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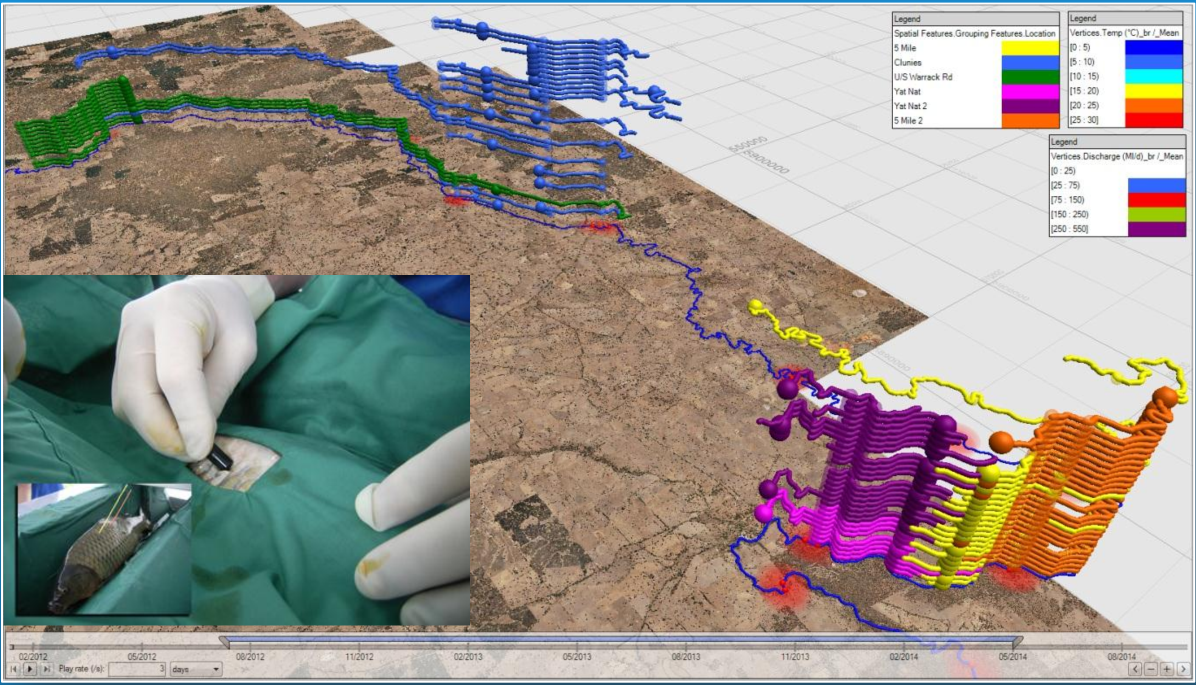
Glenelg River "Judas" Carp Tracking Program



Leigh Thwaites, Josh Fredberg and Stephen Ryan

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October 2014

An interim report to the Glenelg Hopkins Catchment Management Authority

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EXECUTIVE SUMMARY

Common carp (*Cyprinus carpio* L.) are a successful invader and declared pest fish in several countries including Australia, New Zealand, Canada and the United States. When in high abundance, carp cause detrimental changes to benthic habitats, water quality and the distribution and abundance of native flora and fauna. These impacts stem largely from carp’s bottom-feeding behaviour and are most commonly reported in shallow off-stream or within channel habitats where carp aggregate annually to feed and breed.

Carp are a relatively recent arrival to the Glenelg River system (*circa* 2001) and the Glenelg Hopkins Catchment Management Authority (CMA) is currently developing a strategy to slow their spread through the system and manage sites where carp are present to reduce their impact on native fish and overall river health. Key to the development of this strategy is knowledge of the movement patterns and habitat preferences of carp within the Glenelg river system, which may be exploited for control purposes. The objectives of the current project were to: 1) utilize acoustic telemetry and geospatial modeling to investigate carp movement patterns and habitat use, 2) investigate the influence of environmental factors (i.e. temperature and flow) on movement and habitat use, and 3) integrate these data and provide suggestions for potential control measures and future research.

During November 2012, the Glenelg Hopkins CMA established a VEMCO acoustic tracking array to monitor the movement patterns and habitat use of tagged “Judas” carp throughout the Glenelg River system. This strategy is particularly effective as the behaviour of tagged “Judas” carp mirrors that of untagged carp so behavioural patterns of the broader population can be identified and exploited. A total of 26 VEMCO VR2W acoustic receivers were systematically positioned every 10–20 km over 320 km of the Glenelg Rivers main channel between the Rocklands Reservoir and Dartmoor. The array encompasses the current and predicted distribution of carp within the Glenelg River and included known areas of aggregation (e.g. Clunies Hole) and environmental water release sites.

A total of 131 adult carp (mean total length ± S.E. = 480.63 ± 4.46 mm; mean weight ± S.E. = 1738.82 ± 43.70 g) were captured and surgically implanted with VEMCO V13-1L acoustic transmitters. Fish were captured using a variety of techniques including electrofishing and netting. The tagged carp comprised 30 females (23%), 61 males (47%) and 40 of unknown sex (31%). Carp were tagged at 5 sites with the majority being tagged within the upper reaches of

the catchment at Clunies Hole (n = 41; 31%), 5-mile (n = 50; 38%) and two separate sites at Yat Nat (n = 28; 21%). The most downstream tagging location was between Dergholm and Warrock Road where 12 carp (9%) were captured and tagged.

From November 2012 to March 2014, 123 carp (94% of tagged carp) have remained within close proximity of their tagging location (<10 km) indicating that Glenelg River carp prefer to maintain relatively small home ranges and suggests a level of site fidelity to preferred habitat. In contrast, 8 carp (6% of tagged carp) moved substantial distances (>10 km) upstream or downstream of their tagging location (average distance: 40 km ± 3.2 S.E., n = 8) with the longest movement occurring over 53 km between Warrock Road and Harrow. There appears to be no distinct patterns/cues to the observed movements as they occurred periodically over varying temperatures and flows (natural and environmental) with some carp commencing movement during winter and others during spring. Importantly, there is no evidence to suggest that the delivery of environmental flows triggered any of the observed movements.

The movement data collected to date are important in determining the spatial scale at which to manage carp in the Glenelg River. Given that there appears be no predictable large-scale migrations throughout the system, control techniques that exploit this behaviour may have limited effect and a more site specific approach that targets distinct populations or "management units" is likely to have greater impact. However, the application of these techniques will require careful planning, in-field evaluation and long-term monitoring to determine the most cost-effective and sustainable control/management strategies. Ideally, these strategies should aim to achieve predefined management targets (i.e. % population reduction to achieve density thresholds) and rely on an understanding of carp population dynamics (i.e. spawning, recruitment, population estimates), as well as the costs/benefits that each control option achieves in both the short- and long-term (i.e. % removal, improvements in vegetation and water quality).

