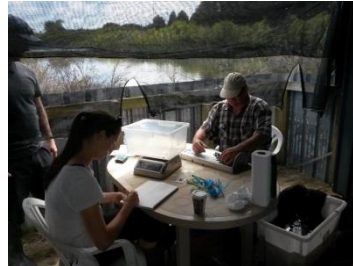


# Fish population and biomass estimates from mark-recapture for Lake Milicich, a shallow Waikato peat lake



## ERI report number 88

A report prepared for the National Institute of Water and  
Atmosphere Ltd, Hamilton

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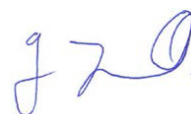


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## Executive summary

Lake Milicich is a shallow (2.3 m maximum depth), 2.01-ha peat lake with a catchment area of 54 ha in dairy and horticultural land uses. A single outlet drain leads to the Mangaotama Stream and the Waipa River. There are dense beds of the *Machaerina (Baumea) articulata* around most of the lake's margin.

The aim of this research was to determine the fish species present in Lake Milicich and to estimate the abundance of the species as part of a wider restoration programme for the lake. We used Gee minnow traps and fyke and gill netting for mark-recapture to estimate the number of fish present in the lake. Population estimates were converted to biomass by multiplying fish number by mean weight for each species. Boat electrofishing was not possible because of the soft margins.

For the marking phase, we used a 4-m long, light-weight aluminium dinghy powered by a 2-HP Johnson outboard to set 20 fyke nets and 10 fine-meshed minnow traps overnight at locations either at the lake edge or the outer edge of the beds of the emergent macrophyte beds. Seven gill nets were set in the deeper areas of the lake for restricted periods during the day to minimise potential bird capture, and fyke nets were retrieved on 17 January 2017. For the recapture phase, 20 fyke nets were again set overnight and 6 gill nets were set during the day, with net retrieval on 24 January 2017, seven days after the marking phase. Gill net mesh sizes were increased for the recapture phase because of the low catch rate of 18-mm mesh gill nets during the marking phase. Fish were lightly anaesthetised in Aqui-S prior to clipping the adipose fin for catfish and the left pectoral fin for eels and rudd. Bullies and gambusia were not marked because of their small size, and no goldfish were caught in the marking phase.

The biomass of catfish ( $84.1 \text{ kg ha}^{-1}$ , 95% confidence limits 63.7 to  $114.6 \text{ kg ha}^{-1}$ ) was very similar to the peat lake Mangahia ( $66 \text{ kg ha}^{-1}$ ). Shortfin eel biomass ( $74.0 \text{ kg ha}^{-1}$ , 95% confidence limits 63.4 to  $87.7 \text{ kg ha}^{-1}$ ) was considerably greater than in Lake Mangahia ( $37 \text{ kg ha}^{-1}$ ; Hicks et al. 2015). As eels were effectively sampled by fyke netting, we assume that the small number of longfin eels captured is a true reflection of their very low abundance in this lake. Our methods and capture locations are likely to have under-sampled juveniles of all species, especially catfish, which would add an age class for catfish to the three that we observed.

Our fishing under-sampled rudd and goldfish, which eventually proved most susceptible to 25-mm mist nets. Although we could not estimate rudd abundance because none of the 8 marked fish were recaptured, there were at least 18 adult fish in the lake and we conclude that a low biomass of rudd (at least  $2.66 \text{ kg ha}^{-1}$ ), is plausible. The abundance of goldfish is also unknown, and only a further mark-recapture estimate is likely to resolve this.

The implication of this survey is that the presence of catfish and rudd, and possibly goldfish, are significant barriers to lake restoration of Lake Milicich unless they are removed, especially as rudd in New Zealand are primarily herbivorous as adults > 150 mm long. Further, inspection of the outlet drain and tributary to the Mangaotama Stream is required to investigate whether invasive fish can migrate from the lower Waikato basin, which would frustrate fish eradication efforts.

Targeted removal of catfish by fyke netting could be worthwhile, and as the catch rates of rudd were very low we conclude that rudd populations are sufficiently small that targeted removal by gill netting may virtually eradicate the herbivorous adults and allow macrophyte restoration to proceed.

## Introduction

Lake Milicich (Figure 1) is a shallow (2.3 m maximum depth), 2.01-ha peat lake with a catchment area of 54 ha in dairy and horticultural land uses. The lake area was remeasured as part of a NIWA/WRC survey in December 2016, and is a revised estimate from the 2.2 ha area reported by Dean-Speirs et al. (2014). A single outlet drain leads to the Mangaotama Stream and the Waipa River. There are dense beds of the *Machaerina* (*Baumea*) *articulata* around most of the lake's margin.

