The use of boat electrofishing for koi carp (*Cyprinus carpio*) removal in the Kauri Point catchment.

CBER Contract Report 69

Client report prepared for
Department of Conservation

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16 May 2008

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Executive summary

The koi carp is an ornamental strain of the common carp (*Cyprinus carpio*) which is believed to be one of the most ecologically detrimental of all freshwater invasive fish species. They are widespread in the Auckland and Waikato region and appear to be spreading both north and south of these areas. The presence of koi carp in 3 ornamental ponds at Kauri Point, Katikati which is located in the western Bay of Plenty region was confirmed in late 2006. Because koi carp is designated an unwanted organism under the Biosecurity Act it was decided by the Department of Conservation (DOC) that an attempt to eradicate them from this locality would occur. One possible option for eradication of koi carp in this catchment was the use of an electric fishing boat from the University of Waikato. This boat operates by putting a pulsed DC current into the water column where it attracts and then incapacitates fish, allowing operators to remove them from the water with hand nets.

The Centre for Biodiversity and Ecology Research (CBER) at the University of Waikato was contracted to attempt to eradicate koi carp from the three ponds at Kauri Point by boat-electrofishing. The objectives were (1) to survey the fish abundance, (2) to remove as many koi as possible in an attempt for eradication and (3) to estimate the proportion of koi carp removed from the system by boat-electrofishing. On 21 and 22 April 2008, a total of 327 fish comprising of 307 koi carp (137.5 kg of biomass), 1 goldfish (*Carassius auratus*) and 19 koi-goldfish hybrids were captured and removed from the 3 ponds located within the Kauri Point catchment by a combination of electric fishing (307 fish) and gill netting (20 fish). The majority of these fish (299 koi, 1 goldfish, 19 koi-goldfish hybrids) were removed from the largest pond (pond A). Boat-electrofishing caught a wide size range of koi (70 mm to 510 mm) and at least four distinct size classes of koi were apparent. The high proportion of juveniles (< 200 mm) caught along with reasonable numbers of mature males and females in pond A strongly suggests that breeding is occurring within the Kauri Point aquatic ecosystem. Results from analysing scales of a small sub sample of koi (n=34) also shows that there was a wide range of ages in pond A (ages 1 to 8 years old). Pond A had a relatively high density of 4.6 koi carp 100 m^{-2} compared to pond B and C which had low densities of 0.5 and 0.2 koi carp 100 m^{-2} respectively. No juvenile carp were observed to be present in ponds B and C.

Population and total biomass estimates for koi carp in pond A prior to removal of fish were calculated to be 358 ± 66 koi carp and 145.14 ± 44.27 kg (mean ± 95% C.I) respectively. 299 koi carp or 122.30 kg of biomass (71-84% of the estimated population) were removed from pond A over two days of electric fishing, leaving a possible 125 koi carp or 67.11 kg of biomass remaining in the pond. Boat-electrofishing proved to be a successful tool for removing a large proportion of the estimated biomass of koi carp in the Kauri Point ponds. Eradication of koi carp by boat-electrofishing from this system was not possible due to poor water visibility (difficult to spot narcotised carp), limited time allocated and successful koi carp breeding occurring in the ponds. Viable options of koi carp eradication in the Kauri Point catchment would involve the partial draining and poisoning of the three ponds and the associated tributaries where koi carp are found.

1. Introduction

The koi carp is an ornamental strain of the common carp (*Cyprinus carpio*) which is believed to be one of the most ecologically detrimental of all freshwater invasive fish species (Crivelli, 1983; Zambrano et al., 2001; Davidson, 2002; Dean, 2003; Koehn, 2003). Koi carp resemble goldfish in most ways except that koi have two barbel pairs at the corners of their mouth. There is a wide variation in colour amongst wild koi carp in NZ, ranging from brilliant red, orange, white or a mixture with irregular blotchings of black, red, gold, orange or pearly white (Tempero, 2004).

Common carp have been implicated to cause major environmental degradation in many freshwater ecosystems due to their feeding mechanisms which result in the turbation of the bottom sediments as well as dislodgement of aquatic plants. Common carp have been recognised as a threat to aquatic ecosystems as they are able to reach high biomasses, they are very tolerant to poor water quality, and they contribute significantly to water quality decline (Crivelli, 1983; Roberts et al., 1995; Zambrano et al., 1999; Barton et al., 2000; Zambrano et al., 2001).

