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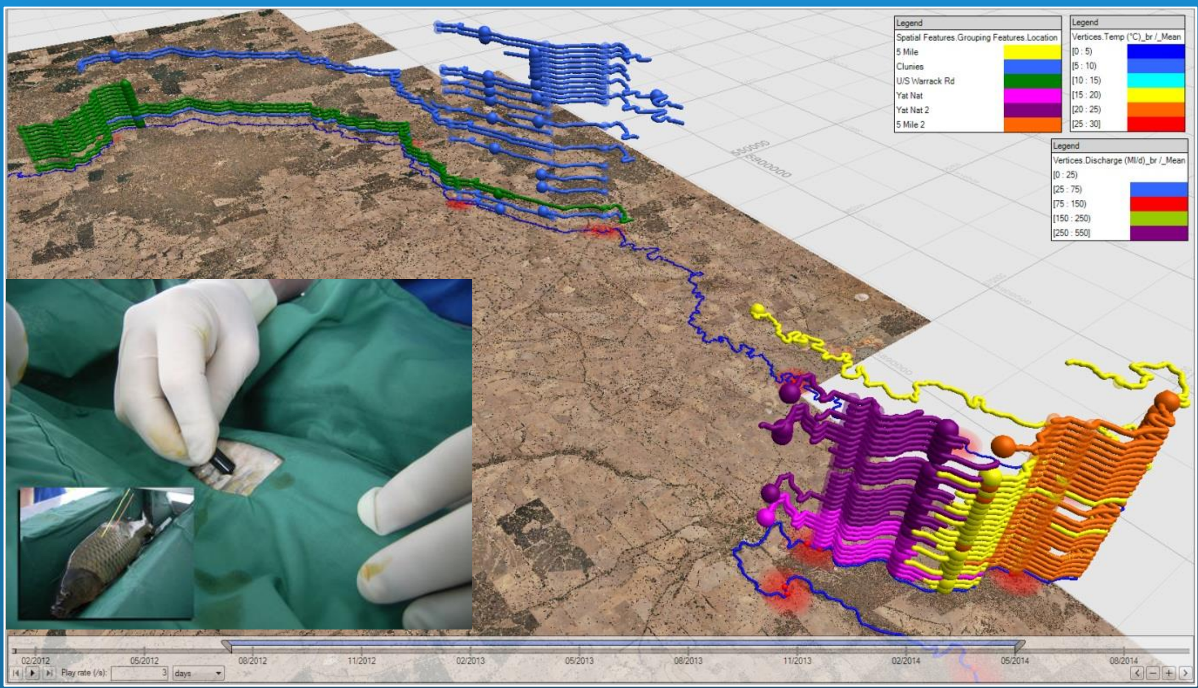

Leigh Thwaites, Josh Fredberg and Stephen Ryan

SARDI Publication No. F2012/000122-3
SARDI Research Report Series No. 854

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

August 2015

An interim report to the Glenelg Hopkins Catchment Management Authority

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

Glenelg Hopkins CMA

SOUTH AUSTRALIA

Government of South Australia
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SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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[1]SARDI Aquatic Sciences, PO Box 120, Henley Beach, SA, 5022
[2]Glenelg Hopkins Catchment Management Authority, 79 French St Hamilton, VIC, 3300

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.pir.sa.gov.au/research

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Author(s): Leigh Thwaites, Josh Fredberg and Stephen Ryan

Reviewer(s): George Giatas and Kate Frahn

Approved by: Assoc Prof Qifeng Ye
Science Leader - Inland Waters & Catchment Ecology

Signed: 

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EXECUTIVE SUMMARY

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 a cost effective carp control strategy is knowledge of the movement patterns and habitat preferences of carp which may be exploited for control purposes, as well as an understanding of the carp population dynamics and the efficiency of potential carp control techniques within targeted systems. The objectives of the current project were to: 1) utilise acoustic telemetry and geospatial modeling to investigate carp movement patterns, 2) investigate the influence of environmental factors (i.e. temperature and flow) on movement, 3) evaluate feasible options for harvesting carp within the Glenelg River, and 4) 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. A total of 26 VEMCO VR2W acoustic receivers were systematically positioned every 10-20 km over 320 km of the river's main channel between the Rocklands Reservoir and Dartmoor. The array encompasses the current and predicted distribution of carp and included known areas of aggregation (e.g. Clunies Hole) and environmental water release sites.

A total of 131 adult carp were captured and surgically implanted with VEMCO V13-1L acoustic transmitters. 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 May 2015, the majority of carp (*n*=121, 92% of tagged carp) 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. In contrast, 10 carp (8% of tagged carp) moved substantial distances upstream or downstream of their tagging location (average distance: 35 km ± 3.4 S.E.) with the longest movement occurring over 53 km

between Warrock Road (Dergholm) and Clunies Hole (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). There is no evidence to suggest that the delivery of environmental flows triggered any of the observed movement.

As the utility of carp management strategies is site specific and dependent on several factors including amenity value, season, scale, hydrology and resources, the feasibility of a range of available management strategies for the Glenelg River was assessed. Of these, targeted harvesting (netting, electrofishing) was considered the most feasible physical control option. To evaluate these harvesting strategies and determine seasonal variation in harvesting efficiency, targeted carp harvesting was conducted within the Glenelg River during 2-8 December 2014 and 15-20 May 2015. Harvesting was conducted within Clunies Hole, Yat Nat 1, 5-Mile and Moree during 2014/15, with an additional three sites targeted during 2015 (Pine Hut, Yat Nat 2 and 5-Mile 2). The harvest incorporated multi-panel monofilament gill nets, small-mesh fyke nets and electrofishing.

A total of 235 carp were captured during the December 2014 harvesting event. The majority were captured within Clunies Hole (147 carp; 65% of total catch) and a further 88 carp were captured across 5-Mile (35 carp; 14.9%), Yat Nat 1 (29 carp; 12.3%) and Moree (24 carp; 10.2%). Similar numbers were captured during May 2015 with a total of 228 carp harvested. The majority of carp were captured within Clunies Hole (94 carp; 41.2% of total catch) and Yat Nat 1 (72 carp; 31.6%), with the remaining carp being captured at Moree (35 carp; 15.4%) and 5-Mile (27 carp; 11.9%). A further 194 carp were captured from three additional sites targeted during the 2015 harvest. Yat Nat 2 yielded the highest catch with 50% (n=97) of the total catch. Whereas, 35.1% (n=68) and 14.9% (n=29) were captured at 5-Mile 2 and Pine Hut, respectively.

Although netting has proven to be an effective carp harvesting technique within other systems, it was the least efficient within the Glenelg River during the 2014 and 2015 targeted harvest. Total combined soak time was 114 h for gill nets and 288 h for fyke nets, however, carp were only captured in gill nets during 2014 (9 carp; 0.10 fish h^{-1}). Carp were captured using electrofishing within the same reaches where netting occurred suggesting a level of net avoidance. Given this low efficiency and potential risks to iconic native fauna such as platypus (*Ornithorhynchus anatinus*), it is recommended that future harvesting activities rely on electrofishing.

Total combined electrofishing catch per unit effort (CPUE) for Yat Nat 1, 5-Mile, Clunies hole and Moree during the 2014 and 2015 harvest was 44.05 fish h^{-1} and 48.72 fish h^{-1}, respectively, while total combined electrofishing CPUE for the additional sites targeted during 2015 was 76.68 fish h^{-1}. CPUE varied across sites and seasons ranging from 25.22 fish h^{-1} at Yat Nat 1 to 55.38 at Clunies Hole during December 2014 and from 30.70 fish h^{-1} at Moree to 101.04 fish h^{-1} at Yat Nat 2 during May 2015.

Distinct differences in carp behaviour were observed between summer (December 2014) and autumn (May 2015) harvesting events. Carp appeared to be widely dispersed during the summer harvest with small numbers of carp (<5) captured at regular intervals, while carp appeared to be aggregated during the autumn harvest with large numbers (20-70 carp) captured in complex snags and shallow reed beds. The aggregations were observed in similar habitat within all harvesting locations suggesting that autumn/winter CPUE could be increased by identifying and directly targeting these habitats across the Glenelg River.

