

6.2 Biomass Estimation of Invasive Fish

Brendan J Hicks, Jeroen Brijs¹, Adam Daniel², Dai KJ Morgan³ & Nicholas Ling

The University of Waikato, Hamilton, New Zealand

Present addresses:

¹ University of Gothenburg, Gothenburg, Sweden

² Fish & Game New Zealand, Auckland/Waikato Region, Hamilton, New Zealand

³ NorthTec, Whangarei, New Zealand

Introduction

Invasive fish have a variety of effects on indigenous fish communities and freshwater ecosystems generally, and the magnitude of these effects is partly dependent on invasive fish biomass. For example, a koi carp biomass of 120-130 kg/ha was sufficient to depress macroinvertebrate and plant biomass, and to elevate chlorophyll *a* concentrations (Haas *et al.* 2007; Bajer *et al.* 2009; Hicks *et al.* 2011). The purpose of this section is to provide (i) estimates of the relative biomasses of invasive fish that have been established by boat electrofishing in a range of lake and riverine habitats in the North Island; and (ii) some estimates of absolute biomass derived from mark-recapture studies in shallow lakes. Collectively, these data provide a basis for future comparisons of invasive fish monitoring information in a region where coarse fish have proliferated.

Relative Biomass Estimates of Invasive Fish in Waikato Lakes

Reliable data on fish abundance are difficult to collect. The reasons for this are varied, but the principle impediments are the selective nature of sampling gear, patchy distribution of the fish themselves, and behaviour of the fish. Boat electrofishing offers a rapid and quantitative sampling tool in non-wadeable freshwater habitats (see Section 4.4), and a number of quantitative surveys have been conducted of shallow lakes in the Waikato region using this method (Table 6.3, Figure 6.2). Between March 2007 and February 2014, this involved 10-minute shots in 16 lakes, with 9-11 shots in each lake, fishing primarily in the littoral zone but also in open water at depths less than 3 m. Two lakes were fished twice (Kimihia and Waahi).

The total weight of each species caught was divided by four times the length of the fishing track, as determined by a Garmin GPSMAP 60Cx global positioning unit, to give a biomass for each species per hectare, with the electrofishing pulsator setting as described in Section 4.4. This approach should be considered as providing a minimum biomass estimate for each species because single-pass boat electrofishing catches on average 48% of the total population, and does not take into account the bias of boat electrofishing against eels and catfish (see sections 4.4 and 6.3).

We caught nine species of non-indigenous fish, mostly koi carp, goldfish, brown bullhead catfish and rudd, and six species of indigenous fish of which shortfin eel, common bully and common smelt were the most widespread (Table 6.3). In most lakes with koi carp, their biomass was the highest of any species, with a maximum of 189 kg/ha in Lake Kimihia in 2012. Koi carp biomasses in lakes Kimihia, Whangape and Hakanoa (Table 6.3), once corrected for the proportion of the total population caught by boat electrofishing, exceeded the biomass threshold of 50-100 kg/ha for impaired water quality and

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TABLE 6.3 Original fish biomass estimates from boat electrofishing in water <3 m deep for 16 Waikato lakes before fish removal. Note: Oranga is a pond on The University of Waikato campus; three adult koi weighing a total of 9.55 kg (13.8 kg/ha) were removed by bow fishing before boat electrofishing.

