

# Comparative fish abundance in the shallow Waikato lakes Whangape and Hakanoa



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by

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Cover picture: Water quality monitoring buoy in Lake Whangape. Photo credit: Warrick Powrie.

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## Executive summary

The Waikato-Tainui College for Research and Development contracted the University of Waikato to conduct boat electrofishing estimates of the fish abundance in lakes Whangape and Hakanoa; both are shallow, riverine lakes in the lower Waikato River floodplain and are about 2,000 years old. Lake Whangape (latitude 37.46853°S, longitude 175.05120°W) is a large (1,450 ha), shallow (maximum depth 2.7 m) lake to the west of the Waikato River; Lake Hakanoa (latitude 37.55258°S, longitude 175.16859°W) is a 52-ha lake in suburban Huntly with a maximum depth of 2.5 m.

We fished 10 sites for 10 mins in both lakes Whangape and Lake Hakanoa; sites fished were 253-609 m long (1,012-2,436 m<sup>2</sup> in area) in Lake Whangape and 125-276 m long (500-1,104 m<sup>2</sup> in area) in Lake Hakanoa.

No submerged aquatic macrophytes were seen in either lake. Fishing was conducted close to the water's edge in Lake Hakanoa, but the shallow margins in Lake Whangape restricted fishing at most sites to 30-70 m from the shoreline. The shoreline was much more accessible in Lake Hakanoa, and was dominated by raupo (*Typha orientalis*) with willows (*Salix* spp.) in places. Submerged tree trunks and logs in Lake Hakanoa made navigation difficult in parts of the lake margins.

We caught a total of 118 fish in Lake Whangape, where shortfin eels (*Anguilla australis*) were the most abundant fish, and 594 fish in Lake Hakanoa, where gambusia (*Gambusia affinis*) the most abundant species. In Lake Whangape, shortfin eels comprised the greatest total biomass (12.4 kg), with koi carp (*Cyprinus carpio*) almost equally abundant (11.4 kg). In Lake Hakanoa, koi carp were most abundant (74.4 kg), followed by shortfin eels (22.1 kg).

Fish were unevenly spread among sites in Lake Whangape and koi carp were relatively sparsely among sites. In Lake Hakanoa, in contrast, fish were more evenly spread among sites, but with higher concentrations of catfish (*Ameiurus nebulosus*) and goldfish (*Carassius auratus*) at a few sites. Biomass of fish caught in each of the ten 10-min fishing shots reflected the numerical distributions, with some wide variations between sites. Fish densities were generally lower in Lake Whangape than in Lake Hakanoa; however, common smelt (*Retropinna retropinna*) and grey mullet (*Mugil cephalus*) occurred in Whangape but not in Hakanoa. Areal fish biomass was dominated by shortfin eels and koi carp in Lake Whangape, but koi carp dominated the fish biomass in Lake Hakanoa, despite the smaller number of carp than eels. This was because of the large mean weight of koi carp (about 1,000 g) compared to the smaller shortfin eels (mean weight about 200 g in both lakes).

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Shortfin eels were much the same in terms of size distribution and mean weight in both lakes, though were more numerous in Lake Hakanoa than in Lake Whangape for the same fishing effort. Mean weights of shortfin eels were 203 g in Lake Whangape and 218 g in Lake Hakanoa and were not different between lakes (ANOVA  $P = 0.799$ ). Modal length was 400-450 mm total length for both lakes.

Fish abundance in Lake Whangape was greatly reduced in 2016 compared to previous years, especially 2010. In 2016, koi carp, goldfish and catfish were only about one-tenth of the density seen in 2010. Shortfin eel abundance, however, was only slightly lower in 2016 (0.40 fish 100 m<sup>-2</sup> compared to 0.59 fish 100 m<sup>-2</sup> in 2010). This difference was not significant (ANOVA  $P = 0.53$ ). The most significant declines in areal biomass occurred in koi carp and goldfish. For example, koi carp declined from 8.89 g m<sup>-2</sup> in 2010 to 0.76 g m<sup>-2</sup> in 2016; the 2016 biomass is much lower than the Waikato average of 3.3 g m<sup>-2</sup> (33 kg ha<sup>-1</sup>) estimated by boat electrofishing from data compiled since 2003. Shortfin eels, by comparison, decreased insignificantly in areal biomass in 2016 (0.81 g m<sup>-2</sup> compared to 1.05 g m<sup>-2</sup> in 2010; ANOVA  $P = 0.48$ ). In 2016 the shortfin eel biomass in Lake Whangape was about one-third of the Waikato average of 2.3 g m<sup>-2</sup> (23 kg ha<sup>-1</sup>) estimated by single-pass boat electrofishing. Mean weight of individual eels was similar in 2016 (202 g) and 2010 (182 g) and not significantly different (ANOVA  $P = 0.65$ ). The weight-length regression equation in our study (weight (g) =  $5.08 \times 10^{-7} \times \text{total length (mm)}^{3.219}$ ) was very similar to the regression equation for the entire North Island (weight (g) =  $3.91 \times 10^{-7} \times \text{total length (mm)}^{3.255}$ ), suggesting that shortfin eels in lakes Hakanoa and Whangape showed similar condition to eels from other North Island locations.