The data collected are important in determining the appropriate strategy to manage carp in the Glenelg River. Given there appears to be no predictable large-scale migrations throughout the system, control techniques that exploit this behaviour will have limited effect (i.e. carp separation cages) and a more site specific approach is required. Of the harvesting strategies trialed during the 2014/15 targeted harvests, electrofishing proved to be the most efficient and observations of aggregation behaviour during the autumn harvest suggest the technique could be further optimised during the cooler months. Ideally, the application of this strategy 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 it 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 significant increase in turbidity at carp densities of 50-75 kg ha^{-1} (Zambrano and Hinojosa 1999), a significant negative effect on water transparency and aquatic macrophyte cover at a mean density of 68 kg ha^{-1} (Vilizzi *et al*. 2014), decline in vegetation cover and waterfowl at ~100 kg ha^{-1} (Bajer *et al.* 2009), shift from clear to turbid water state at 174-300 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).

The Glenelg River is a high profile priority river in Victoria containing ecologically 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.

Where carp are considered a pest, considerable resources have been invested in developing and evaluating novel management strategies. In Australia, there is a national management strategy (Carp Control Coordinating Group 2000) and several texts outlining the species' ecology and management options (Roberts and Tilzey 1996; Koehn *et al*. 2000). Common management methods rely on a strong understanding of carp ecology and aim to target or sabotage exploitable behaviours (i.e. migrations, spawning). The utility of each method is site specific and dependent on several factors including amenity value, season (i.e. spring vs. winter), scale (i.e. individual wetlands, river reach, whole of system), hydrology (i.e. base flow vs. flood) and resource availability. Specific options for carp management include operational and intervention techniques or a combination of both. To date, these largely rely on 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), electrical barriers to restrict movements (Verrill and Berry 1995), barrier netting and liming to sabotage spawning by destroying eggs (Inland Fisheries Service 2008), 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), pheromone traps (Sorensen and Stacey 2004), chemical piscicides (Clearwater *et al*. 2008) and water level manipulations to reduce access to littoral spawning sites and expose eggs to desiccation (Shields 1957; Yamamoto *et al*. 2006). The strategic delivery of water to disadvantage carp by providing a non-preferred inundation regime or mosaics of fast- and slow-flowing habitats has been proposed, but is yet to be fully evaluated (Stuart *et al*. 2011). Genetic ('daughterless' carp; Thresher 2008) and biological (Koi herpes virus; McColl *et al*. 2007) technologies are also in development and although these techniques may promise large-scale population impacts (Brown and Gilligan 2014) they are still many years from deployment.

Key to the development of a cost effective carp control strategy is knowledge of the movement patterns and habitat preferences of carp which may be exploited for control purposes, as well as an understanding of the carp population dynamics and the efficiency of potential carp control techniques within targeted systems. With this knowledge, the appropriate strategy to manage carp can be identified (Stuart and Jones 2006) and the feasibility of control methods such as carp separation cages, targeted harvesting (i.e. netting, electrofishing) or the strategic delivery of environmental water to aggregate carp for trapping can be critically evaluated and/or optimised. In addition, the knowledge gained may support the future roll-out of 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 30 months of the Glenelg River “Judas” carp tracking program (28 November 2012 to17 May 2015) and reports the results of two targeted carp harvesting events which were conducted within the Glenelg River during 2-8 December 2014 and 15-20 May 2015.

1.2. Objectives

The objectives of this study are to:

- Utilise acoustic telemetry and geospatial modeling to investigate carp movement patterns within the Glenelg River system.
- Investigate the influence of temperature and flow (including environmental water delivery) on movement patterns.
- Evaluate feasible options for harvesting carp within the Glenelg River.
- 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) and using the knowledge gained to evaluate feasible carp control techniques across the Glenelg River.

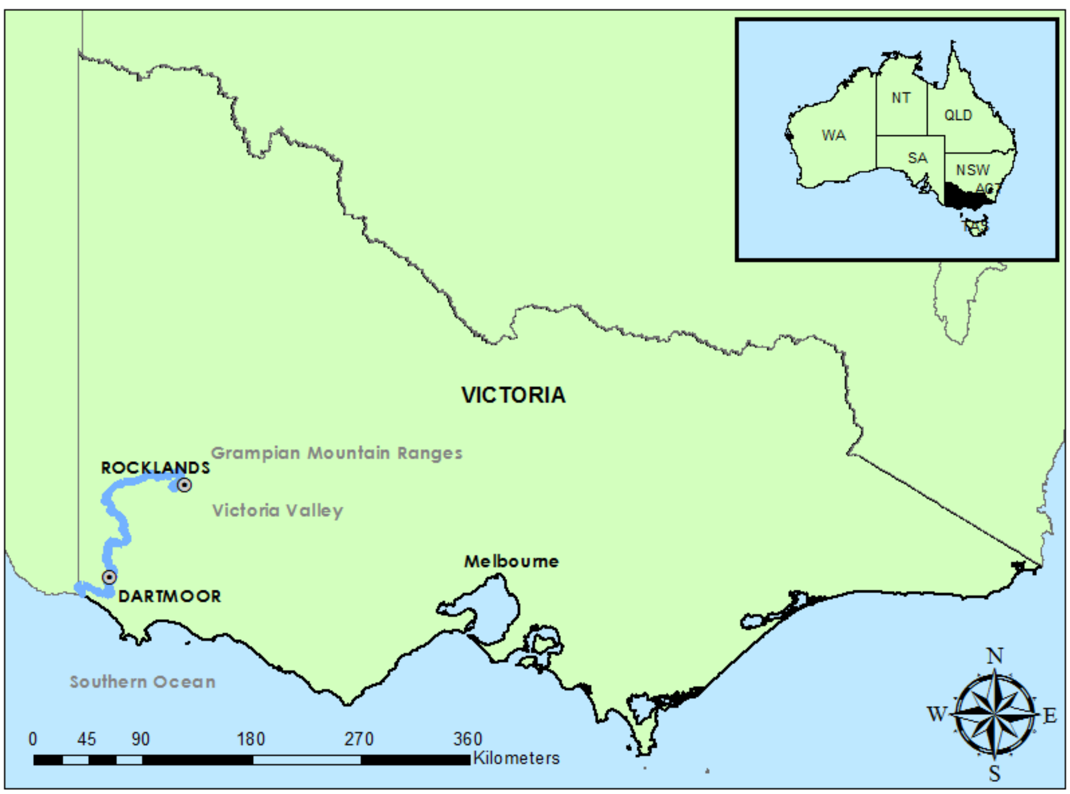

Figure 1. Map showing the location of the Glenelg River system in south-western Victoria, Australia.

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 (Thwaites 2012). 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 positioned 30 cm below the water surface to permit easy access for download and maintenance (i.e. battery exchange).

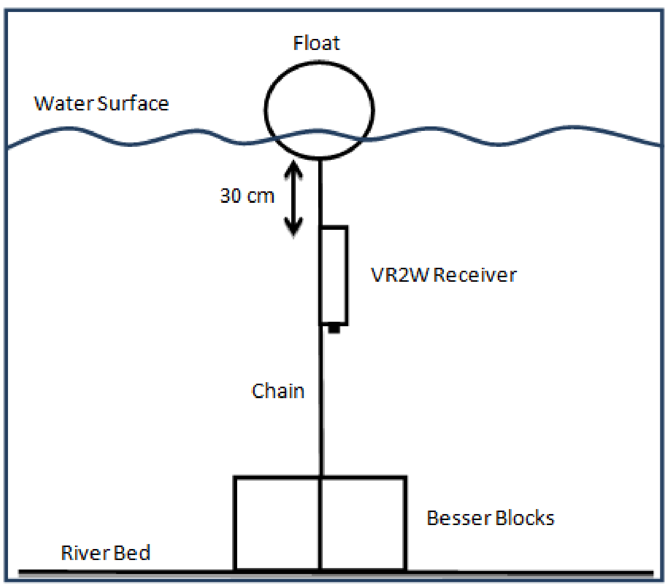

Figure 2. Schematic representation of the VR2W acoustic receiver mooring.