1. INTRODUCTION

1.1. Background

Common carp (*Cyprinus carpio* L.) are a successful invader and a declared pest fish in several countries including Australia, New Zealand, Canada and the United States (Koehn 2004). The success of carp stems from their high fecundity (100,000 eggs.kg^{-1}; up to 1 million eggs.y^{-1}), longevity (28+ years), ability to occupy a broad range of habitats and tolerance to extreme environmental conditions (Smith 2005). When in high abundance, carp cause detrimental changes to benthic habitats, water quality and the distribution and abundance of native flora and fauna (Gehrke and Harris 1994, Miller and Crowl 2006, Matsuzaki *et al.* 2009). Previous research has demonstrated a decline in vegetation cover and waterfowl at ≈100 kg ha^{-1} (Bajer *et al.* 2009), a shift from clear to turbid water state at 200-300 kg ha^{-1} (Williams *et al.* 2002, Parkos *et al.* 2003, Haas *et al.* 2007, Matsuzaki *et al.* 2009) and detrimental effects on aquatic macrophytes at 450 kg ha^{-1} (Hume *et al.* 1983, Fletcher *et al.* 1985, Osborne *et al.* 2005, Pinto *et al.* 2005). These impacts stem largely from carp's bottom-feeding behaviour (Sibbing *et al*. 1986) and are most commonly reported in shallow off-stream or within channel habitats (Parkos *et al*. 2003) where carp aggregate annually to feed and breed (Smith and Walker 2004, Stuart and Jones 2006).

Where carp are considered a pest, considerable resources have been invested to develop and evaluate novel strategies for their control. In Australia, there is a national management strategy (Carp Control Coordinating Group 2000) and several texts outlining the species' ecology (Koehn *et al.* 2000) and management options (Roberts and Tilzey 1996). Internationally, current management options include commercial fishing, steel mesh carp exclusion screens in wetland flow control structures to restrict access to spawning sites (French *et al.* 1999, Hillyard *et al*. 2010), tracking Judas carp to locate and harvest aggregations (Inland Fisheries Service 2008), jumping traps (William's carp separation cages; Stuart *et al.* 2006, Thwaites 2011), push traps (Thwaites *et al.* 2010), water level manipulations to reduce access to littoral spawning sites and expose eggs to desiccation (Shields 1957, Yamamoto *et al.* 2006), electrical barriers to restrict movements (Verrill and Berry 1995) and chemical piscicides (Clearwater *et al.* 2008). Genetic ('daughterless' carp; Thresher 2008), biological (Kio herpes virus; McColl *et al.* 2007) and chemical (pheromones; Sorensen and Stacey 2004) control technologies are in development. The development of new management technologies is also desirable as carp's range is predicted to expand (Koehn 2004) and the eventual control of carp will rely on an integrated approach (Brown and Walker 2004).

The Glenelg River is a high profile priority river in Victoria containing significant flora and fauna and characterised by many reaches in near pristine condition. Carp are a relatively recent arrival to the Glenelg River system (*circa* 2001) and the Glenelg Hopkins Catchment Management Authority (CMA) is developing a strategy to slow their spread through the system and manage sites where carp are present to reduce their impact on native fish and overall river health. While the Glenelg Hopkins CMA has already collected considerable background data (i.e. distribution, abundance, etc) on the species and are currently applying opportunistic control measures they are now seeking to develop a more strategic approach toward managing carp. In this regard, the Glenelg Hopkins CMA engaged the South Australian Research and Development Institute (SARDI) to assist in the development of a cost-effective carp management strategy.

Key to the development of a management strategy is knowledge of carp movement patterns and habitat preferences (i.e. aggregation points, breeding “hot spots”, timing and duration of migrations, etc), in relation to environmental factors (i.e. temperature, flow). With this knowledge, the appropriate spatial scale at which to manage carp in the Glenelg River can be identified (Stuart and Jones 2006) and the utility of control methods such as carp exclusion screens, carp separation cages, targeted harvesting (i.e. netting, electrofishing) or the strategic delivery of environmental water releases to aggregate or disadvantage carp can be evaluated. In addition, the knowledge gained may support the future roll-out of blue sky technologies such as Koi herpes virus and daughterless carp.

During November 2012, the Glenelg Hopkins CMA established a VEMCO acoustic tracking array to monitor the movement patterns of tagged “Judas” carp throughout the Glenelg River system. This strategy is particularly effective as the behaviour of tagged “Judas” carp mirrors that of untagged carp so that behavioural patterns of the broader population can be identified and exploited. This interim report summarises the results of the first 14 months of the Glenelg River “Judas” carp tracking program (28 November 2012 - 14 March 2014).

1.2. Objectives

The objectives of this study are to:

- Utilise acoustic telemetry and geospatial modeling to investigate carp movement patterns and habitat use within the Glenelg River system.
- Investigate the influence of temperature and flow (including environmental water delivery) on movement patterns and habitat use.
- Integrate these data and provide suggestions for potential control measures and future research.

2. METHODS

2.1. Site description

The Glenelg River is located in south-western Victoria, Australia (Figure 1). It is one of the State's longest rivers flowing 500 km from the Victoria Valley in the Grampians Mountain Ranges to the Southern Ocean. The river's basin is a mosaic of farmland, urban/rural development, remnant native systems (i.e. woodlands, grasslands, etc), as well as land undergoing rehabilitation. The river is characterised by a high level of within channel diversity (i.e. pools, runs, riffles, braiding, etc), abundant physical habitat (i.e. snags, diverse vegetation, etc) and relatively natural hydrology. It receives inflows during catchment rainfall events, as well as environmental water delivered from the Rocklands Reservoir. This study focuses on tracking the movement patterns of carp over the 320 km between the Rockland Reservoir (37°14'6.53"S; 141°57'47.09"E) and Dartmoor (37°55'13.01"S; 141°16'32.65"E) (Figure 1).

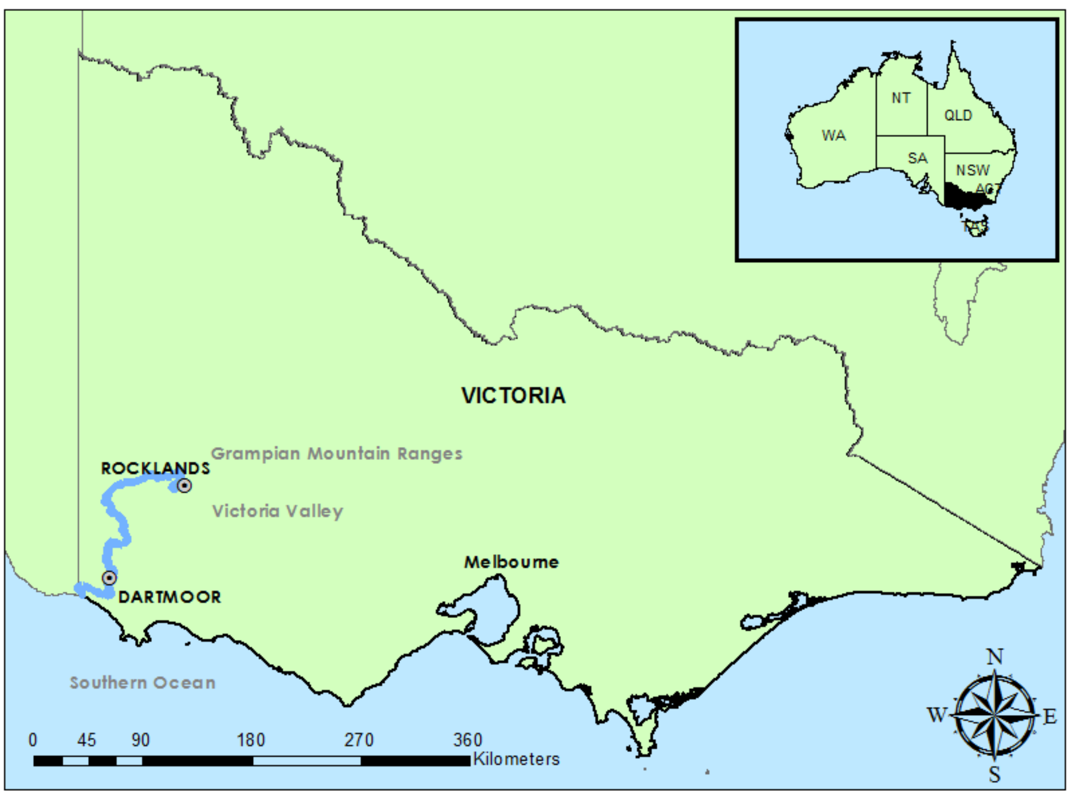

Figure 1. Map showing the location of the Glenelg River system in south-western Victoria, Australia.

