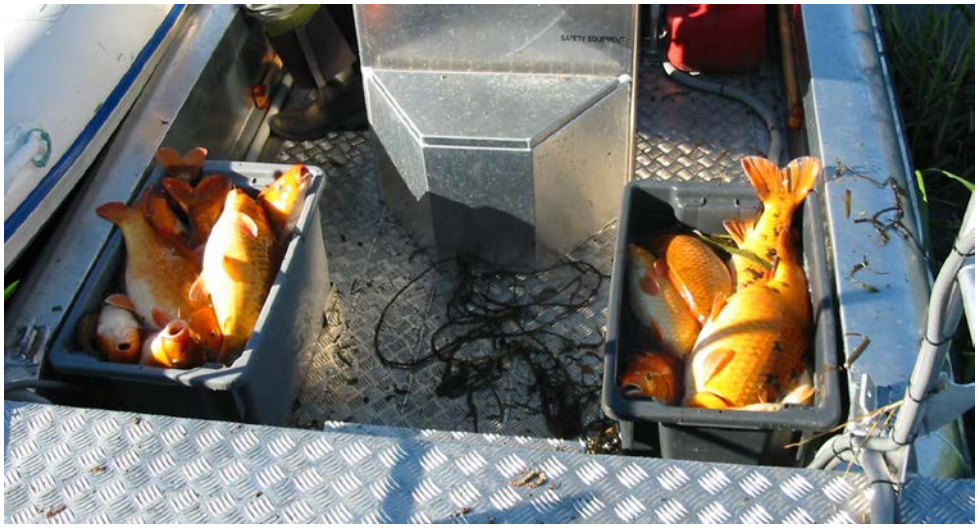
How many koi? Preliminary estimates of koi carp abundance from boat electrofishing

CBER Contract Report 59

by

Brendan J. Hicks



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Cover photo:

Catch of koi carp on board the University of Waikato's electrofishing boat. Photo: Brendan Hicks

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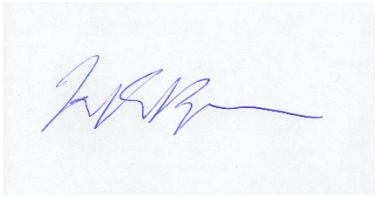

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Abstract

Single-pass boat-based electrofishing estimates of the abundance of koi carp (*Cyprinus carpio*) were made in the Waikato River, associated lakes and tributaries, and in two ponds. Catches were converted to density and biomass estimates using distances estimated from global positioning coordinates and a regression equation that related removal population estimates to the number of fish caught in the first pass. Biomass estimates ranged from 26 to 4,053 kg ha^{-1}, with a median of 548 kg ha^{-1}. Ninety-six of the 105 biomass estimates for sites with koi exceeded 150 kg ha^{-1}, a threshold biomass considered to represent the point at which removal of invasive fish will improve water quality. High as these biomass estimates are, the size frequency distribution suggests that koi are still increasing in abundance in the Waikato basin despite the period of at least 25 years since their initial introduction.

Removal of koi will be challenging. Extrapolations of koi densities to whole lakes suggest that Lake Whangape (1,079 ha) might have 165,000 spawners (604 tonnes), and Lake Waikare (3,438 ha) might have 466,000 spawners (851 tonnes). Lake Waahi (444 ha) might have 32,000 spawners (75 tonnes). Added to this, koi are distributed widely in the Waikato River below the Karapiro Dam, probably downstream as far as the estuary. Preliminary estimates of koi densities in four zones suggest that there are 65,000 koi in the river (70 tonnes) and its side channels. These biomass estimates must be regarded as preliminary because 1) an unknown proportion of the fish sensed the electrical field before falling within the capture voltage gradient threshold and were observed to swim away and 2) densities assumed for extrapolations might not apply to all of the extrapolated area. Despite these reservations, these estimates of koi in the Waikato River are conservative because extensive willow fringes and shallow margins were not fishable with the electrofishing boat. Most tributaries hold koi, and these add to the total. The extensive wetlands of the Waikato Basin (e.g., the Whangamarino and Opuatia wetlands) also hold unknown numbers of koi. Any eradication efforts should initially be focussed on water bodies where natural recolonisation

cannot occur, or where it can be prevented by suitable artificial barriers to the upstream migration of koi.