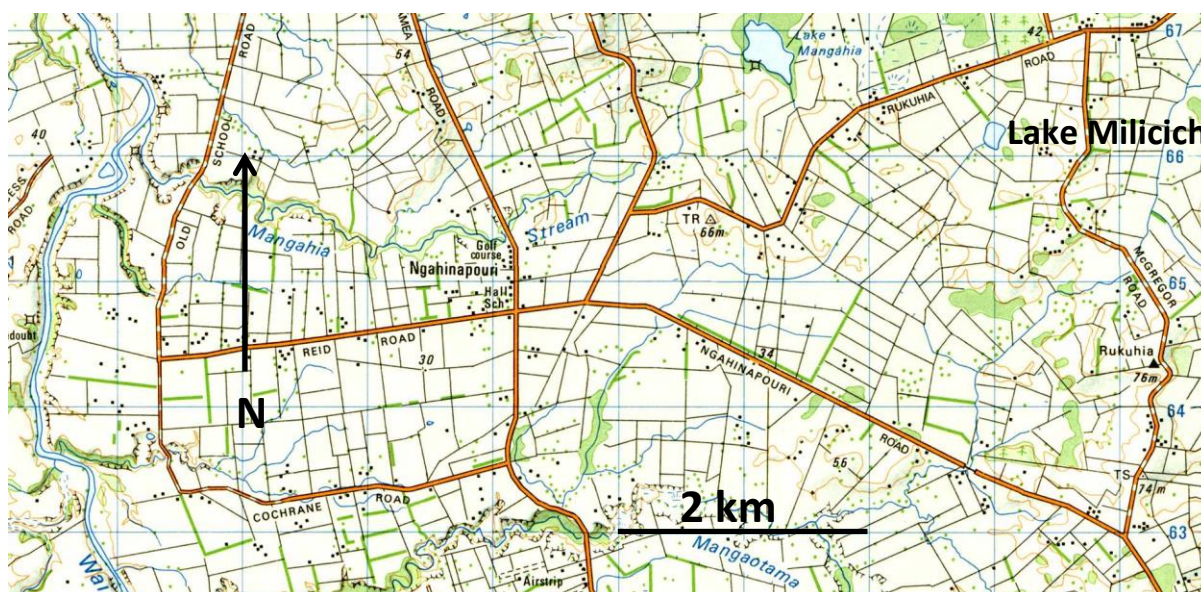


Figure 1. The location of Lake Milicich in the Waipa River catchment.

Table 1. Water quality of Lake Milicich (source: 1977-2010, Dean-Speirs et al. 2014; 2016, NIWA/WRC survey).

Date	Mean SD (m)	Mean				Estimated TLI	pH	Turbidity (NTU)
		chlorophyll <i>a</i> (mg m <sup>-3</sup> )	Mean TN (mg m <sup>-3</sup> )	Mean TP (mg m <sup>-3</sup> )	N/P			
1977	0.5	16.4				5.7		
1988	0.63	57.9	1490	60	24.8	5.6		
1997			2573	280	9.2		9	
2008/2009	1.2	25	1156	61.3	18.9	5.42	7.46	6.16
2009/2010	0.7	192	2576	142	18.1	6.65	7.16	7.46
2016			1040	38	27.4			

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In May 2008, the lake appeared to have better water clarity (Table 1) than similarly sized peat lakes, and the landowner reported that the lake did not experience algal blooms (Neilson & Hamer 2008; Dean-Speirs et al. 2014). No submerged aquatic plants were found in Lake Milicich when it was first surveyed for aquatic plants in 2009 but Dean-Speirs et al. (2014) speculated that they would have occurred in the lake historically. Floating fragments of the invasive bladderwort *Utricularia gibba* were the only plants observed during those surveys, although they were present at insufficient densities to generate a Lake SPI score (e.g. Edwards et al. 2005; Macdonald et al. 2013).

The aim of this research was to determine the fish species present in Lake Milicich and to estimate the abundance of the species as part of a wider restoration programme for the lake. The heavily vegetated riparian area, extremely soft lake margins, and lack of a boat ramp restricted the fishing methods that could be cost-effectively applied. Boat electrofishing, which is particularly effective for catching koi carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*), could not be used because of the soft peat margins could not support the weight of the boat, trailer, and launching vehicle required. The peat pasture adjacent to the riparian area was also too soft for a launch by crane, and launch by helicopter was beyond the budget of this survey. Gee minnow traps and fyke and gill netting were used to apply mark-recapture methods to estimate the number of fish present in the lake, and we extended the population estimates to biomass estimates by multiplying fish number by mean weight for each species.

Robust population estimates by mark-recapture methods require multiple fishing methods to reduce species and size selectivity. For example, mesh sizes determine the sizes of fish caught, and electrofishing is size selective for larger individuals (Chapter 8, Ogle 2015), which could cause electrofishing samples to have higher proportions of large fish than in the population as a whole (Pine et al. 2012). One approach to dealing with such size and species heterogeneity is to use a combination of sampling so that gear selectivity bias is reduced in the aggregate sample (Seber 1982).

