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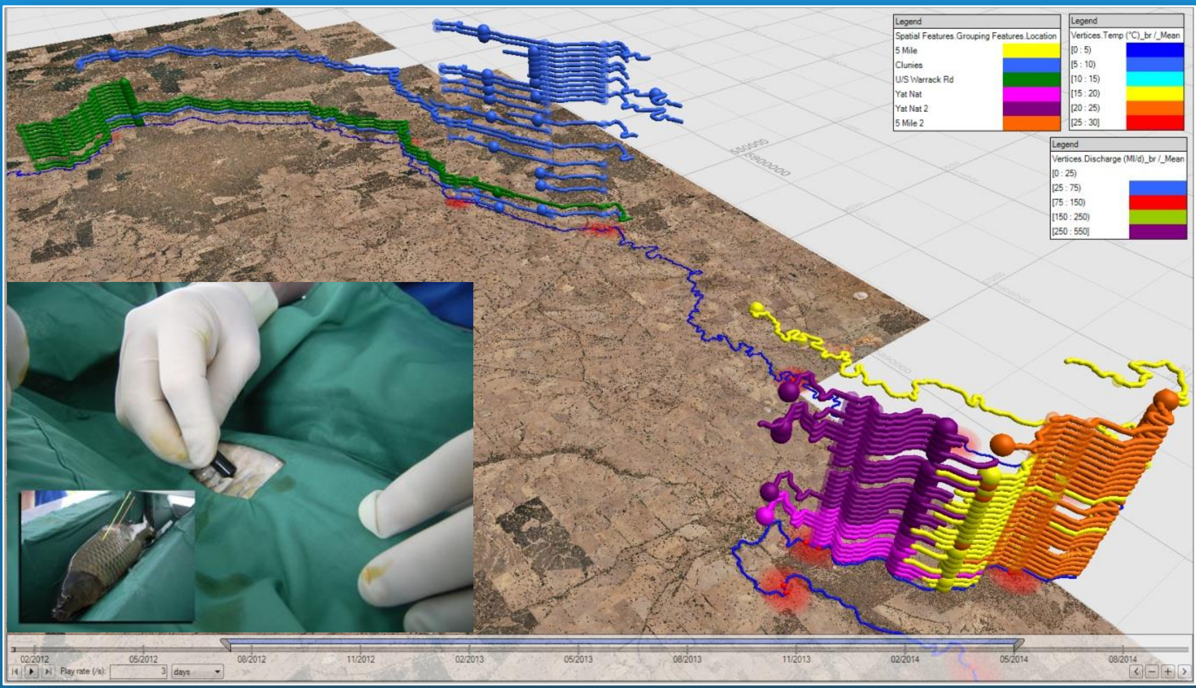
Understanding and managing Common Carp (*Cyprinus carpio* L.) in the Glenelg River, Victoria, Australia



Leigh Thwaites, Josh Fredberg and Stephen Ryan

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August 2016

Final report to the Glenelg Hopkins Catchment Management Authority

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EXECUTIVE SUMMARY

Common carp (*Cyprinus carpio* L.) 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 carp population dynamics and the efficiency of potential carp control techniques within targeted systems. The objectives of this project were to: 1) utilise acoustic telemetry and geospatial modelling 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, 4) estimate the size of the Glenelg River carp population and, 5) integrate these findings 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 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 five 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 2016, the majority of carp (*n*=121, 92% of tagged carp) remained within close proximity to their tagging location (<10 km) indicating that carp in the Glenelg River 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: 36.8 km ± 3.7 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.

As the utility of carp management strategies is site specific and dependent on several factors including season, scale, hydrology and resources, the feasibility of a range of 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) and a further 88 carp were captured across 5-Mile (35 carp), Yat Nat 1 (29 carp) and Moree (24 carp). 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) and Yat Nat 1 (72 carp), with the remaining carp being captured at Moree (35 carp) and 5-Mile (27 carp). A further 194 carp were captured from three additional sites targeted during the 2015 harvest. Yat Nat 2 yielded the highest catch with 97 carp removed. Whereas, 68 and 29 carp were captured at 5-Mile 2 and Pine Hut, respectively. The results of the targeted harvest indicate there has been low level recruitment within Clunies Hole during the previous five years (carp 150-300 mm total length; TL) and limited recruitment success within all other sites targeted across the 2014-15 harvesting event. Larger carp (>450 mm TL) are likely due to limited drought recruitment (2001-2010) and recruitment resulting from flooding that occurred across the catchment during the summer 2010-11 carp breeding season.

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 fish h^{-1} 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 relatively 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.

An understanding of the size of a carp population can assist in making several informed management decisions including the effort required to reduce carp densities to below impact thresholds (<50 kg ha^{-1}). As such, the carp population in the Glenelg River (abundance and densities) was estimated using a Petersen mark-recapture experiment in conjunction with CPUE data derived from the Victoria Environmental Flows Monitoring and Assessment Program (VEFMAP) and Glenelg River geomorphology data.

Mean carp density across the river were estimated to be 25.6 kg ha^{-1} ± 7.8 S.E and 56.0 kg ha^{-1} ± 17.1 S.E and 12.7 kg ha^{-1} ± 3.9 S.E for the upper and lower 95% confidence intervals, respectively. Based on the mean densities derived from the Peterson estimate, a total of 16 sites recorded densities below the carp impact threshold (<50 kg ha^{-1}) while 4 sites recorded densities above the threshold. The Glenelg River carp population was estimated to be ~8,095 individuals at the time of sampling. Accounting for variance associated with this population estimate, it is likely that the true carp population lies somewhere between the upper and lower 95% confidence intervals which were calculated as 17,707 and 4,019 carp, respectively. The results of the population estimate support the findings of the targeted harvest which suggests relatively limited recruitment success within 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; Stuart *et al.* 2006; Thwaites 2011) and a more site specific approach that targets distinct populations or “management units” is required. The estimated population size/densities coupled with a relatively low level of recruitment suggests that ongoing targeted harvesting may be an effective tool for reducing and maintaining the Glenelg River carp biomass below impact density thresholds (<50 kg ha^{-1}). An ongoing control program should also aim to evaluate the feasibility of other options such spawning sabotage or habitat rehabilitation; particularly at areas characteristic of carp spawning and nursery sites such as Clunies Hole. As it appears recruitment is only occurring within a limited number of locations, the successful application of these strategies will complement harvesting efforts and assist in achieving and maintaining density targets. While an integrated approach will aid in controlling numbers and minimising impacts it is important to note that considerable effort is required and that applied control techniques are unlikely to eradicate carp from the Glenelg River. Notwithstanding, the information gathered through an ongoing control program may ultimately support the potential roll-out of bio-control agents that promise significant reductions in carp biomass such as CHV-3 and daughterless carp technologies.

Given the multiple benefits, it is recommended the Glenelg Hopkins CMA continue to apply and develop an ongoing carp control program. This program should aim to achieve predefined management targets (i.e. % population reduction to achieve density <50 kg ha^{-1}) and rely on, and continue to develop an understanding of the carp population in the Glenelg River (i.e. abundance, densities, movements, distribution), as well as the costs/benefits that applied control techniques achieve in both the short- and long-term (i.e. 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 intermediate life history strategy (opportunistic/periodic), 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 (Winemiller and Rose 1992; Smith 2005). Carp are "ecosystem engineers" and when in high abundance, 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), a 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).

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 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 to exclude carp from preferred spawning habitat (Inland Fisheries Service 2008), applying lime to destroy eggs (Inland Fisheries Service 2008), tracking acoustic or radio tagged 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 (Cyprinid Herpes Virus, CHV-3; 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.

The Glenelg River is one of the largest rivers in Victoria and it features significant natural values including a Heritage reach, highly diverse geomorphology and several State and Federally listed plant and animal species. Its headwaters are in the Grampians National park with its estuary flowing through the Lower Glenelg National Park. 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) 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 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 carp population dynamics and the efficiency of potential carp control techniques within targeted systems (Stuart and Jones 2006; Donkers *et al*. 2012; Brown and Gilligan 2014). With this knowledge, the appropriate strategy to manage carp can be identified and the feasibility of control methods such as carp separation cages, targeted harvesting, spawning sabotage or the strategic delivery of environmental water to aggregate carp for trapping can be critically evaluated and/or optimised (Stuart and Jones 2006; Donkers *et al*. 2012; Brown and Gilligan 2014). In addition, the knowledge gained may support the future use of biocontrol technologies such as CHV-3 and daughterless carp.

