

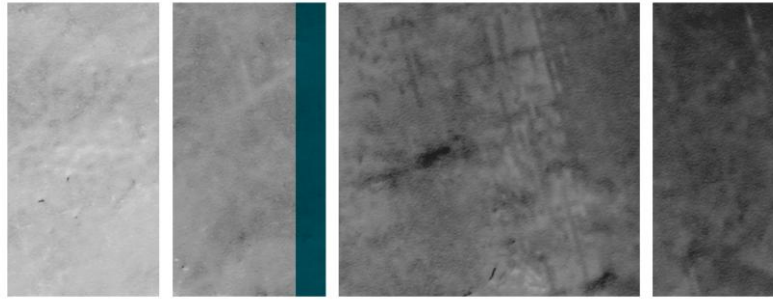


**PESTSMART**

# A manual for carp control: The Tasmanian model

John Diggle  
Jawahar Patil  
Chris Wisniewski





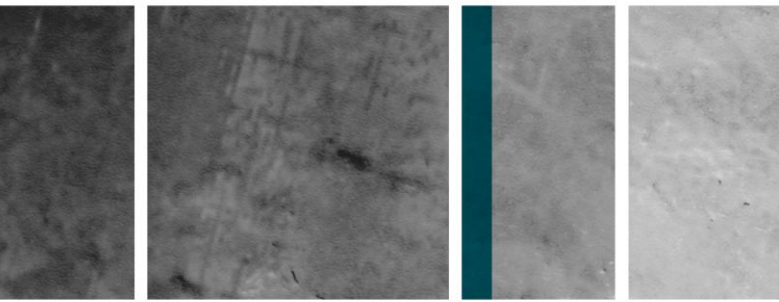
# A manual for carp control: The Tasmanian model

Management of carp in the  
Australian landscape

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17 Back River Road,  
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2012  
*An IA CRC Project*





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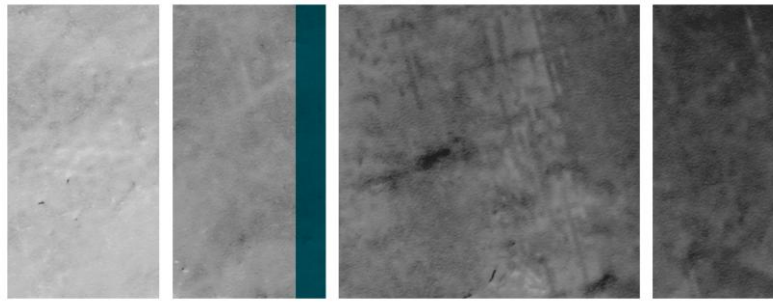
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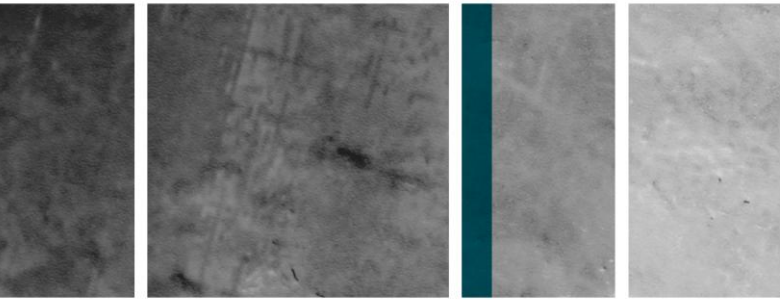
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**Front cover photos:** Clockwise from top left: Barrier net being deployed from boat; Carp front on; Female carp captured using boat electrofishing; Barrier net and trap (photos Chris Wisniewski). Find further information about Inland Fisheries Service (IFS) at: [www.ifs.tas.gov.au](http://www.ifs.tas.gov.au)

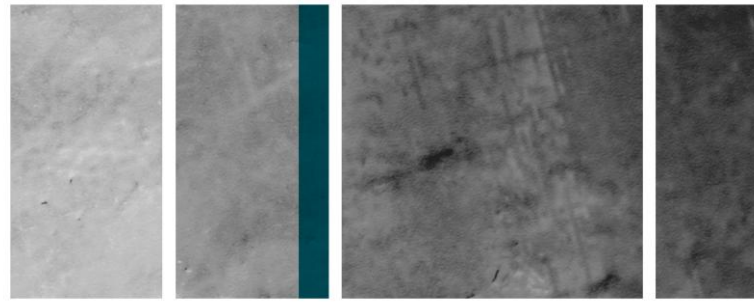


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# 1 Introduction

## 1.1 Forward

The Carp Management Program (CMP) was established within the Inland Fisheries Service (IFS) in 1995, in response to an incursion of *Cyprinus carpio* (carp) found in Lake Crescent, at Interlaken, in the central highlands of Tasmania. The incursion was contained to Lake Crescent and the upstream Lake Sorell. The integrated pest management strategies used have resulted in the successful eradication of carp from Lake Crescent and are ongoing in Lake Sorell.

This manual describes the progressive and integrated approaches that were employed to control/eradicate carp in Tasmania and that are likely to be of relevance elsewhere.

## 1.2 Discovery and threat of carp in the Tasmanian lakes

Tasmanian inland waters are home to a diverse array of native fauna and flora, many of which are endemic, with some threatened and endangered. Lakes Sorell and Crescent are large shallow lakes with extensive wetland areas and aquatic habitat. They also support a recreational angling industry and commercial eel fishery of significant importance to the State's economy.

The discovery of carp in these lakes and their potential spread to other waters across the State posed a severe threat to a range of environmental, economic and recreational values. Given that carp are highly fecund and adaptable, all freshwater resources were considered vulnerable to the invasion as was previously demonstrated by successful carp invasion of the Murray-Darling basin (Gehrke et al 1995, McKinnon 1997), following their introduction to mainland Australia in 1859. In addition to competing with native and other desirable fish species for both food and space (Fletcher et al 1985, Brumley 1991, Koehn et al 2000), carp can inflict major environmental and economic costs by reducing water quality and degrading aquatic habitat (Koehn et al 2000). Carp have been implicated in macrophyte destruction; through direct grazing and physical uprooting of plants; increasing water turbidity; enriching nutrient loads; and reducing invertebrate biomass through predation.

## 1.3 Location and significance of the lakes

Lakes Sorell and Crescent are large, shallow, freshwater, interconnecting lakes located in the South-eastern corner of the Tasmanian Central Plateau (Coordinates: Lake Sorell 147°17'E 42°11'S and Lake Crescent 147°16'E 42°18'S). They are situated approximately 100 kilometres north of Hobart at 800 m AHD at the head of the Clyde River catchment and are about 5310 ha and 2305 ha in area respectively (Heffer 2003) (Figure 1).

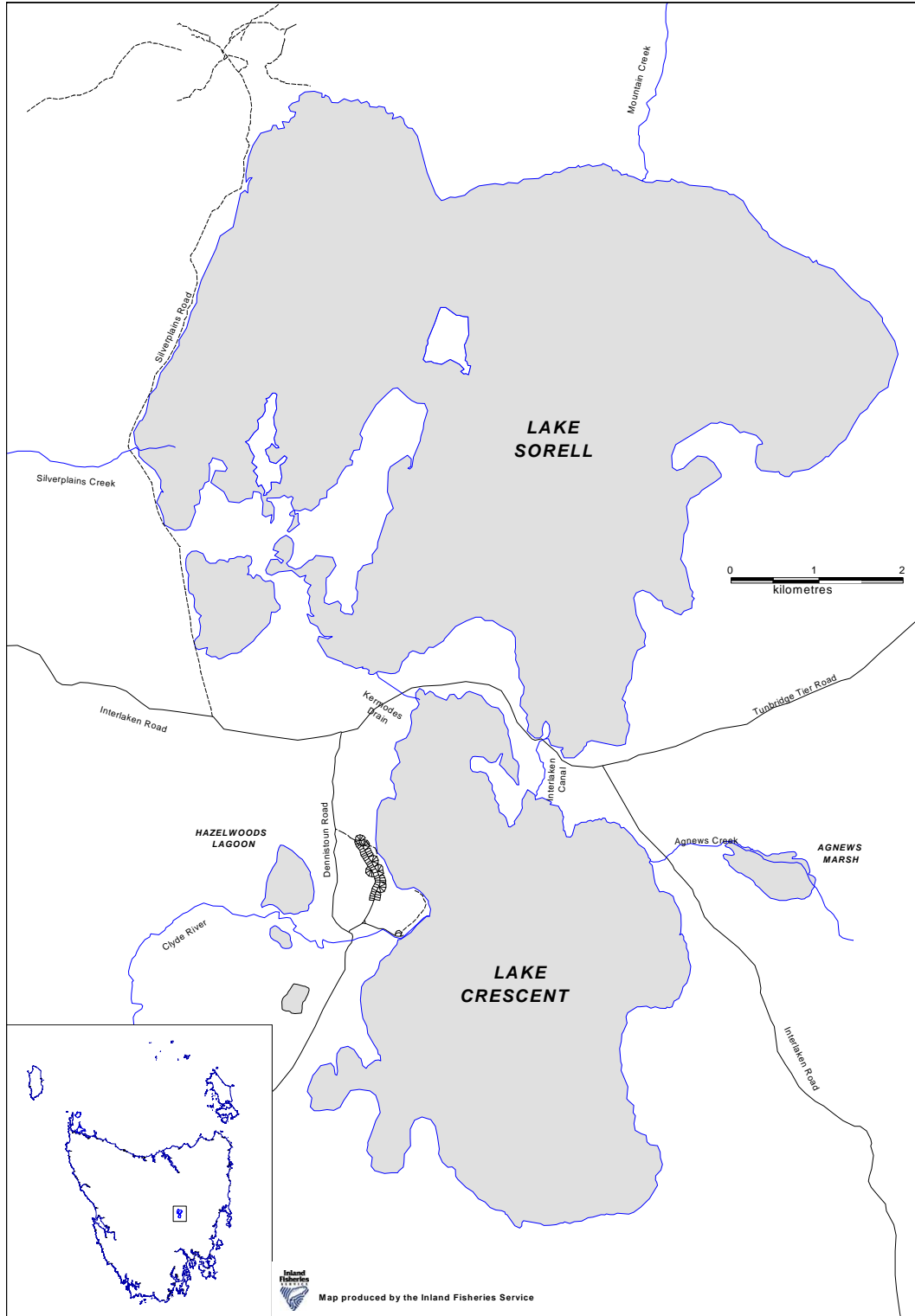
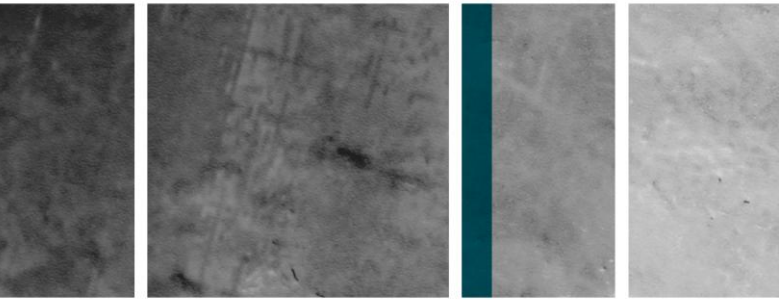
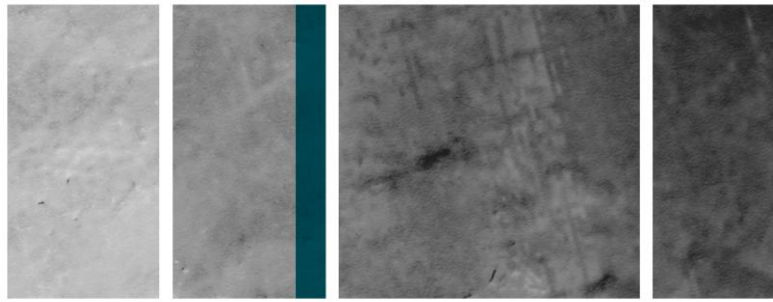