Abundance of all fish species in Lake Hakanoa was greater in 2016 than in 2009 except for common smelt and grey mullet, which were represented by single individuals in 2009 but which were not found in 2016. Areal biomasses of koi carp and catfish in Lake Hakanoa were well above the Waikato averages of 3.3 g m<sup>-2</sup> and 0.4 g m<sup>-2</sup> respectively. Shortfin eels were very similar to the Waikato average of 2.3 g m<sup>-2</sup>.

We speculate that there has been further ecosystem degradation since the collapse of the aquatic macrophytes in Lake Whangape that began in the 1980s following sediment discharges from coal mines. Increases in suspended sediment seems likely to have progressively destabilised the macrophyte beds, and their destruction has been probably been responsible for a positive feed-back loop that has intensified suspended sediment once macrophytes were no longer present to stabilise sediment in the lake bed.

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## 1. Introduction

The Waikato-Tainui College for Research and Development contracted the University of Waikato to conduct boat electrofishing estimates of the fish abundance in lakes Whangape and Hakanoa to compare with previous abundance estimates; both are shallow, riverine lakes in the lower Waikato River floodplain and are about 2,000 years old. Lake Whangape is a large (1,450 ha), shallow lake (maximum depth 2.7 m) to the west of the Waikato River and Lake Hakanoa is a 52-ha lake in suburban Huntly with a maximum depth of 2.5 m (Hamilton et al. 2010).

## 2. Methods

We electrofished both lakes with a 4.5 m-long, aluminium-hulled electrofishing boat equipped with a 5-kilowatt pulsator (GPP model 5.0, Smith-Root Inc, Vancouver, Washington, USA) powered by a 6-kilowatt custom-wound Honda generator. Two anode poles, each with an array of six 1-m long stainless steel wire droppers, created the fishing field in front of the bow, with the boat hull acting as the cathode. We fished both lakes with the pulsator on low range (50-500 V), direct current, and a frequency of 60 pulses per second. For Lake Whangape, we set the pulsator to 15% of low range to give an applied current of about 7 amps root mean square, which varied from 4 to 8 amps as the anodes made intermittent contact with the lake bed in shallow water. For Lake Hakanoa, the pulsator was set to 50% of low range, which gave a consistent applied current of about 3-4 amps root mean square.

We assumed from past experience (Hicks et al. 2006) 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 therefore fished a transect 4 m wide, which was generally consistent with behavioural reactions of fish at the water surface. This assumption was used to calculate the area fished from the linear distance measured with a hand-held Garmin GPSMAP 60Cx global positioning system.

All sites were fished on 24 February 2016 with a consistent fishing time of 10 minutes for each site. Fish were anaesthetised with Aqui-S and fork length (FL) was measured to the nearest millimetre for koi carp (*Cyprinus carpio*), grey mullet (*Mugil cephalus*), goldfish (*Carassius auratus*) and rudd (*Scardinius erythrophthalmus*) and total length (TL) was measured for eels (*Anguilla* spp.). Weight was measured to the nearest gram. Eels were released after allowing recovery from the anaesthetic. Gambusia (*Gambusia affinis*) and common bullies (*Gobiomorphus cotidianus*) were counted but not measured or weighed. Total weights of these species for each site were calculated

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from the counts and mean weights of 1.74 g for common bullies ( $N = 705$ ) and 0.27 g for gambusia ( $N = 341$ ) from Waikato sites (B. Hicks, unpubl. data).

### 3. Study sites

Lake Whangape (latitude 37.46853°S, longitude 175.05120°W) is located to the west of the lower Waikato River and Lake Hakanoa (latitude 37.55258°S, longitude 175.16859°W) is to the east of the river (Fig. 1). Horizontal visibility through the water was measured using a black disc (Davies-Colley 1988); black disc distance was 0.22 m in Lake Whangape and 0.35 m in Lake Hakanoa. Electrical conductivity was measured with a YSI 3200 conductivity meter; in Lake Whangape, with a surface water temperature of 19.1°C at 0855 h, ambient conductivity was 252.1  $\mu\text{S cm}^{-1}$ , and specific conductivity was 284.6  $\mu\text{S cm}^{-1}$ . In Lake Hakanoa, with a surface water temperature of 24.6°C at 1535 h, ambient conductivity was 174.1  $\mu\text{S cm}^{-1}$ , and specific conductivity was 176.3  $\mu\text{S cm}^{-1}$ .

Ten sites were fished in Lake Whangape (Fig. 2) with a further 10 sites in Lake Hakanoa (Fig. 3). Sites fished were 253-609 m long (1,012-2,436  $\text{m}^2$  in area) in Lake Whangape and 125-276 m long (500-1,104  $\text{m}^2$  in area) in Lake Hakanoa (Table 1).