Koi carp were introduced to New Zealand sometime in the 1960's, possibly as part of a goldfish importation and are now widespread in Auckland and Waikato. They appear to be spreading into Northland and they have been found at limited locations in the Taranaki, Manawatu, Wellington, Hawkes Bay and Tasman districts (Tempero, 2004). A sighting of koi carp at Kauri Point, Katikati was reported to Environment Bay of Plenty (EBOP) late in 2006 and the presence of koi was subsequently confirmed in at least two ornamental dams. A decision was made by the Department of Conservation (DOC) and EBOP to carry out a catchment-wide survey. This was carried out on 27 and 28 March 2007 by DOC and it was found that the area containing koi was approximately 600 m long and contained a series of four ponds (Figure 1). Koi were originally observed to be present only in the upper three ponds as the habitat below the ponds was deemed to be of insufficient size and water quality to allow koi to survive for any length of time. Original estimates were around 100 koi present in the top dam (Pond A) as well as a number of small (<300 mm) unidentified dark fish which could either be koi, goldfish or koi/goldfish hybrids. No koi were observed in the middle dam (Pond B) during the visual survey, but previous sightings by the landowner and DOC staff suggested that they were present. In the bottom dam (Pond C) the presence of at least four koi carp were confirmed. Although no successful koi breeding had been confirmed within the system, the presence of at least two distinct size classes and an accurate description by the landowner of spawning behaviour occurring in pond A suggested that breeding may be occurring.

Koi carp is designated an unwanted organism under the Biosecurity Act and the Bay of Plenty falls outside the koi carp containment zone within the Auckland/Waikato regions thus necessitating the eradication of carp if possible from the Kauri Point catchment. Eradication seems achievable in this system as the watercourse begins with an ornamental dam (pond A; Figure 1), drains into the Tauranga Harbour (which prevents natural spread) and it is a restricted system of small ponds. Landowners of the top three ponds were supportive with the idea of eradication and expressed a desire for the eradication of koi to occur as soon as possible. A possible means of eradication included the use of the University of Waikato's electric fishing boat which is a selective method of fishing with a minimal impact on non-target species. On 21 and 22 April 2008, DOC contracted the Centre for Biodiversity and Ecology Research (CBER) at the University of Waikato to attempt to eradicate koi carp from the three ponds in Kauri Point by boat-electrofishing.

The objectives of the project were:
(1) to survey fish abundance.
(2) to remove as many koi as possible in an attempt for eradication.
(3) to estimate the proportion of koi carp removed from the population by boat-electrofishing.

2. Methods

Electric fishing ensued through the use of a 4.5-m long, custom-made electric fishing boat. The boat has a rigid aluminium pontoon hull with a 2 m beam, and is equipped with a 5-kilowatt gas-powered pulsator (GPP, model 5.0, Smith-Root Inc, Vancouver, Washington, USA) which is powered by a 6-kilowatt custom-wound generator. Two anode poles, each with an array of six electrode droppers, created the fishing field at the bow, with the boat hull acting as the cathode.

Electrical conductivity and temperature was measured with a YSI 3200 conductivity meter. The measured conductivity was then used to calculate the settings on the GPP which resulted in all three ponds fished with the GPP set to low range (50-500 V direct current) and a frequency of 60 pulses per second. We adjusted the percent of range setting of the GPP to between 50 and 70% to give an applied current of 3-4 A root mean square. We assumed from past experience that an effective fishing field was developed to a depth of 2-3 m, and about 2 m either side of the centre line of the boat. We thus assumed that the boat fished a transect about 4 m wide, which was generally consistent with the behavioural reactions of fish at the water surface. This assumption was used to calculate area fished from the linear distance measured with the boat's global positioning system.

On 21 April, 4 fishing passes were carried out in pond A, two passes included the entire perimeter, one pass fished the middle section of the pond and the last pass fished both the perimeter and the middle. On the same day two fishing passes occurred in pond B and due to its small size both passes fished the entire pond. On 22 April, 3 fishing passes were carried out on pond A with the whole lake being fished on each pass. Another two fishing passes occurred in pond B but due to drainage of the pond overnight only half the lake was able to be successfully fished on each pass. Two fishing passes in one section of pond C occurred and one fishing pass in the other section as the pond was divided by a wooden barrier which the boat was unable to cross. All habitats in the lakes deeper than 0.3 m were fished and when koi, goldfish or hybrids were spotted they were removed and euthanized. The fish were identified to species level and the fork length (FL) was recorded. Where eels were seen they were not captured. Eight 25-mm mesh gill nets were set in different locations in pond A on the afternoon of 21 April and left until the afternoon of 22 April to determine whether netting could be a feasible approach for the removal of koi carp.