Figure 1: Map of lakes Sorell and Crescent



In times of full supply both lakes have extensive wetland areas that connect to the main lake bodies. Kirkpatrick and Tyler (1988) described the wetlands as some of the largest areas of shallow water in Tasmania. A lakeside reserve in the north-west corner of Lake Crescent is internationally recognised as a significant wetland by its listing under the Ramsar convention. The wetlands around the lakes provide habitat to a diverse range of animals such as invertebrates (including the endemic snail *Austropyrgus* sp.), frogs (with populations of the endangered southern bell frog *Litoria raniformis* previously recorded), snakes, waterbirds, platypus, water rats and the endangered endemic fish, golden galaxias (*Galaxias auratus*) (Figure 2).

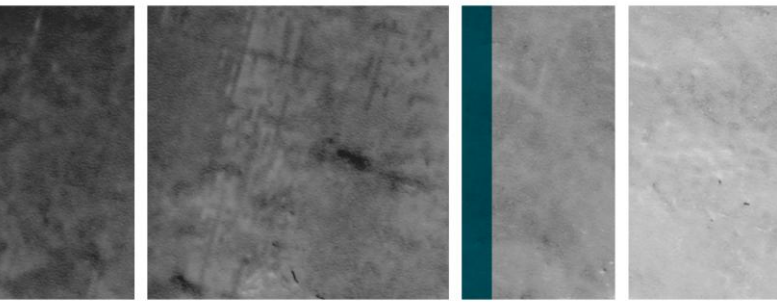


Figure 2: A mature female golden galaxias (Photo: S Hardie).

#### 1.4 Initial incursion response

On the 28th January 1995 an angler found the remains of a fish that was being eaten by a sea eagle. This was handed to the IFS on the 30th January, and confirmed as a carp, presumed absent in Tasmania since an earlier incursion and eradication in 1975. Back pack electrofishing surveys on the 1st February confirmed that carp were present in Lake Crescent. The outflow from Lake Crescent was closed and downstream surveys began immediately. Lake Crescent was closed to the public on 18th February. The outlet structure at Lake Crescent was fitted with an internal 1 mm screen and the outflow was reopened on the 24th February to supply water for downstream domestic and stock use.





Electrofishing boats from New South Wales and Victorian fisheries agencies were shipped in and used for sampling in the surrounding lakes. On the 6<sup>th</sup> March carp were caught by electrofishing in the upstream Lake Sorell. Lake Sorell was closed to the public on the 9<sup>th</sup> March. The IFS ordered an electrofishing boat directly from the manufacturer, Smith-Root, in the USA and this arrived on the 10<sup>th</sup> May 1995.

A Task Force consisting of members from the Inland Fisheries Commission (now Inland Fisheries Service as of March 2000), Parks and Wildlife, Rivers and Water Supply Commission, Bothwell Council, Clyde Water Trust and anglers via the Freshwater Anglers Council Tasmania was established (IFC, 1995). This was refined to a Carp Working Group, which prepared a cabinet submission for funding. On the 1<sup>st</sup> June the Tasmanian State Government approved a budget of \$1 027 000 for the next two years. The budget involved a number of elements including:

- A four person Carp Management Program (CMP) team and associated costs, to work in the field on carp control/eradication – consisting of:
  - a scientific officer to plan and coordinate the program
  - two technical officers to carry out the majority of the field work
  - an inspector to ensure compliance and undertake public education.
- A capital works budget for various purposes including:
  - outlet structure design and construction
  - screen installation
  - purchase of electrofishing boat
  - purchase of appropriate staff accommodation in the area.
- Allocation of funds to address specific problems via consultancies:
  - public awareness and education
  - enhancement of quarantine procedures
  - angling strategy development to address negative impacts of carp on tourism and local business
  - assessment of feasibility of eradication with the fish poison rotenone.

This funding allocation demonstrated a clear commitment by the government to protecting the State from the impacts of carp.

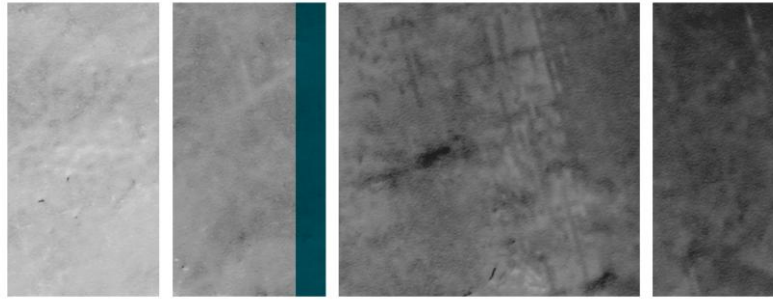
A web based pest fish incursion response tool is now available on the Invasive Animal Cooperative Research Centre website ([www.feral.org.au](http://www.feral.org.au)).

## 1.5 Public relations and education

The CMP team undertook a local education and awareness program with the public both directly and through various media.

Presentations and updates were given regularly and consistently to anglers through their club network and involved discussion on the problems associated with exotic fauna releases.

Interstate visitors were targeted through angling clubs, tourism offices and at points of entry



to the State. Up to date information was provided to the media to show the progress towards eradication with the intention of generating continued support from the community. In 2004 it was considered that the CMP justified a stand-alone annual report which is distributed to key stakeholders and made available on the IFS website.

## 1.6 Objectives

The discovery of carp raised immediate alarm and concern in the Tasmanian community at large, including state agencies, anglers, environmentalists and farmers. In response, the Tasmanian Government initiated a multi-agency approach to address the problem with IFS as the lead organisation. Initially a carp task force was formed, which later evolved into a working group with expert representatives. The task force identified the following objectives:

1. contain carp to the lakes Sorell/Crescent catchment
2. develop a water management plan that provides for and protects the water supplies for Bothwell, Hamilton and irrigators to achieve objective 1 and assist with 3 and 4 below
3. reduce the existing carp population
4. eradication of carp
5. prevent introduction to new water bodies and the reintroduction to cleared waters from both inter and intra state sources
6. undertake legislative and communication strategies to minimise damage to tourism, while facilitating the above objectives.

The working group further refined or included objectives to:

- improve the capacity of the containment screens
- protect native flora and fauna threatened by carp and carp management practices
- gain an understanding of biology and factors contributing to the success of carp in the lakes
- develop guidelines for recreational and commercial access to the lakes.

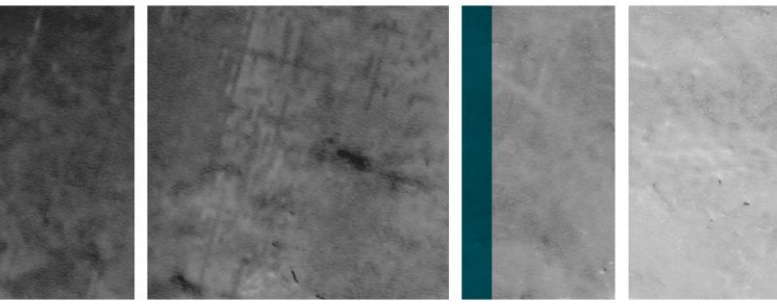
## 1.7 Management options

A number of questions needed to be addressed or evaluated before a suitable management option could be adopted. These ranged from ‘what is the extent of carp distribution within the State?’ to ‘is eradication possible?’ and also ‘can reintroduction be prevented?’

The range of options that were considered for the lakes included:

- do nothing
- contain the carp within lakes Sorell and Crescent
- eradicate the carp, by:
  - draining
  - poisoning
  - physical removal

To do nothing was considered unacceptable given the knowledge from mainland Australia,



particularly the Murray-Darling Basin where impacts of carp on the aquatic system were well documented. Tasmania has a diverse range of aquatic environments and endemic species that would be impacted upon by carp.

Given the lack of knowledge, extent of the problem and perceived resource intensive nature of pest eradication programs around the world, containment/control was identified as the immediate option. However, it was clear that containment would have to be sustained long term with the likely chance that carp would escape containment at some stage.

Despite dozens of other sightings from public and subsequent distribution surveys, carp have not been found to have established elsewhere in Tasmania. One carp was located about one hundred metres downstream of the Lake Crescent outlet structure after a coffer dam was constructed in the outlet canal and the screens were removed to de-silt the canal to aid water release. Three koi carp were seized from a garden pond near Hobart that turned out to be all male. A single hybrid carp/goldfish was also seized from a garden pond in the north east of Tasmania. The consequences of finding an established carp population in any of the major catchments would have required re-assessment of the approach.

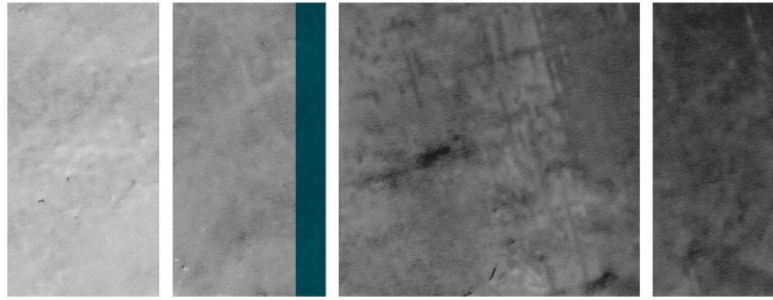
Three main eradication options namely draining, poisoning and physical removal were considered. Draining the lakes was ruled out because it was deemed impossible to achieve given the large flat-pan geography of the lakes. Moreover, the impact on rare and endangered species and the internationally recognised (Ramsar) status of Interlaken Lakeside Reserve wetland precluded draining as an option. Also, the lakes are the source of domestic water supply to the townships of Bothwell and Hamilton and farming in the Clyde River valley further making draining an unviable option.