2.2. VEMCO Acoustic tracking array

A total of 26 VEMCO VR2W acoustic receivers were systematically placed every 10-20 km throughout the Glenelg River system between the Rockland Reservoir and Dartmoor in early spring 2012 (Figure 3). The array was deployed to encompass the current and predicted distribution of carp within the Glenelg River and target environmental water release sites, as well as known aggregation points or “hot spots” such as Clunies Hole and 5-mile (Stephen Ryan, Glenelg Hopkins CMA, pers. comm.). Receivers were deployed within pools as their depth and length permit greater propagation of signals sent by tagged carp which increases the probability of detection. Each VR2W receiver was mounted on a mooring system consisting of a float (12 inch diameter) attached to a length of 4 mm galvanized chain (length was dependent on water depth) which was secured to two besser blocks positioned on the river bed (Figure 2). Each receiver was attached to the chain via a combination of plastic and stainless steel cable ties and was positioned 30 cm below the water surface to permit easy access for download and maintenance (i.e. battery exchange).

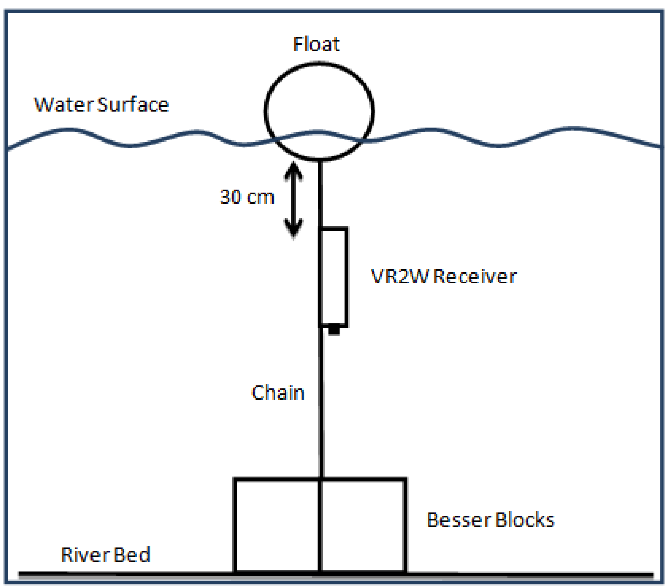

Figure 2. Schematic representation of the VR2W acoustic receiver mooring.

Within the upper reaches (Rocklands Reservoir to Moree; Figure 3), receivers were arranged into a system of ‘gates’ approximately 15 km apart. At each gate, two receivers were placed within relatively close proximity but far enough apart to mitigate the detection of a tagged carp on both receivers at the same time (>600 m). This gating system was adopted to identify directionality of movements and determine if carp remained within certain reaches. For example, if a tagged carp is detected on a gates upstream receiver and not on the downstream receiver then it must be upstream of the gate. Further, if this tagged carp is not detected or only detected on the downstream receiver of the next upstream gate then it must be within the reach between the two gates. This is important in determining the timing, frequency and duration of use at potential aggregation points and breeding locations such as Clunies Hole and 5-mile. Single receivers do not permit this resolution as it is impossible to determine if a detected carp is upstream or downstream of a receiver.

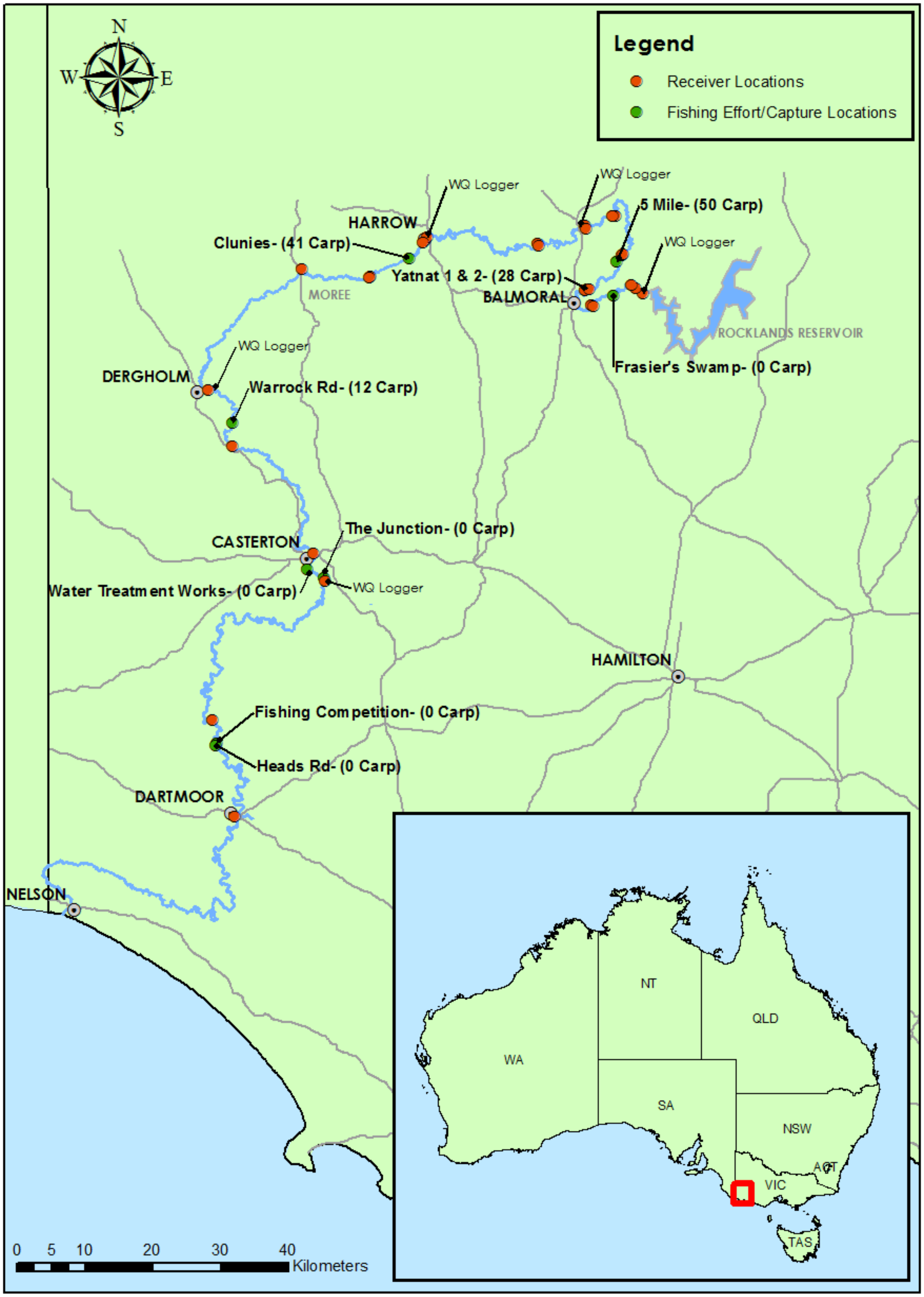

Figure 3. Map showing location of water quality logging stations (WQ logger), VEMCO VR2W acoustic receivers, applied fishing effort and total carp captures within the Glenelg River system.

