Inland Waters and Catchment Ecology

Proof of concept of a novel wetland carp separation cage at Lake Bonney, South Australia

Dr Leigh Thwaites

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A summary report for the Invasive Animals Cooperative Research Centre and the South Australian Murray-Darling Basin Natural Resources Management Board

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EXECUTIVE SUMMARY

- Lake Bonney was disconnected from the main channel of the River Murray in mid-2007, via an earthen bank, to make water savings during drought conditions across the Murray-Darling Basin. Post disconnection, lake water levels reduced via evaporation and salinities increased until the latter half of 2008 (when significant fish kills occurred). To reduce salinity levels, Lake Bonney received a partial refill allocation of 10 GL in November 2008. This water was delivered from the adjacent Chambers Creek via a series of siphons.
- The November (2008) refill created a large aggregation of migrating carp at the inflow point. Approximately 30 tonnes of aggregating carp were manually harvested by commercial fishers and a further five tonnes by the general public. The commercial harvest was extremely labour intensive, and the harvest by the general public was uncontrolled and at times unethical and unsafe (with fishing methods including bows and arrows, pitchforks, spear-guns etc).
- In 2009, a further 26 GL of water was delivered to Lake Bonney. To deliver this water, two box culverts were constructed in the centre of the earthen bank. Given that 35 tonnes of carp were removed during the 2008 filling event, the South Australian Murray-Darling Basin Natural Resources Management Board (SA MDB NRM Board) engaged the South Australian Research and Development Institute (SARDI Aquatic Sciences) to oversee the design, construction and installation of a prototype Wetland Carp Separation Cage (WCSC; including the cage, gantry, hoist and mechanism to empty fish) within one of the culverts. However, due to a lengthy commissioning process the cage remained untested during 2009.
- In June 2010, Lake Bonney received a further 25 GL environmental water allocation. As carp were again expected to attempt to migrate from the lake, the Invasive Animals Co-operative Research Centre (IA CRC) and the SA MDB NRM Board supported a "proof-of-concept" trial of the WCSC. WCSC operation commenced on the 28th September 2010.
- As carp and bony herring were the only fish species expected to enter the cage, the central baffle (comprising jumping and pushing trap elements) was removed to allow the cage to operate as a large scoop trap. In order to permit the unrestricted passage of bony herring, while restricting the passage of carp ≥ 250 mm (total

length, TL), the lower 30 cm section of the upstream cage cladding was constructed using a jail bar configuration with a 31 mm aperture between the bars.

- While carp aggregations formed rapidly within the inflow plume and persisted for approximately 2 months during the 2008 and 2009 water allocations, this response was not observed during the 2010 allocation. In 2010, there were no observable large carp aggregations adjacent to the cage, within the weir pool or within the inflow plume.
- The reduction in the magnitude of carp movement during 2010 is most likely the result of the timing of the allocation, the seasonal increase in water temperatures and the temporal improvement in the lakes water quality.
- A total of 529 carp (mean total length = 607.6 mm ± 8.1 S.E.; mean weight = 4400 g ± 155 S.E.; width ≈ 83 mm) were captured over 13 harvesting events which occurred between 28th September and 25th October 2010. Given their average weight, this equates to approximately 2.3 tonnes of carp.
- Carp spawning activity was observed intermittently in the cage weir pool between the onset and completion of the WCSC trial. However, no young carp were captured in the fyke nets which were set within Lake Bonney in November 2010, and only 57 young carp were detected in December 2010.
- In terms of by-catch, a total of 356 bony herring (mean total length =433.3 mm ± 3.4 S.E.; mean weight = 931.2 g ± 26.7 S.E.; width ≈ 45 mm), 2 goldfish, 1 golden perch and 4 birds were captured.
- The recorded level of by-catch highlights the need to fully assess the resident native fauna assemblage (on a site by site basis) before the installation of any carp trapping infrastructure. If iconic or high value species are encountered then appropriated design modifications and management protocols are required to ensure carp infrastructure has minimal or no impact.
- Although the WCSC operated according to its intended design and function, some operational issues were observed during the 2010 trial. Specifically, these issues were associated with the funnel, the door mechanism, the cage supports and the level of by-catch (particularly bony herring).

BACKGROUND

Lake Bonney was disconnected from the main channel of the River Murray in mid-2007, via an earthen levee, to generate water savings for "critical human needs" in response to ongoing drought conditions across the Murray-Darling Basin (Bond *et al.* 2008; Smith *et al.* 2009). Following disconnection, water levels decreased in the lake through evaporation and salinities gradually increased until the latter half of 2008, when significant fish kills occurred. Consequently, Lake Bonney received a partial refill allocation of 10 GL in November 2008 to reduce salinity levels.

The November 2008 refill created an aggregation of carp at the inflow point. This aggregation formed quickly, persisted for the entire filling event and was comprised of large numbers of adult carp attempting to migrate out of the lake. Approximately 30 tonnes of aggregating carp were manually harvested by commercial fishers and a further five tonnes by the general public. The commercial harvest, however, was extremely labour intensive; and the harvest by the general public was uncontrolled and at times unethical and unsafe (e.g. fishing methods included bows and arrows, pitchforks, spear-guns, etc).

In 2009, the delivery of 26 GL of water to refill Lake Bonney was proposed. Initial plans suggested water delivery over a short period (about two months) during the cooler months (late winter). The intention was to minimise evaporative losses and maintain water conductivity less than 20,000 $\mu S.cm^{-1}$ for as long as possible to prevent further kills of fish (especially of significant conservation and recreational species such as Murray cod and golden perch) and other fauna (e.g. turtles). The upper-limit of 20,000 $\mu S.cm^{-1}$ is the precautionary "threshold" adopted by the South Australian Murray-Darling Basin Natural Resource Management Board to stay within the laboratory derived, salinity threshold of 23,000 $\mu S.cm^{-1}$ for certain species of native fish and turtles (Brad Hollis, SA MDB NRM Board, pers. comm.)

A temporary flow control structure consisting of two box culverts was constructed at the junction of Lake Bonney and Chambers Creek (at Napper's Bridge, on the Morgan Road) to deliver the water. Given that 35 tonnes of carp were removed during the 2008 filling event, the SA MDB NRM Board engaged the South Australian Research and Development Institute (SARDI Aquatic Sciences) to oversee the design, construction and installation of a prototype wetland carp separation cage (including the cage, gantry, hoist and mechanism to empty fish) within one of the culverts.

The Lake Bonney prototype WCSC design aimed to eliminate manual handling requirements and Occupational Health, Safety and Welfare (OHS&W) concerns that were identified during previous work with an earlier prototype WCSC (designed at Banrock Station, South Australia), where 8 tonnes of carp were captured in 4 months (SARDI Aquatic Sciences and The University of Adelaide; unpub. data). Essentially, the Lake Bonney WCSC was developed to be safe, effective, easy to operate and vandal-resistant (as far as possible). The conceptual Lake Bonney WCSC design developed by SARDI Aquatic Sciences incorporated the following key elements:

- Technology to separate carp ≥ 250 mm TL from native fish using jumping (Stuart *et al.* 2006) and pushing trap elements (Thwaites *et al.* 2010),
- Cage cladding (mesh; vertical jail bar design, with a 31 mm aperture between bars) designed to permit the unimpeded passage of small and medium sized native fish, while impeding the passage of carp ≥ 250 mm TL (Thwaites *et al.* 2010; Hillyard *et al.* 2010),
- Infrastructure to mechanically lift and automatically funnel captured fish into trailer-mounted fish bins (Figure 1). When the jumping and pushing trap elements are in use, there are two cage sections (Holding Zone and Carp Cage, Figure 2) and these should be able to be emptied independently. For example all fish in the Holding Zone (potentially including carp and native fish) would be emptied first, so that native fishes can be returned to the water,
- A modular WCSC design permitting straightforward management changes. For example, when fish aggregations comprised entirely of carp or commercial species (e.g. bony herring in South Australia) are present, the central baffle of the cage (comprising the jumping and pushing trap elements) can be removed, and the cage can be used as a large scoop, and
- Compliance with Australian design and OHS&W legislation.

Conceptual sketches of the Lake Bonney WCSC design are below (Figures 1 and 2).