LAKE	SURVEY DATE	AREA (ha)	MAX. DEPTH (m)	n	MEAN FISH BIOMASS (kg/ha)																	
					INDIGENOUS SPECIES						NON-INDIGENOUS SPECIES											
					Shortfin eel	Longfin eel	Common bully	Common smelt	Grey mullet	Tānanga	Koi carp	Goldfish	Catfish	Rudd	Perch	Koi/goldfish hybrid	Tench	Rainbow trout	Gambusia	TOTAL (non-indigenous)	TOTAL (all species)	PERCENT (non-indigenous)
Hakanoa	16 Oct 09	56	2.5	10	8.7	0	0.04	0.010	1.6	0	90.6	4.5	5.6	0	0	0	0	0	0.020	101	111	91
Kainui	18 Sep 09	25	6.7	9	72.0	1.4	0.08	0	0	0	0	3.0	5.9	0.1	0	0	0	0	0.100	9	82	11
Kaituna	14 May 09	15	1.3	10	56.8	0	0.59	0	0.052	0	37.7	77.1	4.8	1.5	0	0	0	0	0.020	121	179	68
Kimihia	21 May 09	58	1.0	10	5.9	0	0.03	0.060	0	0.010	13.9	27.1	1.4	1.0	0	0	0	0	0.100	43	49	88
Kimihia	6 Sep 12	58	1.0	11	7.3	0	0	0	0.1	0	189.4	93.3	11.1	0.9	0	0	0	0	0.100	295	302	98
Koromatua	4 Jun 09	7	0.8	9	31.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0
Mangahia	4 Feb 09	10	1.5	10	24.9	7.6	0	0	0	0	0	78.8	17.6	0	0	0	0	0	0.004	96	129	75
Ngaroto	2 Feb 09	130	3.5	11	6.1	0	0.02	0	0	0	22.2	0	1.7	2.4	0	4.4	0	0	0.012	31	37	83
Ohinewai	28 May 09	16	4.5	8	24.6	1.5	0.03	0	0	0	21.5	0.01	0.6	0	0	9.3	0	0	0.005	31	58	55
Oranga	22 Jan 14	0.69	0.8	10	19.1	0	1.64	0	0	0	0.8	18.4	3.0	0	0	5.3	0	0	0.477	28	49	57
Otamataeroa	28 Apr 09	5	3.0	10	75.9	0	0.11	0	0	0	0	11.4	1.0	0	0	0	0	1.0	0	13	90	15
Puketirini	10 Feb 14	54	64.0	9	1.2	0	0	0	0	0	55.1	0	0	2.4	0.9	0	0	0	0.020	58	60	98
Rotokaeo	12 Dec 08	3.7	1.8	9	26.4	0	0	0	0	0	0	8.6	3.0	0	0	0	0	0	0.020	12	38	31
Rotokauri	29 Sep 09	77	4.0	9	15.2	0	0.22	0.013	0	0	21.6	5.4	0.8	0	0	2.9	0	0	0.020	31	46	66
Rotoroa	9 Jan 12	54	6.0	10	4.5	0	0	0	0	0	0	0	3.1	0.1	6.7	0	8.0	0	0.100	18	23	80
Waahi	8 Mar 07	522	5.0	11	10.2	0	0.01	0.056	0	0.002	29.1	43.0	7.2	1.6	5.9	0	0	0	0.007	87	97	89
Waahi	23 Mar 11	522	5.0	9	5.1	0	0	0.020	0	0	22.2	22.3	2.2	2.3	7.5	0	0	0	0.020	56	62	92
Whangape	24 Aug 10	1450	3.5	9	11.7	0	0.04	0	1.3	0.030	98.8	72.7	4.4	0.5	0	0	0	0	0.020	176	189	93
MEAN					23	1	<1	<1	<1	<1	33	26	4	1	1	1	<1	<1	23	67	91	66

destruction of macrophytes (Bajer *et al.* 2009; Hicks & Ling 2015). Koi carp were not caught in Lake Mangahia during the fishing in February 2009, but 25 carp were caught by boat electrofishing during an intensive fish removal in 2010 (see Mark-recapture biomass estimates later in this section).

In over half of the lakes, non-indigenous fish comprised $\geq 80\%$ of the total fish biomass caught. At a maximum biomass of up to 93 kg/ha, goldfish were the next most abundant non-indigenous species behind koi carp, sometimes exceeding their biomass (e.g. in lakes Waahi and Kimihia in 2009). A severe drought in the summer of 2008 probably reduced the number of koi carp while affecting the goldfish population less because of their extreme tolerance to hypoxia. Tench and rainbow trout were each found in only one Waikato lake (rainbow trout in Lake Otamataeroa where they are stocked; tench in Lake Rotoroa). *Gambusia* were extremely widespread but comprised only a small biomass relative to other invasive fish species.

Relative Biomass Estimates of Invasive Fish in a Large River

The first electrofishing boat survey of the lower Waikato River and its tributaries was conducted between 8-15 February 2005 (Hicks *et al.* 2005). In total, 2,915 fish were caught in the river, comprising seven introduced and six native fish species in 5.63 km of fished length from a total of 27 sites (Figure 6.3). Again, assuming that the fishing track was 4 m wide, the total area fished was 22,520 m² or 2.252 ha.