Within the upper reaches (Rocklands Reservoir to Moree; Figure 3), receivers were arranged into a system of 'gates' approximately 15 km apart. A gate comprised two receivers 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 gate’s 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 for tagging 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 maximising 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 provide 1029 days (~3 years) of continuous tracking (VEMCO 2013).

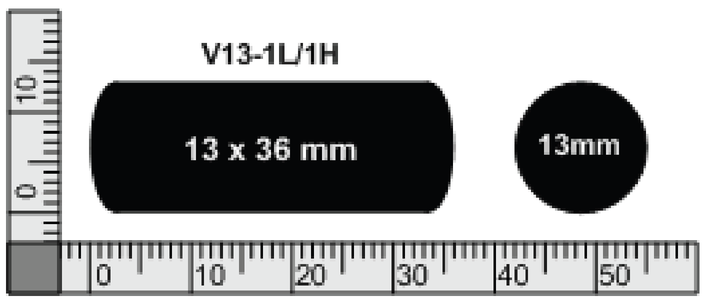

Figure 4. VEMCO V13 coded acoustic transmitter (http://www.vemco.com/pdf/v13_coded.pdf).

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, netting and angling (Table 1). Sampling was conducted at three sites within the upper reaches of the Glenelg River during 2012 and nine sites during 2013 (Table 1, Figure 3). 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 5.0 kW 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 5.0 kW portable electrofisher	2357 s
22/11/12	5-Mile (37°11'42.44"S; 141°54'39.38"E)	Boat mounted Smith-Root GPP 5.0 kW 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 5.0 kW 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 5.0 kW portable electrofisher	3400 s
19/11/13	Yat Nat (37°13'57.06"S; 141°51'42.64"E)	Boat mounted Smith-Root GPP 5.0 kW 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 5.0 kW 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 and individual identification 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 transmitter 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.

2.4. Tracking array downloads and water quality

Following fish tagging, the acoustic tracking array was downloaded on five occasions between April 2013 and May 2015 (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	1st 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	2nd 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	3rd download of receivers	25 receivers were downloaded using the VEMCO software program VUE.
5-6/12/14	4th download of receivers	25 receivers were downloaded using the VEMCO software program VUE and receiver batteries were replaced. The Benison Road receiver (-37.802889°,141.240972°) was removed from the system due it being engulfed by a sand slug.
14-17/05/15	5th download of receivers	24 receivers were downloaded using the VEMCO software program VUE.

2.5. Carp tracking 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).

2.6. Targeted harvest

Assessing the feasibility of available carp management strategies

As the utility of carp management strategies is site specific and dependent on several factors including amenity value, season, scale, hydrology and resources, the feasibility of a range of available management strategies was assessed (Appendix A). Of these methods, targeted harvesting (netting, electrofishing) was considered the most feasible physical control option for the Glenelg River. While a carp separation cage (Stuart *et al*. 2006; Thwaites *et al*. 2010) was also considered feasible, justifying the expenditure associated with installing and maintaining this infrastructure is dependent on identifying large scale carp movements into areas which are suitable for trapping. If this behaviour is not recorded then this option will not be considered feasible. Real-time tracking of carp may also assist in identifying and targeting aggregations however, as this requires carp to be surgically implanted with radio tags or continuous ping acoustic tags it is outside the scope of the current project.

Targeted harvest

To evaluate feasible carp harvesting strategies and determine seasonal variation in harvesting efficiency, targeted carp harvesting was conducted within the Glenelg River during 2-8 December 2014 (summer) and 15-20 May 2015 (autumn). Harvesting was conducted within Clunies Hole, Yat Nat 1, 5-Mile and Moree during 2014/15 with an additional three sites targeted during 2015 (Pine Hut, Yat Nat 2 and 5-Mile 2) (Figure 3). The harvest incorporated multi-panel monofilament gill nets (15 m total length, 3 m depth and 3 panel mesh at 45 mm, 57 mm, 115 mm), small-mesh fyke nets (6 mm stretched mesh, 5 m leader, 3 m funnel, 7 support rings and 3 chambers) and electrofishing. A boat mounted 5.0 kW electrofishing unit (Smith Root Model® GPP) was used in all sites except Yat Nat 2 and 5-Mile 2 where a boat mounted 7.5 kW electrofishing (Smith Root Model® GPP) unit was used.

Fyke and gill nets were deployed at all sites during the 2014 harvest and at Clunies Hole during the 2015 harvest. However, given that a total of 9 carp were captured in nets across both events, netting was abandoned in favor of electrofishing for the remaining six sites during 2015. To optimise catch rates, each gear type was set within the particular habitat and depth where they are most effective (SKM 2006). Fyke nets were set in the littoral zone in close proximity to submergent and emergent vegetation while gill nets were set in open deeper sections of the system. The total amount of nets deployed at individual sites varied based on available habitat but was no less than six fyke nets and three gill nets at each site. All nets were set and managed in accordance to the Glenelg Hopkins CMA regulations. Electrofishing was conducted at all sites during both harvesting events and activities targeted all available habitat including submergent/emergent vegetation, snags, open water, bare banks and runs/riffles where possible. All captured carp (both tagged and untagged) were counted, measured (total length, TL, mm; weight, g) and tag numbers recorded where applicable. All captured carp were euthanised (after Close *et al*. 1997) and native fish were released unharmed.

Catch summary

Each site's catch data are presented as catch per unit effort (CPUE), length-frequency histograms and abundance, total weight and summary statistics. Electrofishing CPUE was standardised to the number of fish captured per hour of "power-on" time (fish h^{-1}) and netting CPUE was standardised by dividing the number of fish captured by the multiple of the number of nets and soak time per net (e.g. 10 fish / (10 nets X 10 hour soak) = 0.1 fish h^{-1}). Catch per unit effort was calculated for each site that was targeted during 2014/15 targeted harvest.

3. RESULTS AND DISCUSSION

3.1. Carp tracking

A total of 131 carp (mean total length (TL) ± S.E. = 481 ± 4 mm; mean weight ± S.E. = 1739 ± 44 g) were captured and surgically implanted with VEMCO acoustic transmitters. Seventy-five carp were implanted during November 2012 (mean TL ± S.E. = 487 ± 7 mm; mean weight ± S.E. = 1812 ± 69 g) and a further 56 carp implanted during November 2013 (mean TL ± S.E. = 472 ± 4 mm; mean weight ± S.E. = 1641 ± 40 g) (Table 3, 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).

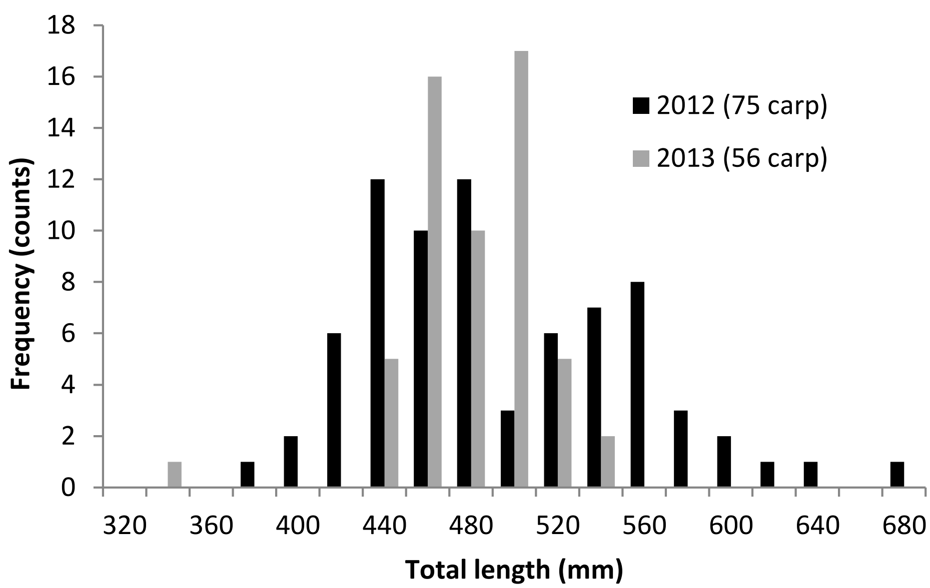

Figure 6. Length frequency distribution for carp captured and tagged during 2012 (*n*=72) and 2013 (*n*=56).