Poisoning was evaluated through a consultancy with Prentiss Inc, a rotenone manufacturer from the United States. Despite being assessed as technically feasible at a cost of 4.8 million dollars US (1998) this option was ruled out due to problems associated with its application to a large water body, the lack of any other case study where treatment had been successful on this scale along with the adverse environmental impact that it would have on the site.

Physical removal was deemed the best option and was underway from the outset as part of evaluating carp distribution, its biology and the population structure in the Tasmanian waters. It became apparent within the first twelve months that physical removal was having a significant impact on the carp population, raising the possibility of eradication. The risk of natural reintroduction following eradication in the lakes was assessed to be low, given the lakes are situated at the head of the Clyde River catchment. The possibility of human interference was not discounted. As prevention of reintroduction is critical for any successful eradication program (Bomford and O'Brien 1995) changes to state fisheries management legislation were made (Appendix 1) to prevent human mediated reintroduction and this included closing the lakes to the public.

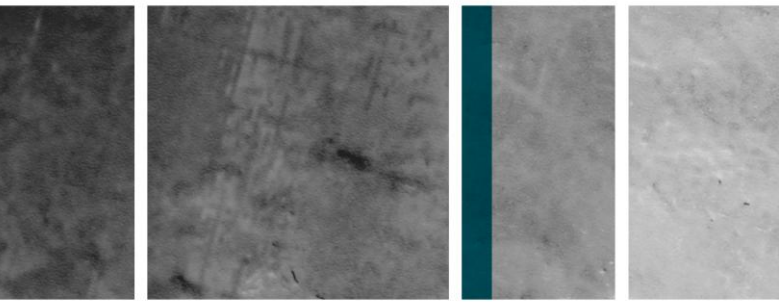
As is common, it was difficult to undertake a cost benefit analysis, another of the key criteria, for eradication rather than control. However, it was clear that if control was the option that this would have to be sustained long term with the likely chance that carp would eventually escape containment at some stage. Again this was a risk that was too great.

The socio-political support was strong from the outset with a funding commitment by the State Government through its forward estimates "for the life of the program". This is evident



by the sustained bipartisan political support over the past 16 years, another key criteria for any eradication program to be successful.

To date physical removal remains the best option to eradicate carp from the Lake Crescent-Lake Sorell system and thus from Tasmania. Although the demands of physical eradication of the carp can be challenging, this possibly remains the most cost effective and environmentally benign option in the long term. Detailed below are the strategies and techniques that were successfully implemented to eradicate carp from Lake Crescent and continue to be employed for their removal from Lake Sorell. The integrated strategies employed focussed on exploitation of the biological vulnerabilities of carp (including their specific behaviours) and optimising capture methods.



## 2 Developing an integrated control program

### 2.1 First steps

First and foremost, the implementation was made possible by allotment of dedicated funding by the Tasmanian Government to establish the Carp Management Program (CMP), including capital works. Implementation of a basic containment strategy began as soon as carp were found in the lakes. As more knowledge was gained and options reviewed, the containment strategy progressively evolved to encompass an eradication strategy.

The Interlaken Canal, which connects Lake Sorell to Lake Crescent, was widened and deepened to allow for better water level manipulation. An ability to control water levels was crucial to prevent any unscreened outflow of water from the lakes into the waters downstream to mitigate carp spread. This was also to allow the ability to manipulate water levels and where possible, limit access by carp into preferred spawning habitat within the lakes. The two lakes and the upper Clyde River were also closed to the public (Appendix 1) and an active compliance operation was undertaken including a public awareness program.

Distribution surveys indicated that if carp had spread downstream then they had not developed self-supporting populations. These downstream surveys have remained an annual feature (16 years), thus far failing to record any signs of carp, suggesting that the containment strategies adopted have been consistently effective, reinforcing the possibility of eradication. If carp had been found outside of the two lakes, the management strategy would have been totally different.

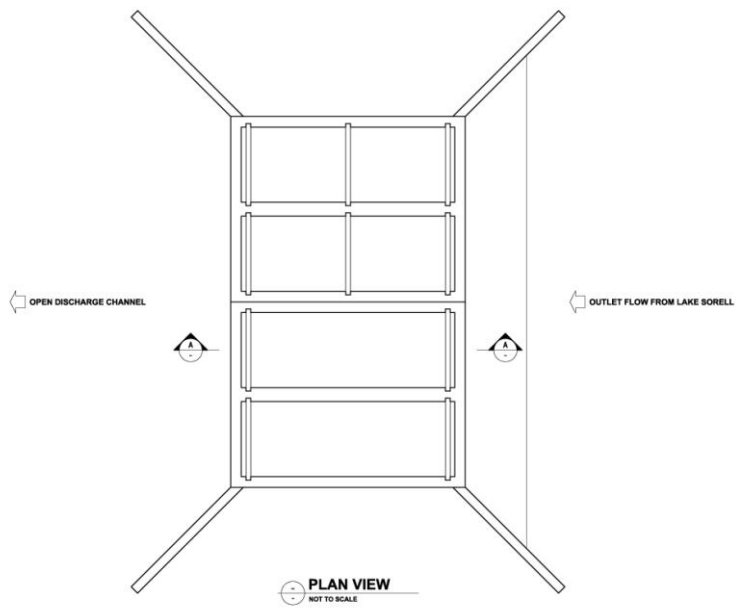
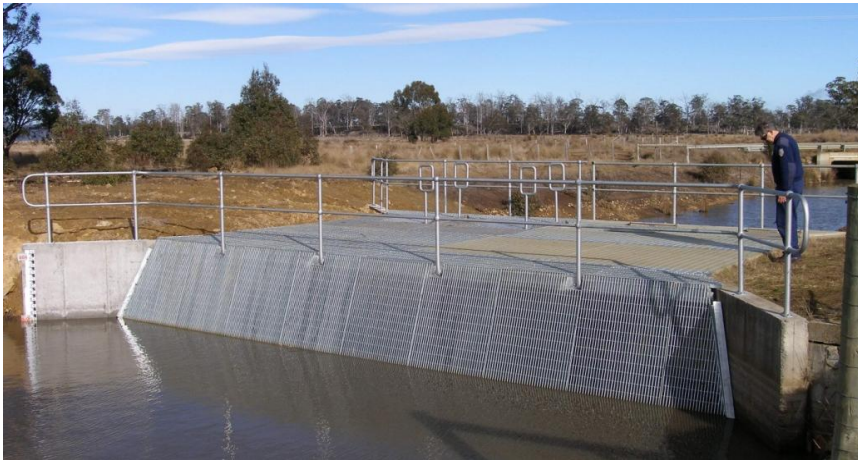
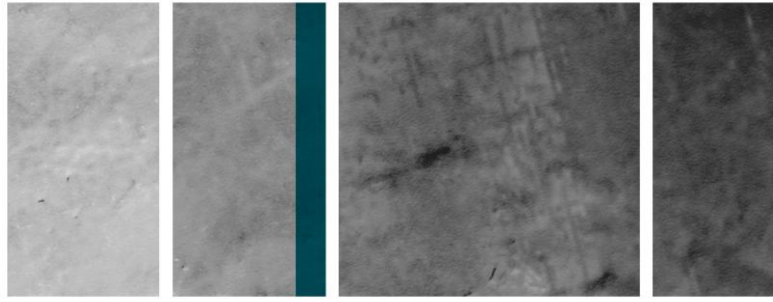
### 2.2 Screening

Since early European settlement the outlets of both lakes had been modified to control their water flow to provide a reliable source of water for downstream use. The existing structure was modified in Lake Crescent and replaced in Lake Sorell allowing all water to be screened prior to release.

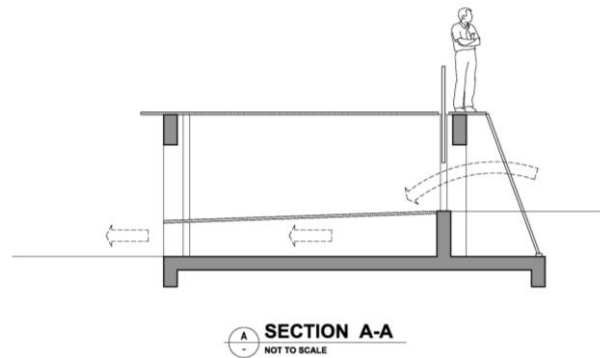
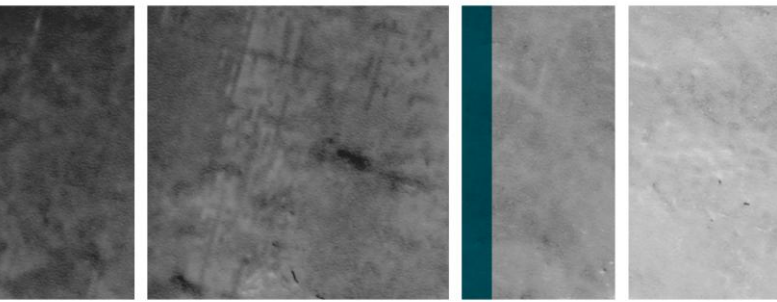
The modified and new structures on each lake's outlet are similar in design. They have a concrete base and walls and both have a coarse front screen of 40 mm deep galvanised grating with 25 mm bar spacings (Figures 3 and 4). The space bars on the grating are run vertically to ensure ease of cleaning with a rake that is used to draw debris to the water's surface for removal. Internally, similar grating is used to support a horizontal screen of finer stainless steel mesh. This stainless steel mesh (1→5 mm) is changed depending on the time of year and potential risk of carp escape.

The 1 mm mesh is in place from the start of October until the end of April – throughout the carp spawning period and autumn to minimise the potential of carp eggs or juveniles escaping containment. From May until the end of September, the mesh size is increased to a 5 mm or greater aperture to allow for increased water transfer over winter. Observations indicate that all juvenile carp have outgrown the 5 mm mesh by the end of April. The screens are cleaned manually (Figures 5 and 6) and this becomes increasingly labour intensive as flow rates increase.





Figures 3 and 4: Lake Sorell outlet structure showing coarse external screen and a plan view of the structure.



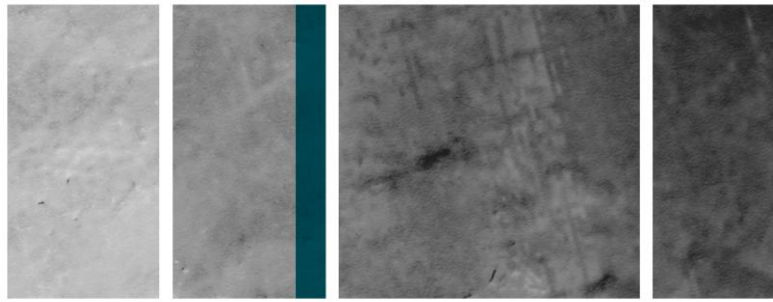
Figures 5 and 6: Cleaning internal fine mesh screens, placed horizontally to assist gravity driven filtration and a section view showing flow through screen.