Koi carp comprised 285 kg, or 69% (range 0-97% per site) of the 410 kg of fish caught. The majority of koi carp were caught in zones 2-4 (Table 6.4), where they occurred in all habitats except mid-channel sand bars. The greatest koi carp biomasses (up to 1,240 kg/ha) were associated with willow (*Salix*) fringes and macrophyte beds. The Waikato River is relatively narrow throughout most of Zone 1, with few beaches or gently shelving littoral areas. These habitats increase in number and extent in Zone 2,



FIGURE 6.2 Peat and riverine lakes of the Waikato region.

and the floodplain is most developed in Zone 3 where extensive flat, off-channel areas are lined by willows and extensive macrophyte beds. The lower end of Zone 4 is influenced by tidal water level fluctuations, and habitat is less usable by koi carp overall. Koi carp abundance reflected these habitat changes, and was highest in Zone 3. Goldfish and rudd, however, were most abundant around macrophyte beds in Zone 2. Abundance of the indigenous grey mullet, a large, benthivorous fish, was lowest where koi carp abundance was greatest, possibly suggesting competitive exclusion of grey mullet by koi carp.

In the Whangamarino River, which flows into the Waikato River from the Whangamarino Wetland, mean biomass of koi carp at 20 sites (326 kg/ha) was higher than in the Waikato River (Hicks *et al.* 2008; Table 6.4). Mean biomasses of goldfish (79 kg/ha) and catfish (5.9 kg/ha) were also higher in the Whangamarino River than in any site fished in the Waikato River, highlighting the importance of wetland tributaries for koi carp.

Mark-recapture Biomass Estimates

To quantify the biomass of invasive fish at representative sites and provide a basis for interpreting single-pass electrofishing estimates, mark-recapture techniques were used between 2010 and 2014 in shallow lakes ranging in area from 0.69 to 36 ha (Table 6.5). In these mark-recapture population estimates, fish were captured by boat electrofishing, fyke netting and pod trapping, marked with a fin clip and released back into the lake. Marked fish were allowed to mix with unmarked fish for a period of 2-6 weeks, and then the lake was re-sampled using the same methods. Non-indigenous fish were removed and humanely destroyed and native species were returned to the lake. Population estimates (N) were made based on the adjusted Petersen method (Ricker 1975), which uses the total number of fish originally marked (M), the total number recaptured (C), and the number of those fish that were marked (R), as follows:

$$N = \frac{(M + 1)(C + 1)}{R + 1} \quad \text{(Equation 2)}$$



FIGURE 6.3 Sites fished in the lower Waikato River between 8-15 February 2005. Green circles = fished sites; red circles = locations of zones breaks. Source: Hicks *et al.* (2005).

TABLE 6.4 Fish biomass estimates from boat electrofishing over 8-15 February 2005 at 27 sites in the Waikato River (separated into zones 1-4; Figure 6.3), and at 20 sites in the Whangamarino River and its tributaries on 3-6 March 2008.

SPECIES	MEAN BIOMASS (kg/ha)				
	WAIKATO RIVER				WHANGAMARINO RIVER
	ZONE 1	ZONE 2	ZONE 3	ZONE 4	
Number of sites	8	6	6	7	20
NON-INDIGENOUS SPECIES					
Koi carp	39.6	147.6	307.8	183.5	325.8
Goldfish	0.2	19.5	16.2	18.7	78.9
Rudd	0.4	7.7	4.2	1.4	2.5
Catfish	0	0	0.7	2.9	5.9
Brown trout	73.2	0	0	0	0
Rainbow trout	6.3	0	0	0	0
Koi-goldfish hybrid	0	0	2.6	0.6	0
Gambusia	0.001	0.010	0.013	0.009	-
INDIGENOUS SPECIES					
Shortfin eel	26.4	11.9	8.0	9.5	13.9
Grey mullet	22.5	16.6	5.3	29.9	9.5
Common smelt	2.8	1.1	0.6	1.4	0.70
Common bully	0.05	0.25	0.05	0.09	0.04
Īnanga	0.08	0.20	0.06	0.03	0.10
Longfin eel	0	0	0	0.19	0.40
Torrentfish	0	0	0	0.001	0
TOTAL SPECIES	172	205	346	248	438
TOTAL NON-INDIGENOUS SPECIES	120	175	331	207	413
% NON-INDIGENOUS SPECIES	70	85	96	83	94