No submerged aquatic macrophytes were seen in either lake (Table 1). Fishing was conducted close to the water's edge in Lake Hakanoa, but the shallow margins in Lake Whangape restricted fishing at most sites to 30-70 m from the shoreline. The shoreline was much more accessible in Lake Hakanoa, and was dominated by raupo (*Typha orientalis*) with willows (*Salix* spp.) in places (Table 1B). Submerged tree trunks and logs in Lake Hakanoa made navigation difficult in parts of the lake margins.

Table 1. Lengths, areas, depths, and macrophytes at sites boat electrofished in A) Lake Whangape and B) Lake Hakanoa on 24 February 2016.

A) Lake Whangape

Site	Habitat	Length (m)	Area (m <sup>2</sup> )	Depth range (m)	Start time (h)	Bank	Macrophytes
1	Littoral edge	176	704	0.3-1.0	1537	Raupo, willow	None
2	Littoral edge	180	720	1.1	1553	Raupo	None
3	Littoral edge	187	748	1.1	1606	Raupo	None
4	Littoral edge	125	500	0.3-2	1622	Raupo	None
5	Littoral edge	197	788	0.3-2	1659	Raupo	None
6	Littoral edge	205	820	0.3-1.0	1716	Raupo and rocks	None
7	Littoral edge	214	856	0.3-1.0	1733	Raupo	None
8	Littoral edge	223	892	0.3-1.0	1747	Raupo	None
9	Littoral edge	265	1060	0.3-1.0	1808	Raupo, grass	None
10	Littoral edge	276	1104	0.3-1.1	1823	Raupo, willow, grass, rocks	None
Total		2,048	8,192				

B) Lake Hakanoa

Site	Habitat	Length (m)	Area (m <sup>2</sup> )	Depth range (m)	Start time (h)	Bank	Macrophytes
1	Midwater littoral	364	1456	0.3-0.5	0855	No bank	None
2	Midwater littoral	427	1708	0.3-0.5	0920	No bank	None
3	Midwater littoral	447	1788	0.4-0.7	0940	No bank	None
4	Midwater littoral	422	1688	0.4-0.7	1001	No bank	None
5	Midwater littoral	609	2436	0.3-0.7	1105	No bank	None
6	Midwater littoral	475	1900	0.4-0.7	1137	Willows	None
7	Midwater littoral	407	1628	0.4-0.7	1201	No bank	None
8	Midwater littoral	288	1152	0.4-1.0	1223	Willows	None
9	Midwater	403	1612	0.8	1327	No bank	None
10	Midwater littoral	253	1012	0.4-0.7	1342	No bank	None
Total		4,095	16,380				



Figure 1. Location of the riverine lakes Whangape and Hakanoa in the lower Waikato River floodplain.

## 4. Results

We fished 4,095 m in length and an area of 16,380 m<sup>2</sup> at a total of ten sites in Lake Whangape (Table 1A, Fig. 2) and 2,048 m in length and an area of 8,192 m<sup>2</sup> at a total of ten sites in Lake Hakanoa (Table 1B, Fig. 3). We caught a total of 118 fish in Lake Whangape, where shortfin eels (*Anguilla australis*) were the most abundant species, and 594 fish in Lake Hakanoa, where gambusia the most abundant species (Table 2).

In Lake Whangape, shortfin eels comprised the greatest biomass (12.4 kg), with koi carp almost equally abundant (11.4 kg). In Lake Hakanoa, koi carp were most abundant (74.4 kg), followed by shortfin eels (22.1 kg; Table 2).



Figure 2. Location of the sites that were boat electrofished on Lake Whangape on 24 February 2016.



Figure 3. Location of the sites that were boat electrofished on Lake Hakanoa on 24 February 2016.

Table 2. Scientific names and combined totals of numbers and biomass of fish caught in ten 10-min fishing shots by boat electrofishing in the in lakes Whangape and Hakanoa on 24 February 2016.

Common name	Scientific name	Status	N fish in ten 10-min shots		Biomass in ten 10-min shots (g)	
			Whangape	Hakanoa	Whangape	Hakanoa
Common smelt	<i>Retropinna retropinna</i>	Native	2	0	6	0
Common bully	<i>Gobiomorphus cotidianus</i>	Native	0	55	0	96
Grey mullet	<i>Mugil cephalus</i>	Native	7	0	5,136	0
Shortfin eel	<i>Anguilla australis</i>	Native	61	105	12,355	22,142
Brown bullhead catfish	<i>Ameiurus nebulosus</i>	Introduced	0	42	0	7,857
Gambusia	<i>Gambusia affinis</i>	Introduced	7	250	7	68
Goldfish	<i>Carassius auratus</i>	Introduced	28	59	8,920	5,199
Koi carp	<i>Cyprinus carpio</i>	Introduced	11	68	11,381	74,434
Koi carp-goldfish hybrid	<i>Cyprinus carpio X Carassius auratus</i>	Introduced	1	15	832	10,382
Rudd	<i>Scardinius erythrophthalmus</i>	Introduced	1	0	313	0
Total			118	594	38,942	120,014