2.3. Acoustic transmitters, carp capture and surgeries

Acoustic transmitters

V13-1L coded acoustic transmitters (147 dB, VEMCO, AMIRAX Systems Inc., Halifax, Canada; Figure 4) with a nominal ping train delay of 120 ± 60 s were used for tracking mature carp >350 mm TL (>550 g) (see Thwaites 2012). With a weight of 11 g, these transmitters are a maximum of 2% body weight of the size class. The nominal ping train delay minimises the potential for acoustic transmitter ping train collisions (Jonathan Mulock, VEMCO, pers. comm.), while maximizing the probability of detection as a carp swims past a receiver. For example, using the recommended ping train delay and a carp swimming at a burst speed of approximately 1 $m.s^{-1}$, an acoustic receiver should log one to two detections as a tagged carp swims through 200 m of a pool (Thwaites 2012). This transmitter’s battery size and programming specification will provide 1029 days (≈3 years) of continuous tracking data (VEMCO 2013).

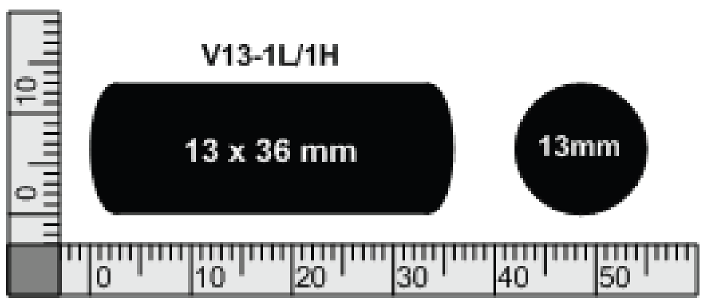

Figure 4. VEMCO V13 coded acoustic transmitter (http://www.vemco.com/pdf/v13_coded.pdf).

Carp capture

Carp capture and acoustic tagging occurred during 20-22 November 2012 and 18-20 November 2013. Carp were captured using a combination of boat mounted electrofishing and netting techniques (Table 1). Sampling was conducted at 3 sites within the upper reaches of the Glenelg River during 2012 and 9 sites during 2013 (Table 1, Figure 4). The sites within the upper reaches were initially targeted as carp were known to be relatively abundant, while the 2013 sites were targeted in an attempt to tag carp across their entire Glenelg River distribution (Iervasi *et al.* 2014).

Table 1. Fishing methods and effort applied to capture carp at various locations on the Glenelg River

Date	Site	Method	Effort
20/11/12	Clunies Hole (37°11'33.18"S; 141°33'59.52"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	2200 s
21/11/12	U/S Warrock Rd (37°24'39.66"S; 141°16'21.89"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	2357 s
22/11/12	5-mile (37°11'42.44"S; 141°54'39.38"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	3466 s
13/11/13	Water Treatment Works (D/S Casterton) (37°36'10.20"S; 141°23'57.37"E)	2x multi-directional fyke/box nets: 2 cm stretched mesh, 6 chambers (80 x 80 cm) with alternating 25 cm funnels, two cod ends, 9.5 m total length.	34 h
14/11/13	The Junction (D/S Casterton) (37°36'50.75"S; 141°25'33.81"E)	16x fyke nets: 5 m wing, 70 cm drop, with 70 cm high 'D' and 3 compartments (funnels), 6 hoops with 6 mm mesh without exclusion grills.	272 h
		2x multi-panel gill net: 15 m long, 3 panels per net including 45 mm, 75 mm and 115 mm stretched mesh set in deep or open water habitats	4 h
15/11/13	Casterton (37°35'18.92"S; 141°24'26.49"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	1200 s
16/11/13	Heads Road (37°50'9.81"S; 141°14'38.77"E)	16x fyke nets: 5 m wing, 70 cm drop, with 70 cm high 'D' and 3 compartments (funnels), 6 hoops with 6 mm mesh without exclusion grills	272 h
16/11/13	Scott’s Creek Rd (Fishing Competition) (37°49'56.65"S; 141°14'54.91"E)	Hook and line Bait; bread dough mix (bread, flour, corn, and vanilla essence), corn, worms and yabbies.	9 anglers (≈14 h per angler)
17/11/13	Frasier’s Swamp (37°14'23.45"S; 141°54'18.03"E)	16x fyke nets: 5 m wing, 70 cm drop, with 70 cm high 'D' and 3 compartments (funnels), 6 hoops with 6 mm mesh without exclusion grills	272 h
18/11/13	5-mile (37°11'10.01"S; 141°55'11.55"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	3400 s
19/11/13	Yat Nat (37°13'57.06"S; 141°51'42.64"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	2224 s
20/11/13	Yat Nat 2 (37°13'52.84"S; 141°52'20.36"E)	Boat mounted Smith-Root GPP 5.0kW portable electrofisher	3010 s
		Total Electrofishing Effort	17,857 s (4.96 hr)
		Total Netting Effort	854 hr
		Total Angling Effort	126 hr

Surgical procedure

Prior to surgery, all captured carp were held in aerated river water within a 1000 L tank. Carp were then anaesthetised (Stage III - loss of reflex reactivity, surgical anaesthesia; MacFarland 1960) in a 50 L aerated fish bin containing AQUI-S® (AQUI-S®, New Zealand Ltd) at a concentration of 35 ppm. Each carp was then assigned a name and length (mm) and weight (g) recorded before being inverted in a v-shaped PVC fish cradle. During surgery, gills were irrigated with an aerated 50% dilute solution of AQUI-S® (17.5 ppm). Each V13-1L transmitter was implanted by first removing six adjacent scales from an area three scales posterior to the right side of the pelvic fin. This area was swabbed with Betadine® (Faulding Pharmaceuticals, Salisbury, S.A., Australia) and absolute ethanol before a 2 cm incision was made through the ventral wall. The tag was inserted into the abdominal cavity anterior to the incision (Figure 5.). The incision was closed using one external suture (Ethicon Inc. Somerville, New Jersey, USA) and sealed with Vet-bond™ (3M Animal Care Products, St. Paul, MN, USA). To permit visual identification of carp implanted with transmitters, two external dart tags (Hall Print, Hindmarsh Valley, S.A., Australia) were inserted between the dorsal pterygiophores (Figure 5.). Carp were then injected in the dorsal musculature with a long-term (2 weeks) antibiotic (Baytril®, Bayer Australia, Pymble, NSW, Australia) at a rate of 0.1 ml kg^{-1} body weight. At the completion of surgery, carp were transferred to an aerated fresh water recovery tank and monitored until they regained equilibrium. Recovered carp were released at the point of capture. All surgical instruments and equipment were sterilised with Betadine® and absolute ethanol and air dried before each surgery. This surgical procedure was adapted from the methods prescribed by Leigh and Zampatti (2013).

Figure 5. VEMCO acoustic transmitter being inserted into abdominal cavity of carp. Insert shows a carp in the v-shaped PVC fish cradle post-operation after insertion of visual identification dart tags (Photo: SARDI).