- gambusia widely present but not enumerated

The greatest biomass of invasive fish was found in Lake Mangahia, which yielded 625 (out of a total of 670) kg/ha, comprising predominantly goldfish and catfish; there were also 37 kg/ha of shortfin eels and 8 kg/ha of longfin eels (Table 6.5A). The lowest invasive fish biomass was in the Rotopiko (Serpentine) lakes, from which rudd have been removed repeatedly by the Department of Conservation since 2001 (e.g. Neilson *et al.* 2004; see Section 5.4). No rudd were caught in these lakes during extensive netting between March and June 2012, and there were only low biomasses of catfish and goldfish (0.4-2.2 kg/ha); shortfin eels dominated the fish communities and ranged from 27-45 kg/ha (Table 6.5E). Lake Kuwakatai, a 36 ha dune lake on northern Auckland's west coast, had only a modest biomass of invasive fish (140 kg/ha) but a large number of rudd, mostly juveniles. Of the lakes surveyed, perch were caught only in Lake Kuwakatai (Table 6.5B). A lower biomass of invasive fish (123 kg/ha) was estimated in Lake Kaituna where koi carp dominated biomass but goldfish and eel were most abundant numerically (Table 6.5C).

TABLE 6.5 Population estimates of non-indigenous and indigenous fish species in shallow lakes (see Figure 6.2) calculated from the adjusted Petersen method (Ricker 1975).

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
A. Lake Mangahia: 25 Mar-23 Apr 2010 (area 10 ha)		
NON-INDIGENOUS FISH		
Catfish	4,875	66
Goldfish	24,245	556
Koi carp*	25	1.4
Rudd*	63	0.69
INDIGENOUS FISH		
Shortfin eel	822	37
Longfin eel	48	7.7
TOTAL	30,078	670
TOTAL NON-INDIGENOUS (%)	29,208	625 (93)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
B. Lake Kuwakatai: Nov 2011-Jan 2012 (area 36 ha)		
NON-INDIGENOUS FISH		
Goldfish	9,324	26
Koi carp	780	33
Perch	2,513	7.6
Rudd	28,934	28
Tench	12,676	43
INDIGENOUS FISH		
Shortfin eel	1	0.08
Kōura (crayfish)	2,400	2.1
TOTAL	56,629	140
TOTAL NON-INDIGENOUS (%)	54,228	138 (98)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
C. Lake Kaituna: 9 Sep-4 Nov 2010 (area 15 ha)		
NON-INDIGENOUS FISH		
Catfish	923	12
Goldfish	2,727	46
Koi carp	619	77
Rudd	302	3.3
INDIGENOUS FISH		
Shortfin eel	4,760	56
Longfin eel	45	1.1
TOTAL	9,376	193
TOTAL NON-INDIGENOUS (%)	4,571	123 (71)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
D. Lake Ohinewai: 17-28 Jan 2011 (area 16 ha)		
NON-INDIGENOUS FISH		
Catfish	1,559	15
Goldfish	878	8.3
Koi carp	8,549	374
Rudd	102	0.92
INDIGENOUS FISH		
Shortfin eel*	792	9.4
Longfin eel*	18	0.36
TOTAL	11,897	424
TOTAL NON-INDIGENOUS (%)	11,087	414 (98)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
E. Rotopiko (Serpentine) lakes: 28 Mar-22 Jun 2012		
South Lake (area 8.3 ha)		
NON-INDIGENOUS FISH		
Catfish	15	0.40
Gambusia*	1	-
Goldfish	20	0.62
INDIGENOUS FISH		
Shortfin eel	638	27
Longfin eel	13	1.4
Common bully*	819	-
Common smelt*	2	-
TOTAL	1,508	29
TOTAL NON-INDIGENOUS (%)	36	1.0 (3)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
North Lake (area 5.3 ha)		
NON-INDIGENOUS FISH		
Catfish	48	2.2
Gambusia*	1	-
INDIGENOUS FISH		
Shortfin eel	546	43
Longfin eel*	6	-
Common smelt*	21	-
TOTAL	622	46
TOTAL NON-INDIGENOUS (%)	49	2.2 (5)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
East Lake (area 1.6 ha)		
NON-INDIGENOUS FISH		
Catfish	8	0.7
INDIGENOUS FISH		
Shortfin eel	269	45
Longfin eel*	3	0.17
Common bully*	819	-
TOTAL	1,099	46
TOTAL NON-INDIGENOUS (%)	8	0.7 (2)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
F. Oranga Lake: 22 Jan-14 Mar 2014 (area 0.69 ha)		
NON-INDIGENOUS FISH		
Catfish	91	51
Goldfish >100 mm	231	126
Goldfish <100 mm*	1,327	8
Koi carp	120	26
Koi carp†	3	14
Koi-goldfish hybrids	18	27
Gambusia*	4,658	1
INDIGENOUS FISH		
Shortfin eel	299	148
Common bully*	1,433	2
TOTAL	8,179	402
TOTAL NON-INDIGENOUS (%)	6,447	252 (63)