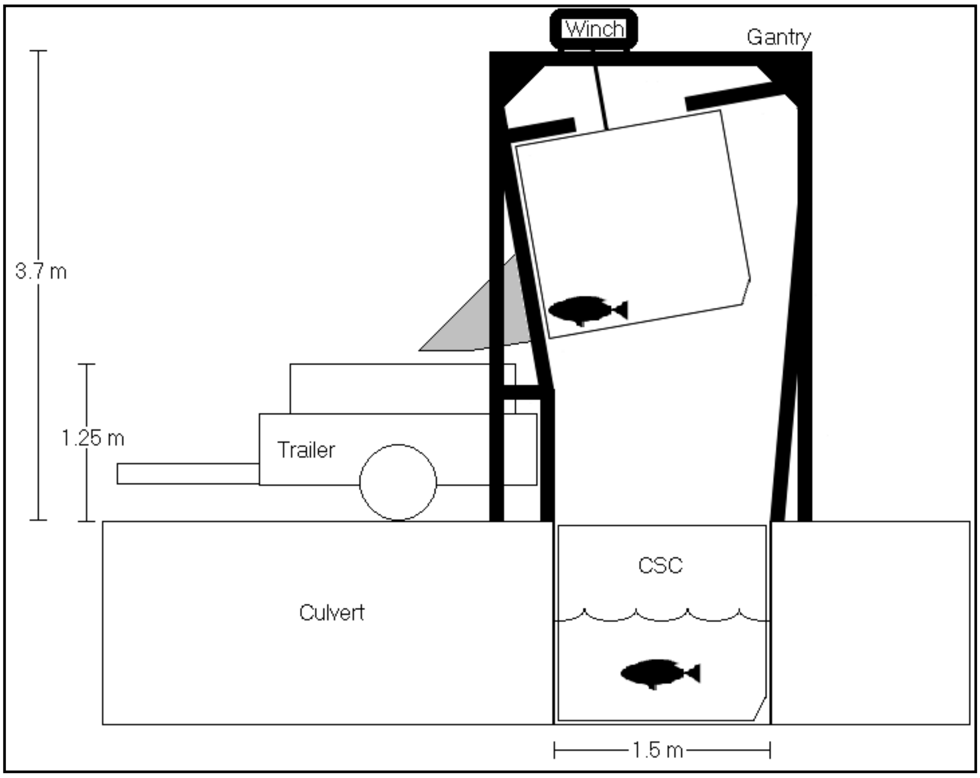

Figure 1. Schematic representation of the conceptual Lake Bonney WCSC lifting infrastructure.

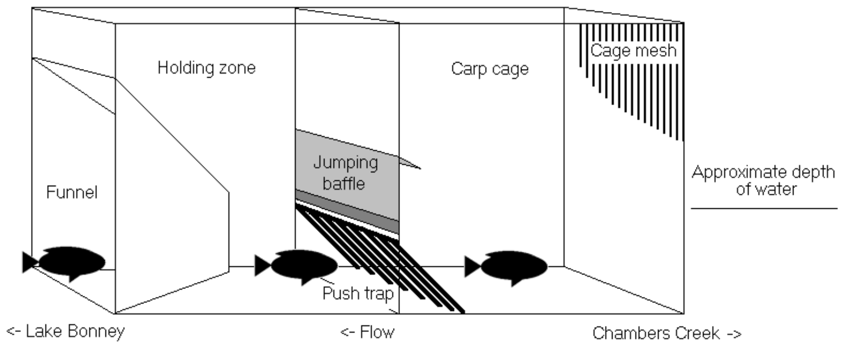

Figure 2. Schematic representation of the Lake Bonney WCSC showing the entrance funnel, holding zone, jump/push trap element, carp cage and jail bar cladding with 31 mm aperture (cage mesh).

SARDI Aquatic Sciences originally contracted Parson's Brinkerhoff (PB) on 20th June 2009 to produce engineering design drawings of the conceptual Lake Bonney WCSC, and to ensure that the design complied with all Australian design and OHS&W legislation.

Cage manufacture from PB's drawings occurred during 10th-19th September 2009 by Artec Engineering and installation occurred during 23rd-25th September 2009. A SARDI OHS&W audit of the near-final WCSC set-up occurred on the final day of installation. Upon installation, it was clear that the set-up was not functional and did not comply with Australian design or OHS&W legislation (in particular, section 3.2 Subdivision 1 [Duties of Designers] of the Occupational Health, Safety and Welfare Regulations, 1995). In regards to the latter, the initial design did not identify and provide controls (fine mesh screening) for the crush/amputation points that existed between the cage and the gantry during operation. Thus, SARDI Aquatic Sciences was required to immediately contract the on-site WCSC fabricator, Artec Engineering, to design, fabricate and install the mesh guarding for the crush/amputation points; calculate new design loadings based on the revised design, and to ensure that the final design/structure complied with Australian OHS&W legislation.

Draft Standard Operating Procedures (SOP) for the WCSC set-up were developed and provided to the SA MDB NRM Board on 3rd November 2009. The mesh guarding of crush/amputation points was installed on 11th November 2009 (Figure 3). An itemised costing for the engineering and construction of the WCSC set-up (including carp pivot and deflector screens, walkways and guarding) is presented in Appendix C.

Figure 3. The Lake Bonney WCSC set-up showing a) the two doors of the cage operating independently to allow each cage section to be emptied separately (with the holding cage door opening first), and b) both doors fully open when cage is fully lifted.

Even though a large aggregation of carp formed within the lake inflow during the 2009 environmental water allocation, cage testing was subsequently not permitted until the SA MDB NRM Board had satisfied all site OHS&W compliance including: installation of appropriate fencing to secure the area, walkway mesh and handrails to both box culverts, development of an overall site OHS&W audit and completion of Standard Operating Procedures (SOP) and the induction of SARDI Aquatic Sciences' staff back onto the worksite. This was completed on 21st December 2009.

Subsequently, a video guide for the operation of the wetland carp harvesting system (WCSC and carp pivot/deflector screens) was developed by SARDI Aquatic Sciences on 7th January 2010, and flow ceased on 19th January 2010. Although the cage remained untested during 2009/10, the set-up was fully commissioned, made OHS&W compliant and vandal resistant.

In June 2010, Lake Bonney received a further 25 GL environmental water allocation. As carp were again expected to attempt to migrate from the lake, the Invasive Animals Co-operative Research Centre and the SA MDB NRM Board supported a "proof-of-concept" trial of the Lake Bonney WCSC. The primary objectives of this trial were to:

- Demonstrate the utility of the Lake Bonney WCSC.
- Finalise the Standard Operating Procedures.
- Document any operational issues associated with the prototype design.

This report describes the work undertaken during 2010, the response of carp and other fishes to the flow and filling event, and provides considerations for future design improvements.

METHODS

Site description

Lake Bonney is adjacent to the Riverland township of Barmera, South Australia (38^{o}12'56.80"S; 140^{o}26'58.98"E). The lake is ≈ 7 km long and 3.5 km wide with an average depth of ≈ 1-2 m. At 8.85 AHD the lake covers ≈ 1684 ha (K. Marsland, SA MDB NRMB, pers. comm.). There is little riparian or submerged vegetation and the lake is exposed to strong wind and wave action (Figure 4).

Pre-disconnection in mid-2007, the mean lake salinity was ≈ 9,000 µS.cm^{-1} (Brad Hollis, SA MDB NRMB, pers. comm.). Post-disconnection, salinity increased (due to evapo-concentration) to ≈ 15,000-20,000 µS.cm^{-1} (20,000 µS.cm^{-1} being the biological trigger point for environmental water allocations). During this study, the lake received water from the River Murray via two culverts (installed in September

2009; removed December 2010) in Chambers Creek at its north-eastern inlet, and lesser inputs from town stormwater and catchment run-off (Figure 4).

Figure 4. Google Earth image of Lake Bonney showing the location of Chambers Creek, the WCSC, the Northern boat ramp, the Hobo temperature logger and the Barmera jetty.