1.2. Objectives

The objectives of this study were 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.
- Estimate the size of the carp population in the Glenelg River (abundance, densities) using a Petersen mark-recapture experiment.
- Integrate these findings 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), as well as land undergoing rehabilitation. The river is characterised by a high level of within channel diversity (i.e. pools, runs, riffles, braiding), abundant physical habitat (i.e. snags, diverse vegetation) and relatively natural hydrology. It receives inflows during catchment rainfall events, as well as environmental water delivered from the Rocklands Reservoir. This study was conducted over 320 km of river between the Rocklands 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 (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).

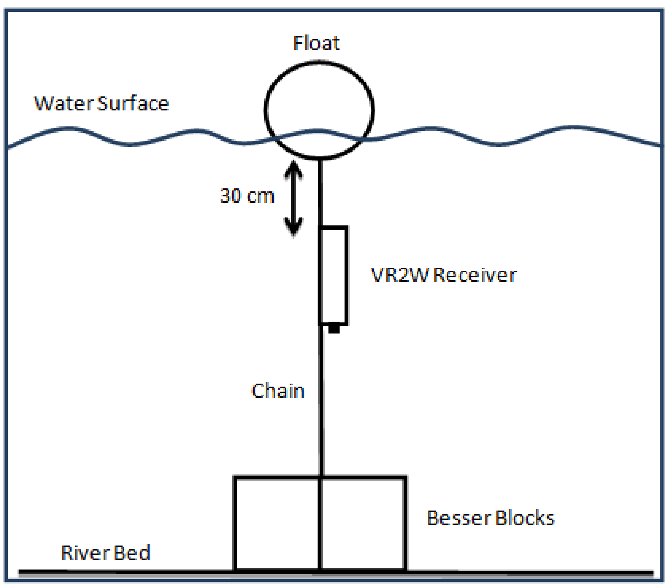

Figure 2. Schematic representation of the VR2W acoustic receiver mooring.

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 ~1,029 days (~3 years) of continuous tracking (VEMCO 2013).

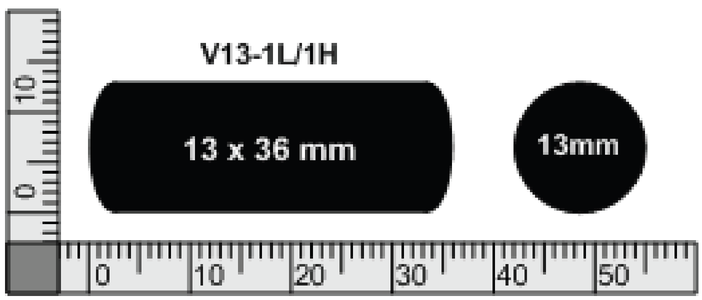

Figure 4. VEMCO V13 coded acoustic transmitter (http://www.vemco.com/pdf/v13_coded.pdf).

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 (Ryan 2013).

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

Date	Site	Method	Effort
20/11/2012	Clunies Hole (37°11'33.18"S; 141°33'59.52"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	2,200 s
21/11/2012	U/S Warrock Rd (37°24'39.66"S; 141°16'21.89"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	2,357 s
22/11/2012	5-Mile (37°11'42.44"S; 141°54'39.38"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	3,466 s
13/11/2013	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
14/11/2013	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
15/11/2013	Casterton (37°35'18.92"S; 141°24'26.49"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	1,200 s
16/11/2013	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
16/11/2013	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)
17/11/2013	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
18/11/2013	5-Mile (37°11'10.01"S; 141°55'11.55"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	3,400 s
19/11/2013	Yat Nat (37°13'57.06"S; 141°51'42.64"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	2,224 s
20/11/2013	Yat Nat 2 (37°13'52.84"S; 141°52'20.36"E)	Boat mounted Smith-Root GPP 5.0 kW portable electrofisher	3,010 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 1,000 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 an individual identification and total length (TL, 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 a 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 six occasions between April 2013 and March 2016 (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
14/02/2012	Acoustic range finding experiment	The identification of the most suitable acoustic transmitters to be used and appropriate locations for the acoustic receivers.
17/09/2012 - 18/09/2012	Study site reconnaissance	Scoping the Glenelg River (Rocklands to Dartmoor) for suitable receiver locations, carp hot-spots and boat launch sites.
23/11/2012 - 28/11/2012	Installation of acoustic receivers	26 VEMCO VR2W receivers were systematically placed every 10-20 km throughout the study site (Rocklands to Dartmoor) (Figure 3).
20/04/2013 - 24/04/2013	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.
13/11/2013 - 17/11/2013	2nd download of receivers and battery replacement	25 receivers were downloaded using the VEMCO software program VUE and receiver batteries were replaced.
11/03/2014 - 14/03/2014	3rd download of receivers	25 receivers were downloaded using the VEMCO software program VUE.
05/12/2014 - 06/12/2014	4th download of receivers	25 receivers were downloaded using the VEMCO software program VUE and receiver batteries were replaced.
		The Beddison Road receiver (37°48'10.40"S; 141°14'27.50"E) was removed from the system due it being engulfed by a sand slug.
14/05/2015 - 17/05/2015	5th download of receivers	24 receivers were downloaded using the VEMCO software program VUE.
08/03/2016 - 10/03/2016	6th download of receivers	24 receivers were downloaded using the VEMCO software program VUE and receivers were removed from the Glenelg River.

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 season, scale, geomorphology, 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 favour 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 with Fisheries Victoria Permit NP231. 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 (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 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.

2.7. Carp population estimates

Mark-recapture population estimates are considered one of the most accurate techniques with the model developed by Peterson (1896) remaining one of the more frequently used for inland waters (see Donkers *et al*. 2012). As such, the Glenelg River carp population was estimated using a Petersen mark-recapture experiment in conjunction with CPUE data derived from the Victoria Environmental Flows Monitoring and Assessment Program (VEFMAP; Iervasi *et al*. 2015) and Glenelg River geomorphology data. The estimate was calculated via a three stage process:

1. The Petersen mark-recapture experiment (Equation 1; Ricker 1975) was used to calculate the abundance (± 95% confidence intervals) and density (kg ha^{-1}) of carp within a 30 km study reach (mean width ~29 m ; surface area ~87 ha) located between Pine Hut and Balmoral weir (situated in central Balmoral) (Figures 3 and 6).

$$\tilde{N} = \frac{(M+1)(C+1)}{(R+1)} \qquad \text{(Equation 1)}$$

where, *M* is the number marked and released, *C* is the number subsequently examined for marks, *R* is the number of marks found (i.e. recaptures) in the sample *C*, *N* is the total (and unknown) number in the population and $\tilde{N}$ is the adjusted Petersen estimate of *N*.

The 30 km study reach was selected for the estimate as: 1) a total of 78 carp were captured, tagged and released back into the reach as part of the broader tracking study, 2) results of the tracking study indicate the carp population within this reach was mixing and that only 1 tagged carp left the reach since the commencement of the study, 3) tagged carp were re-captured across the reach during the 2015 targeted harvesting event, 4) this reach encompassed three VEFMAP sites (Figure 6), and 5) no tagged carp were recaptured within other sites during targeted harvesting.

2. A CPUE to density conversion ratio was then developed to calculate relative densities of carp for 20 VEFMAP sites that were systematically sampled across the river during late-summer/early-autumn 2015 (Table 3, Figure 6). As the 30 km study reach used to calculate carp density from the Peterson estimate encompassed three VEFMAP sites (Yat Nat, 5-Mile and Ross Road), the average VEFMAP CPUE for these sites was used for the conversion ratio (Equation 2). This calculation is based on the assumption that density (abundance) is proportional to CPUE (Ricker 1940; Ricker 1975).

$$D_V = \frac{D_P}{Ave.VC} \times VC \qquad \text{(Equation 2)}$$

where, D_P is the density (kg ha^{-1}) of carp for the 30 km study reach derived from the Peterson mark-recapture experiment, *Ave.VC* is the average CPUE from three VEFMAP sites sampled within the 30 km study reach during 2015, *VC* is the CPUE for each VEFMAP site sampled during 2015 and, D_V is the calculated carp density (kg ha^{-1}) for each VEFMAP site.

3. The numbers of carp surrounding each VEFMAP site was then estimated by determining the surface area (ha) of the reach encompassing the site (defined by the midpoint between sites), calculating the total kg of carp per reach (kg ha^{-1} x ha) and dividing by the average weight of carp for each reach. The number of carp within each VEFMAP reach was then summed to give a total carp population estimate for the Glenelg River. An upper and lower population estimate was also calculated from the 95% confidence intervals derived from the Peterson estimate (Ricker 1975). The surface area of the 30 km study reach and for the reach surrounding each VEFMAP site was calculated from aerial imagery of the Glenelg River (Glenelg Hopkins CMA, unpublished data; Table 3).