Carp were tagged at five of the 11 sites that were targeted, with the majority 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 1, 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.

Date	Site	No. of Carp	Length (mm) Mean ± SE	Length (mm) Range	Weight (g) Mean ± SE	Weight (g) Range	Sex Ratio
20/11/12	Clunies Hole (37°11'33.18"S; 141°33'59.52"E)	41	513 ± 9	420-675	1986 ± 91	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 ± 11	440-555	1961 ± 158	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	441 ± 11	373-624	1407 ± 100	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	457 ± 7	337-533	1464 ± 51	1094-2259	F: 8 M: 20
19/11/13	Yat Nat (37°13'57.06"S; 141°51'42.64"E)	8	480 ± 6	458-513	1809 ± 64	1568-2081	F: 4 M: 4
20/11/13	Yat Nat 2 (37°13'52.84"S; 141°52'20.36"E)	20	490 ± 4	458-522	1821 ± 50	1196-2059	F: 13 M: 7
	Total	**131**	**481 ± 4**	**337-675**	**1739 ± 44**	**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 2012-17 May 2015).

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 near tagging location		121 (92%)
Number of carp that moved from tagging location		10 (8%; 4 male, 6 unknown sex)
Movement distance	Average distance	35 km ± 3.4 S.E.
	Range	10-53 km
Swim speed (minimum)	Average swim speed	4.35 km d^{-1} ± 1.5 S.E.
	Range	0.12-21.5 km d^{-1}

Since tracking commenced (28 November 2012), the majority of fish (*n*=121, 92% 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, 10 carp (8% of tagged carp) moved substantial distances upstream or downstream from their tagging location (average distance: 35 km ± 3.4 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 4.35 km d^{-1} ± 1.5 S.E. with a minimum of 0.12 km d^{-1} and a maximum of 21.5 km d^{-1}. Of the 10 carp that moved from their tagging location, two males and three of unknown sex returned to their initial tagging location after an extended period of absence (mean: 52 d ± 8.9 S.E.; range: 21.5 d-66.5 d) suggesting potential homing behaviour or site recognition (Reynolds 1983; Jones and Stuart 2009) (Figures 7-9). Based on qualitative comparisons between carp movements and water quality parameters, 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 and 9).

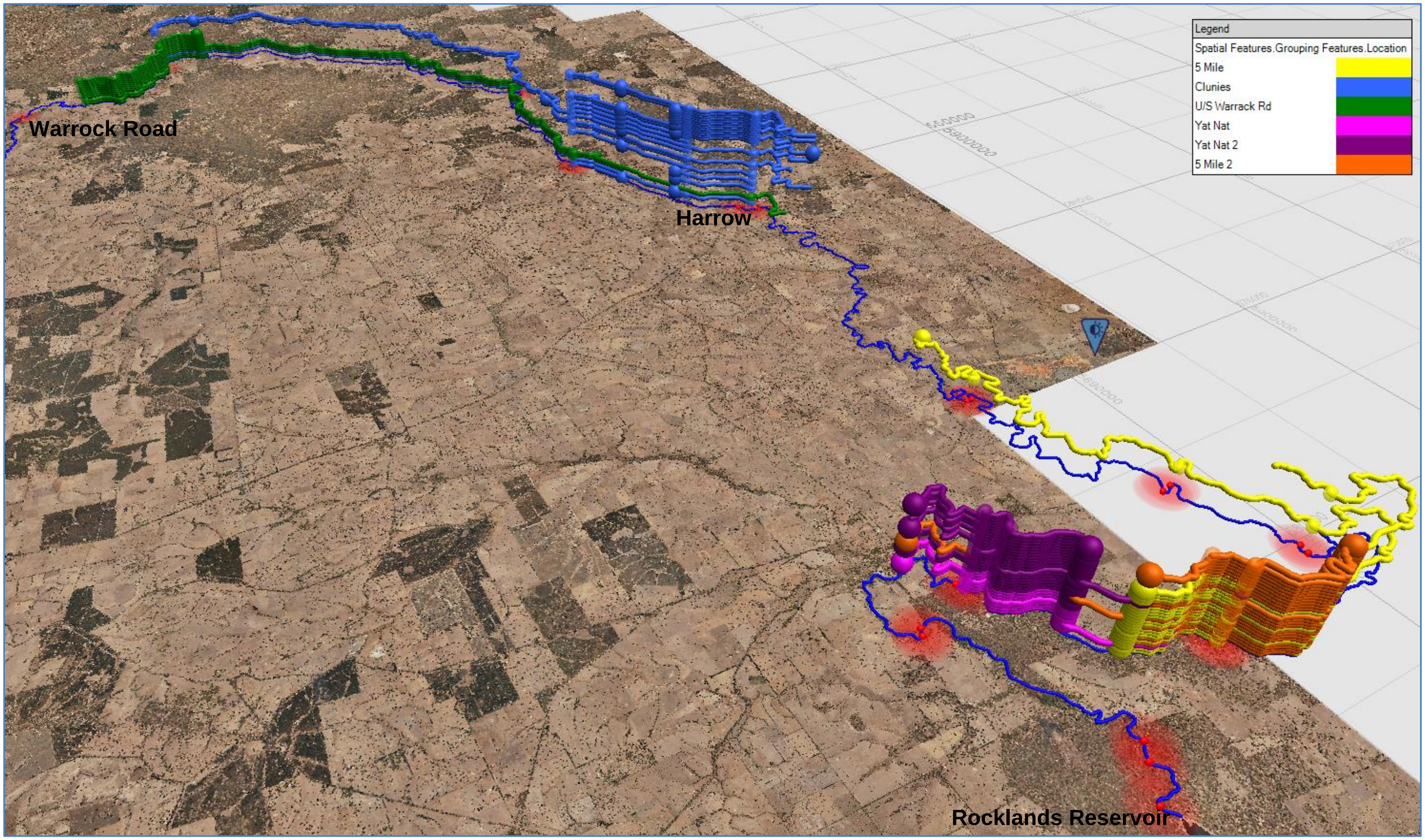

Figure 7. Overview of Eonfusion 2.4 carp tracking model showing the extent of movements of all detected tagged carp (*n*=109) within the Glenelg River system (28 November 2012-17 May 2015). Colours represent tagging location (see legend). Each dot/line represents the extent of movements for individual tagged carp. Red dots represent VR2W acoustic receiver locations.