3. Study Sites

The Kauri Point catchment includes a reasonably small area of land (approximately 250 hectares) and is centred around NZMS 260 U13 GR 27720 64062 (Figure 1). It is approximately 2.5 km long and has two small tributaries. It is situated between Ongarue Point Road to the north and Kauri Point Road to the south within the general area known as Kauri Point. The tributary stream containing the ponds containing koi carp finishes at the top pond with no formed watercourse above this point.

Figure 1: Locations of the three ponds containing koi carp in the Kauri Point catchment on the Katikati peninsula.

The ponds in the Kauri Point catchment had water temperatures of 15-16^{o}C on 21 and 22 April and specific conductivities of approximately 160 µS cm^{-1}. Pond A (Figure 2) had an area of 6,500 m^2, relatively poor water quality and water depths ranging from 1 to 4 m. Aquatic plants present in the pond included water lily (Nymphaeaceae), parrot's feather (*Myriophyllum aquaticum*) and oxygen weed (*Egeria densa*) with riparian vegetation comprising a variety of native (ferns, etc) and introduced (bamboo, willows, etc) species. Pond B (Figure 3) had an area of 1,800 m^2 when it was full but during fishing the water level had been drained and the fishable area of the pond was reduced to around 1,000 m^2. Aquatic plants present in this pond consisted primarily of water lily and the surrounding vegetation was similar to pond A. Activity on the pond (fishing) resulted in significant sediment re-suspension which greatly reduced water clarity.

Figure 2: Pond A which is believed to be the possible liberation point of koi carp in the Kauri Point catchment. Photo: John Heaphy.

Figure 3: Pond B which is one of the ponds that can be drained completely as it has a drain pipe at the end of the pond at the top of the picture. Photo: John Heaphy.

Pond C (Figure 4) had a total area of 1,750 m^2 but it was divided into two sections by a timber barrier preventing the passage of the boat. The pond was situated in the middle of a kiwifruit orchard and so the surrounding vegetation was made up of pasture and kiwifruit plants.

Figure 4: Pond C located in the midst of a kiwifruit orchard. The water level in the pond was higher during the period of fishing. Photo: John Heaphy.

4. Results

We caught and removed 327 fish from the three ponds located within the Kauri Point catchment on 21 and 22 April 2008 with a combination of boat-electrofishing and gill netting. The fish community comprised three introduced species which were koi carp, goldfish (*Carassius auratus*), mosquitofish (*Gambusia affinis*) and koi-goldfish hybrids. The fish caught and removed comprised mainly koi carp (307 individuals) which dominated the biomass with an estimated total of 137.5 kg in the three ponds (Table 1). Mosquitofish (*Gambusia affinis*) and eels were observed to be quite abundant in all three ponds but no attempt was made to capture them or quantify their abundance. Inanga (*Galaxias maculatus*) were captured in the top section of pond C but were returned once electric fishing had stopped. Pond A contained the majority of the koi carp in the Kauri Point catchment and had a total estimated biomass of 180 kg ha^{-1}. As well as koi carp, pond A contained goldfish (1 confirmed individual caught, 240 mm FL) and koi-goldfish hybrids (19 individuals, 255 mm – 410 mm FL) whereas no goldfish or koi-goldfish hybrids were caught in ponds B and C. Boat electrofishing proved to be significantly more successful in the capture of fish than gill netting as it caught 308 individuals with a range of different species and size classes. Gill netting only caught 19 fish (all koi carp) and with the exception of three fish caught by just the tail, all the fish were of a similar size (120-180 mm FL). During electric fishing passes it was observed that large fish were hitting the nets but due to their large size and the small mesh size of the gill nets they were able to avoid capture.

Table 1: Densities and biomasses of koi carp caught in the three ponds in the Kauri Point catchment on 21 & 22 April 2008. Weights of koi carp were calculated using the regression equation: ln weight = 2.7298 ln length - 9.1403 (Tempero, 2004).