* this is the actual number of fish caught because there were no marked fish

† removed by bow fishing

- missing data

In the smallest of the lakes surveyed, Lake Oranga, which was constructed as a storm-water detention pond on the campus of The University of Waikato, only goldfish >100 mm fork length were marked, so juveniles were estimated from the numbers removed during 38 10-minute boat electrofishing shots. This small lake had a goldfish biomass of at least 134 kg/ha (Table 6.5F), which is second only behind the estimate for Lake Mangahia (Table 6.5A). Koi carp were discovered in Lake Oranga about three years ago, and have yet to reach carrying capacity. To the biomass of 26 kg/ha determined by mark-recapture must be added three adults weighing 9.55 kg in total, equivalent to 14 kg/ha, that were removed by bow fishing before the mark-recapture fishing started. This lake therefore had an invasive fish biomass of at least 252 kg/ha, above the threshold considered to contribute to impaired water quality. Lake Ohinewai had the highest biomass of koi carp (374 kg/ha) of any lake for which mark-recapture biomass estimates were made (Table 6.5D).

Summary

In the lakes where invasive fish had not been controlled, biomass ranged from 123 to 625 kg/ha based on mark-recapture population estimates. High biomass of koi carp, which are highly migratory (Daniel *et al.* 2011), reflected ease of access to lakes, highlighting the importance of barriers to exclude koi carp. Lake Ohinewai had 374 kg/ha of koi carp and only 10 kg/ha of eels, but eel biomass seems to be increasing following koi carp removal (see Section 5.2). The rudd removal programme was clearly effective in the Rotopiko (Serpentine) lakes where eel biomass is within the range for most other Waikato lakes sampled (27-57 kg/ha).

Fish biomass estimates from boat electrofishing gave indicative information about the relative abundance and biomass of each species, but this was not always in accordance with the results of mark-recapture studies. For instance, in Lake Kaituna boat electrofishing caught about half of the koi carp population estimated by mark-recapture, whereas in Lake Ohinewai boat electrofishing caught about 6% of the mark-recapture estimate. The relative maximum depths of these lakes (1.3 m for Kaituna and 4.5 m for Ohinewai) suggests that in the deeper lake, many koi carp were out of range of the electrofishing field and evaded capture. In support of this conclusion, the depth sounder on the electrofishing boat did locate large fish at 2-4 m depth that were not caught during the Lake Ohinewai electrofishing.

At riverine sites, koi carp biomass was as high as in most lakes, especially in the Whangamarino River, a known hotspot for koi carp. Shortfin eels and grey mullet showed a somewhat inverse relationship with koi carp biomass between the four zones of the Waikato River, suggesting that competitive exclusion may be taking place and that reduction of carp biomass may help improve eel abundance. The most reliable recent information suggests that koi carp biomass should be <50-100 kg/ha to avoid environmental damage (Bajer *et al.* 2009, Baidou & Goldsborough 2010). Biomass exceeds this level in most sites around the Waikato River, and in its lakes and tributaries, often by a large margin. Goldfish are even more widespread than koi carp, and they are frequently the second most abundant invasive fish. The poor water clarity in Lake Mangahia, where goldfish biomass exceeded 500 kg/ha, suggests that they could be just as problematic as koi carp in terms of water quality impacts.