Fish were unevenly spread among sites in Lake Whangape; most eels were caught at site 4 (Fig. 2) and most goldfish were caught at site 6 (Table 3A). Koi carp were relatively sparsely spread among sites. In Lake Hakanoa, in contrast, fish were more evenly spread among sites, but with higher concentrations of catfish and goldfish at a few sites (Table 3B). Biomass of fish caught in each of the ten 10-min fishing shots reflected the numerical distributions, with some wide variations between sites (Table 4). Fish densities were generally lower in Lake Whangape than in Lake Hakanoa; however, common smelt (*Retropinna retropinna*) and grey mullet occurred in Whangape but not in Hakanoa (Table 5). Areal fish biomass was dominated by shortfin eels and koi carp in Lake Whangape, but koi carp dominated the fish biomass in Lake Hakanoa (Table 6), despite the smaller number of carp than eels. This was because of the large mean weight of koi carp (about 1,000 g) compared to the smaller shortfin eels (mean weight about 200 g in both lakes; Table 7).

Table 3. Number of fish caught in ten 10-min fishing shots by boat electrofishing in A) Lake Whangape and B) Lake Hakanoa on 24 February 2016. Blank cells represent no catch.

A) Lake Whangape

Site	Number of fish per 10-minute shot								
	Common smelt	Gambusia	Goldfish	Grey mullet	Koi carp	Koi-goldfish hybrid	Rudd	Shortfin eel	Total
1								7	7
2		1						5	6
3	1	1	2		2			5	11
4			1					18	19
5			2	4				2	8
6		2	12		3	1			18
7			1	1	2			5	9
8		2	2	2	3			7	16
9			3					8	11
10	1	1	5		1		1	4	13
Total	2	7	28	7	11	1	1	61	118

B) Lake Hakanoa

Site	Number of fish per 10-minute shot							
	Catfish	Common bully	Gambusia	Goldfish	Koi carp	Koi-goldfish hybrid	Shortfin eel	Total
1	1	9	109	14	1		6	140
2	2	2		24	2		17	47
3	14			3	11	2	10	40
4	4		15	1	9	6	3	38
5	11	3	8	3	11	3	14	53
6	1	1	8	5	6	1	26	48
7	6			1	10	1	3	21
8		1		1	7	2	7	18
9	3	5	10	5	2		13	38
10		34	100	2	9		6	151
Total	42	55	250	59	68	15	105	594

Table 4. Biomass of fish caught in ten 10-min fishing shots by boat electrofishing in A) Lake Whangape and B) Lake Hakanoa on 24 February 2016. Blank cells represent no catch.

A) Lake Whangape

Site	Biomass of fish per 10-min shot (g)								
	Common smelt	Gambusia	Goldfish	Grey mullet	Koi carp	Koi-goldfish hybrid	Rudd	Shortfin eel	Total
1								1,446	1,446
2		0.3						690	690
3	2.0	0.3	492		1,317			974	2,785
4			293					3,983	4,276
5			755	2,594				1,022	4,371
6		0.5	3,369		4,586	832			8,787
7			440	632	1,500			864	3,436
8		0.5	373	1,910	3,229			1,247	6,759
9			1,181					1,031	2,212
10	3.6	0.3	2,017		749		313	1,098	4,181
Total	5.6	1.9	8,920	5,136	11,381	832	313	12,355	38,942

B) Lake Hakanoa

Site	Biomass of fish per 10-min shot (g)							
	Catfish	Common bully	Gambusia	Goldfish	Koi carp	Koi-goldfish hybrid	Shortfin eel	Total
1	152	16	29	201	541		1,130	2,068
2	448	3		1,133	1,055		3,494	6,133
3	2,652			1,014	13,789	1,956	2,088	21,499
4	792		4	94	3,303	2,695	304	7,192
5	2,045	5	2	1,145	13,534	2,984	3,477	23,192
6	213	2	2	254	4,502	394	6,300	11,667
7	895			144	12,678	342	442	14,501
8		2		791	10,017	2,011	1,869	14,690
9	660	9	3	406	1,922		2,224	5,223
10		59	27	18	13,093		815	14,012
Total	7,857	96	68	5,199	74,434	10,382	22,142	120,177

Table 5. Density of fish caught in ten 10-min fishing shots by boat electrofishing in A) Lake Whangape and B) Lake Hakanoa on 24 February 2016.