Before the delivery of the environmental water allocation in 2009 the lakes water level was 7.83 AHD and there was a ≈ 1.7 m head differential between Chambers Creek and Lake Bonney. Two box culverts, 1.5 m square with sluice gates at the upstream end (one undershot sluice gate on the northern culvert, and one ‘combination’ sluice gate in the southern culvert, where the WCSC was positioned), were constructed in the centre of the earthen bank to deliver the 26 GL of water. The base of the culvert was ≈ 1 m above the lake’s water level. A rock weir (< 300 mm gauge rock) was also constructed downstream of the culverts to maintain acceptable ‘fish holding/harvesting’ water levels (> 70 cm) within the culvert, and a v-notch was later created within the rock-weir by SARDI Aquatic Sciences’ staff, to facilitate the up-stream movement of carp toward the WCSC (Figure 5). However, the light gauge rock (< 300 mm) proved insufficient to withstand the “filling” flow rates (≈ 1.5 $m.s^{-1}$

culvert^{-1}) utilised during 2009 and the weir and v-notch was destroyed (see Thwaites and Smith 2010). While Thwaites and Smith (2010) recommended the construction of a stepped weir for future trials of the WCSC at Lake Bonney, due to the early onset of the 2010 allocation lake water levels had risen to 9.30 m AHD (1st September 2010) and a secondary weir was not required. As such, the existing weir was reconstructed on the 1st September 2010 using heavier gauge rock (300 mm and 400-600 mm) and embedded railway sleepers. In addition, an agreement was made with the SA MDB NRM Board to maintain slower "fishing" flow rates through the culverts once the weir was constructed. Thus, at the completion of weir construction, flow rates were set at 0.62 m.s^{-1} (± 0.12 S.E.) in the northern culvert and 0.40 m.s^{-1} (± 0.09 S.E.) in the southern culvert containing the trap. Flow rate through the weir v-notch was ≈ 1 m.s^{-1}.

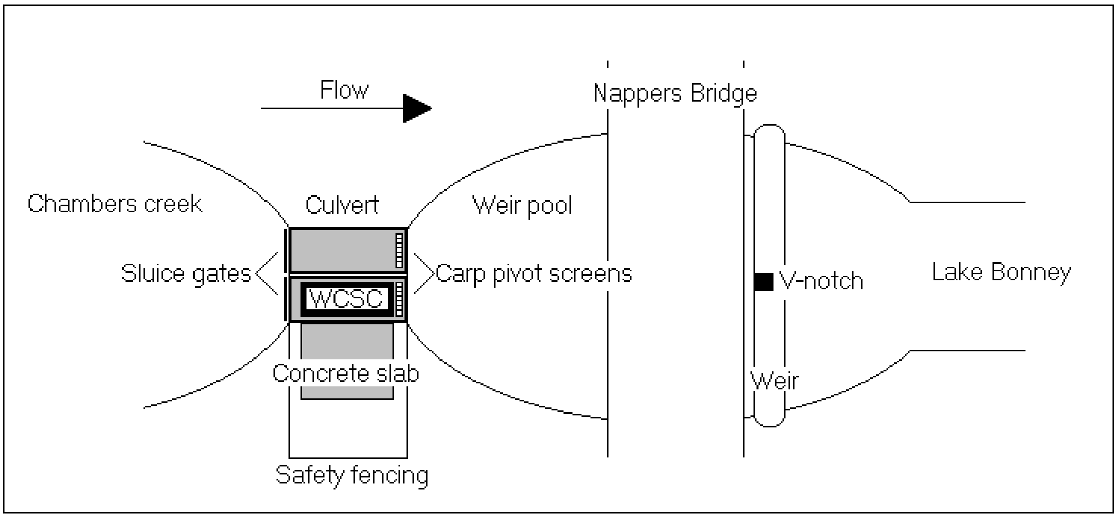

Figure 5. Schematic overview of the Lake Bonney Wetland Carp Harvesting System.

Environmental factors

Environmental factors including natural attractants (e.g. temperature and salinity gradients, current flow, food and 'earthy' odours, acoustic sounds) and chemical attractants (pheromones) are known to trigger innate behaviours in fish, especially those related to movements and migration for feeding and spawning (Hawkins 1986; Sorensen and Stacey 2004; Amoser and Ladich 2005). Thus, environmental data was collected to compare with fish movement patterns. Salinity data (EC; µS.cm^{-1}) was accessed for three sites (Chambers Creek, the Northern Boat Ramp, and the Barmera Jetty) from the SA MDB NRM Board (unpublished), and water temperature was measured at hourly intervals with a HOBO^{TM} water temperature logger (Onset, Cape Cod Massachusetts, USA) (Figure 4).

WCSC - Operation

From the onset of flow (June 2010) carp movement was observed on a daily basis by commercial fishers. To maximise the harvest, WCSC operation did not commence until carp were observed in the weir pool. WCSC operation commenced on the 28th September 2010, for a period of one month and was conducted according the procedures detailed in Appendix B- User Guide. To ensure the safety of all onsite personnel, the Draft SOP detailed by Thwaites and Smith (2010) were verified during the initial stages of operation and utilised for the duration of the trial. The finalised SOP is presented in Appendix A.

All fish were processed immediately after capture. The first 30 fish of each species were measured (TL, mm) and weighed (g) and remaining fish were counted. With the exception of bony herring (a species of commercial value in South Australia), native fish were processed immediately and released into Chambers Creek. Carp and bony herring were taken by commercial fishers.

As carp and bony herring were the only fish species expected to enter the cage, the central baffle (comprising the jumping and pushing trap elements) was removed and the cage was operated as a large scoop trap. To permit the unrestricted passage of the majority (98%) of bony herring while restricting the passage of carp ≥ 250 mm TL, the lower 30 cm section of the upstream cage cladding was constructed using a jail bar configuration with a 31 mm aperture between the bars (after Hillyard *et al.* 2010).

Fyke-netting

Opportunistically, two fyke-nets were set overnight in reeds (the only submerged vegetation in the north-western section of the lake) adjacent to the fresh water channel in November and December 2010, to assess possible carp recruitment that may have occurred as a result of the observed carp spawning. The fyke-nets were made of 8 mm stretched mesh and had a single 6 m leader, 80 cm diameter entrance and a 6 m funnel with three chambers.

RESULTS

Environmental factors

At the onset of the WCSC trial (28th September 2010), lake water temperatures had reached the known 16°C minimum required for carp spawning (Smith 2005). Over the duration of the trial water temperatures were variable but increased to a maximum ≈ 19.1°C on 10th October 2010 before dropping to ≈ 16.3°C on 17th October 2010, after which time temperatures steadily increased to ≈ 19°C in late-October 2010 (Figure 6).

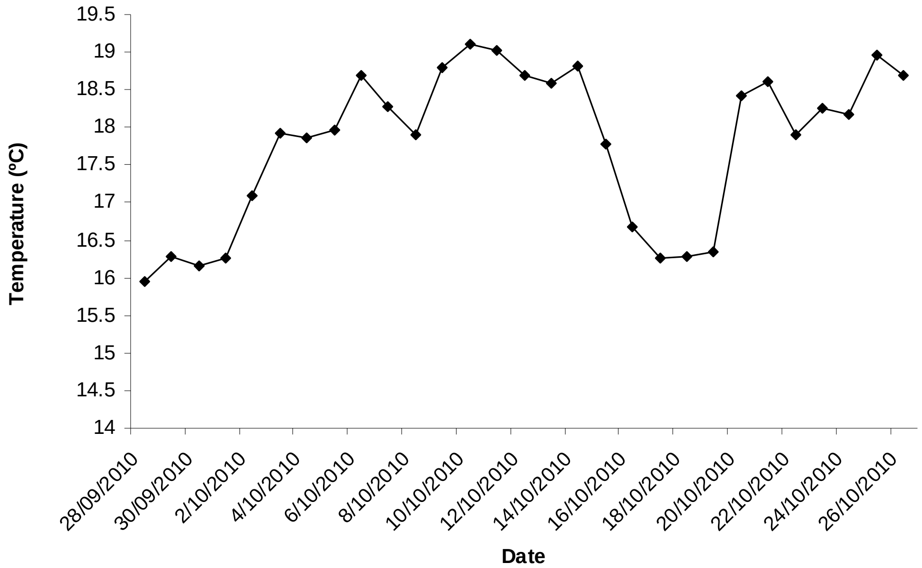

Figure 6. Lake Bonney water temperature for the duration of the WCSC trial.

Lake salinity was ≈ 13,000 $\mu S.cm^{-1}$ at the onset of the environmental water allocation. Although the salinity of the inflowing water was relatively low (273.7 $\mu S.cm^{-1}$ ± 12 S.E.) this had limited effect on within lake salinity levels (Figure 7). Due to the effects of mixing, salinity levels at the Northern boat ramp (≈ 500 m north-east of the inflow) were variable and by the completion of the trial (29th October 2010) had reduced by ≈ 1,100 $\mu S.cm^{-1}$. The effect of mixing was less pronounced at the Barmera jetty with only ≈ 700 $\mu S.cm^{-1}$ drop in salinity levels.