Methods

Fish capture

We used a 4.5-m long electrofishing boat with a 5-kilowatt gas-powered pulsator (GPP, model 5.0, Smith-Root Inc, Vancouver, Washington, USA) powered by a 6-kilowatt custom-wound generator. Two anode poles, each with an array of six droppers, created the fishing field at the bow, with the aluminium boat hull acting as the cathode (Figure 1).

Figure 1. The University of Waikato's electrofishing boat fishing on Lake Waikare near the outlet to the Pungarehu Canal.

Between 13 July 2003 and 16 March 2006 we fished 288 sites on the lower Waikato River, its tributaries and sides channels, and some of its lakes Waikato River sites were primarily at the margins. We also fished the Waitara, Whanganui, Manawatu, Whakatane, and Patea Rivers, and Waimapu and Kopurererua Streams, the lower Karori Reservoir, and ponds near Apata, Bay of Plenty, near Mokoia, southern Taranaki, and at Whitby, Wellington. We caught koi carp at 105 of these sites. Electrical conductivity was measured with a YSI 3200 conductivity meter. Specific conductivity (i.e., standardised to 25^{o}C), ranged from 156 to 256 μS cm^{-1}, so all sites were 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 40 and 70% to give an applied current of 3-4 A root mean square.

Estimation of length and area fished

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 appearance of koi at the water surface. Linear distance fished was estimated from linear distance measured with the global positioning system (GPS). The assumed transect width (4 m) was multiplied by the GPS distance to calculate area fished.

Calculation of density and biomass

We calculated density and biomass from the total numbers of koi caught per location by dividing the number and weight of koi caught by the respective areas fished. This represents a minimum number of koi present. We extrapolated the density and biomass to totals for each location by multiplying the location-specific densities and biomasses by the total habitat area.

Secondly, we applied equation 1 below to the number of koi caught to estimate the total number of fish present. The total number of koi present from previous comparisons of single-pass fishing with multiple-pass removal fish, using the following relationship:

$$Y = 1.55\ X^{1.23} \quad \text{equation 1,}$$

where Y = the number of fish determined from removal estimates, and X = the number of fish caught in the first pass (Hicks et al. 2006). For two-pass removal estimates, the equations of Zippin (1958) as redefined in Armour et al. (1983) and Hicks and McCaughan (1997) were used, and for more than two passes, the program CAPTURE was used (White et al. 1982). We calculated biomass by multiplying the estimated number of koi by the mean koi weight for each site. These estimates were also extrapolated to the density and biomass to totals for each habitat by multiplying these densities and biomasses by the habitat area.

To calculate the number and biomass of koi in the Waikato River we divided the river between Karapiro and Mercer into four zones: zone 1, Karapiro to Hamilton; zone 2, Hamilton to Ngaruawahia; zone 3, Ngaruawahia to Rangiriri; zone 4, Rangiriri to Tuakau (Figure 2). To estimate numbers of koi from Karapiro to the sea we applied the density and mean weight from zone 4 to the residual distance to the sea.

These are first-approximations of koi biomass in New Zealand, and it is not possible to give meaningful estimates of the error (e.g., 95% confidence intervals). Errors involved in point estimates of koi abundance from removal fishing and in mean weights combined means that traditional 95% confidence limits usually exceeded the actual estimates.