Table 3. Summary data for the 20 VEFMAP reaches used to calculate the Glenelg River carp population estimates.

Site/reach	Distance from Rocklands Reservoir (km)	Length (km)	Ave. Width (m)	Area (ha)
Rocklands	5.7	10.6	59.7	63.5
Yat Nat	22.5	18.1	29.0	52.6
5-Mile	32.1	11.2	31.9	35.6
Ross Rd	44.7	12.4	41.4	51.4
Fulham Hole	55.1	12.8	31.0	39.5
The Gorge	73.4	27.5	40.0	109.8
Harrow	107.7	21.6	36.2	78.3
Moree Bridge	119.1	14.9	19.0	28.2
Burkes Bridge	137.5	19.2	21.4	41.1
Harland Hills	152.7	12.7	14.8	18.7
Dergholm-Chetwynd Rd	164.8	13.2	18.4	24.2
Warrock Rd	179.9	12.8	22.6	28.8
Warrock Ford	189.7	10.4	17.6	18.4
Section Rd	199.4	16.1	17.0	27.3
Sandford	219.4	20.1	18.2	36.6
Killara	243.4	29.4	20.6	60.6
Myaring Bridge Rd	275.0	21.2	17.0	36.1
Beddisons Rd	282.5	12.1	16.4	19.8
Burrows Rd	296.3	16.6	19.2	32.0
Dartmoor	313.8	7.8	23.0	17.9

Figure 6. Map showing location of 20 VEFMAP sites sampled across the Glenelg River during late-summer/early-autumn 2015 (adapted from Iervasi *et al*. 2015).

3. RESULTS AND DISCUSSION

3.1. Carp tracking

A total of 131 carp (mean TL ± S.E. = 481 ± 4 mm; mean weight ± S.E. = 1,739 ± 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. = 1,812 ± 69 g) and a further 56 carp implanted during November 2013 (mean TL ± S.E. = 472 ± 4 mm; mean weight ± S.E. = 1,641 ± 40 g) (Table 4, Figure 7). 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).

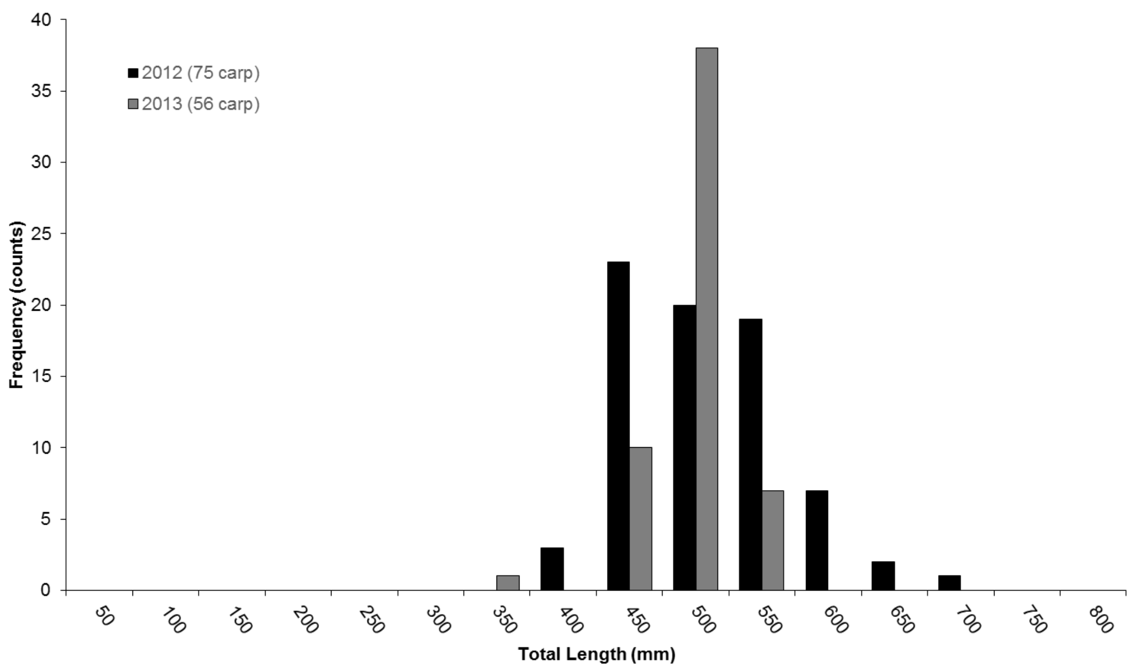

Figure 7. Length-frequency distribution for carp captured and tagged during 2012 (*n*=75) and 2013 (*n*=56).

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 4, 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 4. Summary of carp capture data for the 2012 and 2013 carp acoustic tagging effort.

Date	Site	No. of Carp	Total Length (mm) Mean ± SE	Total Length (mm) Range	Weight (g) Mean ± SE	Weight (g) Range	Sex Ratio
20/11/2012	Clunies Hole (37°11'33.18"S; 141°33'59.52"E)	41	513 ± 9	420-675	1,986 ± 91	1,170-3,950	F: 2 M: 12 N/A: 27
21/11/2012	U/S Warrock Rd (37°24'39.66"S; 141°16'21.89"E)	12	484 ± 11	440-555	1,961 ± 158	1,130-2,980	F: 2 M: 8 N/A: 2
22/11/2012	5-Mile (37°11'42.44"S; 141°54'39.38"E)	22	441 ± 11	373-624	1,407 ± 100	940-3,104	F: 1 M: 10 N/A: 11
13/11/2013	Water Treatment Works (D/S Casterton) (37°36'10.20"S; 141°23'57.37"E)	1*	-	-	-	-	-
14/11/2013	The Junction (D/S Casterton) (37°36'50.75"S; 141°25'33.81"E)	0	-	-	-	-	-
15/11/2013	Casterton (37°35'18.92"S; 141°24'26.49"E)	0	-	-	-	-	-
16/11/2013	Heads Road (37°50'9.81"S; 141°14'38.77"E)	0	-	-	-	-	-
16/11/2013	Scott's Creek Rd (Fishing Competition) (37°49'56.65"S; 141°14'54.91"E)	1*	-	-	-	-	-
17/11/2013	Frasier's Swamp (37°14'23.45"S; 141°54'18.03"E)	0	-	-	-	-	-
18/11/2013	5-Mile (37°11'10.01"S; 141°55'11.55"E)	28	457 ± 7	337-533	1,464 ± 51	1,094-2,259	F: 8 M: 20
19/11/2013	Yat Nat (37°13'57.06"S; 141°51'42.64"E)	8	480 ± 6	458-513	1,809 ± 64	1,568-2,081	F: 4 M: 4
20/11/2013	Yat Nat 2 (37°13'52.84"S; 141°52'20.36"E)	20	490 ± 4	458-522	1,821 ± 50	1,196-2,059	F: 13 M: 7
	Total	**131**	**481 ± 4**	**337-675**	**1,739 ± 44**	**940-3,950**	**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%) were detected and 22 (17%) undetected (Table 5). The majority of undetected carp (*n*=16) were tagged at Clunies Hole with the remaining tagged at Warrock Road and 5-Mile.

Table 5. Summary statistics for Glenelg River carp tracking program (November 2012-March 2016).

Parameter		**Summary statistic**
Total number of tagged carp		131
Number of carp detected		109 (83%)
Number of carp not detected		22 (17%)
Number of carp remaining near tagging location (including undetected carp)		121 (92%)
Number of carp that moved from tagging location		10 (8%; 4 male, 6 unknown sex)
Movement distance	Average distance	36.8 km ± 3.7 S.E.
	Range	10-53 km
Swim speed (minimum)	Average swim speed	3.8 km d^{-1} ± 1.5 S.E.
	Range	0.12-21.1 km d^{-1}

Since tracking commenced (28 November 2012), the majority of fish (*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 display a level of site fidelity (Jones and Stuart 2007; Crook 2004) (Figure 8). In contrast, 10 carp (8% of tagged carp) moved substantial distances upstream or downstream from their tagging location (average distance: 36.8 km ± 3.7 S.E.) with the longest movement occurring over 53 km between Warrock Road (Dergholm) and Clunies Hole (Harrow) (Figures 8 and 9). The average recorded minimum swimming speed between two locations was 3.8 km d^{-1} ± 1.5 S.E. with a minimum of 0.12 km d^{-1} and a maximum of 21.1 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: 40.3 d ± 11.8 S.E.; range: 6.6 d-66.5 d) (Figures 8 and 9) suggesting homing behaviour or site recognition (Reynolds 1983; Crook 2004; Jones and Stuart 2009). 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 autumn and winter and others during spring. Although the spring movements could be associated with breeding migrations (water temperature ≥16°C; Conallin *et al*. 2012), it is important to note that these movements were conducted by <4% of tagged carp and that the vast majority of tagged fish remained within relatively close proximity to their tagging location over the duration of the study (Figure 9).