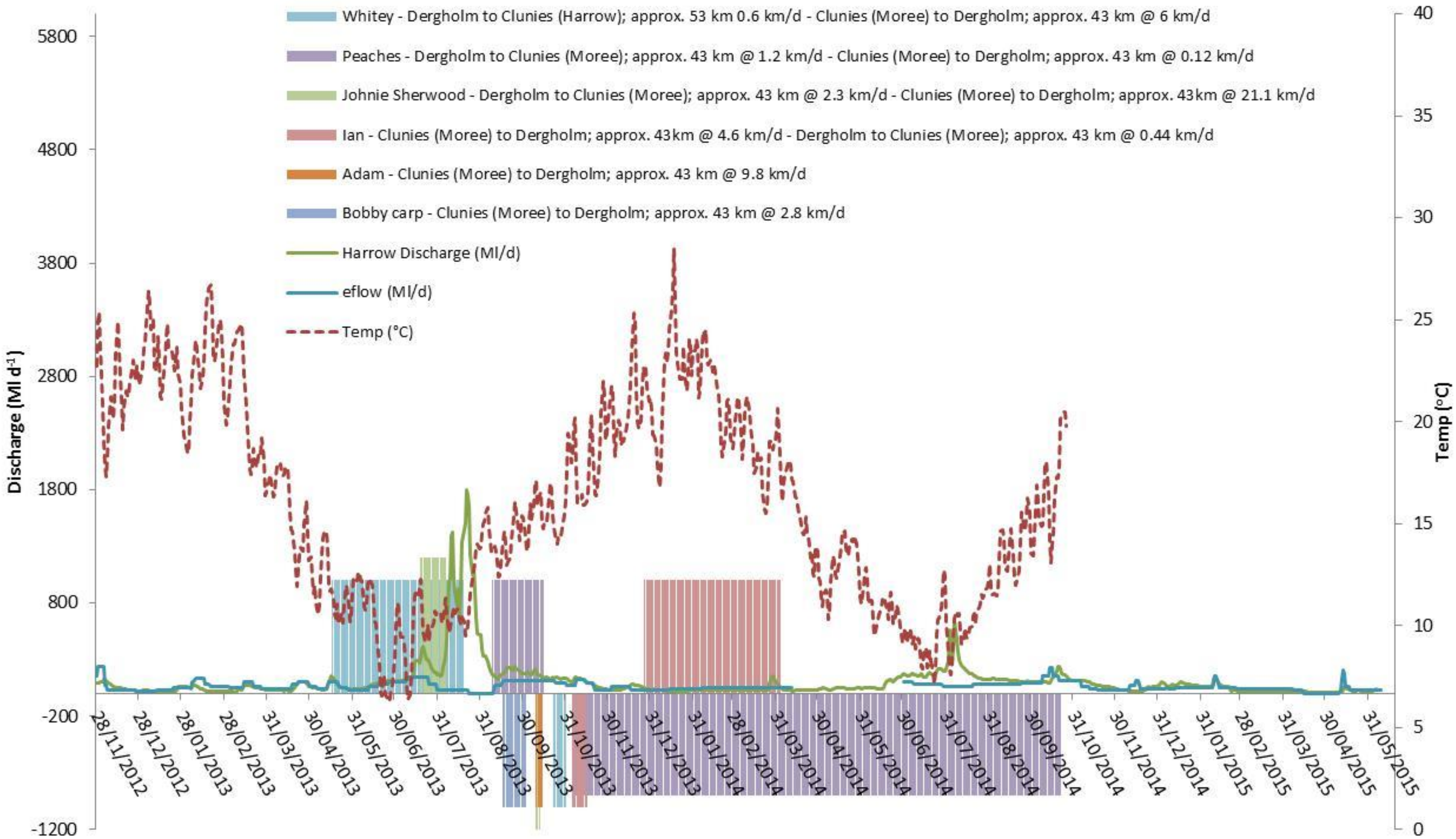

Figure 8. Carp movements (6 individuals) between Dergholm and Clunies Hole, Glenelg River, Victoria. Colour coded columns represent the timing and duration of movements of tagged carp with upstream movements above the x-axis and downstream movements below the x-axis.

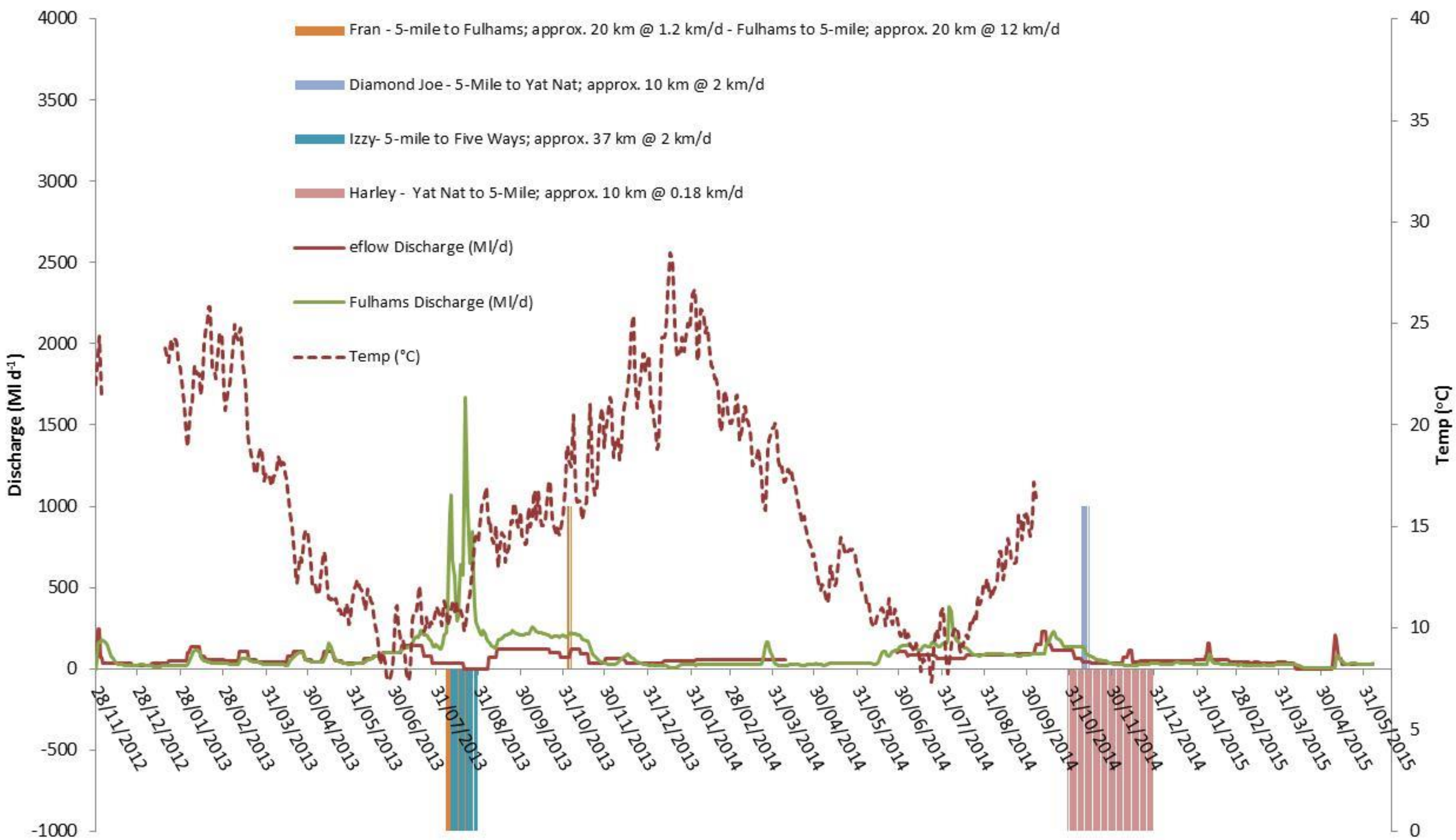

Figure 9. Carp movements (4 individuals) between Fulhams, Five Ways and 5-Mile, Glenelg River, Victoria. Colour coded columns represent the timing and duration of tagged carp movements with upstream movements above the x-axis and downstream movements below the x-axis.

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 our study, movement from the release point was not related to river discharge and water temperature. Osbourne *et al.* (2009) captured and tagged 1265 Koi carp (coloured 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% 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 carp (1607 unknown sex, 1099 males, 504 females, 127 juveniles) 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 carp 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%) 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 recognise 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.

3.2. Targeted harvest

Catch summary - December 2014

A total of 235 carp (mean TL ± S.E. = 492 ± 7 mm; mean weight ± S.E. = 1970 ± 59 g) were captured during the December 2014 harvesting event (Table 5, Figure 10).The majority of carp were captured within Clunies Hole (147 carp; 65% of total catch) and a further 88 carp were captured across 5-Mile (35 carp; 14.9%), Yat Nat 1 (29 carp; 12.3%) and Moree (24 carp; 10.2%). A total of 174 carp (74% of total catch) were in the 500-600 mm TL size class, with the highest frequency count of 79 carp in the 550-600 mm TL size class (~7+ years of age, Smith 2005). Carp >650+ mm TL (~10+ years of age; Smith 2005) represented 8.1% (*n*=19) of the total catch and the majority of these were captured within Clunies Hole (*n*=16). A smaller, sexually maturing cohort (250-300 mm TL; ~1-2 years of age; Smith 2005) represented 14% (33 carp) of the total catch with the majority of these captured in Clunies Hole (*n*=28).