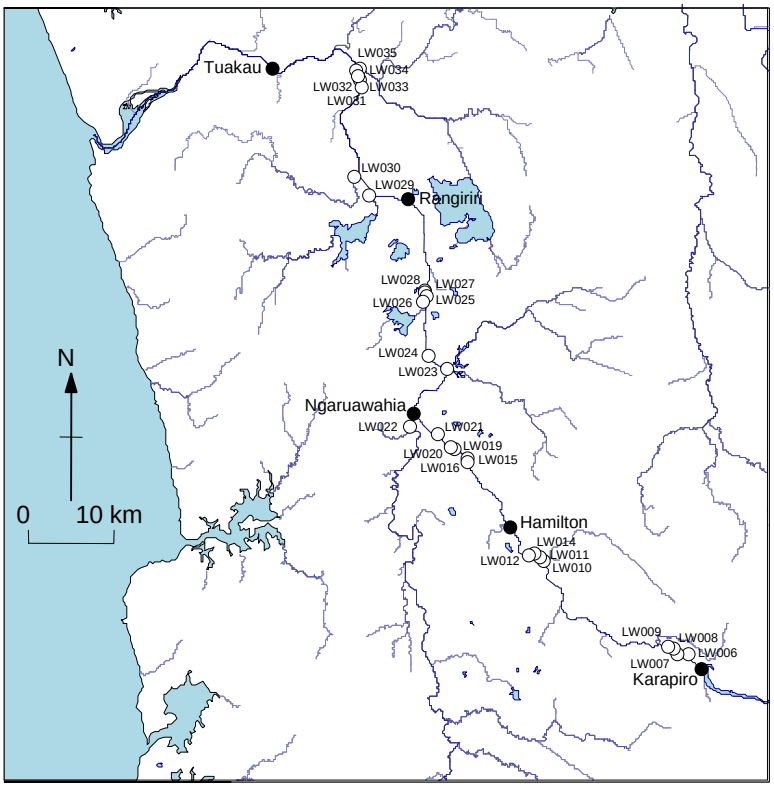

Figure 2. Sites fished in the lower Waikato River between 8 and 15 February 2005. ○, fished sites; ● locations of zones breaks. Source: Fish Database Helper (Jowett 2005). Site codes correspond to the GPS points in Table 1.

Results

Quantitative catches throughout the lower Waikato River basin by electrofishing boat, with distances and areas fished estimated by global positioning, suggest that koi densities ranged from means of 0.84 to 2.08 koi 100 m^{-2} (Table 1). These single-pass catches represent minimum densities because some fish remained uncaught after being repelled by the boat and its electric field.). Mean biomass ranged from 600 to 1062 kg ha^{-1}, and was higher the main channel of the Waikato River than in the lake habitats that we surveyed. Mean fish size was similar in all habitats (Table 2). Because of the variability there was no difference in mean abundance between the four habitats (ANOVA $P \geq 0.23$; Table 1), or in mean lengths and weights of the koi carp (ANOVA $P \geq 0.63$; Table 2). Further details of the mean weights at each site are given in Table 5.

Though lakes appear to hold fewer koi than the Waikato River per unit area, estimates of koi densities in lakes are greater than the Waikato River because of the lakes' considerable surface area. Single-pass electrofishing boat catches of koi in the shallow littoral zone Lake Whangape in September 2003 (during the spawning period) extrapolate to a minimum abundance of 51,500 koi with a biomass of 188 tonnes for the whole shoreline (Table 3B). Correcting this estimate with equation 1 above suggests that the number of spawners, at an estimated density of 11 koi 100 m^{-2} (Table 3A), is closer to 166,000 koi, or 604 tonnes.

Table 1. Mean abundance of koi (*Cyprinus carpio*) estimated by boat electrofishing in 103 sites in the main channel and side channels of the Waikato River, and lakes of the lower Waikato basin. Estimated number of fish was calculated from the equation $Y = 1.55\ X^{1.23}$, where Y = removal population estimate and X = number of fish caught in the first pass.

Habitat	*N*	Koi caught in the first pass			Estimated quantity of koi		
		fish 100 m^{-2}	g m^{-2}	kg ha^{-1}	fish 100 m^{-2}	g m^{-2}	kg ha^{-1}
Main channel	55	2.08	31.4	314	6.79	106.2	1062
Tributaries	26	1.54	28.6	286	3.85	73.0	730
Side channel	12	1.43	27.4	274	4.57	87.7	877
Lake	10	0.84	22.6	226	2.29	60.0	600

Table 2. Mean length and weight of koi (*Cyprinus carpio*) in four habitat types. Main channel and side channels refer to the Waikato River.

Habitat	*N* sites	Mean length (mm)	Mean weight (g)
Main channel	55	388	1869
Tributaries	26	412	2116
Side channels	12	415	2056
Lakes	10	387	1842

Lower fish densities of smaller koi were found in December 2003 after the spawning period when more extensive fishing was undertaken in Lake Whangape. Extrapolating the estimated mean catch rate of 1.85 koi 100 m^{-2} (Table 3A) to the whole 1,078 ha lake suggests a lower total population of 200,000 koi with a biomass of 209 tonnes (Table 3B). Because of its size, Lake Waikare is likely to hold many more fish (possibly 466,000 koi, or 851 tonnes) than Lake Whangape. Smaller water bodies such as the Hikutaia Cut, which is a 10.6 ha lake in a bend of the lower Waihou River, have moderate koi densities (an estimated 0.59-2.42 koi 100 m^{-2}) but fewer fish in total because of their small areas.