## Methods

### *Marking and recapture*

For the marking phase, we used a 4-m long light-weight aluminium dinghy powered by a 2-HP Johnson outboard to set and retrieve 20 fyke nets and 10 fine-meshed minnow traps overnight at locations either at the lake edge or the outer edge of the beds of the emergent macrophyte beds. Seven gill nets were set in the deeper areas of the lake for restricted periods during the day to minimise bird capture, and fyke nets were retrieved on 17 January 2017. For the recapture phase, 20 fyke nets were again set overnight and 6 gill nets were set during the day, with net retrieval on 24 January 2017, seven days after the marking phase (Table 2). We repeated gill netting on 15 and 16 March 2017 for a further attempt at a mark-recapture population estimate. Gill net mesh sizes were increased for the recapture phase because of the low catch rate of 18-mm mesh gill nets during the marking phase. Gill net set times were shorter (2-4 hours) than the overnight sets of Neilson et al. (2004) to both minimise the chance of bird capture and maximise survival of rudd and goldfish for mark and release. Fish were lightly anaesthetised in Aqui-S prior to clipping the adipose fin for catfish and the left pectoral fin for eels and rudd. Bullies and gambusia were not marked because of their small size, and no goldfish were caught in the marking phase.

Table 2. Fishing effort in Lake Milicich during the mark (17 Jan 2017) and recapture (24 Jan 2017) phases.

Net type	Number	Mesh size (mm)	Length (m)	Soak time (h)
<b>17 Jan 2017</b>				
Fyke nets	20	3	–	22
Gill nets	7	18	–	4
Gee minnow traps	10	3	15	6
<b>24 Jan 2017</b>				
Fyke nets	20	3	–	22
Gill nets	3	25	15	2
Gill nets	3	105	50	2
<b>15-Mar-17</b>				
Gill nets	8	25	15	3
<b>16-Mar-17</b>				
Gill nets	8	25	15	3

### *Population estimates*

We used a two-sample Lincoln–Petersen model to estimate fish abundance in Lake Milicich using the R script provided in the Fish Stock Assessment package (Ogle 2016). The simplest and most common capture-recapture study occurs when fish are collected from a closed population and  $M$  fish are marked (with either a batch or individual-mark) and returned to the population. A subsequent sample is taken and the total number of fish ( $C$ ) and the number of previously seen or marked fish ( $R$ ) in the second sample are recorded. Under the assumptions listed below, the ratio of  $M$  to the

unknown total population size  $\hat{N}$  is equal to the ratio of  $R$  to  $C$  (Pine et al. 2012). Equating the two ratios produces the standard Lincoln–Petersen estimator

$$\hat{N} = \frac{MC}{R} \quad \text{eqn 1.}$$

The simple Lincoln-Petersen estimate (eqn 1) is biased for small samples. However,

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

is an unbiased estimator of  $N$  when  $(M+C) \geq \hat{N}$  (Chapman 1951), or is nearly unbiased when  $R > 7$  (Chapman 1951; Krebs 1999; Ogle 2015). Ogle (2015) substituted  $n$  for  $C$  and  $m$  for  $R$  in an otherwise identical equation. The estimated variance of  $\hat{N}$  is

$$\text{var } \hat{N} = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)} \quad \text{eqn 3.}$$

Ricker (1975) regards the  $-1$  in eqn 2 as of no practical significance, which is true for most population estimates, say  $> 20$  fish, and reformulates eqn 2 as

$$\hat{N} = \frac{(M+1)(C+1)}{(R+1)} \quad \text{eqn 4.}$$

Valid application of the Lincoln-Petersen population estimates and related modifications depends on five assumptions being met (Seber 2002; Hayes et al. 2007; Pine et al. 2012; Ogle 2015):

1. The population is closed both physically (i.e., no immigration or emigration) and demographically (i.e., no recruitment or mortality).
2. Marked fish that are returned to the population mix randomly with unmarked fish.
3. All fish within a sample have an equal probability of capture.
4. Fish behaviour or vulnerability does not change after being marked.
5. Marks or tags in recaptured fish are neither lost nor missed.

Confidence intervals for  $\hat{N}$  have been approximated from other distributions depending on characteristics of the data. Seber (2002) suggested that if more than 10% of fish in the second sample are recaptured fish (i.e.,  $R/C > 0.10$ ), then a binomial distribution should be used. Otherwise, if  $R < 50$ , then a Poisson distribution should be used, or if  $R > 50$ , then a normal distribution should

be used. The  $R$  statistical code in the FSA package (Ogle 2016) selects the appropriate distribution based on  $R$  in the sample.

When using the Lincoln–Petersen model, the product of  $M$  and  $C$  should exceed four times the estimated population abundance, i.e.,  $MC > 4\hat{N}$ , multiple gears should be used for marking and recapture to reduce potential gear selectivity effects, and seven or more recaptures ( $R$ ) should be made (Robson and Regier 1964; Ricker 1975).

## Results

We caught 960 fish comprising seven species, including three native and four introduced species (Tables 3 and 4). Fyke nets were the most effective method for eels and catfish, and 25-mm mesh gill nets were most effective for rudd (fork length range 192-304 mm). Within in the limitations of the small sample size, fyke nets and gill nets were equally effective for goldfish (fork length range 100-228 mm).

Table 3. Fish species caught in Lake Milicich in January 2017 and their common and scientific names.

