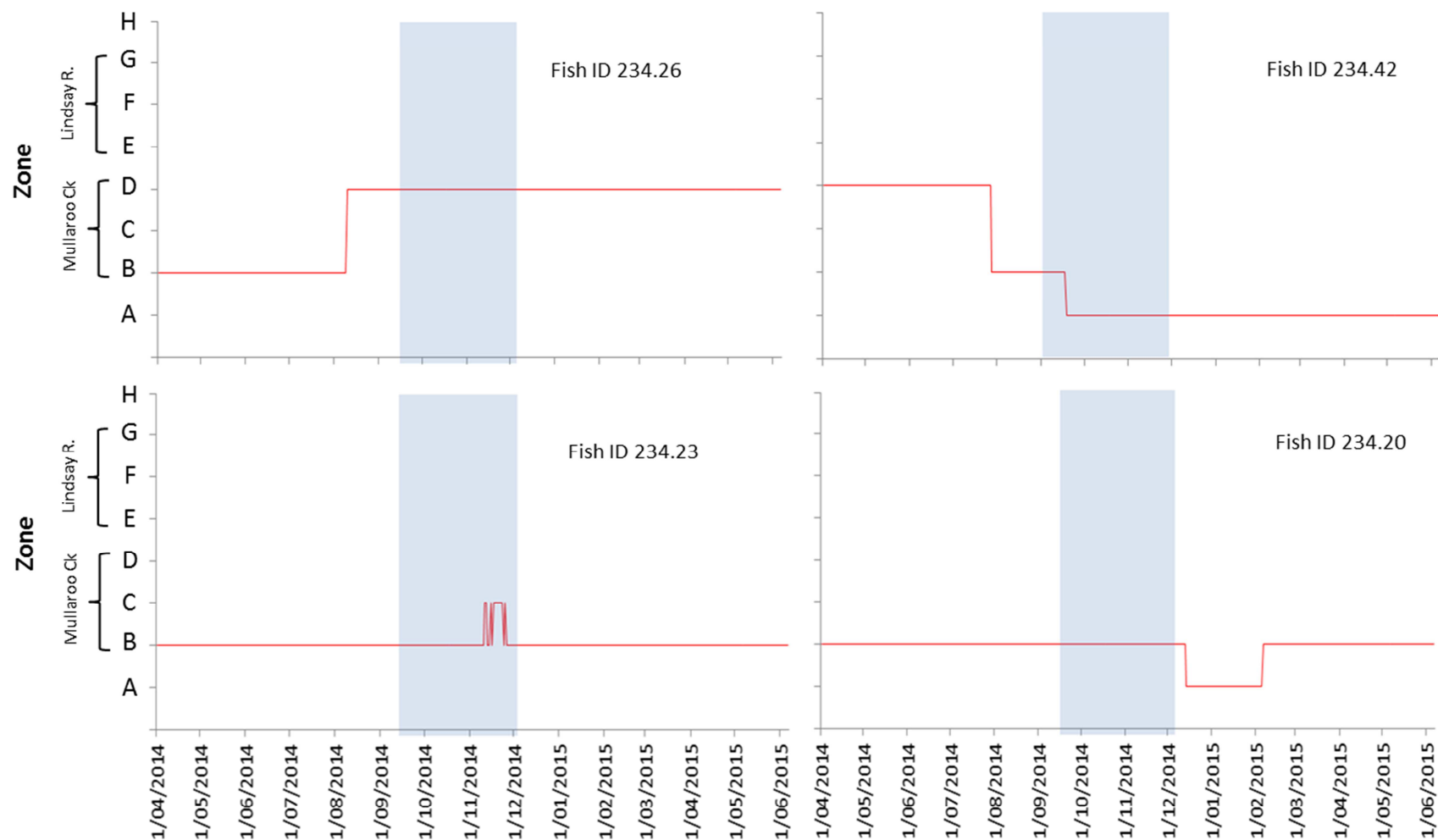


Figure 7. The movement patterns of four individual catfish between March 2014 and August 2015. Core reproductive period highlighted in blue shading. Letters denote specific zones of the study area (see Figure 1).