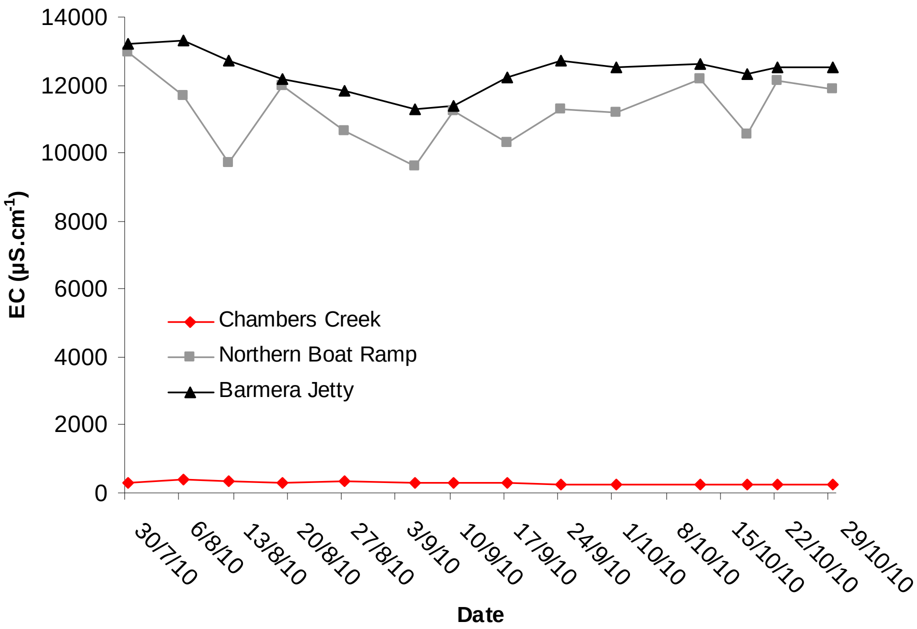

Figure 7. Electrical conductivity (µS.cm^{-1}) within Chambers Creek (in-flow) and Lake Bonney (Northern Boat Ramp and Barmera Jetty) over the duration of the WCSC trial.

Catch rates

A total of 529 carp (607.6 mm TL ± 8.1 S.E.; 4400 g ± 155 S.E.; width ≈ 83 mm) were captured over 13 harvesting events (Figure 8). Given their average weight, this equates to approximately 2.3 tonne of carp. In terms of by-catch, a total of 356 bony herring (433.3 mm TL ± 3.4 S.E.; 931.2 g ± 26.7 S.E.; width ≈ 45 mm) (Figure 9), 2 goldfish, 1 golden perch and 4 birds were captured (Table 1).

Table 1. Catch summary (carp and by-catch) for the duration of the WCSC trial

Date	Carp	Bony herring	Gold fish	Golden perch	Other
28/09/10	13				
29/09/10	11				
30/09/10	3	11			
1/10/10	2	5			
5/10/10	49	27	1		
6/10/10	211	70	1		
7/10/10	57	53			1 shag
8/10/10	16	1			
11/10/10	33	13			
12/10/10	23	54			
15/10/10	20	29			
21/10/10	50	12		1	2 shags + 1 duck
25/10/10	41	81			
Catch Total	529	356	2	1	4

The carp catch was bimodal with two distinct cohorts represented (Figure 8). Standard age at length relationships (Smith 2005) suggest these fish recruited during 2005 (400-550 mm TL) and 2001 (550-800 mm TL). Interestingly, the 2005 cohort coincides with the last significant pulse flow event and 2001 cohort coincides with the last recorded bank-full flows (http://www.waterconnect.sa.gov.au).

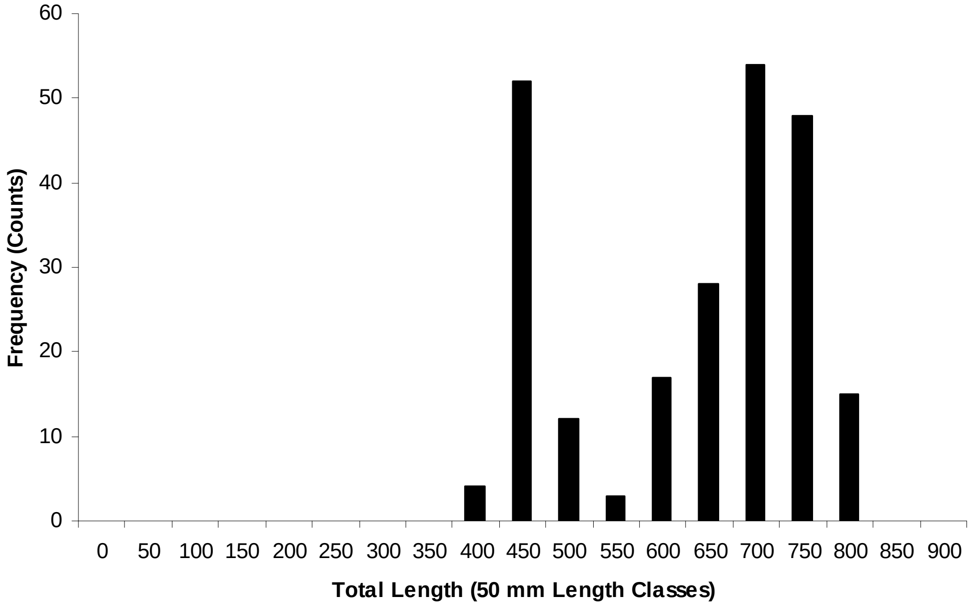

Figure 8. Length-frequency distribution of carp captured during the 2010 WCSC trial

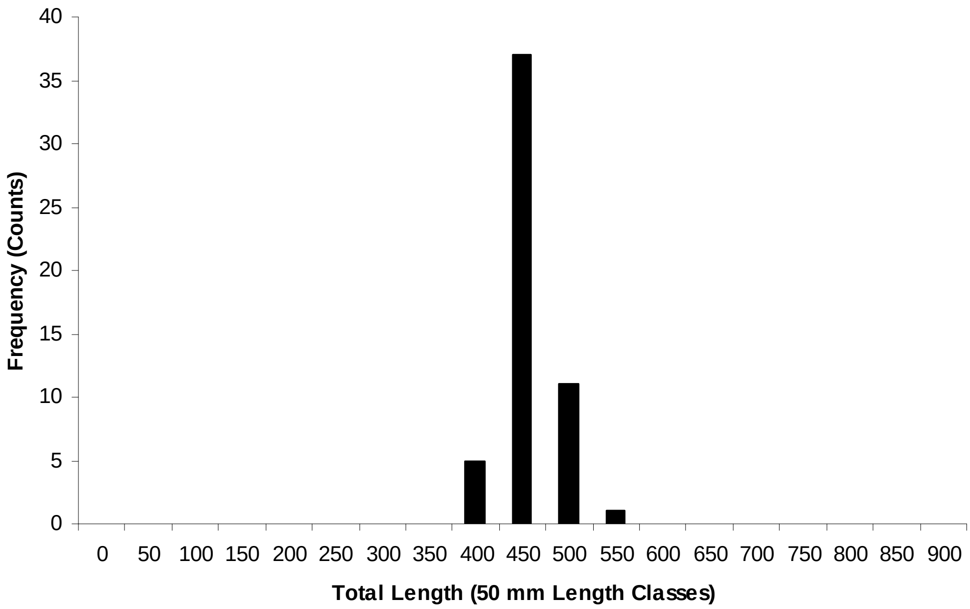

Figure 9. Length-frequency distribution of bony herring captured during the 2010 WCSC trial.

Carp spawning activity was observed intermittently in the cage weir pool between the onset and completion of the WCSC trial. However, no young carp were captured in the fyke nets which were set within Lake Bonney in November 2010, and only 57 were detected in December 2010 (average total length, 54 mm TL ± 3.0 S.E.; size range, 25-162 mm TL) (Figure 10). Using the estimated growth rate of 0.5 mm per day for South Australian carp (SARDI Aquatic Sciences, unpub. data) to back-calculate date of spawning; these fish were spawned on the 4th September 2010 (54 mm TL; ≈ 108 days old), 1st November 2010 (25 mm TL; ≈ 50 days old) and 31st January 2010 (162 mm TL; ≈ 324 days old).

