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Aquatic ecology of Lake Rotokare, Taranaki, and options for restoration



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A report prepared for the Rotokare Scenic Reserve Trust

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Executive summary

Lake Rotokare is a 17.8-ha natural lake in eastern Taranaki, located 12 km east of Eltham in the 230-ha Rotokare Scenic Reserve. In 2008, the Rotokare Scenic Reserve Trust completed construction of an 8.2-km predator proof fence around the reserve.

Frequent algal blooms in summer have led to long periods of lake closure to boating and contact recreation. As there are few lakes in the Taranaki region, these closures are a nuisance to the local community. The objectives of this study were to quantitatively survey the fish community of the lake and to evaluate the lake water quality for the Rotokare Scenic Reserve Trust for the purpose of advising on options for lake restoration.

Water quality has not deteriorated since 1976-1980, and, if anything, has improved. Secchi disc depth in 2013 (1.95 m) was very similar to measurements in summer 1980 (mean 1.93 m on 30 January 1980). Mean dissolved reactive phosphorus (± 95% confidence interval) was greater in 1976 (190±50 mg/m^3) than mean phosphate concentration in 2013 (93±31 mg/m^3, $p < 0.05$, Kolmogorov-Smirnov two-sample test). The thermocline was deeper in 2013 at 6-7 m compared to 3-4 m in 1977. This indicates that a much greater volume of the lake was oxygenated in February 2013 than in February 1977. Also, the intensity of stratification was less in 2013, as the dissolved oxygen concentration below the thermocline was 21-27% compared to just 3% in 1977. This suggests that an improvement in water quality has occurred, probably as a result of stock exclusion.

To sample the fish community, boat electrofishing was used at a total of six sites. The total length fished was 1,656 m, which was 6,624 m^2 in area. Eighty minutes of boat electrofishing caught 234 fish (217 perch, 16 shortfin eels, and 1 longfin eel). Fishing at night showed a 16-fold increase in the catch rate of perch (125 fish/10 min of fishing) compared to fishing during the day (8 fish/10 min of fishing).

Perch dominate the fish community in Lake Rotokare and the biomass and density of eels are low, which is unusual for Taranaki water bodies. The mean density of perch was 4.49 fish/100 m^2, and the mean density of eels was 0.29 fish/100 m^2. The lower eel density may be a result of impaired access for eels or may be the result of predation by perch on migrant juvenile eels. There have been changes in the zooplankton community since 1980. The North American invader *Daphnia galeata* was not found in 1980, and appears to have now replaced the cladoceran *Bosmina meridionalis* and copepod *Boeckella* sp. We also found a diverse rotifer community.

There are several possible management solutions for the lake that might reduce the frequency and duration of phytoplankton blooms, and thereby reduce the need for lake closure. Based on the assumption that high densities of zooplanktivorous fish such as juvenile perch can remove the larger cladocerans that normally control algal blooms, these options include:

1. Assessment of the perch population by hydroacoustic methods, followed by successive perch removals by netting, which could be achieved by volunteers. Follow-up hydroacoustic surveys would establish the success of perch removal. Fishing will not eradicate the perch, but could achieve an improvement in water quality by reducing predation on the zooplankton, thereby allowing zooplankton to effectively graze the phytoplankton.

2. Fish aggregation devices could be trialled to improve capture rates of young-of-the-year perch, which congregate around brushy cover in lakes and preferentially feed on zooplankton.

3. Eels can be effective predators of other fish, but their density is currently too low to control perch densities. Stocking longfin eels into Lake Rotokare could increase their density, which appears at the moment to be recruitment-limited. These long-lived predators could control perch recruitment by eating juvenile perch and, at maturity, the eels would leave the lake to spawn at sea. Closing Lake Rotokare to eel fishing to allow the eel populations to increase, assuming eels can migrate into the lake.

4. Understanding the conditions under which algal blooms establish is a key to their management. Continued monitoring of depth profiles of dissolved oxygen and temperature would show if the trend of reducing intensity and duration of blooms is real or simply a response to normal environmental fluctuations. A lake monitoring buoy would be a good way to achieve real-time monitoring without the need for field visits.