## 2.3 Carp population reduction

The physical removal of a pest fish from a lake system as large as lakes Sorell and Crescent had not previously been recorded, either in Australia or internationally. However, during the initial stage of investigating options for eradication and control, IFS had been intensively fishing down the carp population and it became apparent that this was having a significant impact. Carp population reduction at the lakes was achieved by direct fish down and spawning sabotage strategies that prevent recruitment. The reduction of the carp population also assisted the containment strategy; the lower population densities posed lower risk of human or predator assisted translocation or escape of carp through the screens.

## 2.4 Technique development

Initial carp removal strategies were very basic, relying on visual observations of fish aggregations and non-targeted electrofishing (backpack and boat) or net fishing (gill and seine nets). At this point there was no knowledge of preferred habitat or fish movement under the local conditions. However, as the population size declined the ability to locate aggregations of fish reduced dramatically. To overcome this limitation, integrated strategies with stepwise refinement based on ongoing monitoring, new knowledge and/or emerging concepts were incorporated. These included a strategy to deploy “Judas carp”. These are carp with surgically implanted radio transmitters that provide an effective means to reliably locate carp



aggregations.

These Judas male carp were particularly useful in locating carp aggregations. Deliberately, no female Judas carp were deployed as a strategy to minimise recruitment risk. The Judas fish became a valuable tool not only to target carp aggregations but also to understand carp behaviour, movement and habitat choice. The radio telemetry enabled delineation of inter-seasonal and inter-annual patterns of carp movement and habitat choice in response to changes in lake water level and water temperature (Taylor et al 2012). The resulting knowledge was effectively utilised for:

- fish removal
- identifying life cycle vulnerabilities
- recruitment sabotage and
- resource rationalisation

A relatively seamless integration of telemetry data stored in Windows Access and Windows Arc GIS mapping allowed predictions of aggregations and hot spots that could be targeted during different seasons and environmental conditions, primarily driven by lake level and water temperature. The cumulative knowledge on carp aggregation and behaviour has also enabled the option of removing sexually active Judas fish and at the same time reliably targeting predicted aggregation locations for removal. A detailed description of the radio telemetry technique (Judas carp) and its use in the lakes has been described elsewhere (Macdonald 2003; Taylor et al 2012).

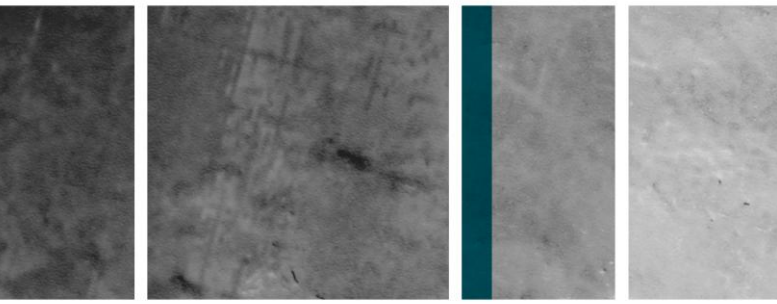
As the strategy evolved from control to eradication, the prevention of recruitment became a high priority. This was accomplished by deploying a combination of wire mesh and purpose-built polyethylene barrier nets to block carp access to their preferred spawning habitats in the macrophyte rich wetland areas. Steel traps and purpose-built super fyke nets were deployed along the barriers at key wetland access points (Figures 7 and 8) to passively trap mature carp pushing into the wetlands. Around the clock deployment of these passive traps was crucial in capturing mature carp during the night and at dawn when their spawning urge is thought to be greatest.



Figure 7: Setting up a barrier trap during autumn.



Figure 8: The same barrier trap in operation during spring.



Choice, selectivity and combination of gear were observed to be very critical for a number of management practices including removal and population estimation of carp. Crucially it was established that different life stages of carp are vulnerable to capture by different mesh sized gillnets (Walker 2003; Donkers et al 2011). Gear selectivity in combination with population structure data and habitat mapping proved valuable in making advance decisions on choice of gear, time of deployment, recall and service. Typically, appropriate size gill nets when used in combination with radio tracking and electrofishing are extremely effective in capturing carp. Standard fyke nets were very efficient for assessing population size, fish down of juvenile cohorts and passive capture of adult fish during the spawning period.

Although the integrated program relied heavily on physical removal, biological and chemical approaches were selectively employed. Specifically, deployment of mature 'lure' odour donor carp during breeding season was found to assist in attracting and trapping mature carp (Patil and Wisniewski 2006). Similarly localised application of lime and rotenone were effective in killing/poisoning unhatched carp embryos and juveniles respectively.

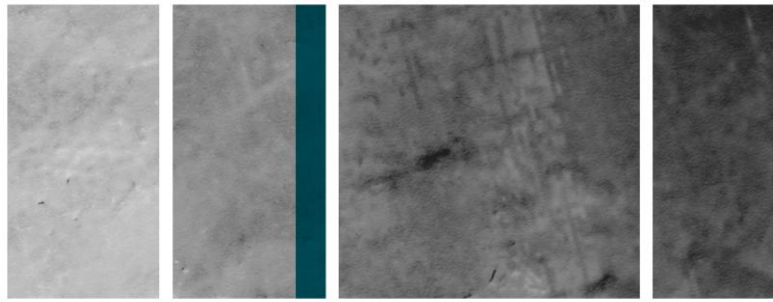
Collectively an environmentally sensitive and integrated carp management strategy was responsible for eradication of carp from Lake Crescent and their current containment to Lake Sorell. Detailed below are the components, observations and techniques that may be useful for carp control elsewhere.

## 2.5 Biotelemetry

Within the first two years of the CMP a large proportion of the carp in Lake Crescent had been removed (Figure 10) and their density in Lake Sorell had remained low. As a result, the catch per unit of effort (CPUE) decreased markedly. This prompted radio transmitter implantation into six mature male carp (Judas carp) and their release into Lake Crescent on 10<sup>th</sup> March 1997. The Judas carp were then monitored on a daily basis by tracking them from a boat as described elsewhere (Macdonald 2003). Through daily observation all six radio tracked fish were detected in one single aggregation on 9<sup>th</sup> April 1997, prompting a combination of gill net deployment and electrofishing that lead to the capture and removal of 202 carp. This success for the first time established a very powerful tool for targeted removal of carp and for monitoring lake wide seasonal and inter-annual movements and habitat preferences of carp (Taylor et al 2011). The success also highlighted the presence of a cryptic population of carp necessitating systematic population abundance estimation. Biotelemetry showed that not all carp behaved the same. For example, some Judas carp were loners and only responded to substantial environmental cues contrary to the schooling behavior generally observed.

The information and knowledge gained through radio tracking was crucial to multiple aspects of the program. First, it facilitated targeted removal of carp, second, it established a detailed understanding of carp movement, behaviour and habitat preferences (including winter aggregation) in the lakes, in relation to both water temperature and lake level. For example, changes in water level (as little as 400 mm) resulted in significant shifts in movement and aggregation patterns (Figures 9 and 10) from year to year. Third, radio tracking assisted in making advance decisions on timing and location of passive barriers and gear deployment. Radio tracking was also critical in locating spawning events, allowing early intervention through liming or spot poisoning with rotenone. Further, the observation that the





Judas male carp preferentially aggregated with mature females during the spawning season prompted the idea that it may be possible to attract sexually active carp to pre-designated sites.

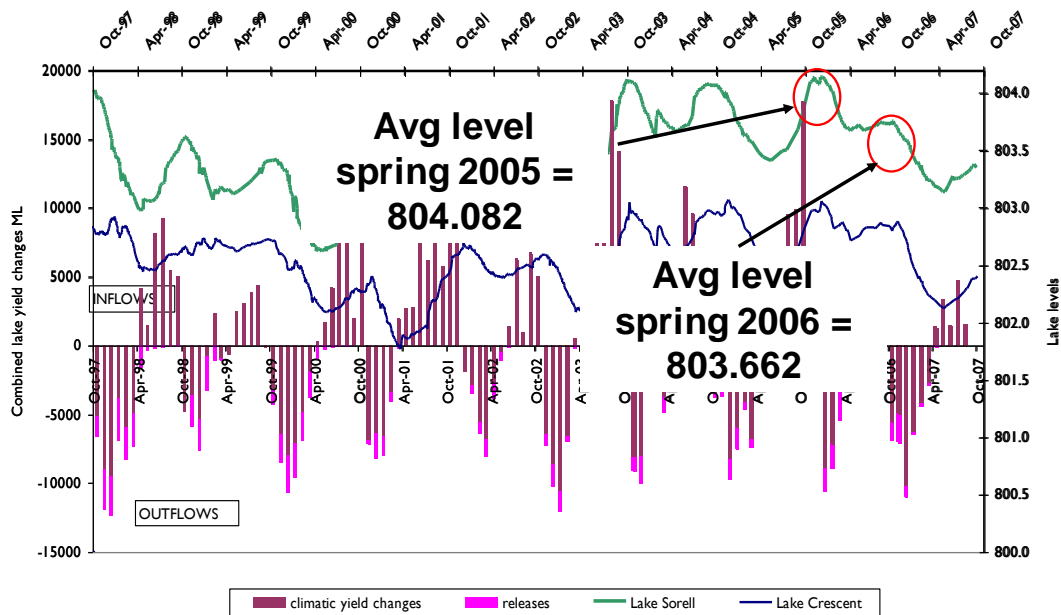


Figure 9: Graph showing varying lake levels between 1997 to 2007, detailing the higher spring lake level in 2005 compared to 2006 (encircled).

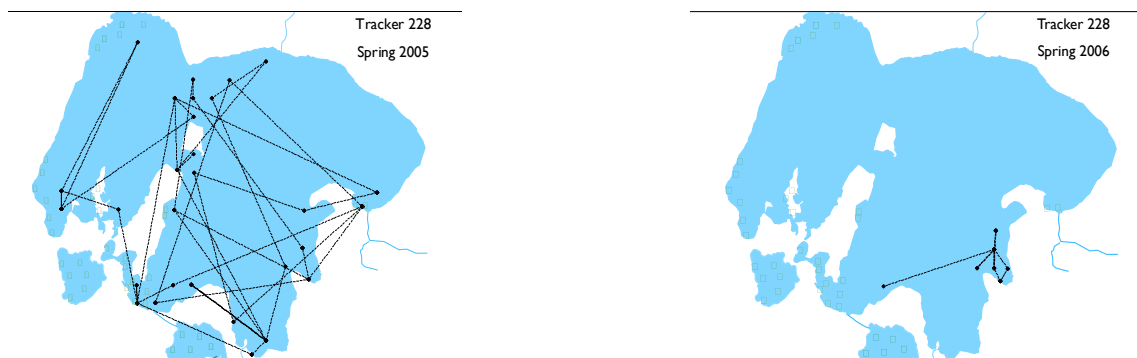
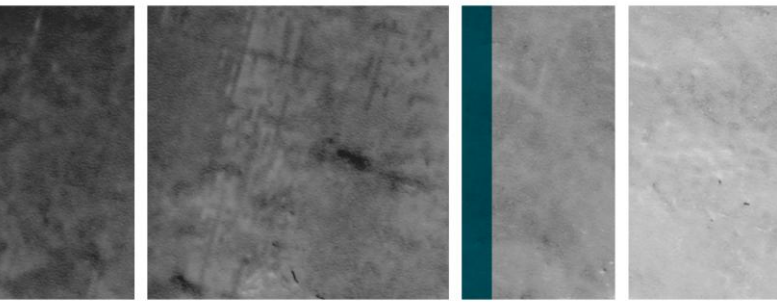


Figure 10: An example of altered spring-time movement of a tracker fish (frequency 151.228) in Lake Sorell in relation to higher (2005) and lower (2006) lake levels, over the corresponding three months.