Common name	Scientific name
<b>Native species</b>	
Shortfin eel	<i>Anguilla australis</i>
Longfin eel	<i>Anguilla dieffenbachii</i>
Common bullies	<i>Gobiomorphus cotidianus</i>
<b>Introduced species</b>	
Brown bullhead catfish	<i>Ameiurus nebulosus</i>
Goldfish	<i>Carassius auratus</i>
Gambusia	<i>Gambusia affinis</i>
Rudd	<i>Scardinius erythrophthalmus</i>

Table 4. The bias of different fishing methods used in Lake Milicich on 17 and 24 January and 15 and 16 March 2017.

Species	Fyke net	Minnow trap	Gill net 18 mm	Gill net 25 mm	Gill net 105 mm	Total
Catfish	359	0	0	0	0	359
Common bully	0	54	0	0	0	54
Gambusia	0	1	0	0	0	1
Goldfish	1	0	0	1	0	2
Longfin eel	4	0	0	0	0	4
Rudd	1	0	2	15	0	18
Shortfin eel	509	23	0	0	0	532
Total	874	78	2	16	0	970

We originally marked 238 catfish, but 42 (18%) of these were found dead on 19 January, possibly as a result of injury from spine punctures by conspecifics during overnight net confinement, and were therefore excluded from population estimates. Other fish marked were shortfin eels (297), rudd (3) and longfin eels (2; Table 5). Common bullies and gambusia were extremely numerous but were not marked.

Shortfin eels and catfish were approximately equal in abundance in Lake Milicich with areal densities of 3.5 fish 100 m<sup>-2</sup> for shortfins (lower and upper 95% confidence limits 3.0 to 4.2) and 3.3 fish 100 m<sup>-2</sup> for catfish (2.5 to 4.5). Point population estimates from the modified Lincoln-Petersen method were 776 catfish and 732 shortfin eels (Table 5), or 169 kg of catfish and 149 kg of shortfin eels (Table 6). The errors for the population estimates were calculated from a binomial distribution, resulting in asymmetrical lower and upper 95% confidence limits (Table 5, Figure 2).

The 42 marked catfish removed as mortalities on 19 January weighed 9.71 kg, and fishing in the recapture phase removed 30.35 kg of catfish, 0.36 kg of goldfish, and 1.16 kg of rudd. The mortalities plus the catfish removed during the recapture phase (40.06 kg) amounted to 24% of the point estimate of biomass of catfish in the lake (169 kg; Table 6).

We repeated gill netting to target rudd and goldfish on 15 and 16 March 2017 (Table 2), catching 7 rudd and 1 catfish. Five rudd survived the netting and were marked with a right pectoral fin clip and released. Netting on 16 March caught a further 3 rudd, none of which were marked, so no mark recapture estimate could be made. Catch rates for the 25-mm gill nets ranged from 0.13 to 0.83 rudd net<sup>-1</sup> set<sup>-1</sup> (mean 0.42 ± 37 SD, *N* = 3). Assuming an individual mean weight of 297 g per fish, the total of 18 rudd that were caught and removed weighed 5.35 kg, so a minimum biomass estimate for rudd in Lake Milicich is 2.66 kg ha<sup>-1</sup>.

Table 5. Mark-recapture population estimates of fish in Lake Milicich in January 2017. Acceptable population estimates met the criterion of  $MC > 4\hat{N}$ . No recaptures ( $R = 0$ ) results in a failure of the population estimation.

Species	<i>M</i>	<i>C</i>	<i>R</i>	Recaptured		Chapman population estimate ( $\hat{N} = (M+1)(C+1) / (R+1) - 1$ )	SE	Lower 95% confidence limit	Upper 95% confidence limit	$MC > 4\hat{N}?$
				Recaptured fish as a proportion of marked fish ( <i>R/M</i> )	fish as a proportion of total captured ( <i>R/C</i> )					
Shortfin eel	297	231	88	0.30	0.38	776	53.8	665	920	yes
Catfish	196	118	31	0.16	0.26	732	99.8	554	997	yes
Longfin eel	2	2	1	0.50	0.50	4	0.9	2	13	no
Rudd	3	5	0	0.00	0.00					failure
Goldfish	0	2	0		0.00					not marked
Common bully	54	0	0	0.00						not marked
Gambusia	1	0	0	0.00						not marked
Total	595	358	120							

Table 6. Mean weights and mark-recapture estimates of areal biomass of fish in Lake Milicich from the modified Lincoln-Petersen method. \* actual weight caught.

Species	Mean weight (g)	Biomass estimate (kg)	Areal biomass (kg ha <sup>-1</sup> )		
			Biomass estimate	Lower 95% confidence limit	Upper 95% confidence limit
Catfish	231.1	169.1	84.1	63.7	114.6
Shortfin eel	191.7	148.7	74.0	63.4	87.7
Longfin eel	510.5	1.8	0.9	0.5	3.3
Rudd*	297.0	2.4			
Goldfish*	181.5	0.4			
Common bully	1.3				