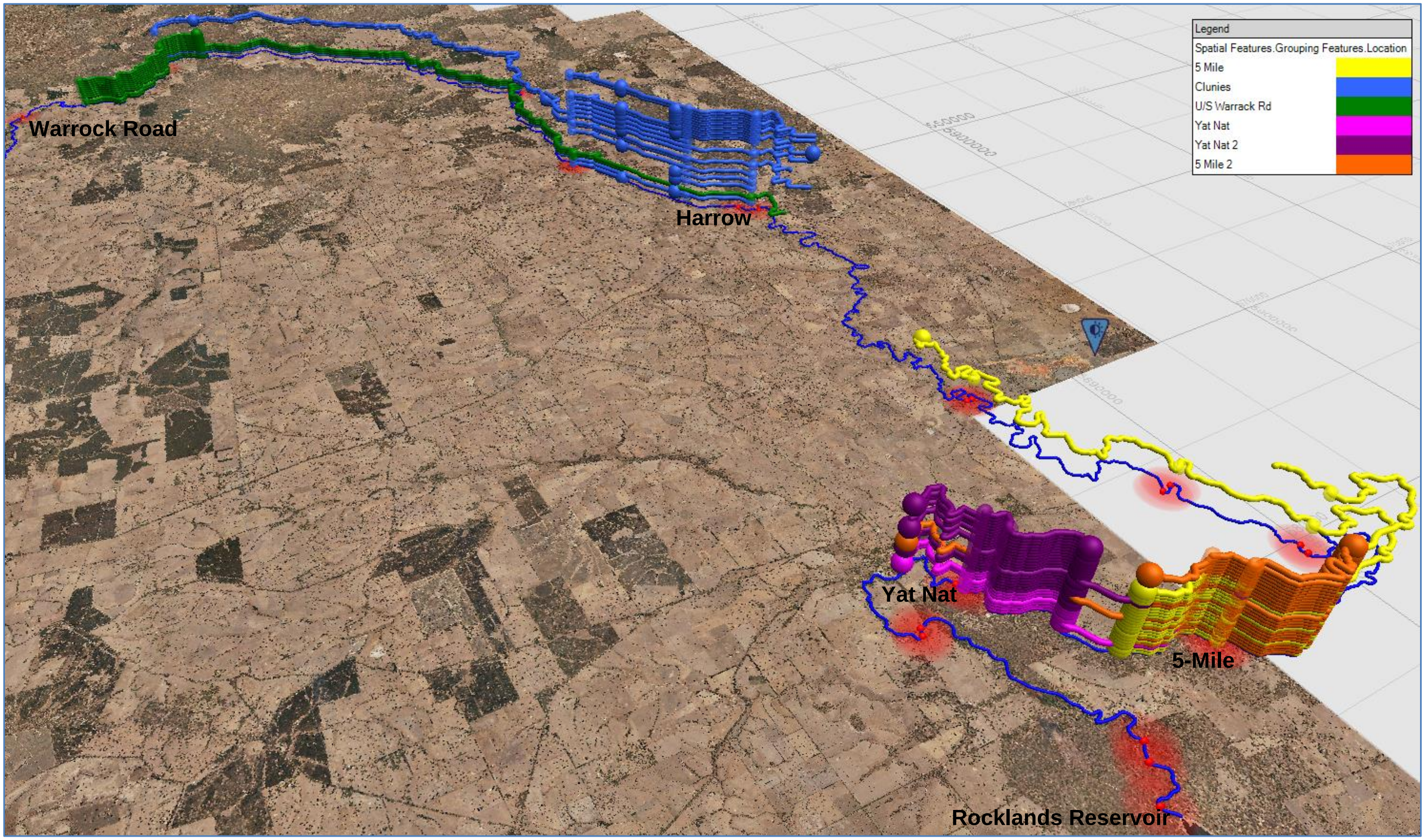

Figure 8. Overview of Eonfusion 2.4 carp tracking model showing the extent of movements of all detected tagged carp (*n*=109) within the Glenelg River system (November 2012-March 2016). Colours represent tagging location (see legend). Each dot/line represents the extent of movements for individual tagged carp. Red dots represent VR2W acoustic receiver locations.

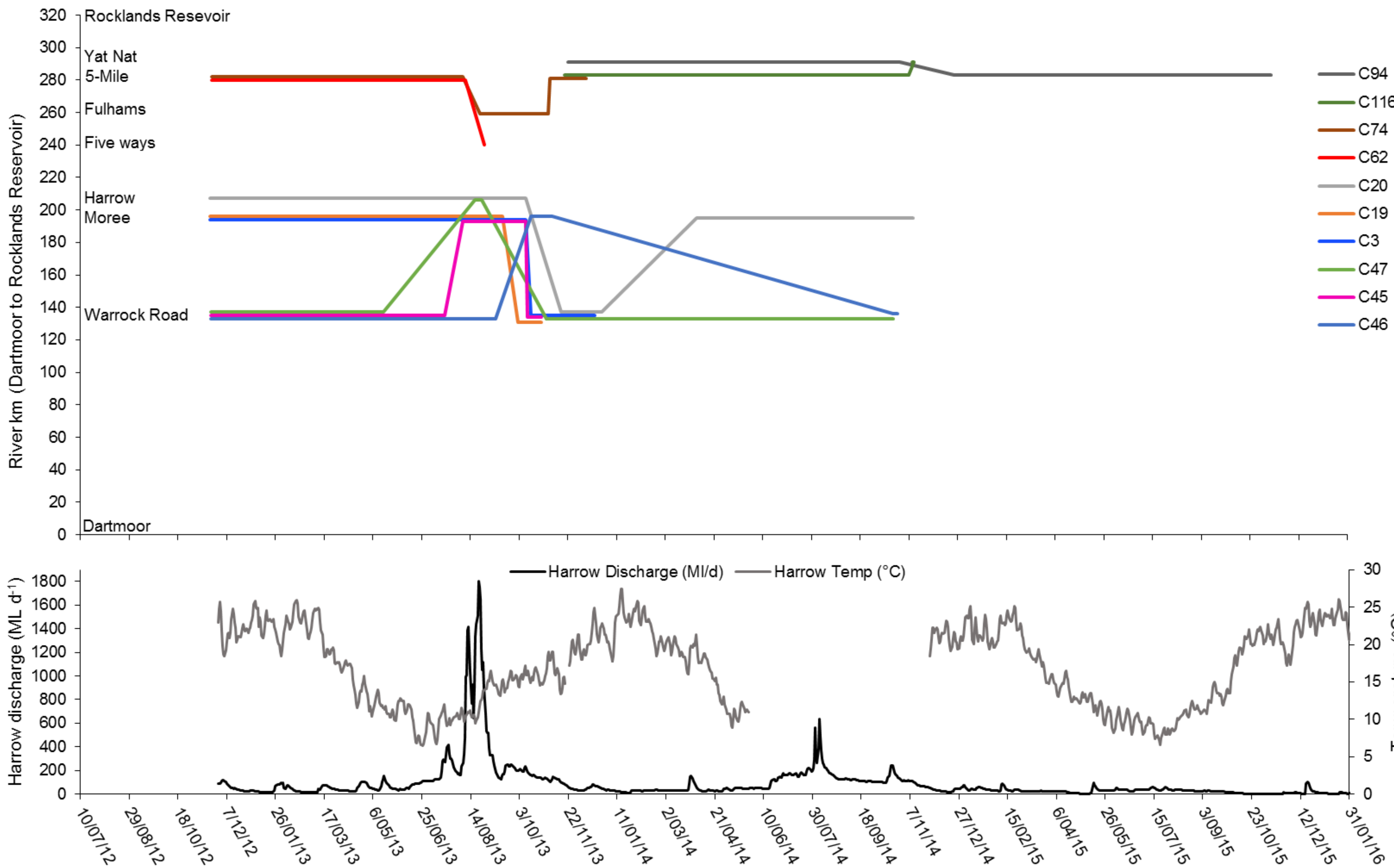

Figure 9. Carp movements (10 individuals; C#, coloured lines) across the Glenelg River and river temperature and flow for the duration of the tracking study. Tracking lines commence at first detection and end at last detection.