2.4. Tracking array downloads and water quality

Following fish tagging, the acoustic tracking array was downloaded in April 2013, November 2013 and March 2014 (Table 2). On each occasion, individual receivers were retrieved and downloaded into VEMCO’s VUE software (Vemco User Environment, 2.0.6-20130212, AMIRIX Systems Inc., Halifax, Canada). Water quality data (temperature and flow) were collected from five permanent logging stations situated along Glenelg River (Figure 3).

Table 2. Acoustic tracking array timeline.

Date	Activity	Comments
14/2/12	Acoustic range finding experiment	The identification of the most suitable acoustic transmitters to be used and appropriate locations for the acoustic receivers.
17-18/9/12	Study site reconnaissance	Scoping the Glenelg River (Rocklands to Dartmoor) for suitable receiver locations, carp hot-spots and boat launch sites.
23-28/11/12	Installation of acoustic receivers	26 VEMCO VR2W receivers were systematically placed every 10-20 km throughout the study site (Rocklands to Dartmoor) (Figure 3).
20-24/4/13	1^{st} download of receivers	25 receivers were downloaded using the VEMCO software program VUE. Receiver R20, located at Bourke’s Bridge, was not downloaded as it was stolen between the time of installation and the first download. Due to the high risk of this being repeated, this receiver was not replaced.
13-17/11/13	2^{nd} download of receivers and battery replacement	25 receivers were downloaded using the VEMCO software program VUE and receiver batteries were replaced.
11-14/3/14	3^{rd} download of receivers	25 receivers were downloaded using the VEMCO software program VUE.

2.5. Data analysis

To determine the extent of carp movement and response to changes in flows and temperature throughout the Glenelg River system, carp positional data were visualised, analysed and described using Eonfusion 2.4 geospatial software (Myriax Pty. Ltd., Hobart, Tasmania, Australia).

3. RESULTS AND DISCUSSION

A total of 131 carp (mean total length (TL) ± S.E. = 480.63 ± 4.46 mm; mean weight ± S.E. = 1738.82 ± 43.70 g) were captured and surgically implanted with VEMCO acoustic transmitters. Seventy-five carp were implanted during November 2012 (mean TL ± S.E. = 487.23 ± 7.05 mm; mean weight ± S.E. = 1812.21 ± 69.33 g) and a further 56 carp implanted during November 2013 (mean TL ± S.E. = 471.80 4.22 mm; mean weight ± S.E. = 1640.54 ± 39.90 g) (Table 3 and Figure 6). The tagged carp comprised 30 females (23%), 61 males (47%) and 40 of unknown sex (31%) (i.e. no milt or eggs visible during stripping or surgery).

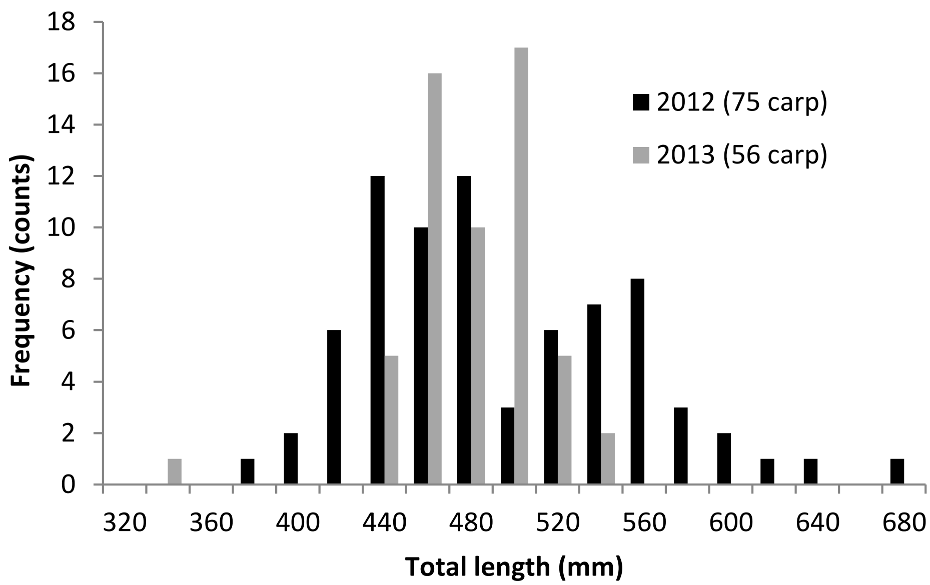

Figure 6. Length frequency distribution for carp captured and tagged during 2012 (*n* = 72) and 2013 (*n* = 56).

Carp were tagged at five of the 11 sites that were targeted with the majority being tagged within the upper reaches at Clunies Hole (*n* = 41; 31%), 5-mile (*n* = 50; 38%) and Yat Nat (*n* = 28; 21%). The most downstream tagging location was between Dergholm and Warrock Road where 12 carp (9%) were captured and tagged (Table 3, Figure 3). Although considerable fishing effort was applied at Frasers swamp and within several reaches below Warrock Road (Table 3, Figure 3), only two small carp were captured that were unsuitable for tagging. While it would have been ideal to implant carp in these regions, the difficulty in catching carp suggests low densities and this is consistent with previous surveys conducted within the Glenelg River (Iervasi *et al*. 2014).

Table 3. Summary of carp capture data for the 2012 and 2013 carp acoustic tagging effort.

			Length (mm)		Weight (g)		
Date	**Site**	**No. of Carp**	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**	**Sex Ratio**
20/11/12	Clunies Hole (37°11'33.18"S; 141°33'59.52"E)	41	512.98 ± 8.74	420-675	1986.02 ± 91.24	1170-3950	F: 2 M: 12 N/A: 27
21/11/12	U/S Warrock Rd (37°24'39.66"S; 141°16'21.89"E)	12	484.17 ± 11.21	440-555	1961.25 ± 158.18	1130-2980	F: 2 M: 8 N/A: 2
22/11/12	5-mile (37°11'42.44"S; 141°54'39.38"E)	22	440.91 ± 11.35	373-624	1407 ± 99.80	940-3104	F: 1 M: 10 N/A: 11
13/11/13	Water Treatment Works (D/S Casterton) (37°36'10.20"S; 141°23'57.37"E)	1*	-	-	-	-	-
14/11/13	The Junction (D/S Casterton) (37°36'50.75"S; 141°25'33.81"E)	0	-	-	-	-	-
15/11/13	Casterton (37°35'18.92"S; 141°24'26.49"E)	0	-	-	-	-	-
16/11/13	Heads Road (37°50'9.81"S; 141°14'38.77"E)	0	-	-	-	-	-
16/11/13	Scott’s Creek Rd (Fishing Competition) (37°49'56.65"S; 141°14'54.91"E)	1*	-	-	-	-	-
17/11/13	Frasier’s Swamp (37°14'23.45"S; 141°54'18.03"E)	0	-	-	-	-	-
18/11/13	5-mile (37°11'10.01"S; 141°55'11.55"E)	28	456.79 ± 6.66	337-533	1463.50 ± 50.99	1094-2259	F: 8 M: 20
19/11/13	Yat Nat (37°13'57.06"S; 141°51'42.64"E)	8	479.63 ± 6.05	458-513	1808.50 ± 64.12	1568-2081	F: 4 M: 4
20/11/13	Yat Nat 2 (37°13'52.84"S; 141°52'20.36"E)	20	489.70 ± 3.99	458-522	1821.20 ± 49.97	1196-2059	F: 13 M: 7
	Total	**131**	**480.63 ± 4.46**	**337-675**	**1738.82 ± 43.70**	**940-3950**	**F: 30** **M: 61** **N/A: 40**

* indicates captured carp were too small to tag.