Interestingly, the repeated and consistent behavioural patterns of individual fish suggested the presence of several ‘personalities’ amongst mature male carp. Whilst some fish readily moved around the lake as the water warmed, others seemed to be more territorial. The territorial fish tended to move only when there were strong reproductive cues, as their





repeated overnight movements (in excess of 14 km) were invariably associated with spawning aggregations. When such aggregations were targeted and broken up these territorial fish often returned to their home range. Understanding these ‘personalities’ of Judas carp was useful and at times critical in making decisions on resource deployment. For example, in a breeding season, any movement of the ‘territorial’ types outside of their home range can be a signal of impending breeding aggregation, an aspect the program has successfully exploited to good effect.

Radio telemetry was also useful in verifying the suspected predation of carp by sea eagles, as on two occasions radio transmitters were located in a sea eagle nest on St Georges Island within Lake Sorell.

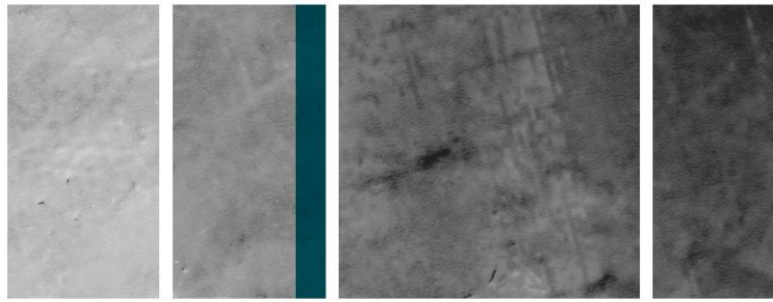
Whilst radio telemetry is a powerful tool for managing pest populations of carp, the current practice of deploying mature males has an inherent risk of contributing to recruitment. Mature males were chosen primarily to locate spawning aggregations. The risk can be largely managed via stringent monitoring of each of the radio tagged individuals, as was successfully demonstrated in Lake Crescent. However, all evidence suggests that the Judas male carp contributed to a large recruitment event that occurred in Lake Sorell in 2009. Therefore, there is an urgent need to develop a suitable sterilisation technique that allows deployment of Judas males that retain the breeding urge but will not contribute their gametes to a potential breeding event. Although there has been some progress in this direction, further substantial and systematic research is required to develop a reliable technique.

## 2.6 Smart carp

It is not possible to remove all of the carp in one go (Bomford and O’Brien 1995). Particularly when carp numbers are reduced to low levels the remnants of the cohort are generally the ‘smart’ fish that have evaded capture and are sensitive to standard or routine fishing techniques. This has been observed time and time again when targeting aggregations of carp in the Tasmanian lakes. For example some radio transmitter fish have shown that they are easily spooked when approached by boat, by wading and while attempting to set fishing gear on them. An accidental bang in the boat, splashing while wading, movement of rocks underwater and the sound of net leads tumbling out of the bin as it is being deployed have all seen aggregations disperse quickly. However, one thing that seems to override this ability to evade capture is the breeding urge, during which time they appear firmly committed to following each other and are available to capture.

## 2.7 Chemo-attraction

Consistent observations that mature carp are attracted to one another particularly in the breeding season and that even the ‘smart’ carp are vulnerable to capture during such aggregations prompted the idea of developing a chemo-attraction based capture technique. In 2005, the program trialled the use of large female carp as pheromone generators to attract other mature fish. These odour donor fish were primed using either pituitary extract from other mature carp (a technique known as hypophysation) or Ovaprim® (Syndel Labs, Canada), a commercially available spawning agent (Patil and Wisniewski 2006). Typically the odour donor carp was placed in fine mesh holding bags behind traps set to attract and capture wild



carp. More recently the program trialled carp which had been surgically implanted with osmotic pumps containing prostaglandin F<sub>2</sub> (PGF<sub>2</sub>α), a known carp pheromonal attractant, which extends the duration of 'attractivity' (Lim and Sorenson 2010). The best results to date have been from the pituitary injected female carp when their ovulation coincides with vital environmental cues. These cues include warming water (>15°C), rising water levels and calm conditions. These trials were successful in capturing carp that had persistently evaded capture by other methods, highlighting the vulnerability of mature breeding-driven carp.

Selection of a suitable site is critical to the success of chemo-attraction trials. Drains and channels that provide access to the wetlands, with gentle flows to capture, carry and disperse chemical (pheromone) plumes into the lake are ideal.

## 2.8 Berley trials

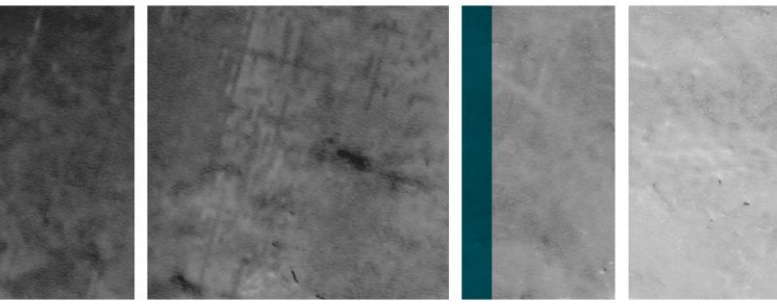
In November 1999 a three month berley trial was commenced in Lake Crescent. A pellet making machine was borrowed from a commercial fish food production plant and a purpose-made food pellet was produced daily on site at the lake with the aim of attracting carp to specific sites. The pellet recipe was a corn and meal based mixture. Three habitat diverse sites were chosen for the trials around the lake. All sites were in areas where carp were known to inhabit or pass by during the summer trial period. A marker buoy was positioned at each site to assist with the consistent laying of the berley and 1 kg of pellets were applied each site every morning for seven days a week over a three month period. The sites were monitored visually and by radio tracking. During the trial period there were 12 radio transmitter fish deployed in the lake. Throughout the trial period there did not appear to be any attraction to the baited sites. After three months, on the final day of the trial, a series of size specific gill nets were placed around the trial sites and the areas were electro fished using boat and back-pack equipment.

No carp were captured or monitored throughout the trial and it is suspected that carp population densities (around 2000 individuals) were too low for this technique to be successful in such a productive natural system.

## 2.9 Population estimation, age and structure

Population estimation and age and structure information aids the planning of fishing effort including the allocation of resources (Donkers P 2003b). Length-frequency information derived from capture data provided information on age structure and growth rates of carp in the lakes. This is essential for predicting suitable gear types (e.g. gill net mesh size) to use in coming seasons and forecasting maturation which may focus effort into spawning prevention and specialised capture methods such as pheromone attractants and trapping.

It is essential to estimate population abundance of carp accurately and as frequently as possible to assist the ongoing fishdown efforts and for making timely management decisions. Although estimating absolute population numbers can be challenging or near impossible in large lakes, the program demonstrated that a simple mark recapture method based on a model developed by Petersen (1896), can be very accurate, provided the underlying assumptions are met (Donkers et al 2011). Deployment of a combination of gear types (to



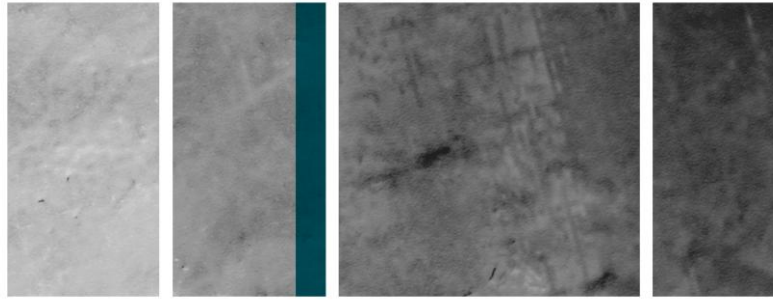
minimise capture bias), use of the Judas fish technique (to increase capture efficiency) and adoption of a reverse-Schnabel approach can result in very accurate population estimation, as was shown to be the case in Lake Crescent (Donkers et al 2011). The mark-recapture population estimates if accurate can assist in making several informed management decisions (including effort required to eradicate and time to fish down a cohort) and comparison of routine but coarse CPUE estimates within and between lakes. More significantly, the estimates were central to support the management and legislative decisions to declare Lake Crescent free of carp and its reopening to the public for fishing and recreational activities. Should it be necessary to estimate population size of new carp cohorts, it is recommended a mark and recapture study be conducted within the first year, to minimise future recruitment risk by allowing as much possible time to recapture fish before they mature.

## 2.10 Recruitment surveys

Despite substantial effort placed on spawning sabotage, it is inevitable that some cryptic or at times large recruitment events occur. Nonetheless, it is essential to detect the frequency and strength of these recruitment events, to plan long term management or eradication strategies. It is particularly important to identify these events as early as possible so that appropriate intervention, such as liming of spawned eggs, isolation and/or spot poisoning of nursery grounds, and or choice of appropriate capture gear for targeting can be implemented. It is also important to predict when a new cohort will become sexually mature so as to direct resources for future spawning sabotage. Despite the vagaries of inter-annual recruitment the CMP has adopted systematic annual recruitment surveys ranging from visual inspection, fine mesh sweeps and back pack electrofishing of known breeding habitat and of sites where radio transmitter fish frequent. Further an annual lake wide fyke net survey has shown that even small cryptic recruitment events that escape early detection can be detected reliably. For Lake Sorell the fyke net surveys involve the deployment of 60 nets over five days (four nights) in early March each year. The nets are typically set in strings of three at 20 locations along the shoreline. Data collected suggests that any carp recruited during the peak spawning period (Nov-Feb) will have grown sufficiently large and mobile to be captured by the fyke nets set perpendicular to the shore. Examples of small cohort detection in the 5310 ha Lake Sorell include a cohort estimated to number around 120 in spring-summer of 2003-04 that was first detected with 24 fish being captured in fyke nets. An even smaller recruitment, estimated to number around 20 fish in spring-summer 2005-06 was detected with the capture of a single fish in 2006.