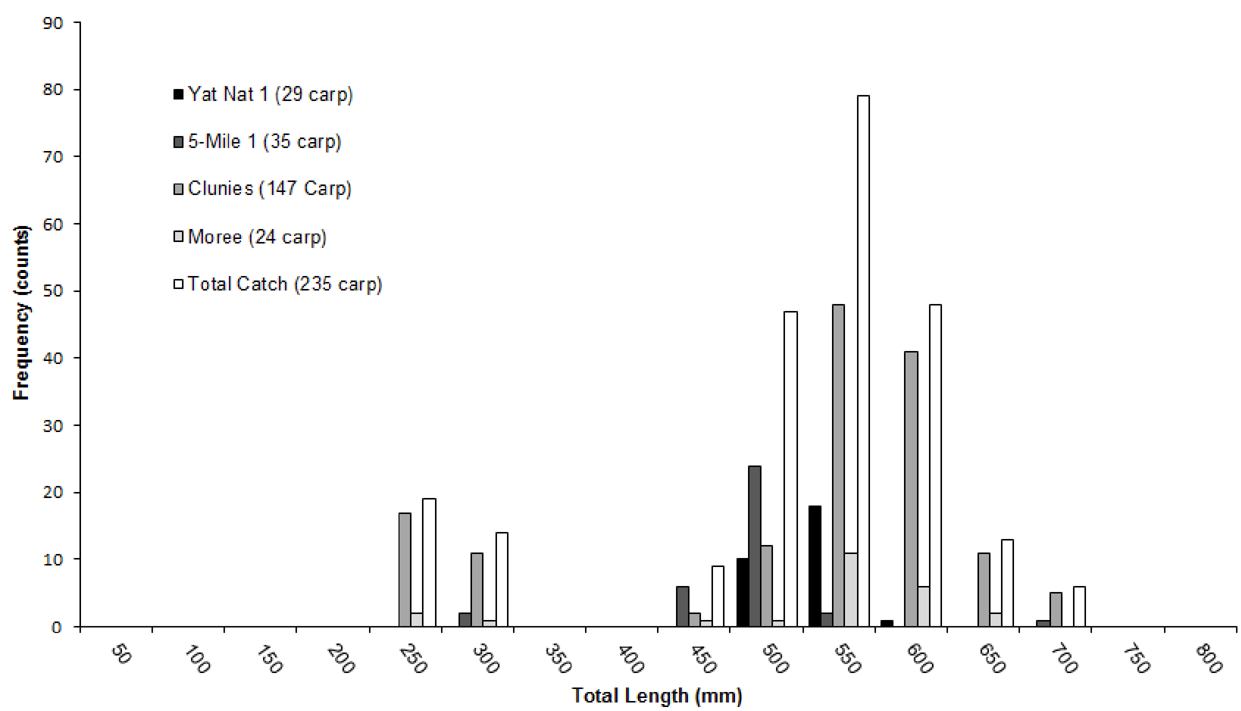

Figure 10. Length frequency distribution for carp captured during the December 2014 carp harvest.

Catch summary - May 2015

A total of 228 carp (mean TL ± S.E. = 462 ± 9 mm; mean weight ± S.E. = 1857 ± 75 g) were captured during the May 2015 harvesting event (Table 5, Figure 11). The majority of carp were captured within Clunies Hole (94 carp; 41.2% of total catch) and Yat Nat 1 (72 carp; 31.6%) with the remaining carp being captured at Moree (35 carp; 15.4%) and 5-Mile (27 carp; 11.9%). A total of 148 carp (64.9% of total catch) were in the 500-600 mm TL size class, with the highest frequency count of 78 fish in the 550-600 mm TL size class (~7+ years of age, Smith 2005). Carp >650+ mm TL (~10+ years of age; Smith 2005) represented 6.1% (*n*=14) of the total catch with the majority of these captured within Clunies Hole (*n*=8) and Moree (*n*=6). A smaller, sexually maturing size cohort (150-300 mm TL; ~1-2 years of age; Smith 2005) represented 19.7% (*n*=45) of the total catch with Clunies Hole being the primary source of this cohort (*n*=41).

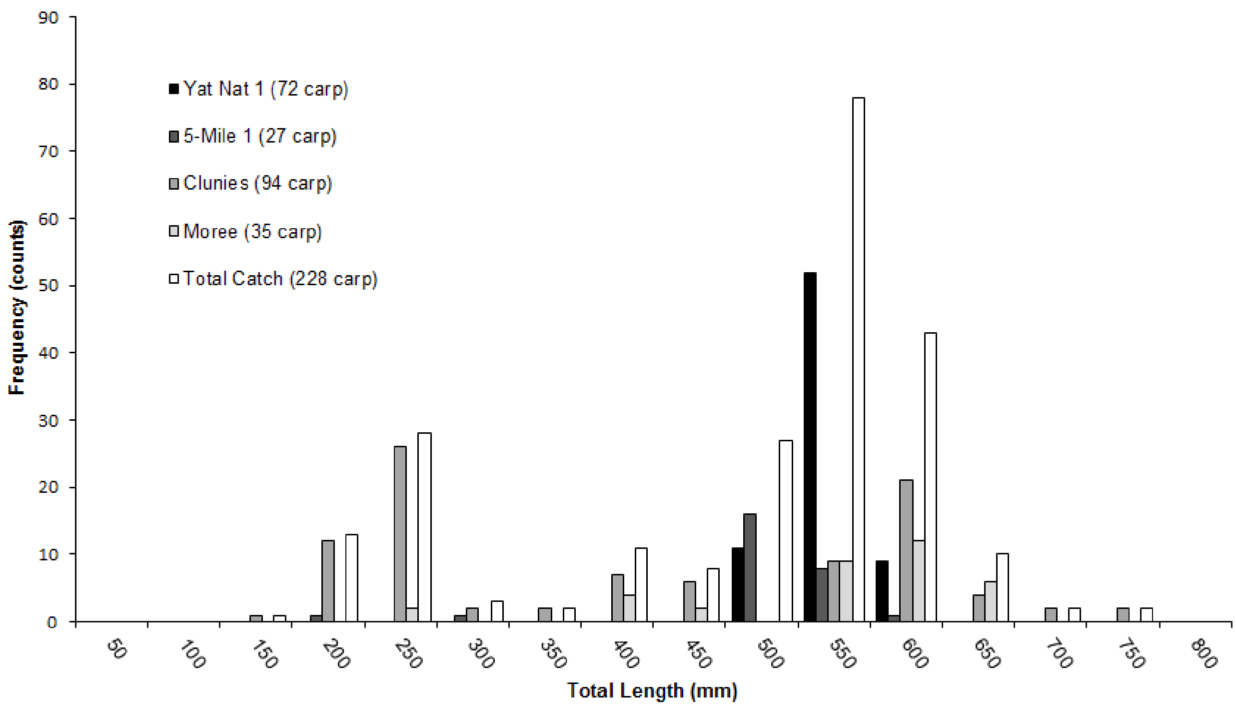

Figure 11. Length frequency distribution for carp captured during the December 2015 carp harvest.

Catch summary - Additional sites May 2015

A total of 194 carp (mean TL ± S.E. = 518 ± 3 mm; mean weight ± S.E. = 2200 ± 41 g) were captured from three additional sites targeted during the 2015 harvest (Table 6, Figure 12). Yat Nat 2 yielded the highest catch with 50% (*n*=97) of the total catch. Whereas, 35.1% (*n*=68) and 14.9% (*n*=29) were captured at 5-Mile 2 and Pine Hut, respectively. A total of 94.8% (*n*=184) carp were in the 500-600 mm TL size class, with the highest frequency count of 85 in the 550-600 mm TL size class (~7+ years of age; Smith 2005). Large carp (650+ mm TL; ~10+ years of age, Smith 2005) accounted for 3.1% (*n*=6) of the total catch across all sites, with Pine Hut (*n*=4) being the main source of these larger fish. Only 1% (*n*=2) of carp were in the 300 mm TL size class (~1-2 years of age, Smith 2005).