Site	No. of fish	Density (fish 100 m^{-2})	Biomass (kg)	Biomass (kg 100 m^{-2})
Pond A	299	4.6	118.5	1.8
Pond B	5	0.5	9.7	1.0
Pond C	3	0.2	9.3	0.5

There was a large range in the sizes of koi carp caught in pond A with fork lengths ranging from 70 mm to 510 mm. The length-frequency distribution (Figure 5) shows that there were at least four size classes of koi carp present (Figure 6) and that small koi carp (< 200 mm) were abundant. Figure 5 also shows that boat electrofishing was more successful than gill netting in catching and removing koi from the ponds in the Kauri Point catchment as many more fish were caught from a greater size range than gill netting. Five koi carp were found in pond B and the sizes of koi in this pond were fairly similar with an average length of 450 mm. Only 3 koi carp were caught in pond C with two of the fish being large individuals (525 and 690 mm) and one smaller (250 mm). A small sub-sample of koi carp (n = 34) from pond A was returned to the laboratory to determine their ages by examining their scales. There was a significant variation in sizes at any given age (i.e. some 200 mm koi were 1-year olds whereas other 200 mm koi were 2-year olds). In pond A, individual koi carp ranged from age 1 through to an age of 8 years-old. The largest fish captured from the Kauri Point catchment was caught in Pond C with a fork length of 690 mm and examination of its scales indicatedit was at least 12 years-old.

The sub-sample of koi carp (n = 34) were also sexed and included 10 mature males, 7 mature females and 17 immature fish which were unable to be sexed. Thus in pond A the sex ratio of males to females was fairly close to 1:1. The 17 indeterminate fish were age 1 and 2 koi carp that had not yet reached sexual maturity. According to the definitions of Fouché et al. (1985), most of the mature females were at reproductive stage III which is in the early development stage where the ovary is opaque and reddish with blood vessels, and eggs are visible to the eye.

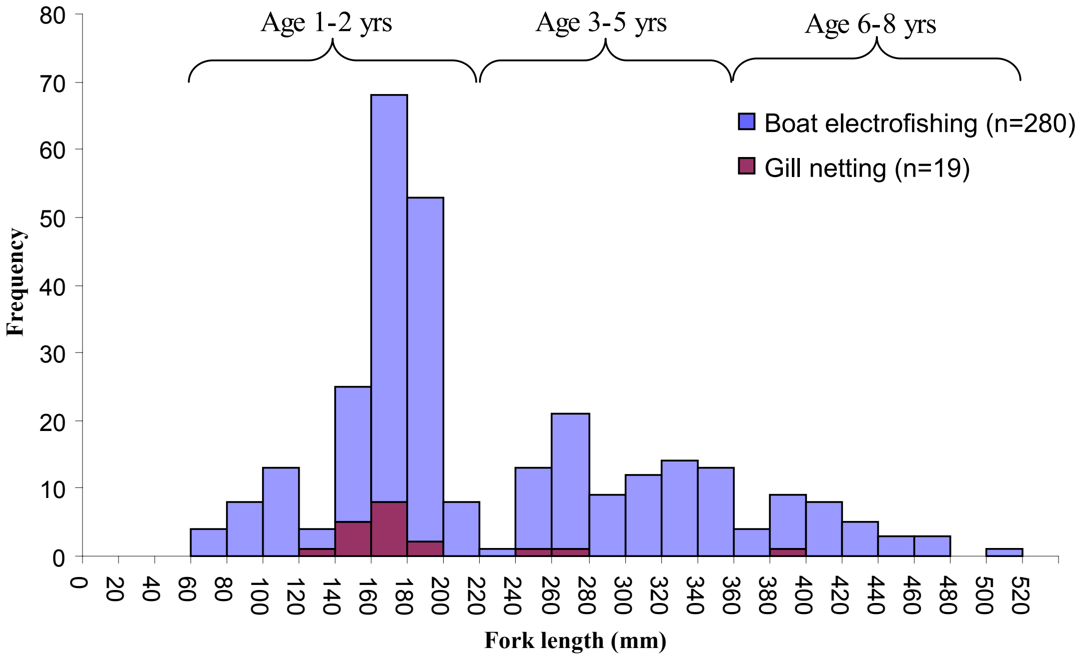

Figure 5: Length-frequency distribution and the associated age groups of koi carp caught by boat electrofishing and gill netting in pond A in the Kauri Point catchment on 21-22 April 2008.

