5.2 Removal of Invasive Fish and Exclusion of Koi Carp from Lake Ohinewai

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Management Issues

The lower Waikato River floodplain contains many shallow lakes. The floodplain has been highly developed for pastoral agriculture, primarily dairy farming, resulting in extensive drainage and flood control measures to regulate river and lake levels. Most lakes have degraded water quality as a result of nutrient and sediment enrichment, and the additional impacts of pest fish such as koi carp, goldfish, catfish and rudd have generally contributed to the total collapse of submerged macrophytes and progression to a highly eutrophic state. Of all New Zealand lakes monitored regularly for water quality, around 25% of those categorised as supertrophic or hypertrophic are on the Waikato River floodplain (Verburg *et al.* 2010).

Lake Ohinewai is a shallow (4.5 m depth), 16.8 ha lake on the floodplain. The lake has a 331 ha catchment that is primarily flat and dominated by intensive pastoral farming with several inlet drains. A single outlet drain leads to Lake Waikare via Lake Rotokawau and passes through a circular road culvert 930 m from the lake outlet. Lake Ohinewai deteriorated from a stable oligotrophic (macrophyte-dominated) state to a stable eutrophic (algal-dominated) state during the early 1990s, and now lacks aquatic macrophytes. In 1981, 80% of the lake was covered in aquatic macrophytes but by 1991 none remained (Edwards *et al.* 2005). Invasion by koi carp over this period was implicated in this change of state.

Control Approaches

To remove koi carp and other invasive fish, three mark-removal events were carried out in Lake Ohinewai in early 2011, late 2011 and late 2014. Three additional removal-only events occurred in early 2013, mid-2013 and late 2013. Fishing methods included boat electrofishing, fyke netting, automated feeder-traps and beach seining; dates for mark-removal and fishing effort are given in Table 5.1.

Boat electrofishing (see Section 4.4) was conducted in 20-minute sampling periods and concentrated on shallow-water habitat near the shore. A mixture of baited and unbaited large and small-mesh fyke nets were set at sites distributed evenly around the lake shore and in the outlet, with fishing effort ranging from 122–240 net nights during the first two mark-removal events. Fyke netting effort was reduced for the final mark-removal event (Table 5.1) as fyke netting was found to be highly effective for eel capture but often produced comparatively low invasive fish catch per unit effort (CPUE) at lower pest

SUGGESTED CITATION FOR SECTION 5.2: Tempero G, Ling N, Daniel AJ, Morgan D 2015. Removal and Exclusion of Koi Carp from Lake Ohinewai. Section 5.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 90–94.

fish densities (<50 kg/ha). Feeder traps ('pod traps'; see Section 6.3) were deployed during the removal phase in late 2011. These traps were found to be highly effective but required a pre-capture feeding period to maximise catch rates, making comparisons of CPUE difficult; consequently they were not deployed in late 2014. Beach seining was attempted during the removal phase in early 2011 using a 100 m fine-mesh seine, however this was abandoned due to obstructions on the lake bed and very low catch rates (two fish from three seines).

Fish were marked using left pectoral fin clips (rudd, goldfish and koi carp) or dorsal spine removal (catfish) and released on the western end of the lake. To satisfy the assumptions of a Lincoln-Petersen mark recapture study (closed population), the fish population was isolated using a temporary barrier in the outlet drain consisting of 30 mm-mesh netting. Population estimates were calculated using the Lincoln-Petersen method with the program Mark-recapture (www.bioquest.org/esteem). Biomass estimates are for fish >75 mm due to the bias of sampling methods toward larger fish.

Following the removal operation in 2011, a permanent adult pest fish barrier was installed on the 1,400 mm diameter culvert under Tahuna Road to block upstream movement of adult invasive fish into Lake Ohinewai (Daniel & Morgan 2011). Telemetry tracking of koi carp in the lower Waikato River and riverine lakes has suggested that up to 75% of koi carp will leave lakes at some point in their life history (Daniel *et al.* 2011). Following installation of the barrier (see Plate 4.7), a second mark-recapture study was undertaken over November 2011 to February 2012 to assess the status of pest fish populations in the lake. In November and December 2014, a third mark-recapture study was undertaken to assess the long-term effectiveness of the barrier.