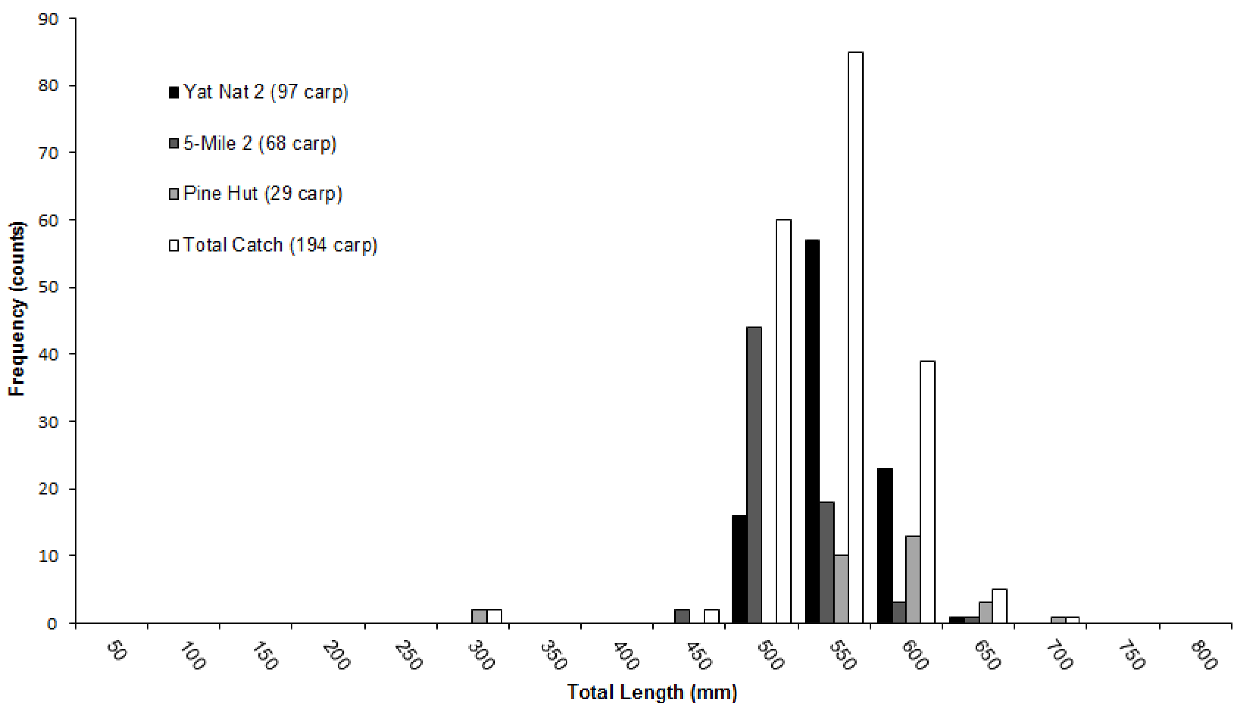

Figure 12. Length frequency distribution for carp captured with three additional sites targeted during the December 2015 carp harvest.

The results of the targeted harvest indicate there has been limited recruitment within the previous 6-7 years. Only a small percentage of the catch was <500 mm TL with the majority of this smaller cohort captured at one location (Clunies Hole). Limited recruitment may be associated with river morphology, habitat availability, management and the relatively "natural" hydrology of the river however, determining the precise mechanisms limiting carp within the Glenelg River warrants further investigation.

Table 5. Summary of carp capture data for the 2014 and 2015 targeted harvest.

			Length (mm)		Weight (g)		
Site	**Harvesting event**	**No. of Carp**	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**	**Total weight (kg)**
Yat Nat 1	Dec-2014	29	512 ± 4	466 - 575	2059 ± 68	1613 - 3362	60
	May-2015	72	524 ± 2	485 - 560	2237 ± 41	1418 - 3345	161
5-Mile 1	Dec-2014	35	466 ± 11	268 - 684	1532 ± 99	291 - 4135	54
	May-2015	27	472 ± 15	189 - 556	1725 ± 89	118 - 2759	47
Clunies	Dec-2014	147	493 ± 11	203 - 665	2025 ± 83	125 - 4285	298
	May-2015	94	390 ± 18	148 - 746	1362 ± 147	49 - 6644	128
Moree	Dec-2014	24	502 ± 22	228 - 639	2158 ± 181	233 - 4298	52
	May-2015	35	522 ± 17	235 - 650	2505 ± 187	241 - 4605	88
Total	Dec-2014	235	492 ± 7	203 - 684	1970 ± 59	125 - 4298	464
	May-2015	228	462 ± 9	148 - 746	1857 ± 75	49 - 6644	424
Grand Total	**2014-15**	**463**	**478 ± 6**	**148 - 746**	**1914 ± 48**	**49 - 6644**	**886**

Table 6. Summary of carp capture data for three additional sites targeted during the 2015 carp harvest.

			Length (mm)		Weight (g)		
Site	**Harvesting event**	**No. of Carp**	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**	**Total weight (kg)**
Yat Nat 2	May-2015	97	529 ± 3	458 - 605	2302 ± 42	1423 - 3618	223
5-Mile 2	May-2015	68	491 ± 4	448 - 604	1846 ± 58	1323 - 4178	126
Pine Hut	May-2015	29	547 ± 16	256 - 660	2690 ± 137	294 - 4557	78
Grand Total	**May-2015**	**194**	**518 ± 3**	**256 - 660**	**2200 ± 41**	**294 - 4557**	**427**

Although netting has proven to be an effective carp harvesting technique within other systems (Inland Fisheries Service 2008), it was the least efficient within the Glenelg River during the 2014 and 2015 targeted harvest. Total combined soak time was 114 h for gill nets and 288 h for fyke nets, however, carp were only captured in gill nets during 2014 (9 carp; 0.10 fish h^{-1}). Carp were captured using electrofishing within the same reaches where netting occurred suggesting a level of net avoidance. This behaviour was recently documented within urban managed aquifer recharge wetlands. A total of eight fyke nets and five 50 m gill nets were set for a period of 24 h with no captures; however, subsequent rotenone activities removed a total of 6000 carp (SARDI, unpublished data). Given this low efficiency and potential risks that nets may pose to iconic native fauna such as platypus (*Ornithorhynchus anatinus*; Grant 1993), it is recommended that future harvesting activities rely on electrofishing.

Table 7. CPUE data (fish h^{-1}) for electrofishing during the 2014 and 2015 carp harvest.

Site	Harvesting event	Total catch	Total Time (h)	CPUE (Fish h^{-1})
Yat Nat 1	Dec-2014	29	1.15	25.22
	May-2015	72	1.03	69.90
5-Mile 1	Dec-2014	35	0.68	51.47
	May-2015	27	0.64	42.19
Clunies	Dec-2014	139	2.51	55.38
	May-2015	94	1.87	50.27
Moree	Dec-2014	23	0.80	28.75
	May-2015	35	1.14	30.70
Total	Dec-2014	226	5.13	44.05
	May-2015	228	4.68	48.72
Grand Total	**2014-15**	**454**	**9.82**	**46.23**

Table 8. CPUE data (fish h^{-1}) for electrofishing within three additional sites targeted during the 2015 carp harvest.

Site	Harvesting event	Total catch	Time (h)	CPUE (Fish h^{-1})
Yat Nat 2	May-2015	97	0.96	101.04
5-Mile 2	May-2015	68	0.83	81.93
Pine hut	May-2015	29	0.74	39.19
Grand Total	**May-2015**	**194**	**2.53**	**76.68**

Total combined electrofishing CPUE for Yat Nat 1, 5-Mile, Clunies Hole and Moree during the 2014 and 2015 harvest was 44.05 fish h^{-1} and 48.72 fish h^{-1}, respectively, while total combined electrofishing CPUE for the additional sites targeted during 2015 was 76.68 fish h^{-1} (Tables 7 and 8). CPUE varied across sites and seasons ranging from 25.22 fish h^{-1} at Yat Nat 1 to 55.38 at Clunies Hole during December 2014 and from 30.70 fish h^{-1} at Moree to 101.04 fish h^{-1} at Yat Nat 2 during May 2015. Yat Nat 2 and 5-Mile 2 had not been targeted during previous electrofishing activities and this may explain the higher CPUE.