Of the 131 tagged carp, a total of 109 (83%) have been detected and 22 (17%) remain undetected (Table 4). The majority of undetected carp (*n* = 16) were tagged at Clunies hole with the remaining tagged at Warrock Road and 5-mile.

Table 4. Summary statistics for Glenelg River carp tracking program (28 November 2012 - 14 March 2014)

Parameter		**Summary statistic**
Total number of tagged carp		131
Number of carp detected		109 (83%)
Number of carp not yet detected		22 (17%)
Number of carp remaining at tagging location		123 (94%)
Number of carp that moved from tagging location		8 (6%; 2 male, 6 unknown sex)
Movement distance	Average distance	40 km ± 3.2 S.E.
	Range	21 - 53 km
Swim speed (minimum)	Average swim speed	4.25 km d^{-1} ± 1.3 S.E.
	Range	0.6 - 12.2 km d^{-1}

Since tracking commenced (28 November 2012), the majority of fish (*n* = 123, 94% of tagged carp) have remained within close proximity to their tagging location (<10 km) indicating that Glenelg River carp prefer to maintain relatively small home ranges and suggests a level of site fidelity to preferred habitat (e.g. spawning sites) (Figure 7). In contrast, 8 carp (6% of tagged carp) moved substantial distances upstream or downstream of their tagging location (average distance: 40 km ± 3.2 S.E.) with the longest movement occurring over 53 km between Warrock Road (Dergholm) and Clunies Hole (Harrow) (Figures 7-9). The average recorded minimum swimming speed between two locations was 4.25 km d^{-1} ± 1.3 S.E. with a minimum of 0.6 km d^{-1} and a maximum of 12.2 km d^{-1}. Of the 8 carp that moved from their tagging location, one male and one of unknown sex returned to their initial tagging location after an extended period of absence suggesting potential homing behavior or site recognition (Reynolds 1983, Jones and Stuart 2009) (Figures 7-9). There appears to be no distinct patterns/cues to the observed movements as they occurred periodically over varying temperatures and flows (natural and environmental) with some carp commencing movement during winter and others during spring. Importantly, there is no evidence to suggest that the delivery of environmental flows triggered any of the observed movements (Figures 8-9).

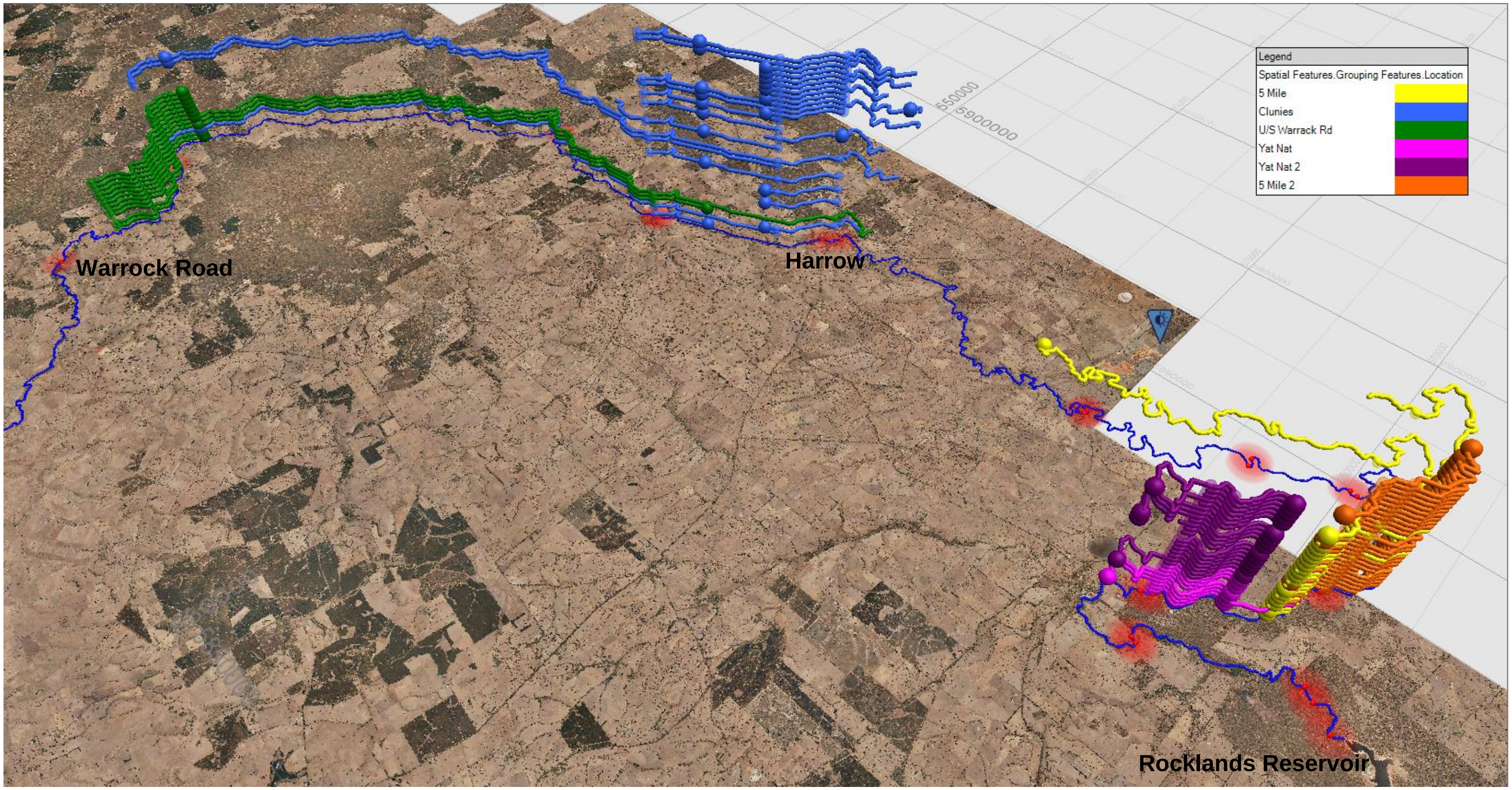

Figure 7. Overview of Eonfusion 2.4 carp tracking model showing the extent of movements of all detected tagged carp (n = 109) within the Glenelg River system (28 November 2012 - 14 March 2014). Colors represent tagging location (see legend). Each dot/line represents the extent of movements for individual tagged carp. Red dots represent VR2W acoustic receiver locations.