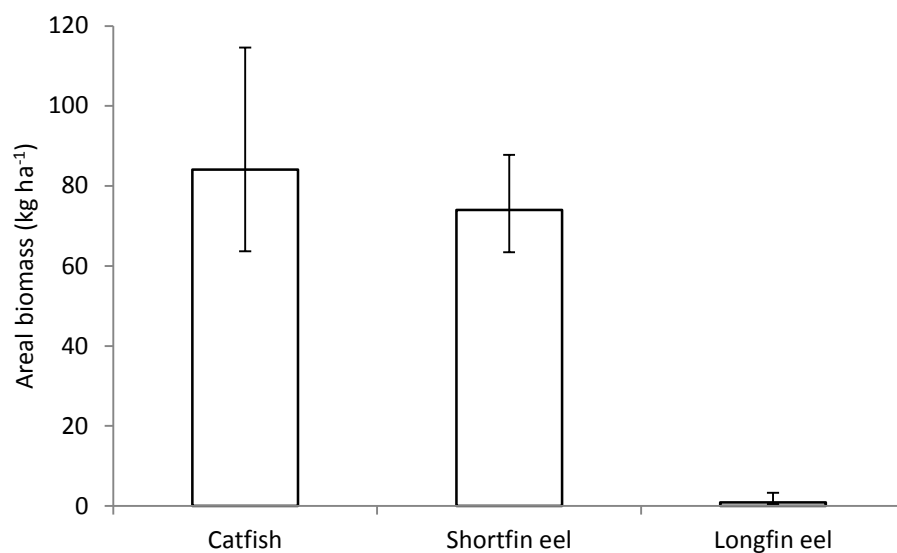


Figure 2. Areal biomass and 95% confidence limits for catfish, shortfin eels, and longfin eels in Lake Milicich in January 2017.

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### Size structure of catfish and shortfin eel populations

Length frequencies (Figure 3A) suggest there were three distinct age classes in the catch of catfish, though the weight frequencies suggest there may be 4 age classes (Figure 3B). Alternatively, both lighter males and heavier gravid females could have comprised the middle length class. Shortfin eels were highly log-normally distributed for both length and weight with no obvious age classes (Figure 4). Weight-length regressions ( $\ln(Y) = \ln(a) + \ln(X)$ , where  $Y$  = weight in g and  $X$  = length in mm) allow weights to be calculated from lengths in future (Table 7).

Table 7. Length-weight regression statistics for fish in Lake Milicich in January 2017.  $P$  for all models <0.001.

Species	Regression statistics				Length range (mm)		Weight range (g)	
	$\ln(a)$	$b$	$N$	$r^2_{adj}$	Minimum	Maximum	Minimum	Maximum
Catfish	-11.043	2.946	233	0.979	175	324	63	432
Shortfin eel	-14.263	3.178	293	0.977	252	765	24	944
Common bully	-13.908	3.624	38	0.918	36	73	0.4	5.0
Rudd	-12.217	3.255	8	0.965	192	304	130	550