Figure 6: Different size classes and visual appearances of koi carp captured and removed from pond A in the Kauri Point catchment on 21-22 April 2008. Photo: John Heaphy.

On 22 April, three successive day-time fishing passes were carried out in pond A. Every pass fished the entire pond which involved a lap around the perimeter and then a pass through the middle. On the first pass (8:55 to 10:05 h) we caught and removed 52 koi carp, followed by 38 koi on the second pass (11:45 to 12:55 h) and 25 koi on the last pass (13:45 to 14:55 h) (Table 2). Applying the method developed by Zippin (1958), as described in Armour et al. (1983), to these multiple-pass reductions the estimated total koi carp population in Pond A on 22 April 2008 was 174 ± 66 fish (Table 2a). Because the probability of capture ($\hat{p}$) was quite low and the variance quite high, the lower bound population estimate of 108 fish is lower than the actual number of fish removed and thus the lower bound population estimate is changed to 115 fish. If we take into account the 184 koi removed on 21 April then the original population size in pond A was estimated to be 358 ± 66 fish and thus there could be as many as 125 koi carp remaining in the pond. Total biomass estimates can be made using the same removal method as described above but replacing numbers of fish with successive biomasses of koi carp removed (Hicks and McCaughan, 1997). Table 2b estimates that on the same day the total koi carp biomass in the pond was 63.1 ± 44.3 kg. The lower bound biomass estimate is again lower than the actual biomass of koi carp removed and thus the lower biomass estimate is adjusted to 40.3 kg. Including the 82.0 kg of koi carp removed from pond A on the 21 April 2008, the original biomass in pond A was estimated to be 145.1 ± 44.3 and so there may be as much as 67.1 kg of koi carp remaining in the pond. Another method of estimating biomass is to multiply the mean weight of koi carp from pond A (0.423) by the population estimate (174 koi carp). Using this equation estimates the total biomass of koi carp on 22 April 2008 as 73.6 kg.

Table 2: Three pass removal population estimate (a) and total biomass estimate (b) of koi carp made from successive captures without replacement during day-time boat electrofishing in pond A, Kauri Point catchment on 22 April 2008. 184 koi carp or 82.0 kg of biomass had already been removed on 21 April 2008. $\hat{p}$ = capture probability; 95% CI = 95% confidence interval; SE = standard error.

a) Removal population estimate

Age class	Number of fish				$\hat{p}$	Population estimate	Variance	SE	95% CI
	1st pass	2nd pass	3rd pass	Sum (M)					
All ages	52	38	25	115	0.3	174	1099	33	66

b) Total biomass estimate

Age class	Total Biomass (kg)				$\hat{p}$	Biomass estimate	Variance	SE	95% CI
	1st pass	2nd pass	3rd pass	Sum (M)					
All ages	18.2	12.8	9.3	40.3	0.3	63.1	490.0	22.1	44.3

Figure 7 shows that numbers of fish and amount of biomass removed from Pond A decreases with each successive fishing episode. The number of fish and amount of biomass removed is far greater in fishing episode 1 compared to fishing episodes 2 to 4. The reason for this is that fishing episode 1 contains over 3 hours of fishing time whereas fishing episode 2 to 4 are each over an hour long. Catch rates (no. of fish per hour) steadily decline in a linear relationship with each successive fishing episode with initial catch rates of 50 fish per hour (fishing episode 1) to approximately 20 fish per hour (fishing episode 4). Assuming catch rates continue to decrease in a linear fashion then it would take a further 3 fishing episodes to reach a catch rate of 0 fish per hour which indicates that only a small proportion of the original number of fish remain in the pond.