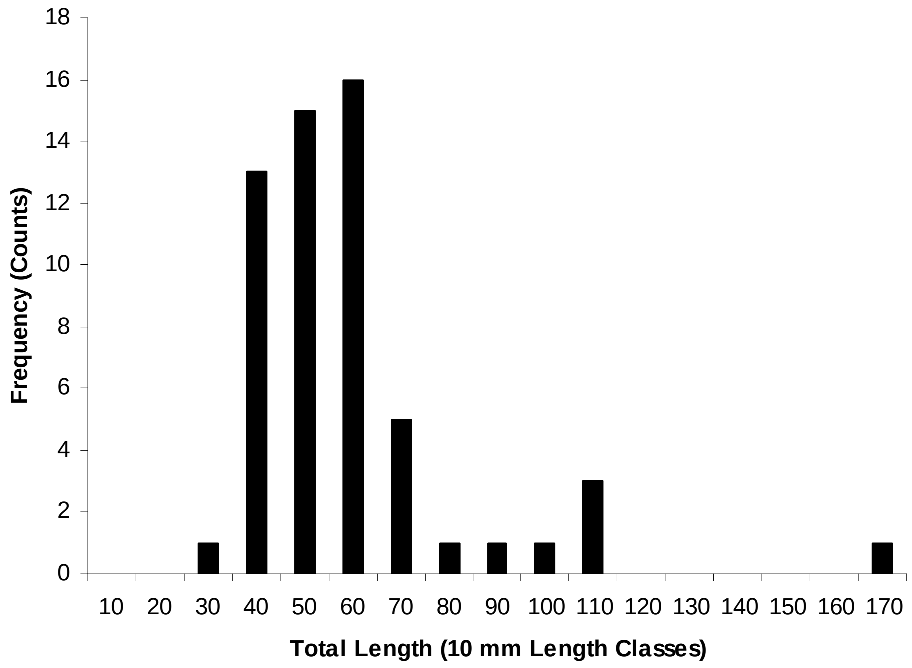

Figure 10. Length-frequency distribution of juvenile carp captured during 2010 WCSC trial.

WCSC operation and flow rates

Although the WCSC operated according to its intended design and function (see Introduction), some operational issues were observed during the 2010 trial. These issues were associated with the funnel, the door mechanism, the cage supports and the level of by-catch (particularly bony herring). These issues are discussed in greater detail in the next section.

Observations of carp and bony herring navigating the v-notch weir and entering the cage indicate the flow rates used in the present study were appropriate.

DISCUSSION

While carp aggregations formed rapidly within the inflow plume and persisted for approximately 2 months during the 2008 and 2009 water allocations (Thwaites and Smith 2010), this response was not observed during the 2010 allocation. In 2010, there were no observable large aggregations adjacent to the cage, within the weir pool or within the inflow plume. Interestingly, sporadic carp movements and catch rates were also noted at Lock 1 and Lock 3 within the main channel of the River Murray (Gary Warwick, commercial fisher; pers. comm.).

The decline in the magnitude of carp movement during 2010 is most likely related to the timing of the water allocation, the seasonal increase in water temperatures and the temporal improvement in the lake's water quality. The 2010 Lake Bonney water allocation commenced 4-5 months earlier than during 2008 and 2009, and the relatively low water temperatures (≈ 10°C) at this time would have precluded any migration attempts in the early stages of the allocation. Indeed, carp are reported to exhibit reduced movements ("overwintering") during the cooler months (Brown *et al*. 2001; Bauer and Schlott 2004). However, as water temperatures began to increase (> 10°C) there was concurrent increase in the numbers of carp within the weir pool and some spawning activity was observed. In a similar study, Conallin *et al*. (in prep) monitored the off-stream movements of carp in response to a winter/spring (June to December) environmental water allocation at Banrock Station, South Australia. In their study, catch rates did not exceed 10 carp per week during June and July (water temp. < 10°C). However, as water temperature increased there was a concurrent increase in catch rates, peaking in mid-August, when water temperatures reached 16°C. In the present study, peak catches were recorded when water temperatures reached 18°C (6th October 2010), these movement patterns observed are comparable to those described by Conallin *et al*. (in prep).

The overall reduction in the magnitude of carp movement is likely due to the water quality within the lake being significantly improved at the reported onset of the carp spawning migration (at water temperatures of ≈ 16°C). During the 2009 allocation (31st July 2009-30th October 2009), salinity levels across the lake were 17,582 $\mu S.cm^{-1}$ ± 415 S.E. (range: 14,441 - 20,511 $\mu S.cm^{-1}$). During 2010, salinity at the Northern Boat Ramp was 11,242 $\mu S.cm^{-1}$ ± 262 S.E., while salinity at the Barmera Jetty was

12,373 µS.cm^{-1} ± 155 S.E. Whiterod and Walker (2006) reported a critical salinity level of 8,330 mg L^{-1} (≈ 13,000 µS.cm^{-1}) where carp sperm activity becomes insufficient for fertilisation. While it is difficult to speculate whether carp can sense this potential, it is likely that improved water quality resulted in the decreased motivation of carp to migrate out of the lake. Indeed, fyke net samples taken during December 2010 indicated that carp had successfully spawned within the lake.

Although carp did not respond as they had in 2008/09, the 2010 water allocation provided sufficient response from carp to test the utility of the WCSC. While the WCSC operated according to its intended design and function (see Introduction), the following operational issues were observed during 2010:

1. *Cage door mechanism*: with the cage doors closed (i.e. the cage in a lowered position) there is a 5 cm gap between the bottom of the door and floor of the cage (Figure 11). When the cage was lifted and tilted during the harvesting process, there is potential for some bony herring and carp to slide into the gap. Then as the doors fully open, the gap closes and the fish are trapped. During this process, some bony herring were cut in half.

   Action: to address this issue it is recommended that the hinging points for the doors be relocated to a position that will minimise or eliminate the gap. To ensure that relocation will not effect the operational function of the door mechanism it is recommended this work be conducted in consultation with SARDI Aquatic Sciences scientists and design engineers.
2. *The funnel assembly*: while emptying the cage, some fish (mainly bony herring) became trapped by the funnel (behind and underneath). Foam inserts were used as an interim measure to reduce this potential; however, some fish still became trapped.

   Action: it is recommended that extra cladding be installed around the funnel assembly to restrict access into the areas that may trap fish.
3. *Cage supports*: the cage supports which run the length of the cage (Figure 11) create an area under the cage, which fish were able to access. Although cross bars were used to block this gap at the upstream end of the trap, some fish (possibly entrained fish) were observed underneath the cage and caught between the support and the underside of the cage floor.

   Action: to mitigate this potential, it is recommended that cross bars be installed to block the downstream gap and, for future iterations of the WCSC, it is recommended that the cage supports be incorporated into the floor assembly. This will effectively prevent fish access as the cage will rest on the floor of the culvert. However, this recommendation will require an engineering assessment to ensure the structural integrity and the OHS&W compliance of the cage assembly is maintained.

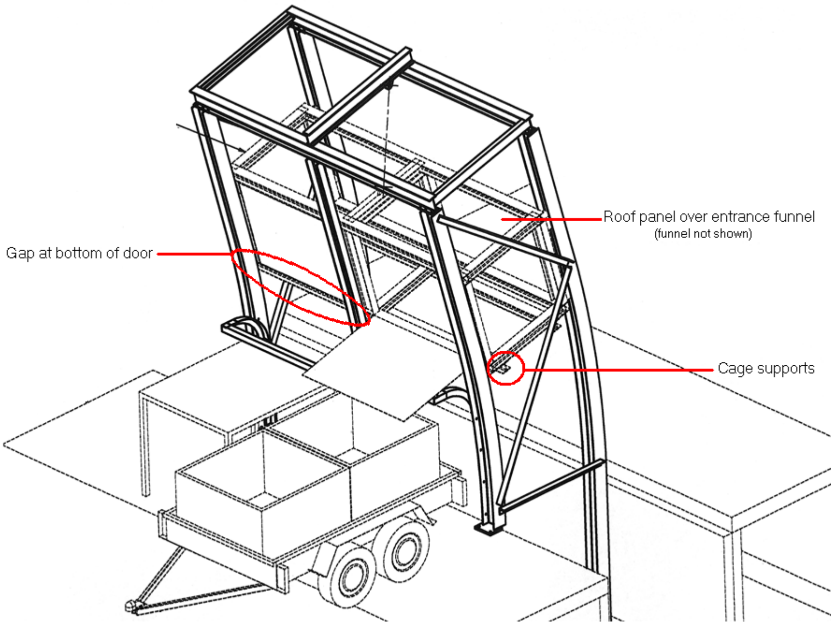

Figure 11. Schematic of WCSC showing components that required further work (note: the funnel assembly is not shown)