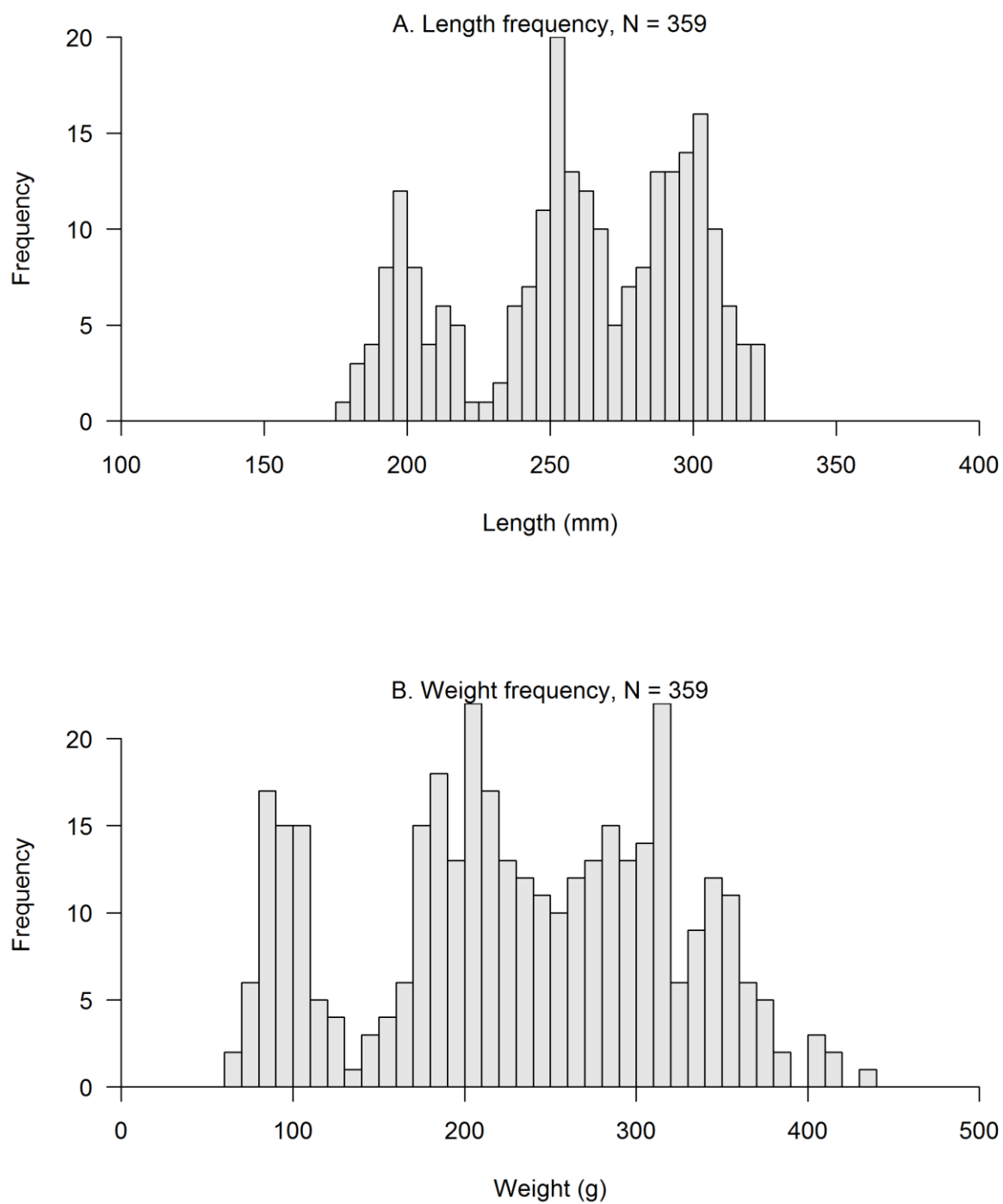


Figure 3. A. Length and B. weight frequencies of catfish in Lake Milichich in January 2017.

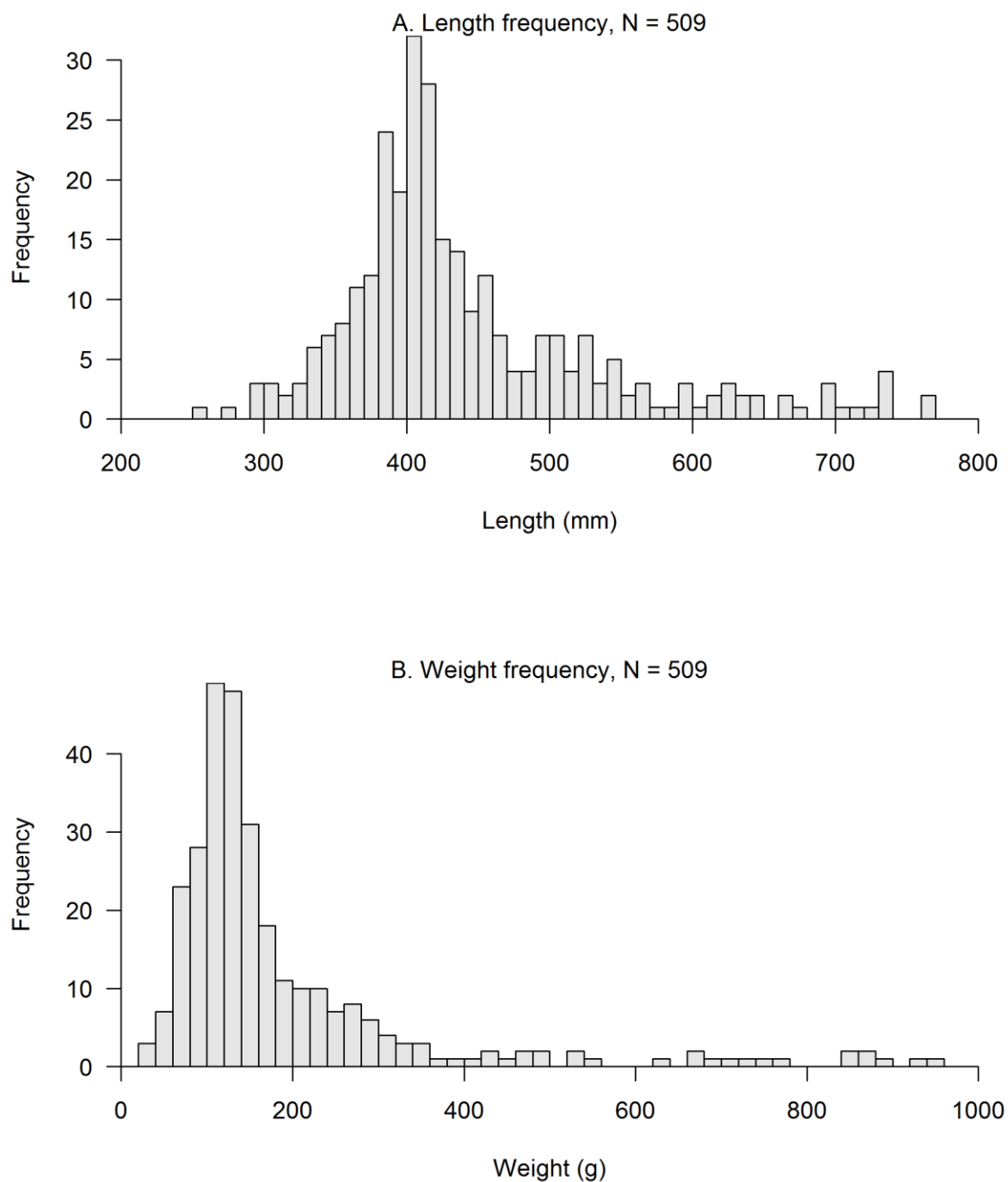


Figure 4. A. Length and B. weight frequencies of shortfin eels Lake Milicich in January 2017.