Extrapolations of single-pass estimates of koi densities in the four surveyed zones (Figure 2; Hicks et al. 2005b) suggest a minimum number of 21,000 koi in the Waikato River (Table 4A). Extending first-pass densities to population estimates with equation 1 suggests that there are at least 65,000 koi between Karapiro Dam and the estuary (Table 4B). The Waikato River has an extensive network of shallow side channels and willow fringes, many of which are impossible to boat electrofish. Our observations show that these hold koi carp, so the extrapolated number and biomass of koi in the Waikato River are almost certainly underestimates. Biomass estimates of koi ranged from 26 to 4,053 kg ha^{-1}, with a median of 548 kg ha^{-1}, showing considerable variation between locations (Table 5). The length-frequency distribution of koi (Figure 3) was strongly bimodal.

Table 3. Number of koi in Waikato lakes estimated from boat electrofishing catches and population estimates.

A. Number of koi caught and estimated population density.

Site	Length fished (m)	Area fished (m^2)	Mean length (mm)	Mean weight (g)	Number caught in first pass	Estimated number of koi	Estimated density (koi 100 m^{-2})	Estimated biomass (kg ha^{-1})
Lake Waikare	1000	4000	406	1826	18	54	1.36	248
Lake Whangape	1716	6864	338	1045	36	127	1.85	194
Lake Whangape	174	696	502	3645	24	77	11.10	4046
Lake Waahi, Metcalfe's farm	388	1552	469	2333	5	11	0.72	169
Lake Waahi, Weaver's Crossi	216	864	339	1092	3	6	0.67	74
Lake Kimihia	830	3320	270	439	8	20	0.60	26
Hikutaia Cut	600	2400	272	513	19	58	2.42	124
Hikutaia Cut	366	1464	303	629	8	20	1.37	86
Hikutaia Cut	2619	10476	286	537	20	62	0.59	32
Pond at Mokoia	215	951	475	3657	9	23	2.43	889
Pond at Apata	441	2274	545	3800	5	11	0.49	188

B. Numbers and densities of koi extrapolated from catches and corrected for population estimates by equation 1.

Date	Extrapolation type	Area used for extrapolation (ha)	Number of koi		Biomass of koi (kg)		
			Extrapolated from catch	Corrected extrapolation	Extrapolated from catch	Corrected extrapolation	
11-Sep-03	Whole lake	3,438	154,721	466,223	282,504	851,272	34,382,471
11-Sep-03	Littoral zone	149	51,476	165,723	187,610	604,000	1,492,800
5-Dec-03	Whole lake	1,079	56,585	199,978	59,111	208,905	10,788,883
2-Nov-03	Whole lake	445	14,327	32,154	33,427	75,022	4,446,946
7-Mar-07	Whole lake	445	14,675	29,795	16,029	32,544	4,446,946
9-Feb-06	Whole lake	48.8	1,175	2,939	516	1,290	487,683
19-Aug-03	Whole lake	10.6	836	2,551	429	1,308	105,600
6-Mar-06	Littoral zone	10.6	202	622	108	334	105,600
6-Mar-06	Littoral zone	10.6	577	1,443	363	907	105,600
9-Jun-05	Whole lake	0.10	16	23	59	85	951
18-Feb-04	Whole lake	0.23	5	11	19	43	2,274

Table 4. Number of koi in the lower Waikato River from the Karapiro Dam to the sea estimated from boat electrofishing catches. Source of data: Hicks et al. (2005b).

A. Extrapolations of number caught to entire river length and both banks.

Zone	*N*	Mean density caught		Mean biomass caught		Distance from the sea (km)		Zone length	Number of koi	Biomass (kg)
	sites	Fish 100 m^{-1}	Fish 100 m^{-2}	g m^{-1}	g m^{-2}	Upstream	Downstream	(km)		
1	4	2.92	0.73	15.8	4.0	152.2	115.8	36.4	2,123	1,152
2	5	11.41	2.85	59.1	14.8	115.8	96.3	19.5	4,449	2,303
3	5	12.85	3.21	147.7	36.9	96.3	67.6	28.7	7,377	8,480
4	6	5.15	1.29	85.6	21.4	67.6	30.5	37.1	3,821	6,353
to sea		5.15	1.29	85.6	21.4	30.5	0	30.5	3,141	5,223
								152	20,911	23,511

B. Number estimated from first-pass to population estimates calculated from equation 1, extrapolated to both banks of entire river length.