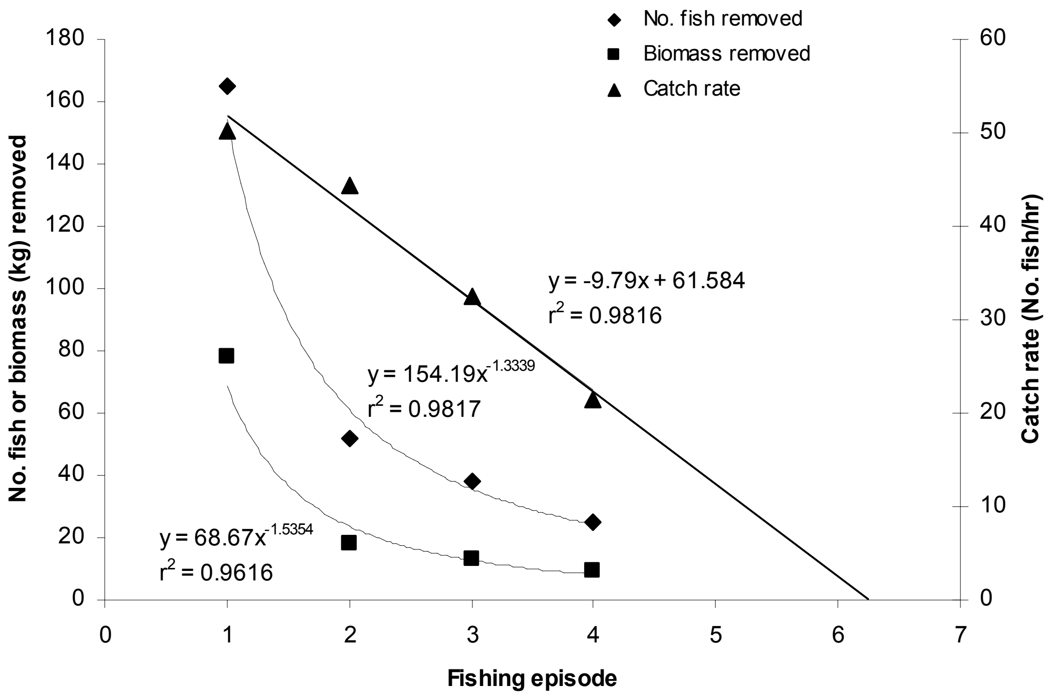

Figure 7: Number and biomass of koi carp removed and the catch rates found during the boat-electrofishing episodes on 21 and 22 March 2008 from pond A in the Kauri Point catchment.

5. Discussion

On 21 and 22 April 2008, a combination of boat-electrofishing and gill netting confirmed that there were koi carp present in all of the three ponds with 299 koi carp captured and removed from pond A (4.6 fish 100 m^{-2}), 5 koi carp from pond B (0.5 fish 100 m^{-2}) and 3 koi carp from pond C (0.2 fish 100 m^{-2}). As well as koi carp in pond A other introduced species removed included 19 koi/goldfish hybrids and 1 goldfish. These fish may have been the unidentified dark fish that had been observed in this pond as all of these individuals were a dark green to brown colour. Previous fishing with the electrofishing boat in the North Island, in waters with similar conductivity and habitats as those in the Kauri Point catchment, with similar electrical pulse and current settings, has caught a full size range of eels, smelt, bullies, grey mullet, rudd, brown bullhead catfish, perch, tench, goldfish, and koi carp (Hicks et al., 2005; 2006). The moderate conductivities of the 3 ponds in the Kauri Point catchment allowed efficient power transfer from the water to the fish as the range of conductivities was about the same as the presumed conductivity of the fish; goldfish have effective conductivities of about 100-160 µS cm^{-1} (Kolz and Reynolds 1989). Given the intense electrofishing effort carried out on the ponds on 21 and 22 April 2008 it is highly likely that koi carp, mosquitofish, goldfish and the koi/goldfish hybrids were the only introduced fish species that are present in these ponds. Boat electrofishing proved to be a lot more successful than the deployment of gill nets as it captured a greater range of koi carp than netting and in far greater numbers.

Over 130 kg of koi carp biomass was removed from the three ponds in the Kauri Point catchment over the two days of boat-electrofishing. Biomass is a more accurate reflection of the potential ecological impact of koi carp than their density and koi carp had a reasonably high biomass in pond A of 1.8 kg 100 m^{-2} or 180 kg ha^{-1}. This value is comparable to the average biomass of koi carp (148 to 308 kg ha^{-1}) found in the main channel of the Waikato River between Hamilton City and Rangiriri (Hicks et al. 2005). The high biomass of koi carp in pond A is of ecological concern for the Kauri Point catchment as they are an unwanted organism and have a deleterious impact on aquatic habitats (Roberts & Ebner, 1997).

