Carp Fishdown – Can we Catch the Last Female?

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Abstract: European Carp (*Cyprinus carpio*) were discovered in 1995 in two Tasmanian lakes – Crescent and Sorell – separated by a canal with screening facilities. The Inland Fisheries Service has reduced these two populations to a fraction of their initial abundance. Tactics have included a wide range of fishing methods, using radio tracked 'Judas' fish to locate and to fish aggregations, and controlling water levels in the lake to restrict new recruitment. The combination of low rainfall and manipulation of water levels, has limited spawning events in Lake Crescent since the summer of 1996/7, however the risk of a successful spawning event is ever present, given vagaries in weather and year-round spawning readiness. Carp live for 20 years or more and the likelihood of completely preventing spawning for this length of time is low. Therefore, the goal is to fish down the populations completely. As this may be unachievable given standard fishing practices, we are estimating the probability of removing the last female carp, given that males are returned to the lakes both to act as aggregators and as radio tracking fish. Given five years of data on fishing effort and catch records, our question is simple: how long to keep fishing and what techniques to use before we can be confident that we have removed the last female carp? In particular, we consider the question of how much effort is required (and how long to continue this effort) once the population is small enough that very few female fish are being caught? We use population models and stock assessment techniques to quantify the progress to date.

Keywords: European Carp; Fishdown; Eradication; Stock assessment

1. INTRODUCTION

European Carp (*Cyprinus carpio*) were discovered in lakes Crescent and Sorell (elevation 800m AHD), Tasmania in 1995. These two large lakes (Crescent=2365 Ha, Sorell=4770 Ha) were immediately closed to the public and a program was initiated by the Inland Fisheries Service (IFS) to minimise the chances of this introduced fish spreading downstream. Other lakes and rivers in the Derwent watershed downstream from lakes Crescent and Sorell provide more suitable habitat for carp, due to their lower elevations and higher water temperatures. The first objective was to ensure physical containment in lakes Crescent and Sorell. This was achieved by installing a containment facility consisting of a series of mesh screens to prevent the transfer of adults, juveniles, eggs or larvae into the Clyde River, downstream from Lake Crescent.

While physical containment of carp in lakes Crescent and Sorell was the initial priority, further management or control of the population is needed to minimise the likelihood of spread by other means. Following containment, removal of carp is necessary to achieve the objective of the eradication of carp from Tasmania. Lakes Crescent and Sorell are considered to be marginal habitat for carp because of their high elevation and relatively low water temperatures, so it was considered feasible to attempt eradication rather than just control of this population. As de-watering was not physically possible given the topography of these lakes, chemical poisoning was suggested, as this is the only other method of eradication that has been successfully used elsewhere [McClay, 2000]. Over the last fifty years, fisheries managers have used rotenone as a piscicide in a powder, liquid or synergised-liquid form or as oral baits. In particular, rotenone has been used to control small isolated populations of European carp in Australia [Barnham, 1998], including populations in Tasmania in the 1970s and 1980s. However the use of rotenone was ruled out partly due to the cost, the logistical difficulties and the perceived ineffectiveness in treating such large volumes of water. Other factors influencing this decision included the presence of a threatened species of fish *Galaxias auratus*, endemic to these two lakes and the requirement that water from these lakes be used for irrigation and human consumption downstream. An alternative form of control for carp is the use of a virus "Spring viraemia" (*Rhabdovirus carpio*) which was considered by Victorian fisheries managers in the 1970s for biological control of carp. Initial trials indicate that this virus is specific to carp but too many risks are associated with the introduction of this rabies-like virus and research was abandoned [Barnham, 1998]. New genetic technologies being developed by CSIRO to control fish populations have the potential to control carp numbers, but will require extensive testing before they can be applied.

The only eradication technique meeting the environmental criteria is physical removal. While physical removal has been successful elsewhere in conjunction with chemical control [Meronek et al., 1996], it is not considered a suitable eradication method for fish by itself [McClay, 2000]. If physical removal is to be used successfully, then new techniques need to be developed, especially to remove the last few fish. The IFS began fishing down carp in February 1995 in an attempt to remove all carp from lakes Crescent and Sorell. New techniques were soon developed by the IFS. Principal amongst these was the release of radio tagged male fish that were targeted by subsequent fishing when 3 or more were in the same location – indicating a possible carp aggregation. There were still doubts that the last fish could be captured using the newly developed techniques so in 1999 the goal of the physical removal was redefined to eradication of all female fish. Male fish would be returned to the lakes to ensure that the carp continued to aggregate, providing the means to remove all female fish, leading to the long-term eradication of the carp populations in these two lakes. In this paper we describe the physical fishdown and the population modelling that we have developed to evaluate the likely success of this approach, and its extension to determine the most efficient approaches to carp eradication in these two lakes.