A significant recruitment occurred in Lake Sorell in 2009. However, spawning events were quickly detected first by visual observation, resulting in liming of defined areas. Those that escaped liming were quickly detected as larvae in back pack electrofishing surveys, leading to spot rotenone poisoning. Others that grew to juveniles were detected in fyke net surveys, leading to targeted fishing. Early detection and intervention in this instance resulted in a significant reduction of about 50% the cohort.

This ability to detect, monitor and effectively remove populations at all densities and life stages is critical for successful eradication.



## 3 Key vulnerabilities and opportunities for control

The common carp is known to be a very hardy species, a trait largely responsible for its successful establishment in places of its introduction. However, a better understanding of its biology through years of observation has enabled the CMP to successfully exploit a number of weaknesses throughout the carp's life cycle. Detailed below are some observations and intervention strategies that may be useful for other carp control programmes elsewhere.

### 3.1 Carp eggs

Carp typically lay their sticky eggs in shallow water amongst the submerged weeds (macrophytes). Where appropriate, several management strategies can be employed to exploit this behaviour:

1. preventing access to breeding habitat
2. physical removal of substrate following spawning and
3. isolation and localised poisoning of spawn beds.

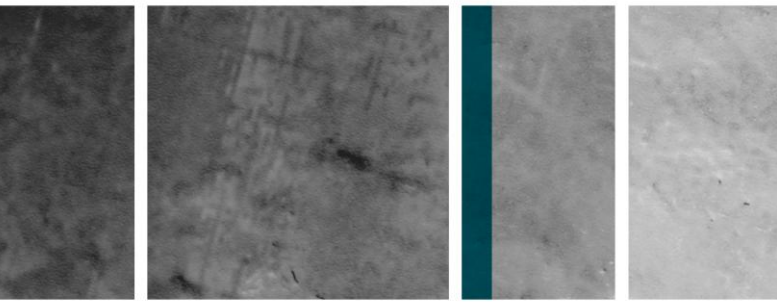
In practice a combination of all the three methods provide best results. As the spawning beds can be detected and defined by visual survey the CMP has successfully used localised application of hydrated lime (Limil®) to rapidly raise the pH level (above 11.0) and kill developing embryos. Typically all stages of carp are vulnerable to any alkaline stress in excess of pH 9.0. The caustic effect of the reactive lime appears to have an added detrimental effect on the developing embryos. Following liming the sites can be monitored using visual inspections and fine mesh net sweeps detect any surviving larvae.

### 3.2 Juvenile carp (larvae to three months)

At about eight weeks after hatching the juvenile carp tend to start dispersing in their wetland nursery. The abundance of these juvenile larvae can be reduced while they are still living within the cover of the wetland vegetation, by dropping water levels, either naturally or by pumping, or releases downstream in a regulated system. Typically falling water levels will concentrate the young carp into depressions and channels as the receding water draws them from the wetlands. Such aggregations can easily be located using backpack electrofishing and can then be poisoned by spot rotenone applications.

### 3.3 Juvenile carp (3-18 months)

Larger juveniles (> 50 mm TL) will begin to disperse out of wetlands into the main water body by the time they are three months old and will start foraging around the edges. At this time they become detectable by fyke nets and remain particularly vulnerable to capture by this method for at least the next 15 months. During winter they form aggregations in deep warm pockets of water similar to those observed in adults. These aggregations can be detected using radio tagging and fished using a combination of electrofishing and gill netting. With the onset of the following spring-summer, warming, shallow bays, particularly on sunny clear days, tend to attract schools of overwintered juvenile fish providing increased opportunity for capture. A muddy bottom with macrophyte cover (*Triglochen* sp.) appears to provide



particularly attractive habitat for feeding aggregations, but water temperature appears to be the primary cue. If the substrate is suitable, the use of seine nets tends to produce good results. A combination of gill nets and electrofishing can be equally effective.

### 3.4 Age at maturity

A good knowledge of age at maturity is critical for efficient management of any biological resource and more so for eradication of pest populations (Donkers 2004). Carp display a wide range of ages at which they mature depending on the climatic conditions and the sex of the fish. A relatively cooler temperature, particularly over the winter in lakes Sorell and Crescent results in comparatively slower carp growth and hence these carp mature more slowly than those on mainland Australia. Males take a minimum of three years to mature (spermiate) and females, four years compared to two years for males and three years for females on mainland Australia. The Tasmanian mark-recapture data shows that a small percentage (< 5%) of females do not mature until seven years of age.

From a carp eradication perspective this provides a four year window to fish down any new cohort, provided all adults from the previous cohorts have been removed and subsequent recruitment has been successfully prevented, a scenario possible at the tail end of an eradication process.

As fish become mature they become vulnerable to additional capture strategies and techniques. Triggered by breeding cues they tend to move actively around the lake and form breeding aggregations, increasing their probability of being captured by passive traps and in Judas carp tracked aggregations. Since males mature at least a year earlier they tend to be susceptible to these techniques earlier, providing an opportunity to remove most (if not all) mature males prior to females in the cohort maturing, limiting reproductive/recruitment potential of the cohort. This fishing induced sex-bias becomes particularly powerful when the number of cohorts present is reduced or restricted by management practices that limit recruitment.

### 3.5 Narrow spawning window

The relatively cooler climate of the Tasmanian lakes also means a relatively shorter window of carp spawning. Typically, the spawning window is restricted to peak spring-summer period (October to February), allowing implementation of a focused and intensive capture of mature fish and spawning sabotage. The spawning cues triggering movement and aggregation of mature fish coincide with rising water levels and water temperatures associated with long daylight periods. Any early (October) spawning events appear to have limited or no recruitment success in the lakes – despite warm day time water temperatures triggering early spawning, low overnight lake temperatures occur due to frequent cold fronts throughout October (Figure 11). Water temperatures below 10°C are known to be lethal to carp eggs (Penaz et al 1983).



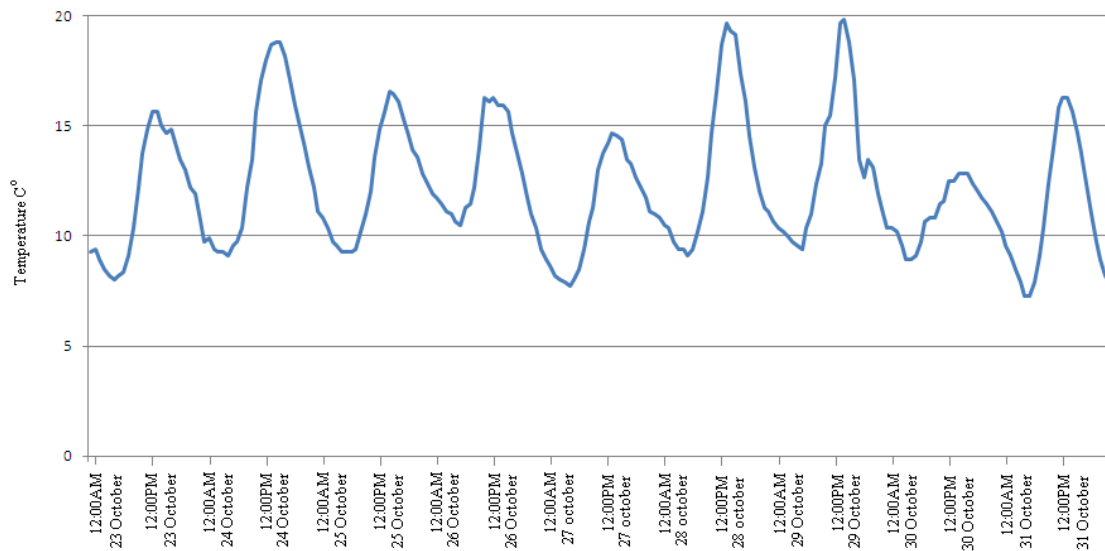
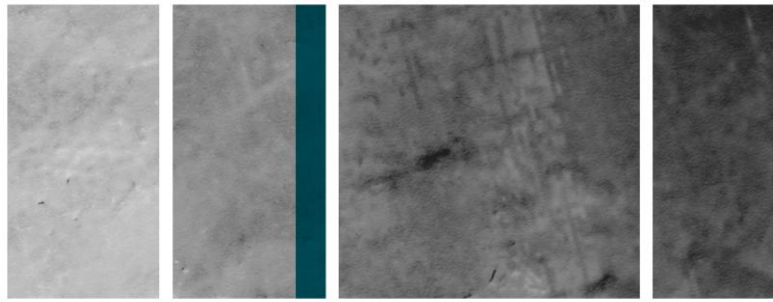


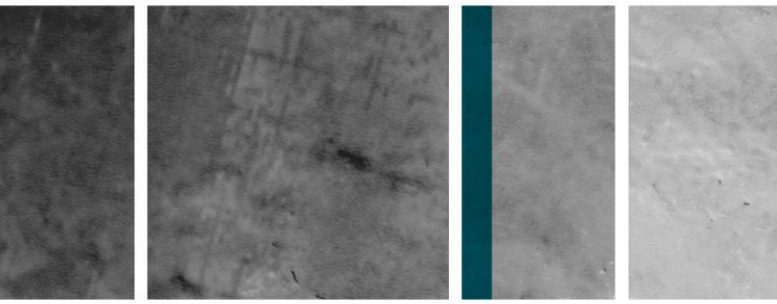
Figure 11: Graph of day/night temperature variations in early spring.

The movement and aggregation of mature carp triggered by the spawning urge make them vulnerable for capture. During the spawning period, adult carp become more ‘catchable’. Carp that have been previously difficult to catch lose their sensitivity to fishing gear and become particularly vulnerable to trapping. Observations from radio tracking have shown that some carp exhibit solitary behaviour but will respond to the spawning cues, moving considerable distances in search of partners making them also vulnerable to capture. Taking advantage of this behavioural susceptibility and with knowledge of preferred breeding habitat, it is regularly possible to capture most mature fish by December significantly reducing the risk of recruitment each year.

### 3.6 Temperature

Carp are known to tolerate a wide range of temperatures, readily surviving winter in frozen over ponds or lakes. However, their preferred temperature range is 23-30°C, with spawning beginning at 17-18°C. In Lake Crescent, carp have been observed spawning in October with water temperatures as low as 11°C. However, there is no evidence of successful recruitment from eggs spawned at such low temperatures. The temperature data collected from Lake Crescent indicates suitable temperatures (17-18°C) for viable spawning are present each year, usually from November to February.