Prior to boat-electrofishing it was not confirmed if koi carp were successfully breeding within the system although it was known that at least two distinct size classes were present. Electric fishing caught a wide size range of koi (from a 70 mm juvenile to a 510 mm adult) in pond A, and the presence of at least four size classes and a high proportion of small fish (<200 mm) strongly suggests that successful breeding is occurring. As expected, by examining the scales of a small sub-sample of koi (n=34) it was determined that there was a wide range of ages in pond A from 1 through to 8 year-old carp. Further evidence of breeding was the presence of mature females in reproductive stage III (according to the definitions of Fouché et al., 1985). Along with reproductively active females there was roughly an equal number of reproductive males which would ensure successful breeding in a pond the size of pond A. Temperatures between 18ºC and 28ºC are optimum temperatures associated with the spawning period of koi carp (McCrimmon, 1968), although spawning has been observed at water temperatures as low as 15ºC (Stuart & Jones, 2002). The mean temperatures in the Katikati area between September and January are easily within the range preferred for koi carp spawning and thus should pose no restriction to successful breeding. No small juvenile koi carp were present in either pond B or C and thus it cannot be confirmed that breeding is occurring in these two ponds. Pond C was home to the largest koi carp caught in the western Bay of Plenty region with a length of 690 mm, a weight of 6 kg and an age in excess of 12 years.

Taking into account the 184 koi carp or 82.01 kg of koi carp biomass removed on 21 April 2008 out of pond A we estimated that the population size and total biomass of koi carp prior to removal of fish by boat-electrofishing was around 358 ± 66 fish and 145.1 ±

44.3 kg, respectively. This is a crude estimate due to the low capture probability of koi carp in pond A ($\hat{p}$ approximately 0.3). Capture probabilities of 0.47 found by Hicks et al. (2005) in the lakes and rivers in the Waikato region and 0.54-0.86 found by Jowett and Richardson (1996) in wadeable New Zealand streams and rivers were somewhat higher than the capture probability found in the Kauri Point ponds. Capture probability is heavily influenced by factors such as water visibility which was found to be very poor in the Kauri Point ponds. Also some koi carp tend to sink to the bottom rather than float to the top when they enter an electro-narcotised state which also has an effect on capture probability. Over the two days of intensive boat-electrofishing we removed 71-84% of the estimated population which leaves a possible total of 125 koi carp or 67.11 kg of koi carp biomass remaining in pond A. Catch rates (number of koi carp removed per hour) were found to decrease linearly with each successive fishing episode and assuming that catch rates continue to decrease at the same rate between episodes then 3 more one-hour fishing episodes would be required to reach a catch rate of 0 fish per hour. However, reaching a catch rate of zero fish per hour does not represent the point where all of the fish have been captured. Continually increasing efforts will result in slowly declining catches.

Although boat-electrofishing removed over 130 kg of koi carp biomass, as a tool for the eradication of koi in the ponds within the Kauri Point catchment it was not successful in any of the three ponds. This can mainly be attributed to the very low water visibility in the ponds which prevented us being able to “stalk” schools of koi and then pulse the current once we were within range of the school. Since we were unable to “stalk” the koi we had to fish with the current continuously on and this can allow some koi to detect the field and escape before they enter tetany (stationary and stiff state). Also the low visibility made it increasingly difficult to capture narcotised koi before they sank. The high proportion of small koi also makes it difficult because the smaller juveniles can be hard to observe and capture because they tend to hide among macrophyte foliage at the edges of the ponds. Gill netting was also not a viable option for the eradication of koi carp due to the low catch rates and the large amounts of aquatic weed which got trapped in the nets, making cleaning of nets almost impossible in some cases. Boat-electrofishing may be able to eradicate the koi remaining in the ponds but this would require an intensive effort spanning a number of days prior to spawning and this would be unlikely to be cost effective given that it is unlikely that every single koi would be captured. Thus for the eradication of koi carp in this system the most viable eradication options remaining would be draining of the ponds, and/or the addition of a poison (i.e. rotenone) followed by the removal of all dead koi. If ponds were being treated one pond at a time then fish barriers would need to be installed to prevent reinvasion from the other ponds.

6. Acknowledgements

We gratefully acknowledge the assistance in the field from David Klee and Reade Bell (University of Waikato) and Jessica Larkin & Natasha Grainger (Department of Conservation). We also appreciate the assistance of Grant Tempero (University of Waikato) in the laboratory with ageing the koi carp and providing valuable information concerning the reproduction and condition of koi carp.

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