4. *By-catch*: the large by-catch of bony herring is attributed to the high abundance and size range of this species within the Lake Bonney (see Thwaites and Smith 2010), and to the cladding used in the upstream section of the trap (i.e. lower 30 cm- jail bars with 31 mm apertures; upper section- 40 x 40 mm grid mesh). In optimising carp exclusion screens, Hillyard *et al.* (2010) recommended a jail bar configuration with a 31 mm aperture between the bars (note: this aperture also applies to the carp push trap; Thwaites *et al*. 2010). The authors report this configuration will permit the unrestricted passage of 98% of bony herring while restricting the passage of carp ≥ 250 mm TL. However, the recommendation was based on the morphology of bony herring with a mean total length of 130.2 mm TL (range 22-457 mm TL). While it is likely the 31 mm aperture allowed smaller bony herring (< 373 mm TL, the minimum length of bony herring caught) to pass through the trap, the mean total length of bony herring captured during the present study was greater than in Hillyard *et al.* (2010), at 433 mm TL (range 373-505 mm TL). The application of full panels consisting of vertical jail bar mesh tailored

to accommodate this larger size class of bony herring would reduce this by-catch significantly. However, the interplay of increasing the aperture while still capturing breeding size carp requires careful consideration. For example, the unimpeded passage of 433.3 mm TL bony herring will require a 45 mm aperture but this will also permit the passage of breeding size carp (350 mm TL). Finally, to discourage the entry of birds, light fingers (of aluminium pipe or similar) should be installed on the entrance funnel. If birds are able push through this barrier then a section of the cage roof above the funnel could be removed (Figure 11). As trapped birds have been observed to rest on the funnel, by removing a section of this panel they should be able to exit the cage. To determine the potential for by-catch and to mitigate with appropriate management and operational protocols it is recommended the WCSC is checked every day during its operation.

The level of by-catch recorded in the present study highlights the need to assess the resident native fauna assemblage on a site by site basis before the installation of any carp management infrastructure. If iconic or high value species are encountered then appropriated design modifications and management protocols are required to ensure carp infrastructure has minimal or no impact (see Smith *et al.* 2009).

ACKNOWLEDGEMENTS

Thanks to all of the staff from SARDI Aquatic Sciences and Artec Engineering that were involved in getting the Lake Bonney WCSC set-up designed and installed and who were instrumental in overcoming the various design/site problems encountered along the way. Darren Jones (Artec Engineering) deserves special recognition for his exceptional workmanship, enthusiasm and determination. Also, thanks to Kelly Marsland and Peter Wanders from the SA MDB NRM Board, Brad Hollis from the Department for Water (DFW) formally from the SA MDB NRM Board, and the commercial fishers Malcolm Wilksch, Gary Warwick and Damien Wilksch for their help and support. Finally, thanks to Dr Katherine Cheshire, Dr Susan Gehrig, Kylie Hall and Wayne Fulton for providing constructive comments on earlier versions of this report. The Invasive Animals Cooperative Research Centre and the SA MDB NRM Board funded this work.

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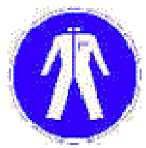
Appendix A

Standard Operating Procedure (SOP) for the Lake Bonney Wetland Carp Separation Cage (WCSC)

Standard Operating Procedure – Wetland Carp Separation Cage (WCSC)

Division Name: SARDI	**SOP No: Leave for the moment**
Group Name: Aquatic Sciences, Inland Waters	**Date of last Revision: 11/02/11**
Brief task description: Wetland Carp Separation Cage	**Date for Review: October 2012**
Approved By: Michael Clark	**Review By (Author): Leigh Thwaites**

Item No	**STEPS** *List the steps required to perform the task in the order they are carried out.*	**HAZARDS / RISKS** *Against each step list the hazards / risks that could cause injury or damage to equipment or the environment.*	**SOLUTION** *List the remedies required to either eliminate or control the risk/s for each step.*	**PROTECTIVE EQUIPMENT** (see below) ***Please specify***
1	Special notes	This document details the Standard Operating Procedure (SOP) for the SARDI Aquatic Sciences Wetland Carp Separation Cage (WCSC). WCSC operation requires the operators to work outdoors, adjacent to water, to use a towing vehicle and trailer, and a 3-phase generator. Note the WCSC site at Lake Bonney is to be accessed from the side access road to avoid personnel traversing the adjacent highway. The WCSC is to be operated by two trained persons at all times. Operators are to ensure a First Aid kit is onsite and that they can summon emergency assistance in the case of an emergency. Personnel using this equipment must be familiar with and understand the requirements of the following Safety Instructions:		

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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		1. General Safety- a. Sun protection (refer to PIRSA SOP 118) b. Manual lifting c. Working safely near water d. Manual Handling 2. Towing vehicle and trailer operation 3. Generator operation 4. Site- general site safety 5. The Wetland Carp Separation Cage Personnel should not use this equipment until they have : 1. Read this Standard Operating Procedure 2. Read and understood all appropriate operators manuals (sluice gates, hoist, generator) 3. Undergone a site induction 4. Undergone practical WCSC operation training The Carp Management Advisory Committee (CMAC) will ensure records are kept of approved WCSC operators and audit compliance.		

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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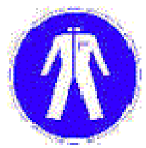
2	Pre- Inspection: Site	• Tripping / Slipping of personnel • Loss of Traction / Bogging of vehicle • Falling into water	• Check and clear site of tripping hazards i.e. rocks, branches, slippery surfaces • Check area before driving onto site • Under take work in adequate light • Ensure fencing and handrails are in place	
3	Pre-Inspection: Wetland Carp Separation Cage (WCSC) check	• WCSC failure (structural integrity) • Crushing of hands, arms and fingers • Amputation of hands, arms and fingers • Electrocution	• Check plant for all aspects of safe operations including that footings, guide runners, door slides hoist chain, lock-out pins, cage, safety guarding, power board, earth stake etc, are free from corrosion, cracks, warping, wear and debris • Check that AA batteries in control pendant are operational and carry spare batteries • Check for tampering and vandalism of site. WCSC	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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4	Position trailer for harvest	• Reversing into WCSC (WSCS failure- structural integrity) • Run over by trailer and/or vehicle (broken bones, lacerations or death) • Reversing off vehicle ramp. • Jack-knife trailer	• Second person to remain in visual and vocal contact with driver and direct reversing vehicle • Check trailer height to ensure it fits under fish guides • Ensure safety bollards are in place	
5	Pre-Start: Generator (also refer to PIRSA SOP 157)	• Electrocution • Asphyxiation • Burns • Inhaling fumes • Fuel ignition • Manual Handling	• Equipment should be serviced according to manufactures manual • Inspect power board, earthing point and all cable connections to ensure working order • Attach generator earth cable to generator and earth stake • Check petrol level • Do not refuel in confined space or near ignition source (naked flame) • Check oil level	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)

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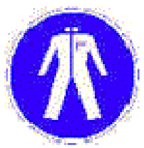
			• Attach generator power cable • Report any faults to manufacture- lock out and tag machine • Ensure two persons are available to load and unload generator.	
6	Starting generator	• Electrocution • Asphyxiation • Burns • Hearing damage • Eye damage • Inhaling fumes	• Ensure all step 5 solutions have been conducted • Refer to manufacturer's recommendations for starting • Ensure exhaust is clear from obstructions • Ensure generator air intake is free from obstructions • Ensure air cooling intake is free from obstruction • Ensure generator is in a well ventilated area	Hearing protection

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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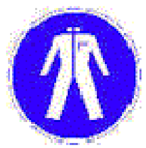
7	Raising and lowering WCSC shut out gate	• Amputation • Crushing • Tripping • Drowning	• Check guide runners are free of debris • Ensure walkway is free from tripping or slipping hazards • Ensure guards are in place and free from damage • Use handles of gate • Do not place fingers or any other limbs through gate/guards • Do not hang over walkway rails • Operator ensures personnel are clear and area beneath Cage is free from any obstructions • Ensure lock pins removed prior to operation	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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8	During WCSC operation	• Amputation • Crushing • Flying debris • Electrocution • Gantry failure	• Both operators to stand behind red line • The control pendant operator must account for all on-site personal before operation and ensure no other persons have entered the site • Ensure generator earth cable is attached • A vocal alert warning must be made before raising and lowering the trap • When lowering cage ensure trap is fully lowered with minimal strain on hoist chain	Eye protection

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)
								

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8a	Faults in WCSC operation	• Amputation • Crushing • Flying debris • Electrocution • Gantry failure	• If any fish catch or jam in the cage use a long pole with a gaff to remove them. Under no circumstances should operators enter the cage or place their hands or limbs in the cage. • If hoist or generator fails during operation, place lock-out pins and tags in appropriate position on gantry and notify the responsible manager to arrange repairs by the manufacturer	
9	Stopping generator	• Electrocution • Asphyxiation • Burns • Hearing damage • Eye damage	• Refer to manufacturers recommendation for stopping • Do not touch exhaust system • Ensure generator is in a well ventilated area	

1 Eye Protection	2 Breathing Protection	3 Head Protection	4 Hearing Protection	5 Hand Protection	6 Foot Protection	7 Protective Clothing	8 Face Protection	9 Other (Please specify)

Appendix B

User guide for the operation of the Lake Bonney wetland carp harvesting system

Scope

This user guide describes the Wetland Carp Harvesting System (WCHS) sited at Lake Bonney and its associated intended use. The Lake Bonney WCHS is the first of its kind, and therefore, this user guide is specifically related to it. This guide is designed to be used in conjunction with strict reference to the draft Standard Operating Procedures (SOP) for the WCSC (Appendix A) and video guidelines (available from the Invasive Animals Cooperative Research Centre (IA CRC) or SARDI Aquatic Sciences (Invasive Species Sub-Program)).