On 15 March 2017 we took a depth profile of temperature and dissolved oxygen (DO) in the deepest part of the lake (2.7 m; 37°53'06.7"S, 175°14'55.8"E) (Figure 5, Table 8). The surface DO was surprisingly low (3.45 mg L<sup>-1</sup>, 38.5%) despite careful calibration of the DO instrument and membrane replacement on the sensor. Surface DO concentrations were quite variable around the lake, ranging from 4.4 mg L<sup>-1</sup> at one site to 5.7-6.1 mg L<sup>-1</sup> at three other sites around the lake (Figure 6, Table 9).

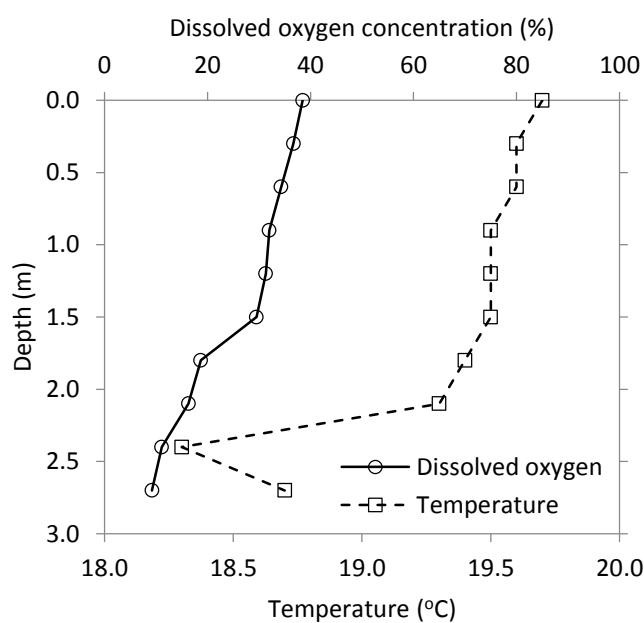


Figure 5. Vertical profile of temperature and dissolved oxygen (DO) in the deepest part of Lake Milicich on 15 March 2017 at 0915 h NZ standard time.

Table 8. Depth profile of temperature and dissolved oxygen (DO) measured in the deepest part of Lake Milicich (37°53'06.7"S, 175°14'55.8"E) on 15 March 2017 at 0915 h NZ standard time.

Depth (m)	DO (mg L <sup>-1</sup> )	DO (%)	Temperature (°C)
0	3.45	38.5	19.7
0.3	3.36	36.7	19.6
0.6	3.39	34.3	19.6
0.9	3.14	32	19.5
1.2	2.85	31.3	19.5
1.5	2.69	29.5	19.5
1.8	1.68	18.7	19.4
2.1	1.49	16.3	19.3
2.4	1.12	11.1	18.3
2.7	0.67	9.2	18.7

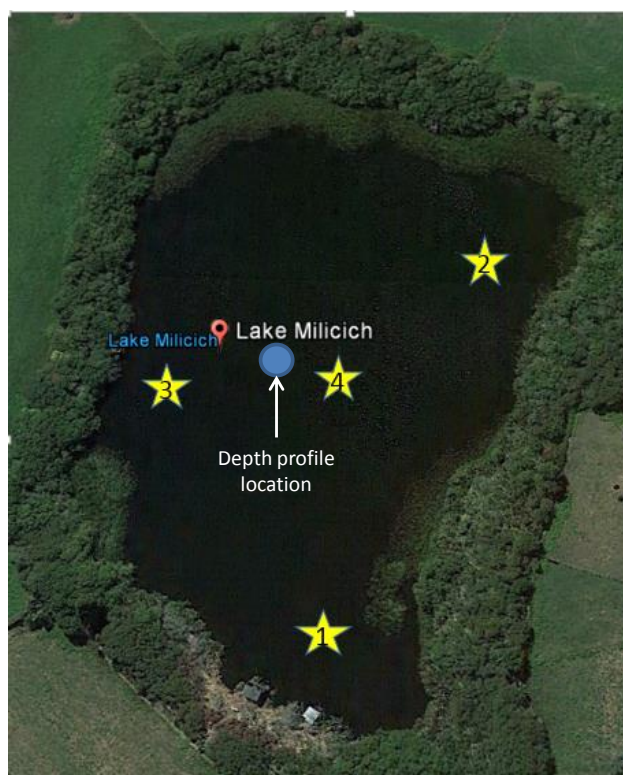


Figure 6. Location of water quality samples in Lake Milicich measured on 15 and 16 March 2017.

Table 9. Surface water quality variables measured in Lake Milicich on 16 March 2017 (Kevin Collier, unpublished data).