Distinct differences in carp behaviour were observed between summer (December 2014) and autumn (May 2015) harvesting events. Carp appeared to be widely dispersed during the summer harvest with small numbers of carp (<5) captured at regular intervals. Catches were generally associated with relatively shallow water (1-2 m) and within-channel and fringing emergent vegetation (i.e. Triglochin and Typha). In contrast, carp appeared to be aggregated during the autumn harvest with large numbers (20-70 carp) captured in complex snags (Figure 13) and shallow reed beds (<1 m) within the littoral zone. Carp were also caught in similar locations to those observed during summer but in lower abundance. The reason for the aggregation behaviour is unclear, however, carp may have been seeking warmer water temperatures associated with the shallow reed beds and snags. Indeed, carp are known to seek and aggregate within warmer water during cool temperate winters (Johnsen and Hasler 1977; Inland Fisheries Service 2008; Penne and Pierce 2008). Regardless of the reason, the aggregations were observed in similar habitat within all harvesting locations suggesting that autumn/winter CPUE could be increased by identifying and directly targeting these habitats across the Glenelg River.

Figure 13. Electrofishing carp from a complex snag within the Glenelg River during the 2015 targeted harvest.

4. CONCLUSION AND RECOMMENDATIONS

The data collected to date are important in determining the appropriate strategy to manage carp in the Glenelg River. Given there appears to be no predictable large-scale migrations throughout the system, control techniques that exploit this behaviour will 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 required. Of the harvesting strategies trialled during the 2014/15 targeted harvests, electrofishing proved to be the most efficient and observations of aggregation behaviour during the autumn harvest suggest the technique could be further optimised during the cooler months. Ideally, the application of this strategy 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 it 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 may 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 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.

- *Optimise electrofishing harvesting* - continue to evaluate and optimise electrofishing as the primary carp harvesting technique. Harvesting should be trialled throughout the carp breeding season (spring- early autumn) and during the cooler months when carp may be aggregating. This work should categorise and record capture locations (i.e. snags, reed beds, temperature profiles etc.) in order to identify seasonal trends in carp distribution which may inform future harvesting events. If carp are found to regularly aggregate at specific locations then directly targeting these, and similar locations may increase CPUE. To assist in identifying and targeting aggregations, real-time tracking of carp tagged with either radio tags or continuous ping acoustic tags should be considered. This harvesting work should also continue to collect the biological/ecological data outlined below.

- *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) and weight (g). Each specimen should be sexed, gonads weighed (GSI, g) and eggs staged. In addition, each specimen should have their 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. Native fish data will aid in determining the response of the rivers native fish assemblage to the reduction in carp numbers.

- *Seek to understand the mechanism limiting recruitment* - Length frequency data indicates there has been limited recruitment in the Glenelg River during the previous 6-7 years. This may be associated with river morphology, habitat availability, management and the relatively “natural” hydrology of the river, however, determining the precise mechanisms warrants further investigation. This knowledge may then be used to develop management strategies that seek to further disadvantage carp (i.e. increase/decreased flow delivery).

- *Mark-recapture experiment* - conduct a mark-recapture experiment to calculate population estimates and 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 future 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).

- *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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6. APPENDIX A

Feasibility of available carp management options for the Glenelg River.

Management option	**Comments**	**Feasible**	
		Yes	**No**
Netting- gill and fyke nets	• Unlikely to catch all carp but will aid in reducing numbers to below impact thresholds densities. • Can remove large tonnages of carp during annual spawning migrations with large nets. • Depending on the level of effort required to achieve a satisfactory reduction in the biomass of carp this may be an expensive option. • There may be some native species by catch, however these fish can be release unharmed. • Require permits, can be labor intensive and difficult at some sites (e.g. navigation issues). • *May be a feasible option but will need to be optimised in order to make it cost-efficient and strategies to mitigate any impact on native fauna will need to developed.*	✓	
Electrofishing	• Similar to netting, this method is unlikely to catch all carp but will aid in reducing numbers. • Requires permits, specific expertise and can be expensive. • There may be some native species by catch, however these fish can be release unharmed. • *May be a feasible option but will need to be optimised in order to make it cost-efficient.*	✓	
Williams carp separation cages (Stuart *et al*. 2006)	• Can remove large tonnages of carp during annual spawning migrations. • Requires expensive infrastructure to mechanically lift and empty captured fish. • Can impact native fish as trapped fishways can become blocked by carp during migration periods. • Requires coordinated removal from traps. • *May be feasible if large scale movements are recorded and the population is sufficiently large to justify the expenditure.*	✓	
Pushing traps (Thwaites *et al*. 2010)	• Field trials have shown this method to work in combination with separation cages (jumping traps). • *May be feasible if the installation of a carp separation cage is justified.*	✓	
Real time tracking of "Judas" carp to locate and harvest aggregations (Inland Fisheries Service 2008)	• Shown to very effective in Lake Crescent (Tasmania) • Requires expertise. • Conducted in conjunction with targeted harvesting. • *May be feasible but will require the implantation of either radio tags or continuous ping acoustic tags. While this is outside the scope of the current project it is recommended to trial this within the system.*	✓	
Exclusion screens (French *et al*. 1999, Hillyard *et al*. 2010)	• By restricting access of adult carp to wetland spawning grounds this can be an effective "localised" control method. • Without active screen management (i.e. opening/closing) or periodic wetland drying there is potential to "compress" larger carp into wetlands. • Flow control structures are required which can be expensive to install and manage. • Will impact large-bodied native fish be restricting wetland access. • *Not feasible as there is limited off-channel habitat.*		✓
Water level manipulations (Shields 1957; Yamamoto *et al*. 2006)	• Used to expose and desiccate eggs on fringing vegetation. • Can be effective for carp which spawn on submerged vegetation. • Requires flow and water level control structures. • Timing of manipulations is critical as there is potential to impact native species spawning. • *Not feasible as there is limited spawning habitat and it will also conflict with the rivers value as a public amenity and irrigation offtake.*		✓

<table>
<tr><th rowspan="2">Control mechanism</th><th rowspan="2">Comments</th><th colspan="2">Feasible</th></tr>
<tr><th>Yes</th><th>No</th></tr>
<tr><td>Draining/drying</td><td>• Draining and drying can be extremely effective in eradicating carp.
• Not species specific, so will impact native fish species present.
• If the water body cannot be fully drained then there is potential to destroy any fish remaining in residual pools with Rotenone (see Chemical piscicides below).
• High possibility of invasive species re-establishing during re-filling.
• Impractical during environmental water delivery.
• Not feasible.</td><td></td><td>✓</td></tr>
<tr><td>Chemical piscicides such as Rotenone (Clearwater et al. 2008)</td><td>• Can be effective at eradicating carp however it is not species-specific and will destroy native fish species.
• May provide localised control in relatively small, isolated waters.
• Will require large quantities of chemical and potentially several applications- can be expensive.
• Lake will need to be isolated and residual chemical treated to avoid downstream mortalities.
• Requires specialised training and permits.
• May be difficult acquiring permits due to presence of native species.
• Not feasible due to current Victoria State regulations.</td><td></td><td>✓</td></tr>
<tr><td>Barrier netting (Inland Fisheries Service 2008)</td><td>• Fine mesh netting is deployed to restrict access of fish to preferred spawning habitat i.e. fringing vegetation.
• Has been effective in Tasmania at reducing spawning success of carp.
• Labor intensive to install, remove and maintain.
• May provide localised management.
• Not feasible as it is expensive and there appears to be limited spawning habitat.</td><td></td><td>✓</td></tr>
<tr><td>Commercial Fishing</td><td>• Can remove large tonnages of carp (e.g. an average of ~500 tonnes per year from Lower Lakes Fishery).
• Unlikely to catch all carp but will aid in reducing numbers on a "localised" scale.
• There may be some native species by-catch, however these fish can be release unharmed.
• Difficult to undertake in most river situations.
• May not be feasible as there may be insufficient carp to support a commercial fishery.</td><td></td><td>✓</td></tr>
<tr><td>Electrical barriers (Verrill and Berry 1995)</td><td>• Used to restrict movements of fish into spawning grounds by establishing an electrical field between two electrodes. Fish are shocked and either turn around or are briefly paralysed and flow downstream before recovery from paralysis.
• Not feasible due to cost, the absence of off-channel spawning grounds and potential risks to the general public.</td><td></td><td>✓</td></tr>
<tr><td>Pheromone lure traps (Sorensen and Stacey 2004)</td><td>• Can be expensive and requires expertise.
• Limited success in field trails.
• Not feasible due to the limited success recorded in field trials.</td><td></td><td>✓</td></tr>
</table>