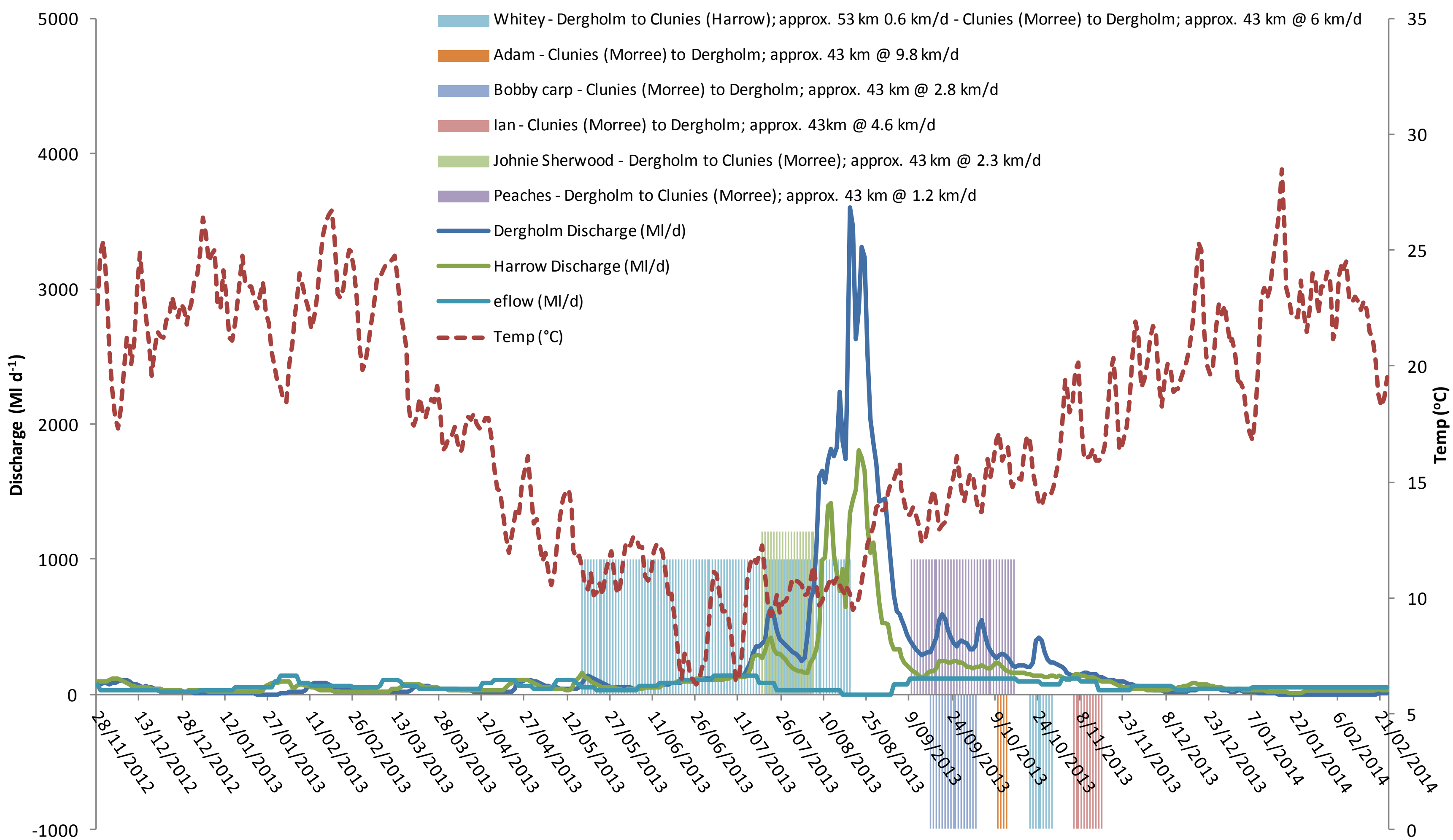

Figure 8. Carp movements between Dergholm and Clunies Hole, Glenelg River, Victoria. Color coded columns represent the timing and duration of movements of tagged carp with upstream movements above the x-axis and downstream movements below the x-axis. Three carp have made upstream movements between Dergholm and Clunies Hole with one carp (Whitey) returning after approx. 2 months. A further three carp have made downstream movements between Clunies Hole and Dergholm.

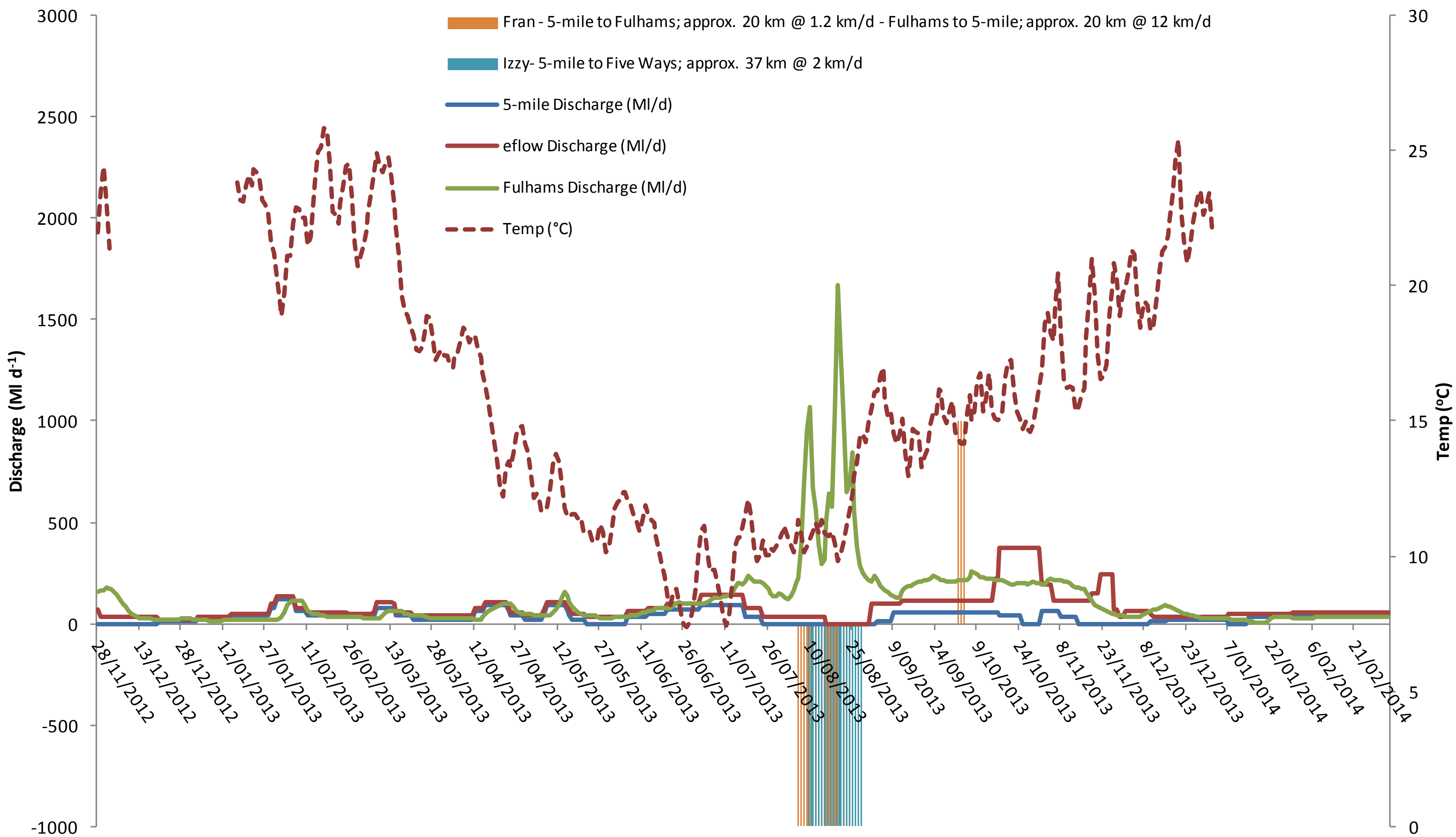

Figure 9. Carp movements between Fulhams, Five Ways and 5-mile, Glenelg River, Victoria. Color coded columns represent the timing and duration of tagged carp movements with upstream movements above the x-axis and downstream movements below the x-axis. Two carp have made downstream movements between 5-mile and Five Ways with one carp (Fran) returning after approx. 2 months.