Introduction

Lake Rotokare is a 17.8-ha natural lake in the New Zealand region of Taranaki, located 12 km east of Eltham in the 230-ha Rotokare Scenic Reserve (http://www.rotokare.org.nz/; Venture Taranaki, no date; Taranaki Catchment Commission, 1980). In 2008, the Rotokare Scenic Reserve Trust completed construction of an 8.2-km predator proof fence around the reserve (http://en.wikipedia.org/wiki/Lake_Rotokare). Lake Rotokare drains via the Ararata Stream, which flows into the Tangahoe River (Fig. 1). The lake is 37 km from the sea at 200 m elevation, with a catchment area of 2.5 ha. The mean annual flow is 50 L/s, with a mean annual low flow of 3 L/s. The lake was formed through the damming of a stream channel below a confluence of two streams by a major landslide; this has resulted in an unusual Y-shaped lake (Fig. 2, Taranaki Catchment Commission, 1980).

Previous surveys of water quality lake ecology were carried out intermittently between 1976 and 1980 to develop a plan to eradicate the introduced South African oxygen weed *Lagarosiphon major*. This report indicated that shortfin eels, European perch, and inanga (*Galaxias maculatus*) were present in the lake. Subsequent fish surveys by the Department of Conservation added longfin eels and banded kokopu to the fish fauna, but did not find inanga (Table 1). Given the distance of the lake from the sea, and the generally low and distribution of inanga, it seems likely that juvenile banded kokopu were mistaken for inanga. Freshwater crayfish (koura, *Paranephrops planifrons*) were recorded by spotlighting in the streams by DOC in 1994 (Freshwater Fish Database Record 13123).

Frequent phytoplankton blooms in summer lead to long periods of lake closure to boating and contact recreation. As there are few lakes in the Taranaki region, these closures are a nuisance to the local community. The objectives of our study were to quantitatively survey the fish community of the lake and to evaluate the lake water quality for the Rotokare Scenic Reserve Trust for the purpose of advising on options for lake restoration.