These results 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 1,265 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 3,337 carp (1,607 unknown sex, 1,099 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. Jones and Stuart (2007) propose that the presence of site fidelity indicates the requirements of carp (i.e. food and habitat) are being met within these locations.

Reynolds (1983) tagged 5,268 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 River Murray 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. Crook (2004) suggests that food availability, predation risk and behavioural interactions with conspecifics may motivate fish to return to their home range. The author also suggests that limited suitable habitat outside of the home range may influence homing behaviour.

3.2. Targeted harvest

Catch summary - December 2014

A total of 235 carp (mean TL ± S.E. = 492 ± 7 mm; mean weight ± S.E. = 1,970 ± 59 g) were captured during the December 2014 harvesting event (Table 6, 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%). The length-frequency distribution of captured carp was bimodal with one mode at 200-300 mm TL and a second at 400-700 mm TL. Of the larger carp, a total of 174 (74% of total catch) were in the 450-600 mm TL size class, with the highest frequency count of 79 carp in the 500-550 mm TL size class. Carp >600 mm represented 8.1% (*n*=19) of the total catch and the majority of these were captured within Clunies Hole (*n*=16). The smaller, sexually maturing cohort (200-300 mm TL) represented 14% (*n*=33) of the total catch with the majority of these captured in Clunies Hole (*n*=28). Length at age relationships developed from otolith micro structure analysis of carp collected from the Glenelg River during 2010-11 indicate that carp 200-300 mm TL range from 0 to 2 years of age while carp 400-700 mm TL range from 1 to 10+ years of age (Glenelg Hopkins CMA, unpublished data).

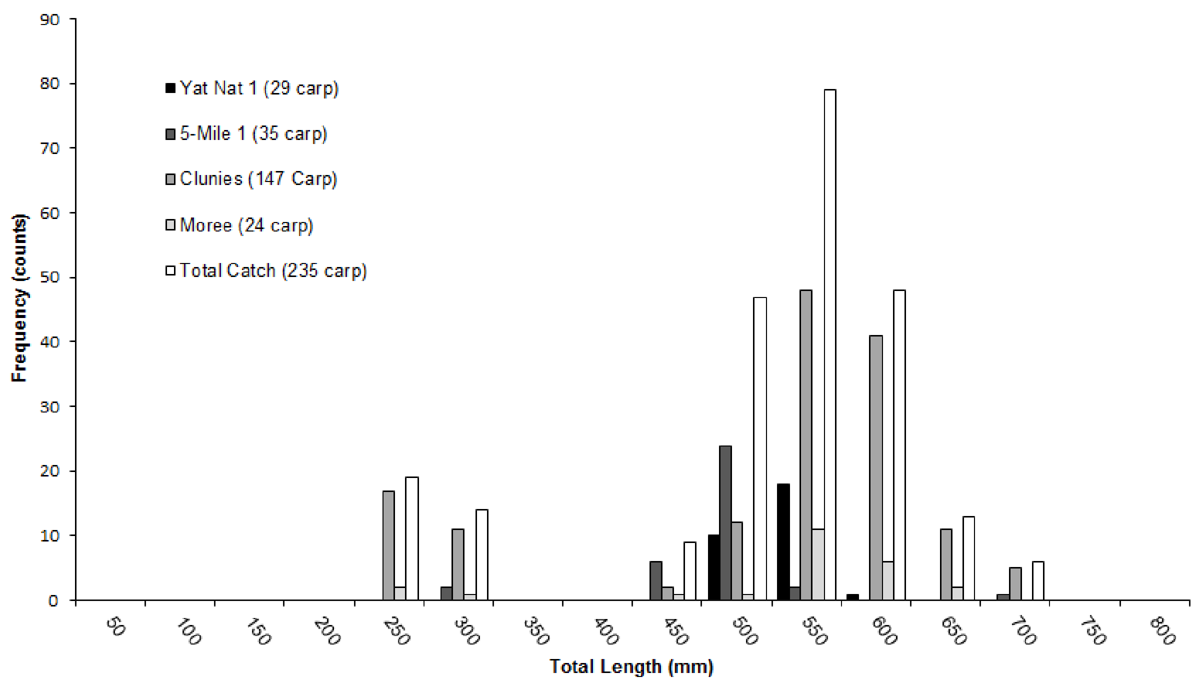

Figure 10. Length-frequency distribution for carp captured during the December 2014 carp harvest.

Catch summary - May 2015

A total of 228 carp (mean TL ± S.E. = 462 ± 9 mm; mean weight ± S.E. = 1,857 ± 75 g) were captured during the May 2015 harvesting event (Table 6, 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%). The length-frequency distribution of captured carp was bimodal with one mode at 150-250 mm TL and a second at 400-650 mm TL. Of the larger carp, a total of 148 (64.9% of total catch) were in the 450-600 mm TL size class, with the highest frequency count of 78 fish in the 500-550 mm TL size class. Carp >600 mm TL represented 6.1% (*n*=14) of the total catch with the majority of these captured within Clunies Hole (*n*=8) and Moree (*n*=6). The smaller, sexually maturing size cohort (150-250 mm TL) represented 18% (*n*=41) of the total catch with Clunies Hole being the primary source of this cohort. Length at age relationships indicate that carp 150-250 mm TL range from 0 to 2 years of age while carp 400-650 mm TL range from 1 to 10+ years of age (Glenelg Hopkins CMA, unpublished data).

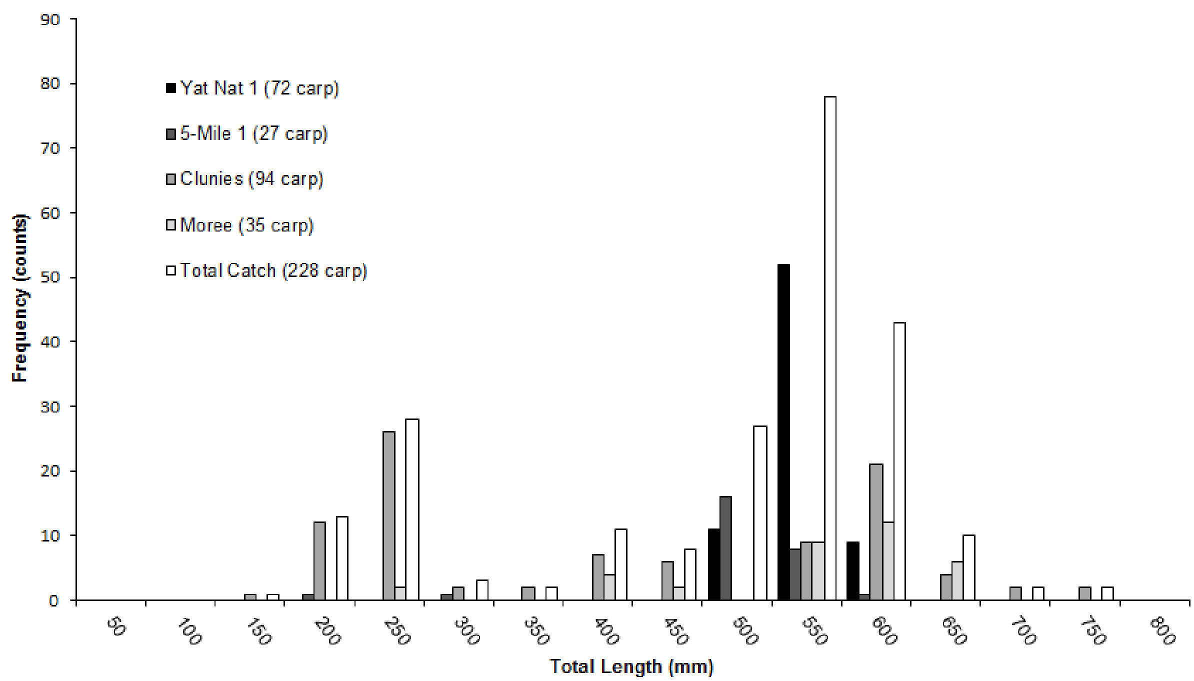

Figure 11. Length-frequency distribution for carp captured during the December 2015 carp harvest.