TABLE 5.1 Fishing effort and timing of three mark-removal and three removal events of non-indigenous invasive fish from Lake Ohinewai. N/A = not applicable.

EVENT	DATE	MARK/ REMOVAL	FISHING METHOD/INTENSITY			
			BOAT ELECTROFISHING (minutes)	FYKE (net nights)	FEEDER (POD) TRAP (net nights)	SEINE (net pulls)
Early 2011	17 Jan 2011-19 Jan 2011	Marking	220	80	N/A	0
	24 Jan 2011-28 Jan 2011	Removal	400	160	N/A	3
Mid-2011	1 Feb 2011-16 Jun 2011	Removal	N/A	N/A	186	N/A
Fish barrier installed on outlet						
Late 2011	17 Nov 2011-21 Nov 2011	Marking	220	240	1	N/A
	29 Nov 2011-16 Jan 2012	Removal	220	122	81	N/A
Early 2013	7-8 Jan 2013	Removal	100	10	N/A	N/A
Late 2013	2 Dec 2013	Removal	130	N/A	N/A	N/A
Late 2014	18 Nov 2014-20 Nov 2014	Marking	360	56	N/A	N/A
	2 Dec 2014-4 Dec 2014	Removal	360	59	N/A	N/A

Monitoring

The initial mark-removal effort in early 2011 reduced the invasive fish biomass by 1.11 tonnes comprising koi carp (84.3%), goldfish (6.5%), catfish (9.5%), rudd (0.4%) and carp-goldfish hybrids (0.2%). Initial biomass estimates for these species at the start and end of this period are given in Table 5.2, along with biomass estimates determined in subsequent fish removals. A further two tonnes of exotic fish biomass (90% koi carp, 7% goldfish, 3% catfish) were removed between February and June 2011. These efforts resulted in more than 79% of the koi carp biomass being removed during this period, reducing the estimated biomass to below 100 kg/ha. Following this removal and the installation of a one-way pest fish barrier, a further mark-removal programme was conducted from November 2011 to January 2012. Initial estimates of koi carp biomass showed a further reduction in biomass to <50 kg/ha indicating significant loss of carp biomass from the lake in the intervening period, presumably resulting from downstream movement of carp through the one-way barrier.

Adult koi carp are known to undertake significant migrations between suitable feeding and spawning habitat as adults. It is therefore inferred that the reduction in carp biomass occurred as a result of adult carp leaving the lake during winter. The lake outlet barrier appeared to have reduced the biomass of carp only, as the biomass of other invasive species in the lake remained largely unchanged. Poor recapture rates in late 2011 for both marked and unmarked goldfish resulted in population estimates with unacceptably wide confidence intervals, therefore population and biomass estimates are not presented for that species (Table 5.2). By late 2014 the koi carp biomass had further reduced to 13 kg/ha, and following removal of a further 44 kg of biomass, estimated koi carp biomass was 10 kg/ha, 3% of the original biomass in the lake. It should be noted that the mean weight of captured koi carp reduced from 0.889 kg prior to the removals to 0.614 kg, indicating a reduction in large breeding fish from the lake. Reductions in biomass have also been observed in catfish (-39%) and goldfish (-63%) from initial estimates in early 2011 compared to late 2014.

Outcomes

The reduction in invasive fish biomass has been associated with modest improvements in water clarity, with Secchi disc depth increasing from 0.30 m to 0.45 m between 2011 and 2014. Following extended periods of settled weather during the early summer, Secchi depths of up to 0.9 m have been recorded. Positive changes in the eel population have also occurred, with small increases in shortfin eel fyke net CPUE from 9.8 fish/net/night in early 2011 to 15.3 fish/net/night in late 2014. Longfin eel CPUE increased from 0.2 fish/net/night to 0.3 fish/net/night for the same period. Further analysis of eel population structure is still being conducted, but anecdotal observations suggest an increase in the number of large eels in excess of 1 kg. Rudd numbers have remained stable with only a handful of individuals caught each year. Other introduced species, such as perch and tench, remain absent from the lake. Although there have been no quantitative assessments, it is clear that macrophytes are regenerating along lake edges, although these are primarily non-indigenous species of *Myriophyllum* and *Ludwigia*.