Zone	*N*	Mean estimated density		Mean estimated biomass		Distance from the sea (km)		Zone length	Number of koi	Biomass (kg)
	sites	Fish 100 m^{-1}	Fish 100 m^{-2}	g m^{-1}	g m^{-2}	Upstream	Downstream	(km)		
1	4	8.2	2.06	33.1	8.3	152.2	115.8	36.4	5,984	2,411
2	5	39.8	9.94	205.2	51.3	115.8	96.3	19.5	15,513	8,004
3	5	41.4	10.35	482.0	120.5	96.3	67.6	28.7	23,761	27,666
4	6	14.3	3.57	234.0	58.5	67.6	30.5	37.1	10,584	17,360
to sea		14.3	3.57	234.0	58.5	30.5	0	30.5	8,701	14,271
								152	64,543	69,711

Table 5. Abundance of koi carp determined by boat electrofishing in the Waikato River, its tributaries, and some lakes and streams.

Site	*N* sites	Mean fish weight (g)	Density caught (fish 100 m^{-2})	Biomass caught (g m^{-2})	Biomass caught (kg ha^{-1})	Estimated density (fish 100 m^{-2})	Estimated biomass (g m^{-2})	Estimated biomass (kg ha^{-1})
Waikato River tributaries								
Waahi Stream	2	3566	0.49	17.6	176	0.90	32.0	320
Whangape Stream	4	1493	0.98	14.6	146	2.77	42.0	420
Whangamarino	7	1616	1.23	19.9	199	3.68	59.4	594
Unamed tributary opposite Kimihia	2	2253	1.24	27.9	279	2.39	53.9	539
Opuatia Stream	1	1353	1.78	24.2	242	5.57	75.4	754
Mangawara River	1	1836	2.14	39.3	393	6.53	119.9	1199
Mangatawhiri	4	2525	2.26	57.1	571	6.95	175.3	1753
Kimihia Stream	4	1452	2.78	40.4	404	4.20	60.8	608
Waikato River main channel								
Victoria Bridge, Hamilton	1	3845	0.20	7.7	77	0.36	14.0	140
Meremere	6	2898	0.32	9.3	93	0.97	28.1	281
Taupiri	2	2316	0.39	9.0	90	1.40	32.5	325
Fairfield Bridge, Hamilton	1	2311	0.47	10.8	108	1.13	26.2	262
Ohinewai	6	2556	1.03	26.4	264	2.67	68.2	682
Opposite Kimihia Stream	4	2305	1.81	41.7	417	6.05	138.5	1385
Huntly	17	2070	2.41	49.8	498	8.49	183.7	1837
Main channel	14	807	2.67	21.5	215	8.67	66.8	668
Fairfield to Pukete	1	380	2.95	11.2	112	14.63	55.7	557
Rangiriri	1	2116	5.18	109.5	1095	19.16	405.3	4053
Pukete	2	357	5.53	19.7	197	11.80	42.1	421
Waikato River side channels								
Rangiriri	1	2508	0.13	3.2	32	0.29	7.3	73
Huntly	11	1904	1.55	29.6	296	4.96	95.0	950
Lakes and ponds								
Pond at Apata	1	3800	0.22	8.4	84	0.49	18.8	188
Lake Kimihia	1	439	0.24	1.1	11	0.60	2.6	26
Lake Waahi, Metcalfe's farm	1	2333	0.32	7.5	75	0.72	16.9	169
Lake Waahi, Weavers Crossing	1	1092	0.33	3.6	36	0.67	7.4	74
Lake Waikare	1	1826	0.45	8.2	82	1.36	24.8	248
Hikutaia Cut	3	557	0.51	2.8	28	1.46	8.0	80
Pond at Mokoia	1	3657	1.68	61.5	615	2.43	88.9	889
Lake Whangape	2	3301	1.99	65.6	656	6.48	212.0	2120
Other streams								
Waimapu Stream, BOP	1	7437	0.03	2.1	21	0.05	3.9	39