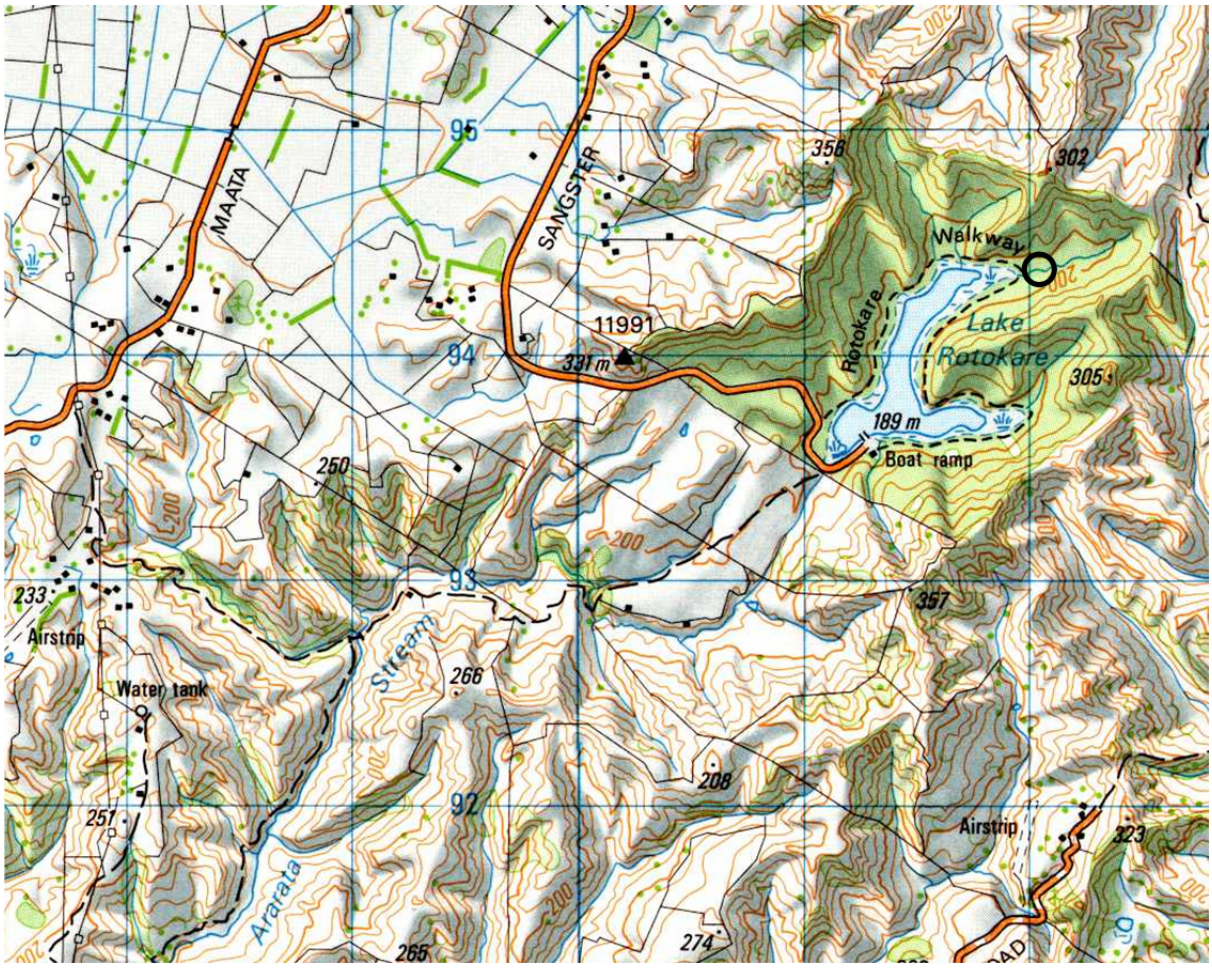

Figure 1. Location of Lake Rotokare in the Tangahoe River catchment. Open circle indicates small stream sampled for banded kokopu.

Table 1. Fish previously recorded in Lake Rotokare. Source: http://www.rotokare.org.nz/fauna.asp

Scientific name	Common name	Abundance
Anguilla australis	Shortfin eel	Common
Anguilla dieffenbachii	Longfin eel	(unknown)
Galaxias fasciatus	Banded kokopu	Common
Perca fluviatilus	Perch	(unknown)

Methods

Water quality

Conductivity and Secchi disc depth

Electrical conductivity of the water was measured with a YSI 3200 conductivity meter as both ambient and specific conductivity (i.e., corrected to a water temperature of 25^{o}C). Water clarity was measured at site 7 (Fig. 3) by the black disc method (Davies-Colley 1988), being the distance at which a 3-cm diameter black disk is just visible. Secchi disc depth, the distance at which a 20-cm disc with black and white quadrants just disappears from view, was also recorded.

Dissolved oxygen

Dissolved oxygen (DO) concentration and temperature were measured as both percent saturation and absolute values in mg/L with a YSI 600 DO meter at the water surface and then in 5-L water samples collected from 1-m intervals to the lake bed with a Schindler-Patalas trap.

Dissolved nutrients

A 50-mL subsample was extracted from Schindler-Patalas trap samples with a syringe and then filtered through a 0.45-µm filter. Dissolved nutrients in each subsample were measured by the University of Waikato with an Aquakem nutrient analyser. These results were compared with extensive water quality analyses and measurements conducted between 1976 and 1980 by the Taranaki Catchment Commission (Taranaki Catchment Commission 1980).