Lessons Learned

It is highly likely that the biomass of koi carp in this lake contributed to persistently poor water quality and the algal-dominated eutrophic state. Eradication of a population of koi carp from a waterbody is unlikely using active fishing methods without resorting to options such as poisoning, and the costs required to reduce biomass by active fishing rise exponentially as fish biomass declines. Thus, it is much cheaper to fish a population biomass from 400 to 300 kg/ha than it is to fish a population from 200 to 100 kg/ha. Cheap and effective devices that reduce fish biomass in passive ways are therefore highly cost-effective if they can exploit particular fish behaviours such as migration.

TABLE 5.2 Total biomass (kg) of koi carp, goldfish and catfish removed from Lake Ohinewai during three removals and three mark-removals conducted between 2011 and 2014. Population estimates and biomass (95% confidence limits in parentheses) of invasive fish in Lake Ohinewai prior to and following fish mark-removals are also presented. A one-way barrier was installed on the lake outlet following the mid-2011 removal. N/A = Not available.

	TOTAL BIOMASS REMOVED (kg)	INITIAL POPULATION (*n*)	POPULATION FOLLOWING REMOVAL (*n*)	INITIAL BIOMASS (kg/ha)	BIOMASS FOLLOWING REMOVAL (kg/ha)	BIOMASS REMOVED (%)
KOI CARP						
Early 2011	938	8,831 (533-12,129)	7,509 (4,211-10,807)	374 (234-513)	318 (178-457)	15
Mid-2011	1,814	N/A	N/A	N/A	N/A	N/A
Late 2011	149	1479 (796-2,163)	1187 (504-1,871)	45 (24-66)	36 (15-57)	20
Early 2013	35	N/A	N/A	N/A	N/A	N/A
Late 2013	24	N/A	N/A	N/A	N/A	N/A
Late 2014	44	490 (215-764)	392 (117-666)	13 (6-20)	10 (3-18)	20
CATFISH						
Early 2011	105	1566 (1,277-1,854)	896 (607-1,184)	15 (12-17)	8 (6-11)	43
Mid-2011	54	N/A	N/A	N/A	N/A	N/A
Late 2011	33	1407 (1,042-1,772)	1,176 (811-1,541)	12 (9-15)	9 (7-13)	16
Early 2013	11	N/A	N/A	N/A	N/A	N/A
Late 2013	2	N/A	N/A	N/A	N/A	N/A
Late 2014	29	815 (609-1,020)	658 (452-863)	9 (7-11)	7 (5-10)	19
GOLDFISH						
Early 2011	62	942 (332-1,551)	530 (0-1,139)	9 (3-14)	5 (0-10)	44
Mid-2011	145	N/A	N/A	N/A	N/A	N/A
Late 2011	24	N/A	N/A	N/A	N/A	N/A
Early 2013	6	N/A	N/A	N/A	N/A	N/A
Late 2013	1	N/A	N/A	N/A	N/A	N/A
Late 2014	19	471 (283-659)	295 (107-483)	3 (2-4)	2 (1-3)	37

In this study, the installation of a simple barrier to allow adult carp to leave but not return to the lake appears to have achieved an effective reduction in biomass from an estimated ~100 kg/ha in mid-2011 to <50 kg/ha in late 2011, thereby removing some 850 kg of carp biomass from the lake during this six month period through passive measures. Further reductions in koi carp biomass have occurred due to active removal and ongoing passive exclusion by the outlet barrier. The cost of actively fishing the population with a wide range of methods, including 40 fyke nets, multiple other large nets and traps, seining and electrofishing over several months, was estimated at around 1,288 person hours and in excess of $40,000 to achieve a reduction in biomass from 374 kg/ha to c.100 kg/ha. The installation of the carp exclusion screen, which achieved a further c.50 kg/ha biomass reduction, was therefore highly cost-effective at around $5,000. Furthermore, it required relatively little maintenance at around six visits per year to clear debris and ensure that the hinged weighted bars were still moving freely. Such devices may be effective aids to reduce carp biomass if installed at locations that allow the migratory movement of adult carp to be exploited.