Catch summary - Additional sites May 2015

A total of 194 carp (mean TL ± S.E. = 518 ± 3 mm; mean weight ± S.E. = 2,200 ± 41 g) were captured from three additional sites targeted during the 2015 harvest (Table 7, 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. The length-frequency distribution of captured carp was bimodal with a small mode at 250-300 mm TL and a second at 450-650 mm TL. Of the larger carp, a total of 94.8% (*n*=184) were in the 450-600 mm TL size class, with the highest frequency count of 85 in the 500-550 mm TL size class. Carp >600 mm TL 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 250-300 mm TL size class. Length at age relationships indicate that carp 250-300 mm TL range from 1 to 2 years of age while carp 450-650 mm TL range from 2 to 10+ years of age (Glenelg Hopkins CMA, unpublished data).

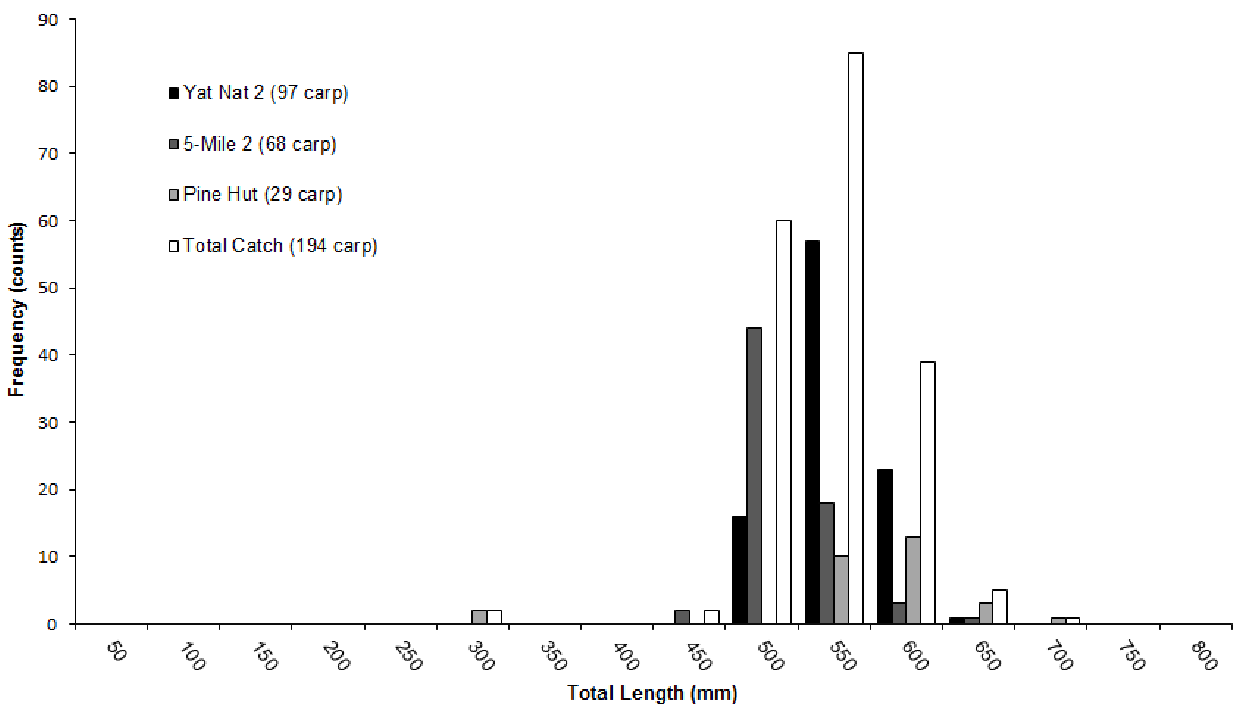

Figure 12. Length-frequency distribution for carp captured with three additional sites targeted during the December 2015 carp harvest.

Table 6. Summary of carp capture data for the 2014 and 2015 targeted harvest.

			Total 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	2,059 ± 68	1,613 - 3,362	60
	May-2015	72	524 ± 2	485 - 560	2,237 ± 41	1,418 - 3,345	161
5-Mile 1	Dec-2014	35	466 ± 11	268 - 684	1,532 ± 99	291 - 4,135	54
	May-2015	27	472 ± 15	189 - 556	1,725 ± 89	118 - 2,759	47
Clunies	Dec-2014	147	493 ± 11	203 - 665	2,025 ± 83	125 - 4,285	298
	May-2015	94	390 ± 18	148 - 746	1,362 ± 147	49 - 6,644	128
Moree	Dec-2014	24	502 ± 22	228 - 639	2,158 ± 181	233 - 4,298	52
	May-2015	35	522 ± 17	235 - 650	2,505 ± 187	241 - 4,605	88
Total	Dec-2014	235	492 ± 7	203 - 684	1,970 ± 59	125 - 4,298	464
	May-2015	228	462 ± 9	148 - 746	1,857 ± 75	49 - 6,644	424
Grand Total	**2014-15**	**463**	**478 ± 6**	**148 - 746**	**1,914 ± 48**	**49 - 6,644**	**886**

Table 7. Summary of carp capture data for three additional sites targeted during the 2015 carp harvest.

			Total 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	2,302 ± 42	1,423 - 3,618	223
5-Mile 2	May-2015	68	491 ± 4	448 - 604	1,846 ± 58	1,323 - 4,178	126
Pine Hut	May-2015	29	547 ± 16	256 - 660	2,690 ± 137	294 - 4,557	78
Grand Total	**May-2015**	**194**	**518 ± 3**	**256 - 660**	**2,200 ± 41**	**294 - 4,557**	**427**

Recruitment

The results of the targeted harvest indicate there has been low level recruitment occur within Clunies Hole during the previous five years (carp 150-300 mm TL; 0-2 years) and limited recruitment within all other sites targeted across the 2014-15 harvesting event. Clunies Hole is predominately shallow, well-vegetated, slow-flowing habitat which is characteristic of areas that carp actively seek for spawning and nursery sites (Koehn and Nichol 1998; Smith and Walker 2004; Stuart and Jones 2006; Conallin *et al*. 2012). Although it may be logistically difficult, managing recruitment within this location via techniques designed to sabotage spawning including liming eggs (Inland Fisheries Service 2008), water level manipulations to desiccate eggs (Shields 1957; Yamamoto *et al*. 2006) or habitat rehabilitation/restoration to reduce the area of swamp/marsh should be considered as part of an ongoing carp control program.

The limited recruitment across others sites targeted during the 2014-15 harvest may be associated with river geomorphology, habitat availability, management and the relatively “natural” hydrology/condition of the river. The Glenelg River is characterised by many reaches in near pristine condition, few barriers to fish passage, limited low head weirs and associated weir pools and a high level of within channel diversity (i.e. pools, runs, riffles, braiding). It contains abundant physical habitat in most reaches (i.e. snags, diverse vegetation), no off-channel carp breeding sites (i.e. wetlands, marshes; Koehn and Nichol 1998) and has relatively natural hydrology with environmental flows delivered primarily to enhance natural flow. In addition, the only other site that provides conditions characteristic of carp spawning and nursery sites is Frasers Swamp, however no carp were captured at this location during the acoustic tagging effort (Tables 1 and 4) and carp were not recorded moving into or toward this site over the duration of the tracking study. The limited spawning/nursery sites coupled with the overall condition of the river may be disadvantaging carp and limiting recruitment within the Glenelg River. Indeed, increased carp numbers are correlated with the increasing levels of environmental disturbance (Gehrke 1997). Determining the precise mechanisms limiting carp within the Glenelg River warrants investigation as it may provide opportunities to further disadvantage the species.

Carp >450 mm TL (2-10+ years) are likely due to limited drought recruitment (2001-2010) and recruitment resulting from flooding that occurred across the catchment during 2010-11. Although carp are resistant and resilient to drought conditions in comparison to native species (Crook *et al*. 2010), their numbers were reported to steadily decrease across other invaded systems throughout the recent extended drought (King *et al*. 2010; Wilson *et al*. 2015). Given that carp invaded the Glenelg River toward the onset of the drought (*circa* 2001), it is likely the prevailing conditions (i.e. limited connectivity, resources and spawning habitat) restricted population growth prior to the 2010-11 flood.