2. PHYSICAL REMOVAL

2.1 Fishing Methods

A number of methods have been used to fish carp in both the lakes since 1995 and both the methods and their application have changed over time. Gear types have included fyke nets, seine nets, gillnets, traps, backpack electrofishing and boat electrofishing. Initially the fishing gear types were used somewhat randomly. Later, the IFS started targeting habitat favoured by carp and adapted fishing techniques based on previous catch rates and experience. Catch rates increased following the introduction of new gear types or techniques but soon fell as their effectiveness declined. March 1997 saw the first use of radio tagged male fish as tracker, or "Judas", fish to identify aggregations and to help understand carp habitat preference and behaviour. When several radio tagged fish are in the same location, this indicates an aggregation of carp, which is then targeted using fishing techniques most applicable to the situation.

As the population declined it became clearer that removing the last carp from the lakes would be difficult if not impossible unless a new strategy was developed. The logic behind the new strategy that followed is that it is not necessary to remove all the carp from the lakes if all individuals of one sex, preferably females, can be removed. Because the carp have a tendency to aggregate, it was reasoned that it would be possible to leave a number of male carp in the lakes to serve as aggregators. It is hoped that these aggregations will attract the remaining females and enable them to be captured. The established Judas fish technique is used to target these aggregations.

2.2 Spawning events

Summer water temperatures typically reach the minimum for spawning (17°C) in the period from November to March, but only in the shallow flooded margins of the lake. Since these optimal spawning conditions and habitat have been identified, the water level at Lake Crescent has been managed to maintain static and falling water levels during the peak summer spawning periods, thus restricting the availability of water warmer than the 17°C minimum. Management of low water levels in Lake Crescent has been easier in recent years due to several years of below average rainfall and increased demand downstream for irrigation. Water levels in Lake Sorell have been harder to manipulate due to its position above Lake Crescent and its uncontrolled inflows; flooded margins have not been reduced as effectively as in Lake Crescent.

Since 1995, there have been five successful spawning events, where success is measured by the recruitment of juveniles. Two of these recruitment events occurred in Lake Crescent, during the summers of 1995/1996 and 1996/1997. In Lake Sorell, three recruitment events are known to have occurred, with low numbers of recruits during the summers of 1995/1996 and 1997/1998 and higher numbers of recruits in the summer of 1999/2000.

In addition to these recruitment events, there were two additional spawning events observed in Lake

Crescent in the summers of 1999/2000 and 2000/2001. Both these spawning events coincided with discharges of water from Lake Sorell to Lake Crescent through a 1km canal during periods of warm weather. The inflow of water to Lake Crescent attracted spawning aggregations that were detected and spawning fish were caught and removed on both occasions. In 1999, carp were observed spawning on macrophytes in the canal. A total of 247 carp were captured from the canal and an excavator was used to remove all macrophytes, thus reducing the likelihood of successful recruitment. There has been no evidence of successful recruitment from the 1999 spawning (new recruits are first caught when aged around 1 year old). In November 2000, 182 fish were caught in two spawning aggregations, spawning on debris in the canal and spawning in the Clyde Marshes, again with some macrophyte and debris removal. While it is still too early to be certain, it appears that there has been no successful recruitment from the 2000 spawning.

3. MODELLING THE POPULATION IN LAKE CRESCENT

3.1 First estimates – standard Petersen

The population of carp in Lake Crescent is thought to be much larger than the population in Lake Sorell (based on catch rate data), so Lake Crescent was chosen for two mark-recapture studies, to collect data that could be used to assess the population size in this lake. In the first mark-recapture study, 366 fish (males and juveniles) were tagged and released over a period of 17 days in November and December 1998. This initial study had a distinct recapture period and was designed to enable a standard Petersen analysis of the population. In December 1999 a second ongoing mark-recapture-re-release study was initiated and an additional 202 fish (males only) were tagged and released between December 1999 and June 2001. Some tagged male fish were re-released following recapture to help maintain the number of male fish in the lake and so promote aggregations of male fish, while also maintaining tagged fish for population estimates. The second study was designed to collect cumulative data for more sophisticated population estimates than a standard Petersen estimate.