A) Lake Whangape

Site	Density of fish (number 100 m <sup>-2</sup> )								
	Common smelt	Gambusia	Goldfish	Grey mullet	Koi carp	Koi-goldfish hybrid	Rudd	Shortfin eel	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.48
2	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.29	0.35
3	0.06	0.06	0.11	0.00	0.11	0.00	0.00	0.28	0.62
4	0.00	0.00	0.06	0.00	0.00	0.00	0.00	1.07	1.13
5	0.00	0.00	0.08	0.16	0.00	0.00	0.00	0.08	0.33
6	0.00	0.11	0.63	0.00	0.16	0.05	0.00	0.00	0.95
7	0.00	0.00	0.06	0.06	0.12	0.00	0.00	0.31	0.55
8	0.00	0.17	0.17	0.17	0.26	0.00	0.00	0.61	1.39
9	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.50	0.68
10	0.10	0.10	0.49	0.00	0.10	0.00	0.10	0.40	1.28
Mean	0.02	0.05	0.18	0.04	0.08	0.01	0.01	0.40	0.78

B) Lake Hakanoa

Site	Density of fish (number 100 m <sup>-2</sup> )							
	Catfish	Common bully	Gambusia	Goldfish	Koi carp	Koi-goldfish hybrid	Shortfin eel	Total
1	0.14	1.28	15.48	1.99	0.14	0.00	0.85	19.89
2	0.28	0.28	0.00	3.33	0.28	0.00	2.36	6.53
3	1.87	0.00	0.00	0.40	1.47	0.27	1.34	5.35
4	0.80	0.00	3.00	0.20	1.80	1.20	0.60	7.60
5	1.40	0.38	1.02	0.38	1.40	0.38	1.78	6.73
6	0.12	0.12	0.98	0.61	0.73	0.12	3.17	5.85
7	0.70	0.00	0.00	0.12	1.17	0.12	0.35	2.45
8	0.00	0.11	0.00	0.11	0.78	0.22	0.78	2.02
9	0.28	0.47	0.94	0.47	0.19	0.00	1.23	3.58
10	0.00	3.08	9.06	0.18	0.82	0.00	0.54	13.68
Mean	0.56	0.57	3.05	0.78	0.88	0.23	1.30	7.37

Table 6. Areal biomass of fish caught in ten 10-min fishing shots by boat electrofishing in A) Lake Whangape and B) Lake Hakanoa on 24 February 2016.

A) Lake Whangape

Site	Areal biomass of fish ( $\text{g m}^{-2}$ )								
	Common smelt	Gambusia	Goldfish	Grey mullet	Koi carp	Koi-goldfish hybrid	Rudd	Shortfin eel	Total
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.99
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40
3	0.00	0.00	0.28	0.00	0.74	0.00	0.00	0.54	1.56
4	0.00	0.00	0.17	0.00	0.00	0.00	0.00	2.36	2.53
5	0.00	0.00	0.31	1.06	0.00	0.00	0.00	0.42	1.79
6	0.00	0.00	1.77	0.00	2.41	0.44	0.00	0.00	4.62
7	0.00	0.00	0.27	0.39	0.92	0.00	0.00	0.53	2.11
8	0.00	0.00	0.32	1.66	2.80	0.00	0.00	1.08	5.87
9	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.64	1.37
10	0.004	0.00	1.99	0.00	0.74	0.00	0.31	1.08	4.13
Mean	0.00	0.00	0.59	0.31	0.76	0.04	0.03	0.81	2.54

B) Lake Hakanoa

Site	Areal biomass of fish ( $\text{g m}^{-2}$ )							
	Catfish	Common bully	Gambusia	Goldfish	Koi carp	Koi-goldfish hybrid	Shortfin eel	Total
1	0.22	0.02	0.04	0.29	0.77	0.00	1.60	2.94
2	0.62	0.00	0.00	1.57	1.47	0.00	4.85	8.52
3	3.55	0.00	0.00	1.36	18.43	2.61	2.79	28.74
4	1.58	0.00	0.01	0.19	6.61	5.39	0.61	14.38
5	2.60	0.01	0.00	1.45	17.18	3.79	4.41	29.43
6	0.26	0.00	0.00	0.31	5.49	0.48	7.68	14.23
7	1.05	0.00	0.00	0.17	14.81	0.40	0.52	16.94
8	0.00	0.00	0.00	0.89	11.23	2.25	2.10	16.47
9	0.62	0.01	0.00	0.38	1.81	0.00	2.10	4.93
10	0.00	0.05	0.02	0.02	11.86	0.00	0.74	12.69
Mean	1.05	0.01	0.01	0.66	8.97	1.49	2.74	14.93

Table 7. Mean weights of fish caught in ten 10-min fishing shots by boat electrofishing in A) Lake Whangape and B) Lake Hakanoa on 24 February 2016. Blank cells represent no data.