The floodplain inundation associated with the 2010-11 floods coincided with the carp breeding season (spring-summer), providing ideal conditions for successful spawning and recruitment. Indeed, carp numbers are commonly reported to increase as a result of floodplain inundation (Brown *et al*. 2003; Stuart and Jones 2006; Bice 2014; Thwaites 2014; Koehn *et al*. 2016). This response is primarily associated with increases in available spawning habitat including inundated submerged, terrestrial and amphibious vegetation (Nicol *et al*. 2013; Thwaites 2014), enhanced primary and secondary production through nutrient release (Junk *et al*. 1989; Ribeiro *et al*. 2004; Balcombe and Arthington 2009) and decreased predation risk (Bajer and Sorenson 2010). Notwithstanding, the actual contribution to the adult population may have been marginal as high levels of mortality for juvenile carp (~80% for carp 1 year of age, ~46% for carp 2 years of age; Koehn *et al* 2016) likely limited the number that reached sexual maturity. Indeed, Wilson *et al*. (2014) recorded an initial spike in carp numbers post flood however, numbers declined substantially across the following two years before stabilising at levels marginally higher that those recorded pre-flood (Wilson *et al*. 2014).

Evaluation of applied harvesting techniques

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 6,000 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 targeted harvesting activities rely on electrofishing.

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 8 and 9). CPUE varied across sites and seasons ranging from 25.22 fish h^{-1} at Yat Nat 1 to 55.38 fish h^{-1} 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.

Table 8. 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 9. 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**

Distinct differences in behaviour and habitat preference 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*). The preference for these habitats may be associated with improved foraging opportunities, refuge and predator avoidance (Jones and Stuart 2007; Butler and Wahl 2010). In contrast, carp appeared to be aggregated during the autumn harvest with relatively large numbers (20-70 carp) captured at several locations characterised by complex structural woody habitat (Figure 13). Carp were also caught in similar locations to those observed during summer but in much lower abundance. These results are consistent with previous research that demonstrated higher movement rates throughout spring and summer and aggregation behaviour during autumn and winter (Johnsen and Hasler 1977; Inland Fisheries Service 2008; Penne and Pierce 2008; Butler and Wahl 2010; Donkers *et al*. 2012; Taylor *et al*. 2012).

The preference to aggregate within structural woody habitat during winter may be associated with a range of benefits this habitat can provide including: a velocity refuge (Koehn and Nichol 2014), territorial markers (Crook and Robertson 1999), increased foraging opportunities and predator avoidance (Jones and Stuart 2007; Butler and Wahl 2010). Further, carp may have been seeking warmer water temperatures as they are known to aggregate within warm water during cool temperate winters (Johnsen and Hasler 1977; Inland Fisheries Service 2008; Penne and Pierce 2008). Regardless, 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 river.

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

3.3. Carp population estimates

Population estimate for Yat Nat, 5-Mile and Pine Hut reach

A total of 78 carp were tagged during 2012 (*n*=22) and 2013 (*n*=56) with 6 recaptured during the 2015 targeted carp harvest. In total, 293 carp were captured during this event (Table 10). Re-captures were confirmed by the presence of external dart tags and/or the detection of internal acoustic tags by a handheld VR100 receiver (VEMCO, AMIRAX Systems Inc., Halifax, Canada). Of the 78 tagged carp, a total of 47 were detected by acoustic receivers and therefore still active within the reach during 2015. Given that only one carp had left the reach during the study period, it is likely the 30 undetected carp represent loss through mortality. This is in reasonable agreement with estimated mean survival rates for carp reported by Koehn *et al*. (2016). Using their rates and the average age of carp when tagged (mean ± S.E. = 3.28 ± 0.07 years; range = 1.6-6.5 years; Glenelg Hopkins CMA, unpublished data) at least 40 tagged carp were likely to have survived since the 2012-13 tagging rounds. As such, the total number of tagged carp detected during 2015 (47 carp) was used as the number marked and released (*M*) for the Petersen population estimate.

The Petersen population estimate for carp with the 30 km study reach between Balmoral weir and Pine Hut was ~2,016 individuals at the time of sampling, with the upper and lower 95% confidence intervals equating to 4,410 and 1,001 carp, respectively. Using the 87 ha surface area of the reach this equates to a density of 50.05 kg ha^{-1} for the Petersen estimate and 109.5 for the upper 95% confidence interval and 24.9 kg ha^{-1} for the lower. For the Petersen estimate, this indicates the 2015 targeted harvest reduced the carp population within the reach by ~14.5% (6.6% for the upper confidence interval; 29.3% for the lower) thereby reducing the density to 42.8 kg ha^{-1} which is below reported impact thresholds (<50 kg ha^{-1}; Zambrano and Hinojosa 1999; Pinto *et al*. 2005; Bajer *et al*. 2009; Matsuzaki *et al*. 2009; Vilizzi *et al*. 2014).

Population estimate for Glenelg River

Using the calculated densities from the Peterson estimate for the 30 km study reach, CPUE from 2015 VEFMAP sampling and the CPUE to density conversion factor, the carp density for each VEFMAP site was calculated (Table 10). Mean carp density across the 20 VEFMAP sites was 25.6 kg ha^{-1} ± 7.8 S.E for the Petersen estimate and 56.0 kg ha^{-1} ± 17.1 S.E and 12.7 kg ha^{-1} ± 3.9 S.E for the upper and lower 95% confidence intervals, respectively. Based on the densities derived from the Peterson estimate, a total of 16 sites recorded densities below the carp impact threshold (<50 kg ha^{-1}) while four sites recorded densities above the threshold (Yat Nat, 5-Mile, Fulham Hole and Dergholm-Chetwynd Rd; Table 10). A total of seven sites were above the threshold for the upper 95% confidence intervals while only one site was above the threshold for the lower interval. Future targeted carp control activities should prioritise sites with densities >50 kg ha^{-1} and aim to reduce densities to below impact threshold levels. In this regard, reducing densities derived from the Peterson estimate for Yat Nat, 5-Mile, Fulham Hole and Dergholm-Chetwynd Rd reaches to 50 kg ha^{-1} requires the removal of approximately 231, 553, 430 and 788 carp, respectively.

The total abundance of carp for each reach was estimated from calculated densities for 20 VEFMAP sites and the surface area (ha) of the reach surrounding these sites (Table 10). The sum of these estimates gives a Glenelg River carp population estimate of ~8,095 individuals at the time of sampling. Accounting for variance associated with this population estimate (i.e. conversion ratios, using averages), it is likely that the true carp population lies somewhere between the upper and lower 95% confidence intervals which were calculated as 17,707 and 4,019 carp, respectively (Table 10).

The above estimates are based on 12 of the 20 VEFMAP sites where carp were captured during the 2015 VEFMAP sampling round. The zero catch rates for the remaining eight sites indicates an extremely low biomass and suggests the habitat within these reaches is unsuitable for carp (Crook 2004). Indeed, no carp have been captured within seven of these sites since VEFMAP sampling commenced in 2009 and only nine carp have been captured within “the Gorge” site across the 2013 (n=4) and 2014 (n=5) sampling rounds (Ryan 2013; Iervasi *et al*. 2014; Iervasi *et al*. 2015).

The results of the population estimate support the findings of the targeted harvest which suggests relatively limited recruitment success within the Glenelg River. Even though carp have been within the river since *circa* 2001 they have been unable to obtain the numbers and densities observed within other invaded systems. Carp are capable of achieving densities as high as 3,144 kg ha^{-1} (Harris and Gehrke 1997) and have been recorded to reach densities of ~1,000 kg ha^{-1} within a five year period in constructed urban wetlands (SARDI, unpublished data). While urban wetlands are significantly different from the Glenelg River this highlights how rapidly carp populations can grow under favourable conditions.

Table 10. Summary data for Glenelg River carp population estimates (CPUE and average weight; Glenelg Hopkins CMA, unpublished data).

Site/Reach	CPUE (fish h^{-1})	Ave. Weight (kg)	Density (kg ha^{-1}) Petersen	Lower 95%	Upper 95%	No. of carp Petersen	Lower 95%	Upper 95%
Rocklands**	-	-	-	-	-	-	-	-
Yat Nat	43.3	2.0	63*	31	138*	1,659	824	3,630
5-Mile	46.7	1.7	68*	34	148*	1,459	724	3,192
Ross Rd	13.3	2.8	19	10	42	354	176	774
Fulham Hole	60.0	3.4	87*	43	191*	1,009	501	2,208
The Gorge	-	-	-	-	-	-	-	-
Harrow	3.3	3.0	5	2	11	128	64	280
Moree Bridge	23.3	2.5	34	17	74*	378	188	827
Burkes Bridge	10.0	2.7	15	7	32	219	108	478
Harland Hills**	-	-	-	-	-	-	-	-
Dergholm-Chetwynd Rd	83.3	2.6	121*	60*	265*	1,127	560	2,466
Warrock Rd	26.7	2.8	39	19	85*	392	195	858
Warrock Ford	30.0	1.2	44	22	95*	687	341	1,502
Section Rd**	-	-	-	-	-	-	-	-
Sandford**	-	-	-	-	-	-	-	-
Killara**	-	-	-	-	-	-	-	-
Myaring Bridge Rd	9.1	0.9	13	7	29	532	264	1,163
Beddisons Rd	3.0	0.6	4	2	10	150	75	329
Burrows Rd**	-	-	-	-	-	-	-	-
Dartmoor**	-	-	-	-	-	-	-	-
					Total	8,095	4,019	17,707

*above 50 kg ha^{-1} impact threshold.