The IA CRC "Guidelines for the selection and implementation of carp management options at wetland inlets" report (Smith *et al.* 2009) should also be consulted first to determine the suitability of any proposed site for the installation of carp management options, including WCHS.

Introduction

The Wetland Carp Harvesting System (WCHS, Figure 1) was developed by SARDI Aquatic Sciences, to catch carp ≥ 250 mm (total length, TL) emigrating from Lake Bonney during the delivery of an environmental water allocation. The WCHS comprises a Wetland Carp Separation Cage (WCSC; including the cage, gantry, hoist and generator) and associated infrastructure (e.g. carp pivot screens and carp deflector screens). It is positioned in one of two box culverts in Chambers Creek. Both culverts have sluice gates, which control the delivery of water and which may disconnect the lake. The Lake Bonney WCHS is fully compliant with all Australian design standards and OHS&W legislation and is designed to lift up to 1.5 tonne of carp per haul.

Figure 1. Photograph of the Wetland Carp Harvesting System (WCHS) at Lake Bonney, incorporating the Wetland Carp Separation cage, gantry, hoist, carp pivot screens and carp deflector screens. Completing the infrastructure are sluice gates (out of view, river [left] side of culverts), walkway mesh, handrails and security fencing.

The Wetland Carp Separation Cage (WCSC)

The WCSC incorporates central jumping and pushing trap elements, separating a ‘holding zone’ and a ‘carp cage’ (Figure 2). The jumping trap element is a height adjustable mesh barrier extending and maintained approximately 15 cm above the water’s surface (at ‘pool level’) that carp must jump. It incorporates a non-return slide on the river side of the barrier to prevent carp from jumping the barrier in the reverse direction. The pushing trap element consists of a series of weighted one-way steel ‘fingers’, hinged from individual sleeves over a supporting shaft (the sleeves maintain the gaps between fingers and negate the lateral movement of fingers) suspended within a frame. The gap between the ‘fingers’ (31 mm) and ‘finger’ weights are minimised to allow the easy passage of carp ≥ 250 mm (Total Length, TL) out of the lake. To ‘push through’ the one-way element, carp must push (lift) at least one finger far enough to create a gap that will allow it to either swim directly underneath the lifted finger or between the lifted and adjacent fingers. Once a carp has pushed through, the finger(s) then fall shut, preventing carp from pushing back through the fingers.

While most carp that enter the 'holding zone' will proceed to either jump or push their way into the 'carp cage', some will remain in the holding zone and need to be sorted from large-bodied native fish (the latter to be returned to the water). All adult carp that pass the trap elements, via jumping or pushing, are contained within a holding cage to enable removal. The cage is lifted, and the zones emptied, via infrastructure (gantry and hoist) designed to mechanically lift and automatically funnel captured fish into trailer mounted fish bins. The WCSC is a modular design that also permits straightforward management changes. For example, when fish aggregations, comprised entirely of carp or commercial species (i.e. bony herring in South Australia) are present, the central baffle of the cage (comprising the jumping and pushing trap elements) can be removed, and the cage can be used as a large scoop trap.

Cladding at the rear of the cage (mesh; vertical jail bar design, with a 31 mm aperture between bars) is designed to permit the unimpeded passage of small and medium sized native fish, while preventing the passage of carp ≥ 250 mm TL (Thwaites *et al.* 2010; Hillyard *et al.* 2010)

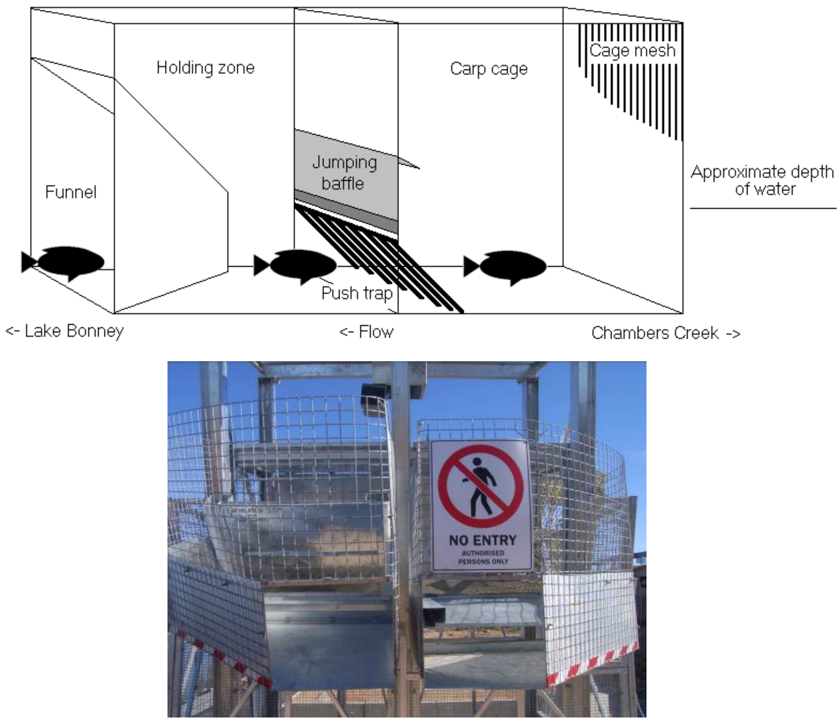

Figure 2. Schematic representation of the WCSC showing the entrance funnel, holding zone, jump/push trap element, carp cage and jail bar cladding with 31 mm aperture (cage mesh). Photograph of the WCSC set-up showing the two doors of the cage operating independently to allow each cage section to be emptied separately (with the holding cage door opening first).

Carp Pivot Screens and Carp Deflector Screens

Carp Pivot Screens are based on the original jail bar design and have 10 mm diameter bars spaced at 31 mm apart. They were specifically designed by SARDI Aquatic Sciences for application at Lake Bonney, where there are high flows (> 1.5 $m.s^{-1}$) and vandalism. The carp screen is held in position by a 'pivot frame' which is fabricated from C-section. This frame is hinged and bolted to the base of the culvert. Using a braked-winch, the pivot frame holding the jail bar screen can be set at any angle (0-90^{o}) or can be raised and locked in a vertical position (90^{o}), where it can act as a traditional carp screen. The jail-bar screen can also move vertically in the pivot frame to act as the gate for the WCSC or to be completely removed from the culvert for maintenance (Figure 3). All components were hot-dip galvanised to avoid corrosion.

Carp Deflector Screens were also designed for application at Lake Bonney, to work in conjunction with the carp pivot screens to prevent carp in the lake from jumping the carp pivot screens while they are in their operating position e.g. lowered to the water surface, yet allow entrained debris and fauna (i.e. carp, turtles, bony herring) to be washed over the top of the screen. The carp deflector screens were positioned out of the water, ≈ 15 cm above the top of the pivot screen. This nominal distance is less than the mean depth (> 15 cm) of carp expected to jump vertically over the screens, and greater than the mean width (≈ 9 cm) of large-bodied fauna expected to wash over the screens on their sides (Hillyard *et al.* 2010). While it was not ideal to allow some carp into the lake, it was unavoidable due to the conflicting requirements of containing the existing population of carp, while dealing with other operational constraints;

- A desire to periodically deliver near maximum flow volumes through both culverts, to achieve predetermined water allocation time frames.
- Resultant high-velocity flows.
- Fouling due to entrained debris and fauna.