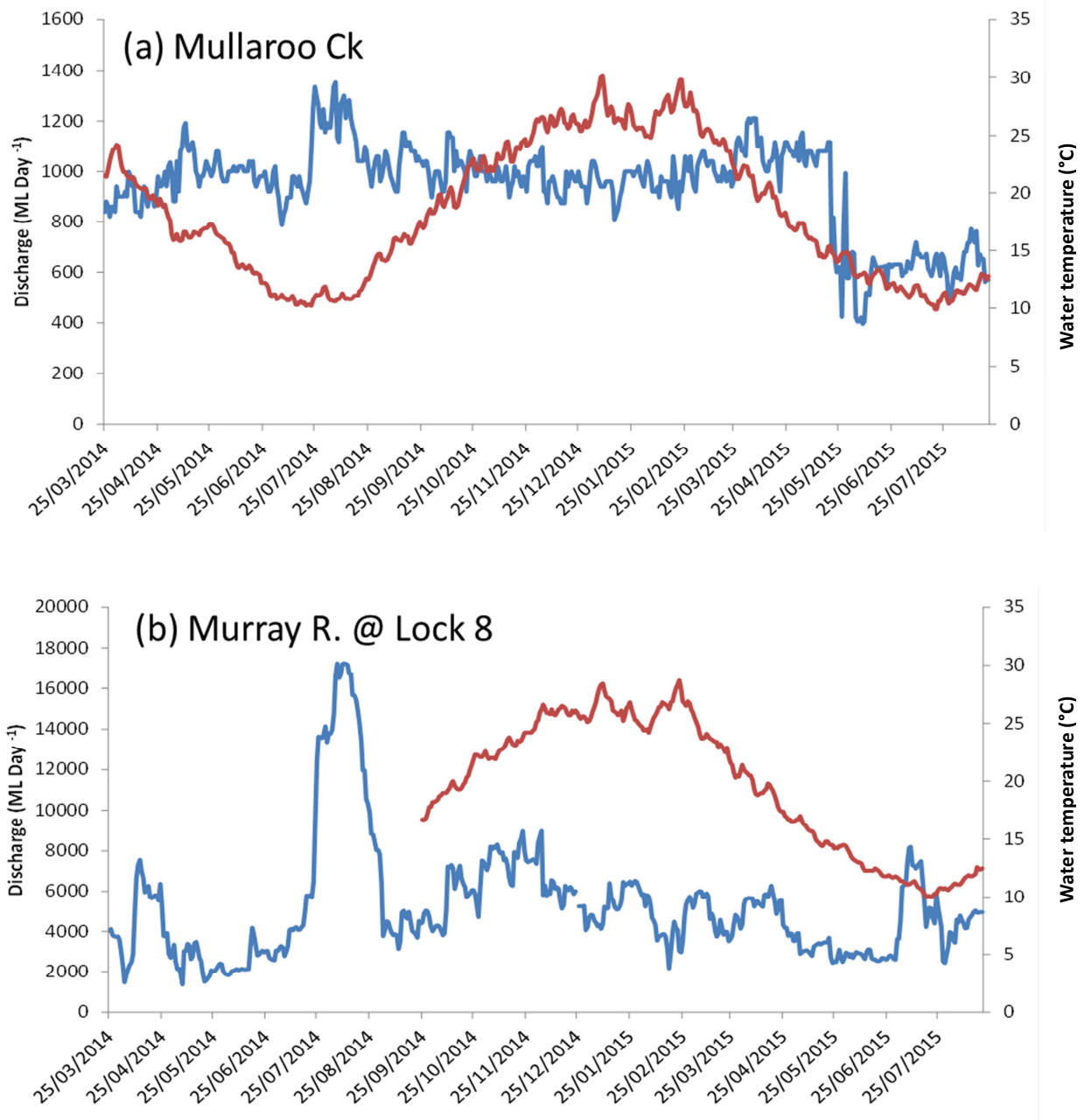


Figure 4. Average daily discharge (blue) and water temperature (red) in (a) Mullaroo Creek and; (b) the Murray River at Lock 8 during the monitoring period.

5 Future direction

The data collated in the first year of the study has demonstrated encouraging results, with high detection and transition rates between zones throughout the Lindsay Island anabranch system for all four species. The multitude of fish movements between anabranches and the Murray River main channel further highlights the importance of these habitats for fish in the region. The forthcoming formal analyses will aid the identification of the drivers of such movements, and importantly, enable an assessment of how this may change following the operation of the new infrastructures (regulator and fishway on Mullaroo Ck). Indeed, this data will provide the basis of such an assessment for the program in June 2016.

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

- Anabranch use by Murray cod during the spawning period, particularly the upper Mullaroo Creek during simulated flooding;
- Fishway use by the four study species on the Lindsay River and Mullaroo Creek under different regulator operational scenarios;
- Habitat use and possible expansion of preferred habitat availability under new floodplain operations (for both native and exotic species).

There is also scope for incorporation of Murray cod movement data collected in the earlier study (Saddler and O'Mahony 2009) and 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.

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 be undertaken to ensure sufficient replicates for each fish species are present for effective monitoring and data analysis. Secondly, a requirement for biannual maintenance and data downloading from logging towers is required in late winter and summer. The late winter download will ensure that the loggers are able to record the large volume of data expected to be stored during the core reproductive period, while the summer download will free up the loggers 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 downloading trips will also provide opportunities for manual tracking of fish to determine within zone habitat selection and identify post spawning mortality (if any).