**no carp have been captured within these sites since VEFMAP sampling commenced in 2009.

4. CONCLUSION

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 (e.g. 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 this technique could be further optimised during the cooler months. The estimated population size/densities coupled with a relatively low level of recruitment suggests that ongoing targeted harvesting may be an effective tool for reducing and maintaining the Glenelg River carp biomass below impact density thresholds (<50 kg ha^{-1}). While harvesting effort should be applied across the known distribution of carp, greater effort should be focused at locations where carp densities exceed impact thresholds. The numbers/densities presented herein can be used to estimate the success of applied control activities in the short-term (i.e. % population reduction and resulting densities) but will need to be re-estimated periodically (every 1-2 years) to account for future changes in the population (e.g. successful recruitment events). Given that carp are a long lived species (28+ years), even low levels of annual recruitment will contribute to a steady increase in the population. An understanding of population change will aid in determining the success of ongoing control efforts and also assist in establishing management objectives (Donkers *et al*. 2012; Brown and Gilligan 2014). An ongoing control program should also aim to evaluate the feasibility of other options such as spawning sabotage (Inland Fisheries Service 2008; Shields 1957; Yamamoto *et al*. 2006) or habitat rehabilitation/restoration, particularly at areas characteristic of carp spawning and nursery sites such as Clunies Hole. As it appears recruitment is only occurring within a limited number of locations, the successful application of these strategies will complement harvesting efforts and assist in achieving and maintaining density targets.

While an integrated approach (i.e. harvesting, spawning sabotage) will aid in controlling numbers and minimising impacts of carp it is important to note that considerable effort is required and that applied control techniques are unlikely to eradicate carp from the Glenelg River (Brown and Walker 2004). Notwithstanding, the information gathered through an ongoing control program may ultimately support the potential use of bio-control agents that promise significant reductions in carp biomass such as CHV-3 and daughterless carp technologies (Brown and Gilligan 2014).

Knowledge of the densities, movements and distribution of carp will aid in formulating a bio-control release strategy that should achieve the greatest population reduction. This knowledge will also assist in developing a clean-up strategy, particularly for sites where the highest mortalities are expected. Further, reducing or maintaining the current biomass through ongoing control will limit the level of clean-up and potential negative impacts associated with the mortality of a larger biomass (i.e. poor water quality, offensive odours). Finally, as modelling suggests a moderately aggressive CHV-3 treatment is likely to reduce the population by ~77% or ~90% when combined with daughterless carp technology (Brown and Gilligan 2014), complementary techniques will still be needed to aid in controlling resistant carp and limiting population recovery.

Given the multiple benefits, it is recommended the Glenelg Hopkins CMA continue to apply and develop an ongoing carp control program. This program should aim to achieve predefined management targets (i.e. % population reduction to achieve density <50 kg ha^{-1}) and rely on, and continue to develop an understanding of the carp population in the Glenelg River (i.e. abundance, densities, movements, distribution), as well as the costs/benefits that applied control techniques achieve in both the short- and long-term (e.g. improvements in vegetation and water quality).

5. RECOMMENDATIONS AND FUTURE RESEARCH

- *Optimise electrofishing harvesting and develop a harvesting database* - continue to evaluate and optimise electrofishing as the primary carp harvesting technique. Harvesting should continue to be evaluated throughout the carp breeding season (spring-early autumn) and during the cooler months when carp may be aggregating. While effort should be applied across the known distribution of carp, initial efforts should prioritise breeding areas and reaches where densities exceed impact thresholds. The information collected during each harvesting event should be recorded in a dedicated database. The database should include time, date, location, habitat characteristics, river conditions (i.e. flow, height), environmental data (i.e. temp, light conditions, wind direction/speed, temp, DO, turbidity), harvesting strategy, methods and settings (if using electrofishing) and the biological information outlined below. The information will assist in optimising harvesting by identifying 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. The information collected during ongoing harvesting can also be used to support the potential use of biocontrol agents.

- *Evaluate complementary control techniques* - This work should focus on evaluating the feasibility of control techniques that aim to sabotage spawning and limit recruitment within the system. The program should aim to develop an understanding of peak spawning times (GSI analysis; see below) and to identify all locations that are characteristic of carp spawning and nursery sites such as Clunies Hole. Potential sites could be identified through existing programs (i.e. VEFMAP) and habitat mapping, and verified via larval and young-of-year sampling. The feasibility of control techniques such as spawning sabotage (liming, water level manipulations; Appendix A) or habitat rehabilitation/restoration (i.e. returning Clunies Hole to channel) should then be trialled within these locations. The success of applied techniques can be monitored by comparing densities of larval and young-of-year carp post treatment to baseline data collected through the site identification process. Given there appears to be limited recruitment within the Glenelg River, the successful application of these strategies could have a significant impact on the carp biomass. The larval sampling could also be used to assess the influence (if any) of natural and environmental flow on the spread of carp via larval drift.

- *Seek to understand the mechanism limiting recruitment* - Length-frequency data and the results of the population estimate indicate there has been relatively limited recruitment in the Glenelg River since carp invaded the system (*circa* 2001). This may be associated with environmental conditions, river geomorphology, 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, habitat rehabilitation).

- *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 (Gonadosomatic Index, GSI, g) and eggs staged. In addition, each specimen should have their otoliths removed for ageing and determination of their natal origin which will aid in identifying if the Wannon River or other systems (via translocation) are acting as potential carp seed stocks. These data will aid in determining the optimal time to harvest or apply techniques which aim to sabotage spawning (i.e. as defined by GSI and egg staging). 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 river’s native fish assemblage to the reduction in carp numbers.

- *Potential release of bio-control agents* - carp bio-control agents such as CHV-3 and daughterless carp technology promise significant reductions in carp biomass across targeted systems. While the release of these agents is not yet certain, positive research outcomes (e.g. no identified risk to native species/humans) coupled with growing public and political support for CHV-3 suggests it may eventually be released. As such, it is recommended that Glenelg Hopkins CMA consider developing a program designed to facilitate the planned strategic release of this agent. This program should also consider an un-planned release as there is a possibility that infected carp may be translocated into the system, even by well-meaning members of the public.

- *Mark-recapture experiment* - to account for future changes in the population (i.e. successful recruitment events), understand the success of applied control activities (i.e. % population reduction and resulting densities) and estimate the effort required to achieve future carp management objectives/targets, it is recommended that population estimates are conducted every 1-2 years. This work should utilise methods similar to those described herein and be done in conjunction with VEFMAP sampling to increase the probability of re-capture.

- *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 VEFMAP. In addition, to evaluate the environmental benefits associated with managing carp, water quality and aquatic vegetation should be monitored within all control sites.

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7. 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 labour 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. • *Could be feasible as there appears to be limited spawning habitat, however it may conflict with the rivers value as a public amenity and irrigation offtake.*		✓

Control mechanism	**Comments**	**Feasible**	
		Yes	**No**
Draining/drying	• 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.*		✓
Chemical piscicides such as Rotenone (Clearwater *et al*. 2008)	• 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.*		✓
Barrier netting (Inland Fisheries Service 2008)	• 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 logistically difficult*		✓
Liming to destroy eggs (Diggle *et al*. 2004; Diggle *et al*. 2012)	• Hydrated lime can be used to raise pH >11 to kill carp eggs. • Requires detailed knowledge of spawning locations and times as eggs hatch within 2 days @ 25ºC. • There is a need to understand impacts on non-target species. • Can be logistically difficult to apply lime across all spawning locations. • *Could be feasible if only a few spawning "hot spots" are identified*.		✓
Commercial Fishing	• 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.*		✓
Electrical barriers (Verrill and Berry 1995)	• 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.*		✓
Pheromone lure traps (Sorensen and Stacey 2004)	• Can be expensive and requires expertise. • Limited success in field trails. • *Not feasible due to the limited success recorded in field trials.*		✓