Both cold and warm water temperatures drive different behavioural responses in carp. The warming of shallow water and lake margins during spring and summer brings about feeding aggregations, whilst triggering breeding aggregations of mature carp. Feeding aggregations are consistently found throughout the summer period in the sheltered bays but accumulation of zooplankton (*Daphnia* sp.) blooms on windward exposed shores can also trigger feeding aggregations. During the coldest part of winter, generally the weeks preceding the solstice, the water temperature reaches its lowest, with margins, and at times large expanses of the lakes’ surface, freezing. This triggers winter aggregations of carp in deeper areas of the



lakes, which also provides opportunity for targeted capture. These deep water aggregations are targeted using selective mesh 500 m long deep-drop gill nets that are used to encircle the carp and then the carp are herded into the nets using the electrofishing boat. Depending on the size class(es) of carp that are being targeted often multiple nets of varying mesh sizes are set to catch the different cohorts (Walker 2003).

Generally, the water temperatures in Lake Sorell and Lake Crescent are similar with some subtle differences. For example, Lake Sorell, the larger of the lakes responds more slowly to air temperature changes. The variation in mean daily temperatures in Lake Sorell is smaller, so short periods of high or low air temperatures have a lesser effect on Lake Sorell compared to Lake Crescent. These subtle differences in response to temperature can sometime have significant management consequences. For example, it takes longer for Lake Sorell to warm up in spring, resulting in a slightly shorter window for carp spawning.

### 3.7 Schooling behaviour

Carp have shoaling/schooling tendencies. Feeding, spawning and/or temperature cues and habitat attributes can all induce or attract aggregations or schooling behaviour of carp that can be targeted for capture (Figures 12 and 13). Generally soft, vegetative sediments tend to attract carp aggregations, hence a good knowledge of the lake habitat is invaluable in implementation of capture strategies. Carp implanted with radio transmitters can assist in locating aggregations and building knowledge of preferred sites/habitats that can be consistently targeted during fishing operations.

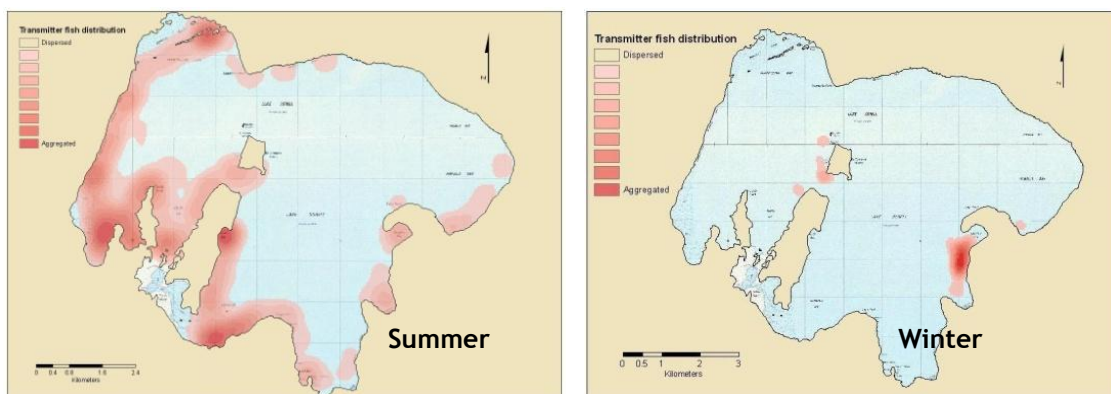


Figure 12: Carp distribution hotspots in Lake Sorell.

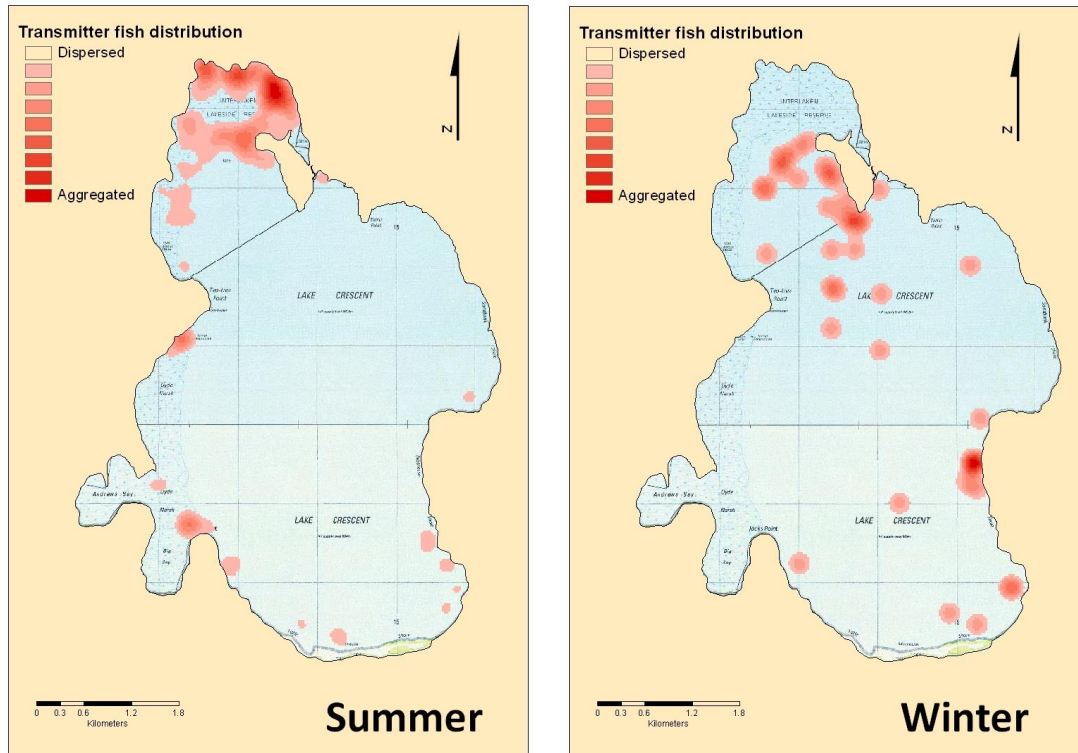
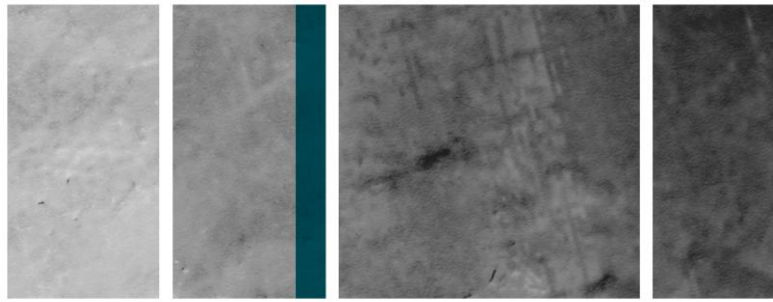


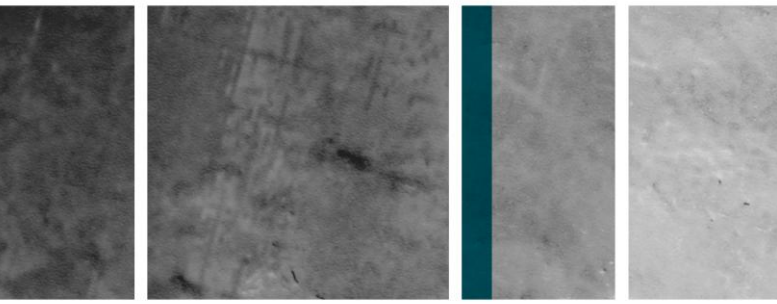
Figure 13: Carp distribution hotspots in Lake Crescent.

### 3.8 Water levels and the drought

Lake level is an important parameter that determines recruitment success of carp and more significantly it can be regulated to minimise this risk, with the exception of unusually wet years. Carp recruitment was restricted in Lake Crescent to the summers of 1995/96, 1996/97 and 2000/01 – all of which preceded wet winters. Higher water levels provided extended spawning habitat through the shallow wetlands, amenable to quick and localised rises in water level that induced carp spawning.

The ability to regulate water levels as a means of restricting access to breeding habitat would assist in limiting breeding and recruitment success in lakes Crescent and Sorell, although this ability is limited due to the demands to retain water in the lakes for downstream use. However, a combined lake level management strategy with continual increases in capacity to manipulate water levels has assisted in mitigating recruitment risks.

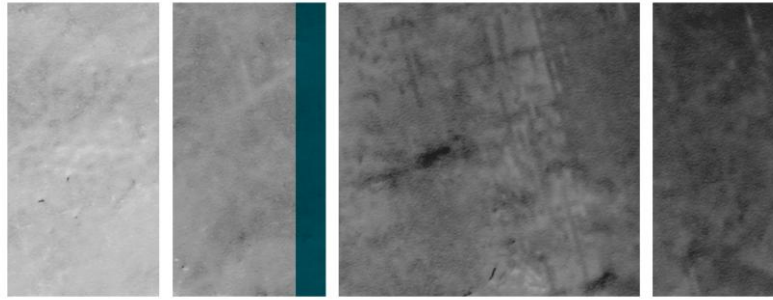
In contrast to wet periods, drought provides reduced recruitment opportunity for carp and therefore increased chances of eradication. Even when water levels are low the warming temperature cues continue to draw carp into the shallow margins making them vulnerable for capture. The falling lake levels limit access to suitable breeding habitat and possibly repress spawning as is supported by recruitment failure during drought years (2002-2007). Low water levels also limit habitat diversity for winter aggregations allowing a far more focused and targeted removal.



## 4 Operational table

Table 1: Typical seasonal carp management activities in Lake Sorell.

| Month                     | Activities/ Opportunity  |
|---------------------------|--|
| June-July-August          | <p>Cold weather - Carp aggregations in deep water</p> <p>Track the radio transmitter fish weekly</p> <p>Focus on high pressure weather systems and cold still conditions</p> <p>Target aggregations</p> <p>Carry out equipment and gear maintenance and repairs</p>  |
| September                 | <p>Set all barrier nets in place</p> <p>Set gill nets behind barrier nets</p>  |
| October-November-December | <p>First environmental spawning cues and carp activity increases through this period</p> <p>Reduce containment screens to 1 mm mesh</p> <p>Monitor and radio track daily</p> <p>Deploy all gear to actively target carp movement</p> <p>Open all barrier traps/fykes</p> <p>Monitor for signs of recruitment</p> |
| January-February          | <p>Seek out and target aggregations in the shallow margins using radio transmitter Judas carp</p>  |
| January-February cont.    | <p>Monitor for signs of recruitment</p> <p>Reverse barrier traps/fyke nets to sample for recruitment as water levels recede</p>  |
| March                     | <p>Seek out and target aggregations</p> <p>Survey lake wide with fyke nets for juvenile carp resulting from spring-summer recruitment (24 strings of 3)</p>  |
| April                     | <p>Seek out and target aggregations</p> <p>Increase containment screens to 5 mm to allow greater outflow over winter</p>   |
| May                       | <p>Review progress and develop new operational plan</p>  |



## 5 Eradication

### 5.1 The Lake Crescent example

As shown through this report, with sustained effort, it is possible to achieve all six key criteria in the Bomford and O'Brien (1995) model for eradication. These criteria are:

1. Rate of removal exceeds the rate of increase at all population densities
2. Immigration rate is zero
3. All carp must be at risk
4. Populations can be monitored at all densities
5. Discounted cost-benefit analysis favours eradication over control
6. Suitable socio-political environment

It is useful to know that based on these criteria the eradication of carp has been achieved in a water body as large as Lake Crescent using integrated fish down techniques. In the case of the Tasmanian situation the most difficult criteria to meet proved to be that 'the rate of removal exceeds the rate of increase at all population densities'. Through the Tasmanian program it has been shown that the size of cohorts can be reduced systematically and within a window of seven years eradication is possible. The most difficult action was blocking spawning despite having reduced the population to small size. In Lake Crescent this coincided with drought conditions and the maintenance of intensive effort. The last wild carp was removed from Lake Crescent in December 2007 (Figure 10).