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 into regulator operational procedures will be an important component in the management of future watering regimes within the Icon site.

References

- Department of Sustainability and Environment (2010). Murray Darling Basin, The Living Murray Environmental Works and Measures Plan Upper Lindsay Watercourse Enhancement Proposal, Lindsay Island Works Stage 1.
- Mallen-Cooper, M., King, A., Koehn, J., Saddler, S., Scharpe, C., Stuart, I. and Zampatti, B. (2010). Fish requirements for the proposed Upper Lindsay Watercourse Enhancement project. Report prepared for the Mallee Catchment Management Authority.
- O'Connor, J.P., Koehn, J.D., Nicol, S.J., O'Mahony, D.J. and McKenzie, J.A. (2009). Retention of radio tags in golden perch (*Macquaria ambigua*), silver perch (*Bidyanus bidyanus*) and carp (*Cyprinus carpio*). *Marine and Freshwater Research* **60**, 334-340.
- Saddler, S., O'Mahony, J. and Ramsey, D. (2008). Protection and enhancement of Murray Cod populations. Arthur Rylah Institute for Environmental Research Technical Report Series No. 172. Department of Sustainability and Environment, Heidelberg, Victoria.
- Saddler, S. and O'Mahony J. (2009). Observations on the movement of Murray Cod under varying flow conditions within Mullaroo Creek. A report to the Mallee Catchment Management Authority. Arthur Rylah Institute for Environmental Research. Department of Sustainability and Environment, Heidelberg, Victoria.

Appendix 1. Size and tag details of individual fish implanted with radio telemetry tags in Lindsay Island anabranch study from March 2014 – August 2015.

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Murray cod	i	880	11000	153.1	Tag active
Murray cod	i	920	12000	153.2	Tag active
Murray cod	i	1140	25000	153.3	Tag active
Murray cod	i	720	8000	153.4	Tag active
Murray cod	i	718	5300	153.4	Tag active
Murray cod	i	965	14000	153.5	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
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	1150	29000	173.5	Tag active
Murray cod	b	588	3130	173.11	Tag active
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	173.20	Tag active
Murray cod	b	550	2700	173.21	Tag active

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
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
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	Tag expired
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	132.20	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	b	395	980	132.37	Tag active
Golden perch	b	430	1024	132.38	Tag active
Golden perch	i	402	900	132.40	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	153.20	Tag active
Golden perch	i	475	1820	153.28	Tag active
Golden perch	i	451	1450	173.4	Tag active
Golden perch	i	480	1690	173.6	Tag active
Golden perch	b	425	1100	173.38	Tag active
Golden perch	i	380	940	173.39	Tag active
Golden perch	d	460	1135	173.40	Tag active
Golden perch	i	465	1250	173.41	Tag active
Golden perch	i	490	1860	173.42	Tag active
Golden perch	i	440	1080	173.43	Tag active
Golden perch	b	360	860	173.45	Tag active
Golden perch	d	375	700	234.1	Tag active
Golden perch	d	370	670	234.2	Angled

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
Golden perch	b	446	1340	234.2	Re-used tag
Golden perch	i	320	570	234.3	Tag active
Golden perch	i	430	1148	234.4	Tag active
Golden perch	i	456	1140	234.5	Tag active
Golden perch	d	405	940	234.6	Tag active
Golden perch	d	386	720	234.8	Tag active
Golden perch	d	353	630	234.9	Tag active
Golden perch	d	340	570	234.12	Tag active
Golden perch	i	374	790	234.13	Tag active
Golden perch	d	423	1080	234.16	Tag active
Golden perch	b	375	718	234.17	Tag expired
Golden perch	d	357	644	234.24	Tag expired
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	234.60	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	490	1150	234.11	Tag active
Catfish	i	485	960	234.14	Tag active
Catfish	i	401	535	234.15	Tag active
Catfish	b	458	900	234.18	Tag expired
Catfish	d	348	366	234.19	Tag expired
Catfish	b	426	610	234.20	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	234.40	Tag expired
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

Species	Capture Zone	Length (mm)	Weight (g)	Fish ID	Comments
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 active
Carp	i	520	2860	132.20	Re-used tag
Carp	i	380	940	132.39	Tag active
Carp	i	515	1670	153.1	Tag active
Carp	d	545	2222	153.2	Tag active
Carp	i	585	2830	153.3	Tag active
Carp	i	590	3515	153.5	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	i	690	5550	153.26	Re-used tag
Carp	b	502	1772	153.26	Angled
Carp	b	640	3470	153.27	Angled
Carp	i	695	5950	153.40	Tag active
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	i	390	930	173.44	Tag active
Carp	i	490	1890	173.46	Tag active

www.delwp.vic.gov.au