A) Lake Whangape

Site	Mean individual weight (g)							
	Common smelt	Gambusia	Goldfish	Grey mullet	Koi carp	Koi-goldfish hybrid	Rudd	Shortfin eel
1								206.6
2								138.0
3	2.0		246.0		658.5			194.8
4			293.0					221.3
5			377.5	648.5				511.0
6			280.8		1528.7	832		
7			440.0	632.0	750.0			172.8
8			186.5	955.0	1076.3			178.1
9			393.7					128.9
10	3.6		403.4		749.0		313.0	274.5
Total	2.8		318.6	733.7	1034.6	832	313.0	202.5

B) Lake Hakanoa

Site	Mean individual weight (g)						
	Catfish	Common bully	Gambusia	Goldfish	Koi-goldfish hybrid	Koi carp	Shortfin eel
1	152.0			13.8		541.0	225.6
2	224.0			49.1		527.5	218.2
3	197.5			338.0	978.0	1253.5	
4	198.0			94.0	449.2	367.0	101.3
5	185.9			381.7	994.7	1230.4	248.4
6	213.0			83.3	394.0	750.3	242.3
7	149.2			144.0	342.0	1267.8	147.3
8				791.0	1005.5	1431.0	267.0
9	220.0			134.3		961.0	171.1
10				9.0		1454.8	162.6
Total	191.3			97.5	692.1	1094.6	217.9

Shortfin eels were much the same with regards to size distribution and mean weight in both lakes, though were more numerous in Lake Hakanoa than in Lake Whangape for the same fishing effort. Mean weights of shortfin eels were 203 g in Lake Whangape and 218 g in Lake Hakanoa (Table 7) and were not different between lakes (ANOVA  $P = 0.799$ ). Modal length was 400-450 mm TL for both lakes (Fig. 4).

Shortfin eels in Lake Whangape looked healthy, with vibrant colours and no sign of skin lesions (Fig 5A). There was no difference between the length-weight regressions for the shortfin eels from both lakes (Table 8). Regression slopes were identical between lakes, as shown by the insignificant interaction term ( $P$  for Lake\*Ln(length) = 0.654). Natural log of length was a significant covariate ( $P$  for Ln(length) < 0.001), and there was no difference between lakes (Lake  $P = 0.821$ ). Therefore, the relationship between length and weight for shortfin eels from both lakes is best described by the equation

$$\text{weight (g)} = 5.08 \times 10^{-7} \times \text{total length (mm)}^{3.219},$$

where  $N = 166$ ,  $r^2 = 0.981$ , and  $P < 0.001$ . Some koi carp were particularly brightly coloured in Lake Whangape (e.g., Fig. 5B).

Table 8. Analysis of covariance for length-weight regressions for shortfin eels from lakes Whangape and Hakanoa caught by boat electrofishing on 24 Feb 2016.

Source	Type III sums of squares	df	Mean squares	F ratio	$P$
Lake	0.001	1	0.001	0.051	0.821
Ln(length)	176.446	1	176.446	8,707.09	<0.001
Lake*Ln(length)	0.004	1	0.004	0.202	0.654
Error	3.283	162	0.02		

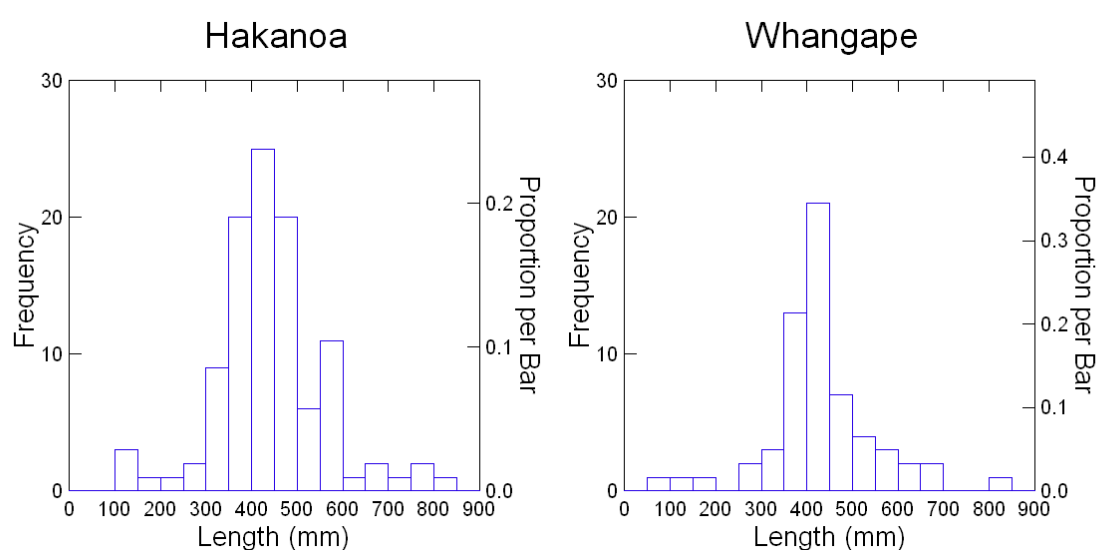


Figure 4. Length frequency of shortfin eels caught by boat electrofishing in lakes Hakanoa and Whangape on 24 February 2016.  $N$  fish = 105 for Hakanoa and 61 for Whangape.