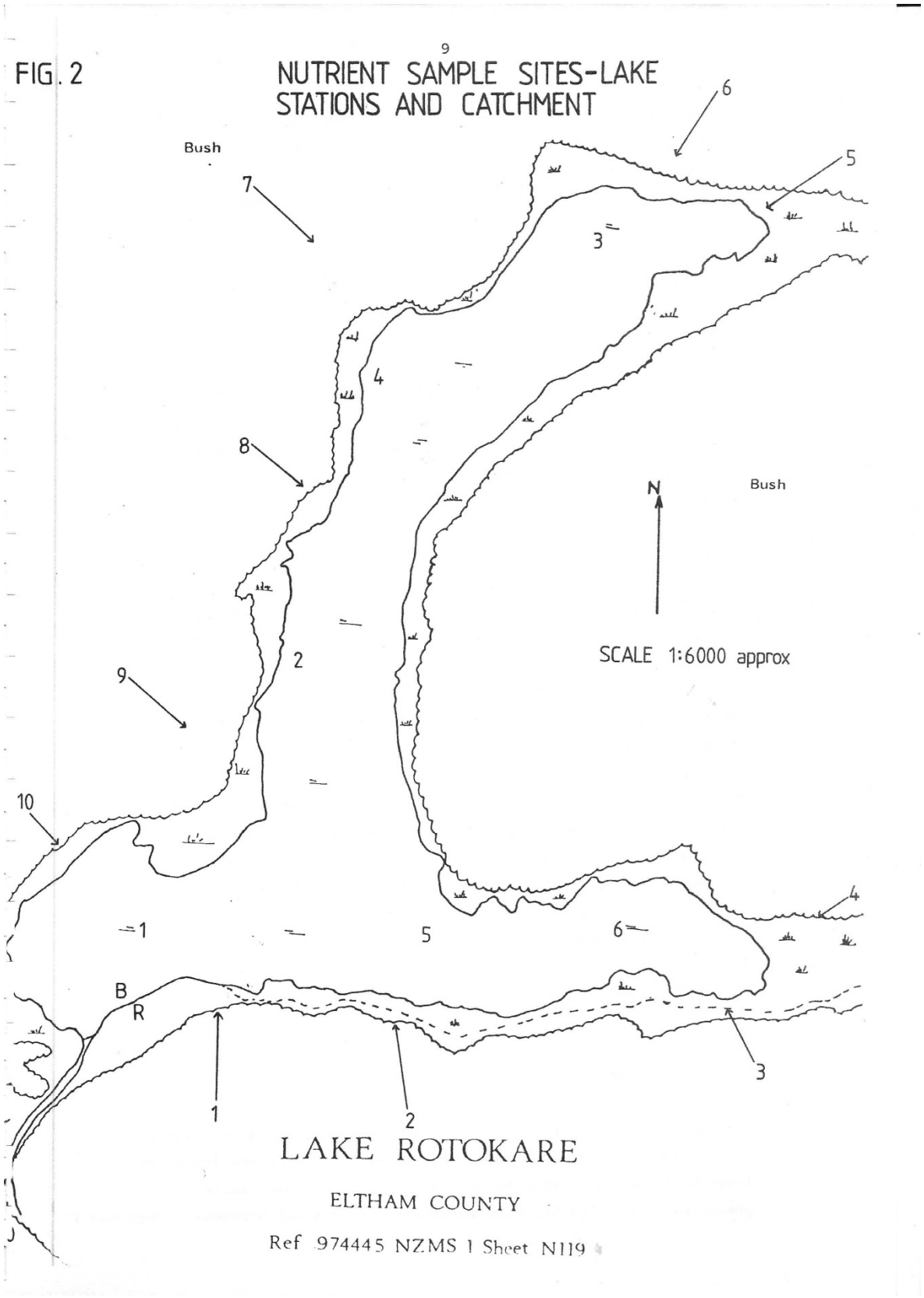

Figure 2. Sites sampled for water quality in Lake Rotokare between 1976 and 1980. Numbered arrows indicate inflows to the lake (source: Taranaki Catchment Commission 1980).

Fish

To sample the fish community, we used a 4.5 m-long, aluminium-hulled electrofishing boat with a 5-kilowatt 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 stainless steel droppers, created the fishing field at the bow, with the boat hull acting as the cathode (Hicks et al. 2006). A total of six sites in Lake Rotokare were fished, three of which were fished twice (Fig. 3). The total length fished was 1,656 m and the total area fished was 6,624 m^2.

The measured conductivity was then used to calculate the settings on the GPP, which resulted in the lake being fished with the GPP set to low range (50-500 V direct current) and a frequency of 60 pulses per second. We adjusted the GPP to 65% of range to give an applied current of 3.5-amp root mean square. 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. This equates to a transect about 4-m wide, which was generally consistent with the observed behavioural reactions of fish to the electrical field at the water surface. This assumption was used to calculate area fished from the linear distance measured with the boat's global positioning system.

We estimated banded kokopu abundance at night at about 2200 h on 9 February 2013 in a shallow stream that entered Lake Rotokare at its northern end (Fig. 1; 39° 26' 47.72"S, 174° 24' 45.38"E). The stream was illuminated with a Lightforce 100-W spotlight.