As carp are positively rheotactic (Smith *et al.* 2005), it is anticipated that entrained carp washed over the screens, should subsequently orientate back into the flow and be vulnerable to capture in the WCSC.

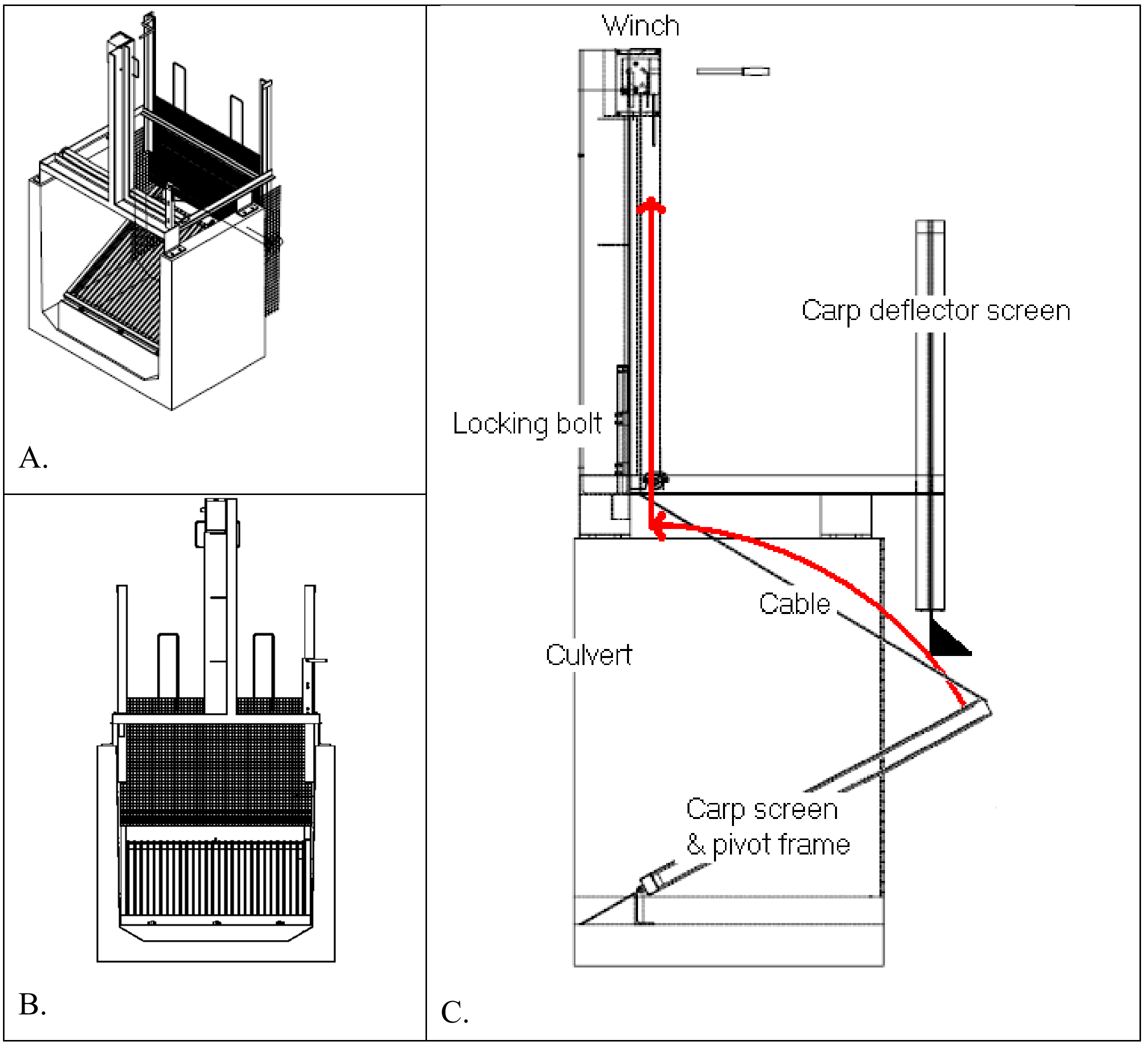

Figure 3. Workshop drawings of the carp pivot screen: A) Screen at 33°, B) screen in culvert fitted to the camber at the base of culvert C) showing the multi-function of the carp pivot screen- the red line indicates the direction of movement.

Operation of the WCHS at Lake Bonney

NOTE: This user guide must be read and used in conjunction with the entire SOP for the WCSC (Appendix A), before and during cage operation.

Arriving at the site

- Reverse car and trailer into the southern side of the compound, and position the trailer centrally below the funnels. Be careful not to reverse the trailer into the gantry structure – a second person providing directions will prevent this.
- Undertake a site and hazard assessment, ensuring that there are no hazards e.g. tripping, slipping, biological (e.g. snakes).
- Inspect plant for all aspects of safe operation, and ensure there are no obvious corrosion or vandalism issues.

Connecting WCSC to 3-Phase generator.

- The 3-phase generator can be operated out of the tray of a utility vehicle, to avoid excessive handling (weight of generator is > 120 kg).
- Open all doors/windows (if applicable) for good ventilation, and ensure that no items are blocking the air intake or exhaust. Also ensure that flammable items are positioned > 1 m from the exhaust.
- Connect the 3-Phase and Earth cables to generator, then to the hoist power box on side of the gantry.
- Check power box for biological hazards (e.g. spiders).
- Keep hoist power ‘off’ until the generator is started.

Preparing cage and carp screens for operation

- Raise carp deflector screen, to enable carp pivot screen to be raised into a vertical position where it will act as a ‘door’ for the WCSC.
- Remove T-piece protecting the winch cabling.
- Add winch handle and raise carp screen to the vertical position.
- Start generator according to manufacturer’s instructions and turn the hoist power to “on”. NOTE: The hoist is operated by a remote pendant. The

remote's 'safety-off' switch should be checked on every operation and reset when the control is turned on. Then, use the "Up" and "Down" buttons to raise and lower the cage, respectively. There are two speeds for the hoist: slow (1 $m.s^{-1}$, up/down buttons half depressed) and fast (4 $m.s^{-1}$, up/down buttons fully depressed).

- With all personnel standing at the front of the trailer (well away from the cage as it is operated), use the hoist remote control to raise the cage off the 'safety pins'. The remote operator should then remove the safety pins from the gantry structure and return to the front of the trailer.
- Completely lower the cage to the operating/fishing position.
- Raise the carp screen, so that the base of the screen is just out of the water and fish from the lake are able to access the cage (the screen can be completely removed for cleaning/maintenance).

Checking cage

- Using the hand-winch, fully lower the carp pivot screen into the vertical position, to hold carp back while the trap is being raised.
- Raise the cage using the hoist remote. Notice that as the cage is raised, the two doors open automatically and separately. The door to the 'Holding Zone' opens first; allowing native fish to be separated from carp and returned to the water. The cage can rest in this position until native fish are sorted. By fully raising the cage the door to the "Carp Cage" is opened and separated carp are funnelled into the trailer mounted fish bins. Otherwise, if the WCSC is operating as a scoop trap, the cage can be fully raised immediately and carp from the "Holding Zone" and the 'Carp Cage' should fall directly into the trailer for immediate transport and processing. Check the funnel for any trapped fish.

Re-setting the cage

- Using the hoist remote, fully lower the cage.
- Using the hand-winch, raise the carp pivot screen to enable fish to access the cage.

Packing up – leaving the trap out of the water

- At the completion of fishing, the cage should be raised out of the water so that the safety pins can be re-positioned. Then, slowly lower the cage onto those pins - the holding position.
- Re-set the carp pivot screens by winding them down until the top of the screen is positioned at the water surface.
- Replace the T-piece, which protects the winch cable and prevents people from tripping when the cage is not in operation.
- Replace carp deflector screen.

References

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Appendix C

Itemised cost breakdown for engineering and construction of the Lake Bonney Wetland Carp Harvesting System.

Item	Cost (inc. GST)
Engineered drawings of SARDI concept	$36,100
Gantry and Cage	$31,950
Cage Cladding	$3,476
Separation Technology (Push and Jump Trap)	$2,000
Safety Screens/Guarding	$7,535
Carp Pivot Screens and Deflector Screens	$11,110
Walkway, Hand rails and Associated Guarding	$6,000
Hoist	$9,350
Electrical Wiring	$3,400
Generator	$6,500
Total	$117,421

Note: All prices were current September 2009 and do not include costs associated with SARDI conceptual development, earthworks, culvert, site fencing or any other associated infrastructure (i.e. weirs). **Cost will vary on a site by site basis**.