A. A large shortfin eel (845 mm total length, weight 1,283 g)



B. A large orange-coloured koi carp (464 mm FL, weight 1,757 g)



Figure 5. Fish from Lake Whangape caught by boat electrofishing on 24 February 2016: and A. a large shortfin eel (845 mm total length, weight 1,283 g), and B. a large orange-coloured koi carp (464 mm FL, weight 1,757 g). Photos: Brendan Hicks.



Figure 6. Charlotte Caldwell returning shortfin eels to Lake Whangape after capture and processing. Photo: Brendan Hicks.

## 5. Discussion

Fish abundance in Lake Whangape was greatly reduced in 2016 compared to previous years, especially 2010. In 2016, koi carp, goldfish and catfish were only about 1/10<sup>th</sup> of the density seen in 2010. Shortfin eel abundance, however, was only slightly lower in 2016 (0.40 fish 100 m<sup>-2</sup> compared to 0.59 fish 100 m<sup>-2</sup> in 2010; Table 9A). This difference was not significant (ANOVA  $P = 0.53$ ). The most significant declines in areal biomass occurred in koi carp and goldfish (Table 9B). For example, koi carp declined from 8.89 g m<sup>-2</sup> in 2010 to 0.76 g m<sup>-2</sup> in 2016; the 2016 biomass is much lower than the Waikato average of 3.3 g m<sup>-2</sup> (33 kg ha<sup>-1</sup>) estimated by boat electrofishing by Hicks et al. (2015a; p117). Shortfin eels, by comparison, decreased insignificantly in areal biomass in 2016 (0.81 g m<sup>-2</sup> compared to 1.05 g m<sup>-2</sup> in 2016; ANOVA  $P = 0.48$ ). In 2016 the shortfin eel biomass in Lake Whangape was about one-third of the Waikato average of 2.3 g m<sup>-2</sup> (23 kg ha<sup>-1</sup>) estimated by single-pass boat electrofishing. (2015a; p117). Mean weight of individual eels was similar in 2016 (202 g) and 2010 (182 g) and not significantly different (ANOVA  $P = 0.65$ ). The weight-length regression equation in our study (weight (g) =  $5.08 \times 10^{-7}$  length (mm)<sup>3.219</sup>) was very similar to the regression equation for the entire North Island (weight (g) =  $3.91 \times 10^{-7}$  length (mm)<sup>3.255</sup>; Jellyman et al. 2013), suggesting that shortfin eels in lakes Hakanoa and Whangape showed similar condition to eels from other North Island locations (Fig. 7).

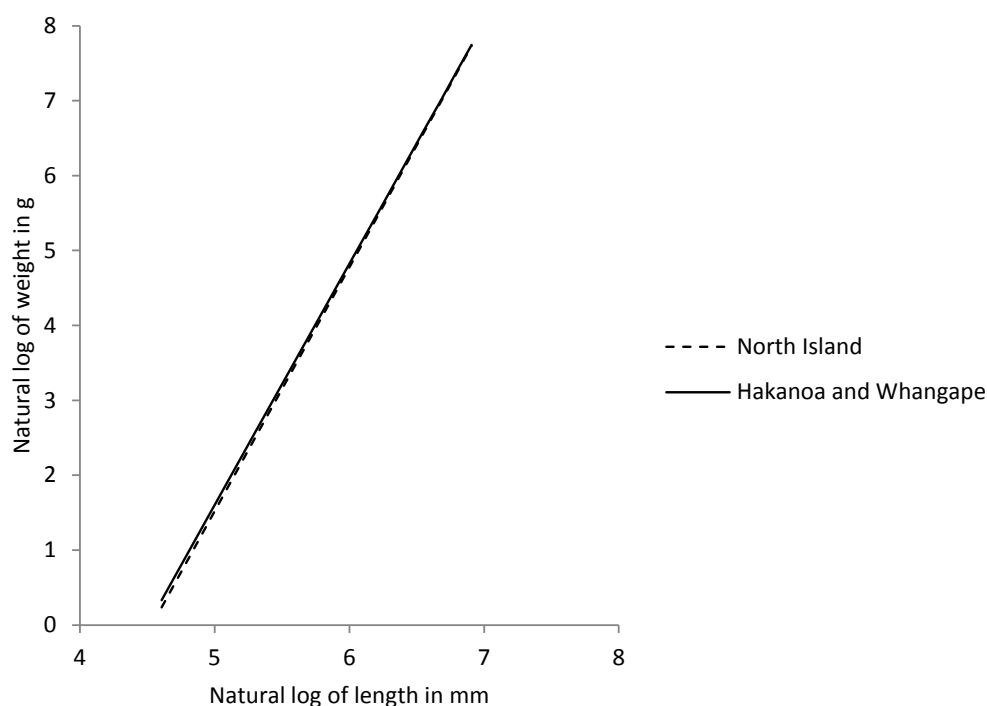


Figure 7. Length-weight relationships of shortfin eels in lakes Hakanoa and Whangape on 24 Feb 2016 compared to parameters from the North Island, New Zealand. (Source: Jellyman et al. 2013.)