The Inland Fisheries Service have collected biological data for most of the fish caught (tagged and untagged) since 1995. Much of these data include detailed biological information, including length, weight, sex and gonad indices. Otoliths have been collected for some of these fish and approximately 1000 of these are currently being aged. The age composition data will be used to construct an age-length key, at which point the size-structured model will be converted to an age-structured model. Data on fishing effort were also collected, including length of fishing operation, location and gear type used, as well as the number of fish caught.

Population estimates can be made using these data and a variety of standard mark recapture techniques. Donkers [1999] used Petersen and Schnabel estimators and investigated the use of change of ratio estimators to estimate the initial population size and the size of the two known recruitment events in Lake Crescent. This work, and other unpublished work at the IFS, produced estimates of an initial (January 1995) population of 4900 fish with combined recruitment of 3800 from the two successful spawning events. The Petersen method assumes no tag loss and does not account for fish mortality. It is most reliable when considering a short recapture period, such as after the first tag study, and it cannot be used to estimate the mortality rate. Double tagging studies have been started to estimate the rate of tag loss. Initial observations are that the rate of tag loss is low. A sequential mark and recapture method described below has been started in part to estimate the mortality rate. When analysing tag data where both the tagging and recapture occur over a longer period of time, other methods can be used to address these issues.

3.2 An alternative Model

We use a modelling framework outlined by Tuck et al. [2001], which enables an estimate to be made of the pre-tagging abundance and annual recruitment using daily catches. This accommodates tag data that have been collected over an extended period. Tuck et al. [2001] use a semi-parametric model to account for daily catches, releases and recaptures. We base our model on their "No-Selectivity model" [Tuck et al., 2001], and then further modify this model to incorporate age/size structure. There have only been sufficient data to date to apply this approach to Lake Crescent.

Let N_t be the number of fish in the population on day t, and C_t the number of fish caught on day t, then the daily population dynamics are described by:

$$N_t = (N_{t-1} - C_{t-1})S + f(R_y), \qquad (1)$$

where $S = exp(-M/365)$ and M is the annual natural mortality rate. In theory, the mortality rate, M, can be estimated from the data. Where this is not possible, M can be estimated independently from age composition data. The initial population is given by N_0, a parameter to be estimated by the model, with day 0 taken as January 31, 1995. R_y recruits are added to the population in November of year y, so $f(R_y) = R_y$ if day t corresponds to a recruitment day and $f(R_y) = 0$ otherwise. As spawning occurs in the summer months, recruits are not large enough to be caught until the following November. We assume all recruits first become available to the fishery at around one year of age. As there are only two confirmed recruitment events in Lake Crescent, this gives us two recruitment parameters to estimate, R_1 on November 1, 1996 and R_2 on November 1, 1997.

Similarly, the number of tagged fish in the population on day t is

$$m_t = (m_{t-1} - r^*_{t-1})S + p_t, \qquad (2)$$

where p_t is the number of tagged fish released on day t, and $m_0 = p_0 = 0$ and r_t is the number of tagged fish recaptured on day t. Tuck et al [2001] modify their recapture rate to allow for tag loss. We initially assume there is no tag loss as the data to estimate tag loss rates are only now being collected.

The number of observed recaptures on day t is assumed to follow a binomial distribution, $r_t \sim B(\beta_t, C_t)$, with mean μ_t defined by:

$$\mu_t = E[r_t] = \frac{m_t}{N_t} C_t = \beta_t C_t. \qquad (3)$$

In certain circumstances, the Poisson distribution approximates the binomial distribution, and thus $r_t \sim Po(\mu_t)$, inferring random, non-clumped returns of tagged compared to untagged fish.

Tuck et al [2001] use the Poisson approximation and find maximum likelihood estimates of pre-tagging available abundance, N_0, and net recruitment in year y, R_y, by maximising the log-likelihood function given by:

$$L(r; N_0, R_y) = \sum_{t:\mu_t \neq 0} (r_t \ln(\mu_t) - \mu_t). \qquad (4)$$

For small catch sizes the Poisson approximation to the binomial distribution is poor, and this approximation deteriorates further as the ratio of tagged to untagged fish increases. Our carp catch data includes both small catch sizes and tagged fish to total fish ratio is approximately 0.35 to wards the end of the time series. Hence we used both the Poisson approximation, above, and the binomial distribution directly, maximising the log-likelihood function given by:

$$L(r, C; N_0, R_y) = \sum_{t:\mu_t \neq 0} (r_t \ln(\mu_t / C_t) - (C_t - r_t)\ln(1 - (\mu_t / C_t))). \qquad (5)$$

For the case where mortality is zero, the population estimates obtained from this method are $N_0 = 7032$, for the 1995 population with R_1 and R_2 estimated at 1408 and 875 respectively. This preliminary estimate does not make use of the size data, which the IFS used for earlier population estimates, $N_0 = 4900$, $R_1 + R_2 = 3800$, total population of 8700. While there is significant difference in the recruitment estimates from these two estimates, the total fish numbers, $N_0 + R_1 + R_2$, 9315 and 8700 are reasonably close. Population estimates using the Poisson approximation gave a total difference of only 11 fish.