Variable	Site 1	Site 2	Site 3	Site 4
Temperature (°C)	20.6	21.3	21.8	21
DO (mg L <sup>-1</sup> )	4.4	6.1	6.2	5.7
DO (%)	49	69	70	65
Conductivity (µS cm <sup>-1</sup> )	135.8	134.4		136.1
Secchi depth (m)				0.91

## Discussion

We believe that the five assumptions of mark-recapture were met once the catfish mortalities were excluded from the marked total. The biomass of catfish in Lake Milicich (84.1 kg ha<sup>-1</sup>, 95% confidence limits 63.7 to 114.6 kg ha<sup>-1</sup>) was very similar to the peat lake Mangahia (66 kg ha<sup>-1</sup>; Hicks et al. 2015). Shortfin eel biomass in Lake Milicich (74.0 kg ha<sup>-1</sup>, 95% confidence limits 63.4 to 87.7 kg ha<sup>-1</sup>) was considerably greater than in Lake Mangahia (37 kg ha<sup>-1</sup>; Hicks et al. 2015) or Lake Ohinewai (14-41 kg ha<sup>-1</sup>; Hicks and Tempero in press). As eels were effectively sampled by fyke netting (recapture rate 30-50%; Table 5), we assume that the small number of longfin eels estimated is a true reflection of their very low abundance in this lake. Our methods and capture locations are likely to have under-sampled juveniles of all species, especially catfish, which would add an age class for young-of-the-year catfish to the three age classes that we observed.

Our fishing under-sampled rudd and goldfish, which eventually proved most susceptible to 25-mm mist nets. Rudd are effectively caught by gill netting, as Neilson et al. (2004) showed in the Rotopiko peat lakes. Although we could not estimate rudd abundance from mark-recapture because none of the marked fish were recaptured, we caught 18 adult fish so we conclude that a minimum biomass of rudd in Lake Milicich is  $2.66 \text{ kg ha}^{-1}$ , similar to the shallow Waikato lakes Mangahia, Ohinewai, and Kaituna ( $0.69\text{-}3.3 \text{ kg ha}^{-1}$ ; Hicks et al. 2015a). The abundance of goldfish is also unknown, and only a mark-recapture estimate using boat electrofishing is likely to resolve this. However, when rudd and goldfish are abundant, e.g., 28 and  $26 \text{ kg ha}^{-1}$  respectively in Lake Kuwakatai, North Auckland, fyke netting was a reasonably effective method of capture (Hicks et al. 2015b), so the low catch rates that we found in Lake Milicich confirms that rudd and goldfish biomasses are low.

The implication of this survey is that the presence of catfish and rudd, and possibly goldfish, are significant barriers to lake restoration of Lake Milicich unless they are removed, especially as rudd in New Zealand are primarily herbivorous as adults  $> 150 \text{ mm}$  long (Kane 1995). Further, inspection of the outlet drain and tributary to the Mangaotama Stream is required to investigate whether invasive fish can migrate from lower Waikato basin, which would frustrate fish eradication efforts.

The total phosphorus concentration measured in December 2016 ( $38 \text{ mg m}^{-3}$ , TN:TP 25:1) is similar to other peat lakes in the region, ( $18\text{-}34 \text{ mg m}^{-3}$ ), which typically have high total nitrogen concentrations and hence high TN:TP ratios (29:1-64:1) with the exception of Lake Mangahia ( $720 \text{ mg m}^{-3}$ , TN:TP 4:1; Hamilton et al. 2010). High TN:TP ratios are likely to minimise the probability of nitrogen-fixing cyanobacterial blooms, and P is likely to be the nutrient that limits fish production in Lake Milicich.

One overnight set of 20 fyke nets on 23-24 January 2017 removed 24% of the total biomass of catfish, so further targeted removal of catfish by fyke netting could be worthwhile. Gill netting for rudd and goldfish on three occasions was unable to produce mark-recapture estimates of the number and biomass of rudd and goldfish and few of these fish were caught by fyke netting. However, gill-net catch rates were very low (mean  $0.42 \pm 0.37 \text{ rudd net}^{-1} \text{ set}^{-1}$ ) compared with initial removal netting in the Rotopiko lakes complex ( $7.4 \pm 6.9 \text{ rudd net}^{-1} \text{ set}^{-1}$ ; Neilson et al 2004). We thus conclude that the rudd population is sufficiently small that targeted removal by gill netting may virtually eradicate the herbivorous adults and allow macrophyte restoration to proceed. Low DO concentrations (Table 9) may limit the abundance of rudd, though the DO depth profile that we recorded may not be characteristic of the lake. Heavy rainfall (148 mm on total) 4-10 days before the DO measurements (Figure 7) may have reduced DO concentrations by flushing anoxic groundwater into the lake.

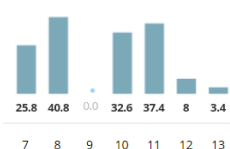


Figure 7. Daily rainfall recorded in mm at Hamilton Airport in March 2017 before dissolved oxygen profiles were measured in Lake Milicich. The X axis is the day in March. Source: New Zealand MetService, <http://www.metservice.com/towns-cities/hamilton>. Accessed 30 March 2017.

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