Abundance of all fish species in Lake Hakanoa was greater in 2016 than in 2009 except for common smelt and grey mullet, which were represented by single individuals in 2009 but which were not found in 2016 (Table 9). Areal biomasses of koi carp ( $8.97 \text{ g m}^{-2}$ ) and catfish ( $1.05 \text{ g m}^{-2}$ ) in Lake Hakanoa (Table 9B) were well above the Waikato average catches of  $3.3 \text{ g m}^{-2}$  and  $0.4 \text{ g m}^{-2}$  respectively (Hicks et al. (2015a; p117). Shortfin eel biomass ( $2.74 \text{ g m}^{-2}$ ) was similar to the Waikato average of  $2.3 \text{ g m}^{-2}$ .

Table 9. Comparative densities and biomasses estimated from boat electrofishing in Lake Whangape between 2008 and 2016. A. Density and B. areal biomass.

A. Density

Species	Density (fish $100 \text{ m}^{-2}$ )				
	Whangape			Hakanoa	
	5-Sep-08	24-Aug-10	24-Feb-16	16-Oct-09	24-Feb-16
Catfish	0.03	0.09	0.00	0.12	0.56
Common bully	0.03	0.27	0.00	0.38	0.57
Common smelt	0.09	0.00	0.02	0.01	0.00
Gambusia	0.00	0.00	0.05	0.00	3.05
Goldfish	1.00	9.34	0.18	0.06	0.78
Grey mullet	0.49	0.05	0.04	0.01	0.00
Inanga	0.00	0.10	0.00	0.00	0.00
Koi carp	0.32	0.96	0.08	0.33	0.88
Koi carp x goldfish hybrid	0.03	0.00	0.01	0.00	0.23
Rudd	0.03	0.19	0.01	0.00	0.00
Shortfin eel	0.51	0.59	0.40	0.11	1.30
Total	2.52	15.35	0.78	1.01	7.37

B. Areal biomass

Species	Areal biomass ( $\text{g m}^{-2}$ )				
	Whangape			Hakanoa	
	5-Sep-08	24-Aug-10	24-Feb-16	16-Oct-09	24-Feb-16
Catfish	0.12	0.39	0.00	0.56	1.05
Goldfish	2.71	6.54	0.59	0.45	0.66
Grey mullet	3.82	0.12	0.31	0.16	0.00
Koi carp	5.89	8.89	0.76	9.06	8.97
Koi carp x goldfish hybrid	0.48	0.00	0.04	0.00	1.49
Rudd	0.03	0.04	0.03	0.00	0.00
Shortfin eel	0.54	1.05	0.81	0.87	2.74
Total	13.59	17.05	2.54	11.10	14.93

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Boat electrofishing is a useful survey tool but like all fishing methods it has its own biases. The abundances of eels and catfish were most likely underestimated in this survey because previous boat electrofishing has shown that first-pass estimates of eels can be as low as 5-19% of the population estimate (Hicks et al. 2006; Hicks, unpublished data). Comparison of fishing methods show that capture efficiency for boat electrofishing in Lake Kaituna was 22% for koi carp and 13% for goldfish but only 5% for catfish and 6% for shortfin eels (Hicks et al. 2015b; p127).

Fish abundance estimates referred to in this report are derived from single-pass boat electrofishing, so are robust estimates of relative abundance but are not estimates of absolute abundance, which can be derived from removal electrofishing. Independent population estimates ( $Y$ ) compared to first-pass catches ( $X$ ) from boat electrofishing had the relationship  $Y = 1.55 X^{1.23}$  (adjusted  $r^2=0.84$ ,  $N=35$ ,  $P < 0.001$ ; Hicks et al. 2006).

We speculate that there has been further ecosystem degradation since the collapse of the aquatic macrophytes in Lake Whangape that began in the 1980s following sediment discharges from coal mines (Hayes and Rutledge 1991; Wells et al. 1988). Increases in suspended sediment seems likely to have progressively destabilised the macrophyte beds, and their destruction has been probably been responsible for a positive feed-back loop that has intensified suspended sediment once macrophytes were no longer present to stabilise sediment in the lake bed. The original state of Lake Whangape was an aquatic macrophyte community comprised entirely of native macrophytes (Kirk 1871). The lake was still well vegetated in 1991 but was degraded by increased turbidity and invasion of exotic species (Hayes and Rutledge 1991; Champion et al. 1991). Koi carp were apparently absent from Lake Whangape in 1986-87 (Hayes 1989). Assessments of the submerged plant index (SPI) of the aquatic macrophyte community in 2005 suggest that the LakeSPI score was 0, with no macrophytes present (Edwards et al. 2010). The dramatic reduction in catfish, goldfish, and carp appears to be the result of continuing habitat degradation and reduced habitat availability due to lower water levels. Shortfin eels and the migratory grey mullet, however, appear to have maintained their abundance between 2010 and 2016.

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## 6. Acknowledgements

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