This model also provides an estimate of the current population, as of August 2001, $N_{2001} = 729$, with 282 of these fish tagged. The estimate for N_0 depends directly on the assumed rate of natural mortality, M, as it is back calculated to 1995 from the start of the tagging study; M is poorly defined for this population. Estimates for R_1 and R_2 are less sensitive to the value of M and N_{2001} is quite stable. Natural mortality appears to be very low above one year of age, the age at which carp are first caught in the gear types used, so for these initial population estimates, we assumed zero mortality.

3.3 Size/Age Structure

A size structured version of this model will be used to segregate the catch data into three distinct cohorts.

$$N_{i,t} = (N_{i,t-1} - C_{i,t-1})S + f(R_y), \qquad (6)$$

In this case, $N_{i,t}$ is the number of fish in cohort i on day t, and the recruits R_1 and R_2 are added to the appropriate cohort. An assignment rule is used to place fish for which length was not recorded into an appropriate category. The division of length data into age data is somewhat arbitrary based on analysing monthly length frequency data, separating obvious modes and arbitrarily setting boundaries where modes merged. Brown et al. [2000] suggests that once carp reach 480mm, their age can be anywhere in the range from 5 to 24 years old. Hence, no attempt was made to subdivide fish larger than 480 mm (age 5 years). Once the otoliths are aged, this assignment of age data to length data will be done more accurately and a model with full age based population estimates will be possible.

3.4 Future Analysis

Future analysis of this data will include analysis of sex ratio through the construction of a two sex age structured model, allowing estimation of the number of female fish left in the lake. Formulation of and age and sex based model is important for estimating the number of female fish remaining in the lake. In addition, analysis of catch-effort data could be used to direct fishing effort in removing the remaining females.

4. CONCLUSIONS

Eradication of fish from a large lake has been considered to be impossible, as the effort to remove the final few percent of fish increases rapidly. Radio tracking has been used in lakes Crescent and Sorell to increase fishing efficiency and assist in capturing those last few percent of fish, targeting effort in particular on aggregations as indicated by the presence of three or more radio tagged fish in one location. However, it was anticipated that as the numbers of carp in the lakes declined, aggregations would cease and the effectiveness of targeting radio tagged fish would diminish. A new approach would be needed to remove the final few fish from the lake.

Redefining the objective of this approach, to the removal of a viable breeding population, provided a new option – the removal of all female fish from the lake. Removal of all males would also have worked, but as males can fertilise the eggs from many females, removing males would not provide the immediate reduction in spawning potential that female removal provided. The success of this approach will depend on the degree to which the last few female fish will continue to aggregate with the male fish. At some time the option of artificially stimulating a spawning event (by releasing warm water into Lake Crescent) will be explored. This option has associated risks that need to be balanced against the costs of continued fishing and the risks of an uncontrolled spawning event occurring – for example after strong rains.

We have developed a modelling approach to provide managers with information on the relative risks of alternative approaches to removing the last few female fish. We started with a simple mark and recapture model fitted to the available data. We are currently extending the model to incorporate size composition so that we can distinguish the two spawning events in the lake, and will soon be incorporating age directly so that mortality can be estimated, and the pattern of historic recruitments determined.

At some time we will be dealing with the probability of capturing the last female fish from the lake so that we can provide a decision matrix that balances the amount and duration of fishing effort against the probability that a single female fish remains. This area of the model still requires more thought.

The success of physical eradication as described above depends on restricting future spawning events as it is impossible to remove the female population in less than a year. Spawning has been successfully controlled in Lake Crescent, but not in Lake Sorell. A fine-mesh screened weir has been constructed between Lakes Crescent and Sorell so that female carp cannot move between the two lakes. Once females are eradicated from Lake Crescent, Lake Crescent will provide a buffer between Lake Sorell and downstream areas. This provides some risk management while new techniques are developed to control the spawning of carp in Lake Sorell. Techniques being investigated include the use of ripe male or female fish to attract other carp into traps situated in barrier nets across likely spawning areas or, in the future, the use of genetic technologies to reduce spawning success of the remaining fish.

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