The results of the current study are consistent with previous investigations of carp movement in the southern hemisphere (Reynolds 1983, Stuart and Jones 2006, Jones and Stuart 2009, Osbourne *et al.* 2009). Jones and Stuart (2009) investigated the movement of carp in the Barmah-Millewa forest and main channel of the River Murray (mid-Murray region) using radio-telemetry and also found high levels of site fidelity, with 35% and 65% of tagged fish remaining within 20 and 100 m of the tagging locations, respectively, whilst only 12.5% moved large distances (>127 km). Similar to the present study, movement from the release point was not significantly related to river discharge and water temperature. Osbourne *et al.* (2009) captured and tagged 1265 Koi carp (colored variant of common carp) at 14 sites in the lower Waikato River, New Zealand. A total of 76 carp (6%) were recaptured with 85% of these <5 km from their release site and one ≈75 km from the release site (51% moved upstream, 41% moved downstream and 8% remained at release site). The authors concluded that the majority of New Zealand Koi carp display a high level of site fidelity, remaining resident to areas for long periods of time (>3 years in some cases). Stuart and Jones (2006) used recapture data to determine the minimum upstream or downstream distance that 3337 (1607 unknown sex, 1099 males, 504 females, 127 juveniles) carp moved from the Barmah-Millewa forest on the River Murray. A total of 293 recaptures were recorded (110 males, 91 females, 86 sex unknown, six juveniles) with 80% of these moving <5 km and 7% ≥100 km with a maximum recorded distance of 890 km.

Reynolds (1983) tagged 5268 carp between Lock 4 and 5 on the River Murray, South Australia to determine movement patterns. A further 423 fish were captured and tagged from Gurra Lakes and translocated to the main Murray River channel between Lock 4 and 5 to determine if carp display homing ability. A total of 74 (1.4%) of tagged carp were recaptured with the maximum distance covered of 80 km upstream and 73 km downstream. Although river conditions varied considerably during the study (i.e. major floods and extended periods of low flow) there was also no relationship between the distance and direction of movement with time of year or water levels. The author concluded that carp make random, short distance movements and attributed this to the species reproductive strategy (i.e. utilising wetlands/backwater to lay adhesive demersal eggs). In regard to homing, a total of 19 carp were recaptured with 12 of these returning to Gurra Lakes suggesting that carp prefer a home range and have some form of homing ability or at least the ability to recognize backwaters once they have inhabited them. Indeed, Jones and Stuart (2009) also observed a level of homing behaviour with some carp returning to their tagging location after a period of absence.

4. CONCLUSION AND RECOMMENDATIONS

The movement data collected to date are important in determining the spatial scale at which to manage carp in the Glenelg River (Stuart and Jones 2006). Given to date there appears to be no predictable large-scale migrations throughout the system, control techniques that exploit this behaviour may have limited effect (i.e. carp separation cages; Stuart *et al.* 2006, Thwaites 2011) and a more site specific approach that targets distinct populations or “management units” is likely to have greater impact (e.g. the targeting of aggregations with traditional netting techniques and electrofishing; Inland Fisheries Service 2008). However, the application of these techniques will require careful planning, in-field evaluation and long-term monitoring to determine the most cost-effective and sustainable control/management strategies. Ideally, these strategies should aim to achieve predefined management targets (i.e. % population reduction to achieve density thresholds) and rely on an understanding of carp population dynamics (i.e. triggers for successful spawning/recruitment, population structure, etc), as well as the costs/benefits that each control option achieves in both the short and long-term (i.e. % removal, improvements in vegetation and water quality).

Recommendations

- *Tracking “Judas” carp* - continue tracking to capture seasonal and annual variation in carp movements and habitat use. This is particularly important as carp movements have been shown to vary considerably from year to year. Daniels *et al*. (2011) reported significantly higher movements in the first year of their study and this was attributed to low river flows. As flows increased in the second year carp were found to maintain much smaller ranges. If increased/decreased movements are observed or if targeted harvesting (see below) impacts carp behaviour then appropriate control strategies can be developed.

- *Environmental triggers* - although there is currently no evidence to suggest that changes in temperature, natural flows or the delivery of environmental flows are stimulating carp movements, given the limited temporal scale of the current project thus far it is recommended to continue investigating the influence of these potential behavioural triggers.

- *Targeted harvesting* - trial an array of targeted harvesting techniques at known aggregation points (i.e. Clunies Hole, 5-mile) on multiple occasions during the carp spawning season (i.e. September, November, January, March). The success of each harvesting technique and the data collected (see below) will aid in defining the optimal control strategy (techniques and timing) to harvest carp from the system. To identify the most effective carp harvesting techniques and collect biological/ecological data it is recommended that the following sampling/harvesting techniques be applied:
    - Omni-directional small single winged fyke nets - 5 m wing, 70 cm drop, with 70 cm high 'D' and 3 compartments (funnels), 6 hoops with 6 mm mesh.
    - Multi-directional fyke/box nets - 2 cm stretched mesh, 6 chambers (80 cm x 80 cm) with alternating 25 cm funnels, two cod ends, 9.5 m total length.
    - Box traps - 400 mm in length with two square ends (250 x 250 mm) with 70 mm openings at each end, brown in colour and targeted.
    - Backpack electrofishing (Smith Root® LR-24).
    - Boat mounted electrofishing (boat mounted Smith-Root GPP 5.0kW portable electrofisher).
    - Stop nets to contain carp within specific locations that are being targeted.

- *Biological/ecological data* - all carp captured during harvesting events should be counted and bulk weighed to determine relative abundance and total weight. Native fish should be measured for length (TL, mm) and weight (g) and released unharmed. Captured carp should be measured for length (TL, mm), width/depth (mm) and weight (g). Each specimen should be sexed, gonads weighed (GSI, g), eggs staged and their gut contents analysed. In addition, each specimen should be inspected for disease and parasites and otoliths removed for aging and determination of their natal origin. Environmental parameters should also be collected including habitat type and water quality (temperature, salinity, dissolved oxygen, pH, and turbidity). These data will aid in determining the optimal time to harvest (i.e. pre-spawning as defined by GSI and egg staging) and identify the most appropriate habitat/micro-habitats to target. In addition, length frequency data and age estimations can be used to identify years of high breeding/recruitment success and determine associated environmental triggers.

- *Mark-recapture experiment* - conduct a mark-recapture experiment to calculate population estimates and the current density (kg Ha^{-1}) of carp within defined management units (i.e.

Clunies Hole). This experiment should use the ratio of acoustic tagged to non tagged carp captured during targeted harvesting events. The total number of acoustic tagged carp within each management unit can be determined from tracking data and Eonfusion analysis. The results of this experiment will aid in establishing and monitoring carp management objectives/targets for the Glenelg River (i.e. % population reduction to achieve target carp density thresholds).

- *Cost-benefit analysis* - conduct cost-benefit analysis to determine the most cost-effective harvesting strategy. This analysis should account for the total number of carp captured for each harvesting technique, required resources and total time spent to calculate cost per carp removed. A cost-benefit analysis of recent carp harvesting within the Torrens Lake (Adelaide) showed that electrofishing was the most cost-effective harvesting strategy, while traditional netting techniques were found to be the most expensive for that system (SARDI, unpublished data).

- *Monitoring* - given that applied control techniques may alter the behaviour of carp and that reducing the biomass may increase recruitment by decreasing density-dependent limiting factors, it is recommended that a long-term monitoring program be implemented. This program should continue to collect the biological and ecological data outlined above and could be linked to existing ongoing programs such as the Victoria Environmental Flows Monitoring and Assessment Program (VEFMAP).

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