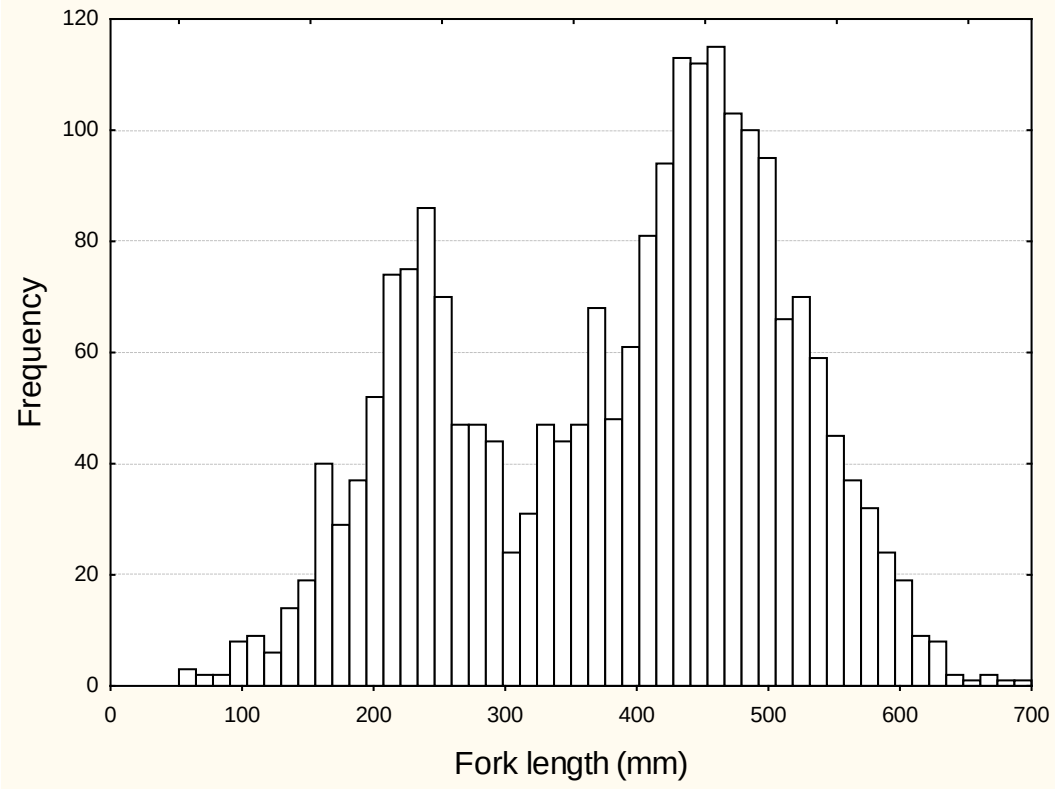

Figure 3. Length frequency of koi (*Cyprinus carpio*) in the Waikato River, its lakes, and tributaries (N = 2,223) between 13 July 2003 and 16 March 2006.

Discussion

Numerous as koi carp are in the Waikato basin, their distribution is very variable. Koi appear to move in schools, and aggregate during the spawning season, which accounts for some of the variability. The length-frequency distribution shows a predominance of age 2 and age 6 fish (Tempero et al. 2006). This suggests that koi recruitment is very successful in the Waikato basin. These biomass estimates must be regarded as preliminary because 1) an unknown proportion of the fish sensed the electrical field before falling within the capture voltage gradient threshold and were observed to swim away and 2) densities assumed for extrapolations might not apply to all of the extrapolated area. Capture probability can also vary considerably with fish size, turbidity, and river discharge (Lyon et al. 2014), which adds

to the uncertainty of fish abundance estimates from boat electrofishing. Nevertheless, these criticisms apply to most other forms of fish capture.

Northern Hemisphere studies have compared fish biomass and water quality, and have suggested threshold biomasses at which fish removal can improve water quality (e.g., Cooke et al. 1993; Hosper and Jagtman 1990). The assumptions implicit in such conclusions are that fish, especially invasive species, can increase nutrients by their excretion and benthic feeding habits. Some fish are planktivorous and remove the large grazing zooplankton that would otherwise control phytoplankton abundance. The threshold biomass suggested is 150 kg ha^{-1}; 96 of the 103 biomass estimates for sites with koi in the Waikato Basin exceeded 150 kg ha^{-1}, and thus reduction of koi biomass to below this threshold is likely to precipitate a natural improvement of water clarity.

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