As is to be expected, with its greater natural variations, size and recruitment opportunities Lake Sorell requires increased effort and resources. Despite being close to a complete eradication a number of times recruitment has occurred from a small adult population. The eradication of carp from Lake Crescent has now allowed increased effort and resources to be focussed on Lake Sorell and the recruitment event of 2009 resulted in refocussed tactics including implanting juvenile carp with radio transmitters, more barrier nets and a far greater effort to capture the remnant population of each cohort of carp that make it through to maturity.



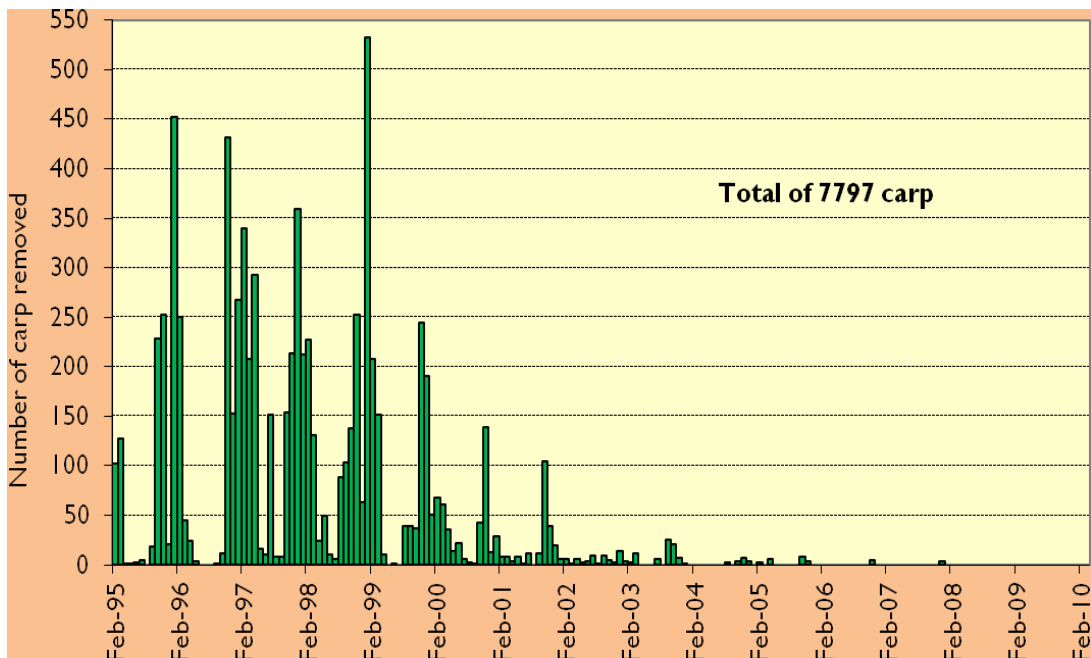
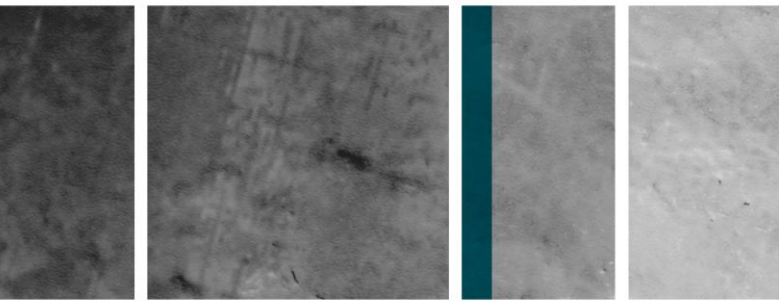


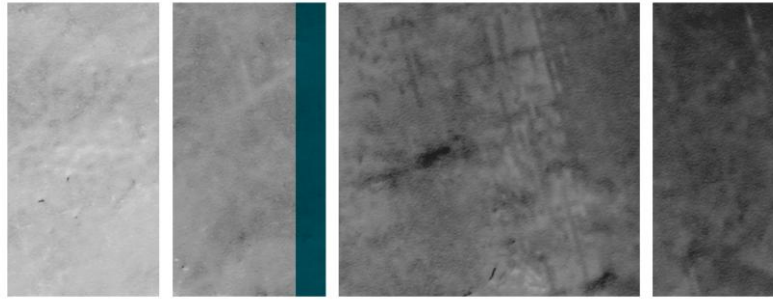
Figure 14: Progress of the Lake Crescent carp eradication.

## Acknowledgements

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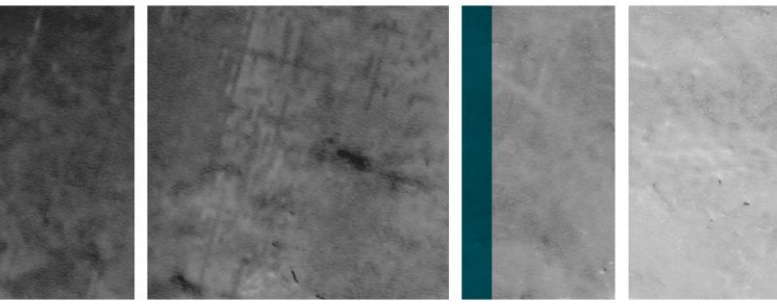
The project team thanks Peter Sorensen for the collaborative work that was undertaken in relation to the pheromone trials and to Wayne Fulton and Kylie Hall from the IA CRC for their support throughout this project.

Numerous staff have worked on the Carp Management Program over the past 17 years and have assisted in gathering data and knowledge. In particular the dedication, passion and efforts of Rob Cordwell, Terry Byard and Paul Donkers are recognised in the attempt to eradicate carp from Tasmania.



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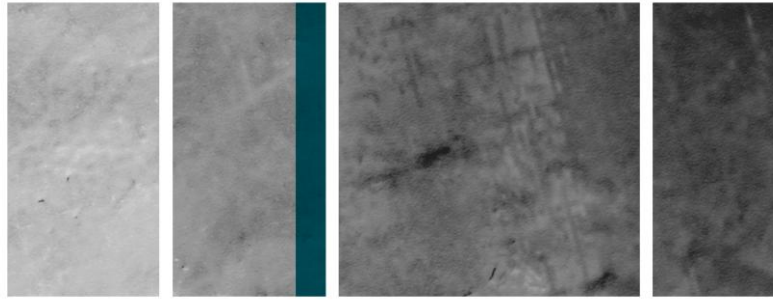
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## Appendix 1. Legislation and lake closure

In order to prevent the transfer of carp from lakes Crescent and Sorell to other Tasmanian waters, the closure of these lakes to the public, was seen as a priority. This was initially facilitated through the section on noxious fish under the provisions of the Fisheries Act 1959.

The use of fish as bait by anglers also came under scrutiny and regulations were enacted stating that a person must not use whole or part of a fish as a bait to take fish in any inland waters that are not subject to tidal movement.

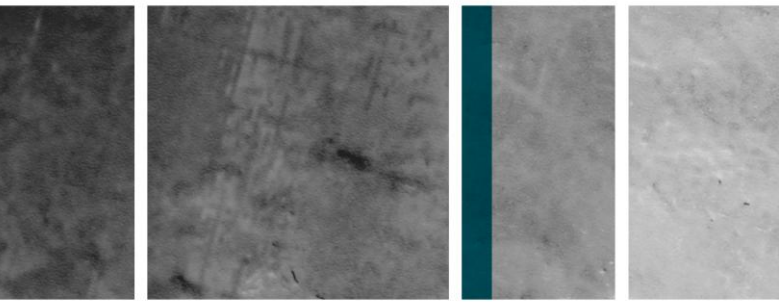
With the implementation of the *Inland Fisheries Act 1995* (<http://www.thelaw.tas.gov.au>) carp were declared a 'controlled fish' (section 149) and managed under the provisions of the sections 150 (Offences relating to controlled fish), 151 (Notification of location of controlled fish) and 152 (Removal or destruction of controlled fish).

In order to support the containment strategy, Lake Crescent was quarantined. The quarantine measures comprised of the closure of Lake Crescent and the upper Clyde River to the public. The closure officially commenced on 17 February 1995 and was in place for nine years before the risk of carp being transferred from the lake was assessed as low. In contrast, with a small carp population, Lake Sorell remained open to the public until 2010 when a substantial carp cohort was found.

Detection of carp in the lakes also resulted in reassessment of the legislation, resulting in the inclusion of a scheduled list of 71 exotic fish species that pose a risk of establishing in Tasmania.

Legislation that has been introduced to assist pest fish control in Tasmania includes:

- *Inland Fisheries Order 1996 (Destruction of Controlled Fish)*
- *Inland Fisheries Order 2003 (Delay or Prevention of Spread of Controlled Fish)*
- *Inland Fisheries Order 2007 (Controlled Fish)*



At the time of closure of Lake Crescent in 1995, the following public notice was placed in the three regional newspapers in Tasmania. It has since been updated to reflect legislation changes.

#### **Closure of Lake Crescent**

In pursuance and exercise of the Powers conferred on me under Section 42L of the Fisheries Act 1959, I Wayne Fulton being the Commissioner of Inland Fisheries, declare the waters of Lake Crescent and its surrounds to its high water mark closed to the public for all purposes.

The above action has been taken as a precaution to assist in preventing the spread of European carp which were recently found in Lake Crescent. As the carp have adhesive eggs which may be laid in summer, closure will prevent these eggs from being spread on boats, outboards, waders clothing etc.

The closure includes, but is not limited to, access for angling, boating of any sort, wading, swimming, duck shooting or any purpose that results in contact with the water.

**Wayne Fulton**  
**Commissioner IFC**



Figure 15: Lake Crescent closure sign.





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