Length-weight relationships were used to calculate fish weights (Table 2). Parameters *a* and *b* were applied to the equation:

$$W = a\,L^b,$$

where W = weight in g and L = length in mm (fork length for perch and total length for eels).

Temperature and dissolved oxygen profile were measured at site 7 (Fig. 3) with water samples retrieved from each depth with a 5-L Schindler-Patalas trap.

Table 2. Length-weight relationships used to calculate fish weights.

Species	*a*	*b*	r^2	*N*
Shortfin eel	0.000000366	3.270	0.982	370
Longfin eel	0.000000271	3.353	0.996	113
Perch	0.000005780	3.159	0.984	210

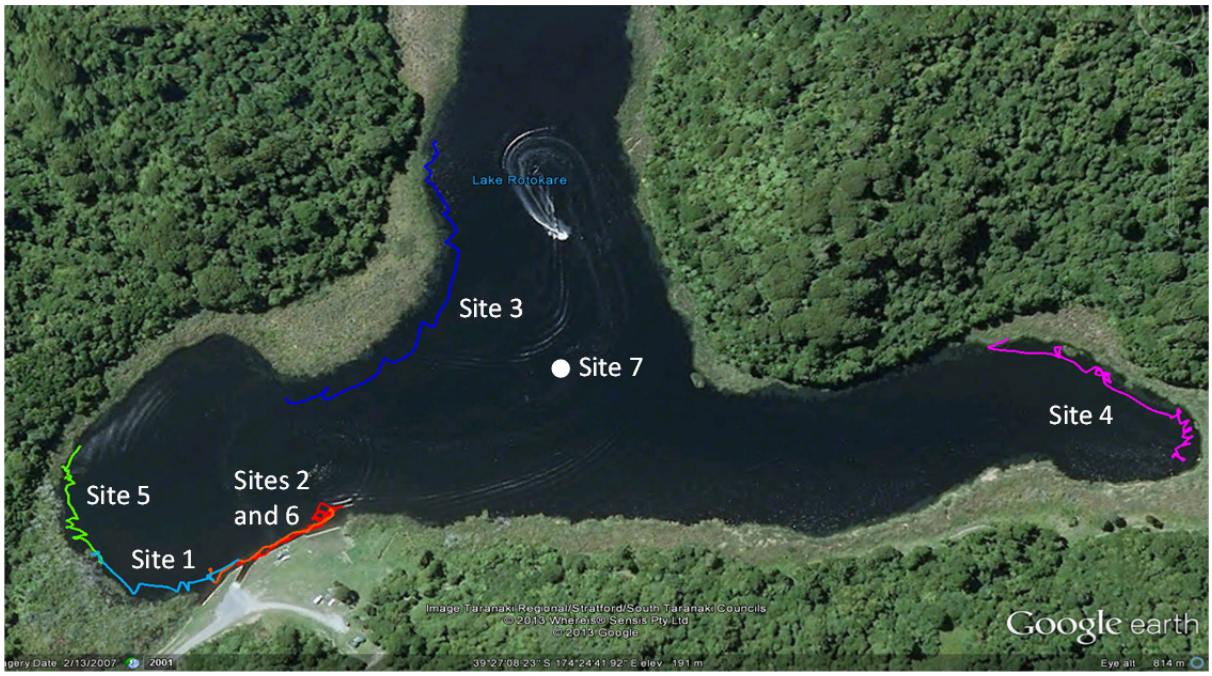

Figure 3. Location of boat electrofishing tracks (shown as coloured traces) that were fished in Lake Rotokare, Taranaki, on 9 and 10 February 2013. The same location was fished twice as sites 2 and 6.

Zooplankton and phytoplankton

Zooplankton and phytoplankton were sampled at site 7 (Fig. 3) with a 45-µm mesh plankton net hauled three times from a depth of about 10 m to the surface. The contents of each haul was added separately to screw topped plastic container. The sample was well mixed, and split in half; sugared formalin was added to one half (final concentration about 5%) to preserve the integrity and shape of the zooplankton. Ethanol was added to the other half to achieve a final concentration of 40%; this sample was used for phytoplankton analysis.

Results

Water quality

Conductivity and Secchi disc depth

Surface water temperature at the start of fishing at 1449 h on 9 February 2013 was 20.6°C. Electrical conductivity was 112.8 µS/cm (ambient) and 123.1 µS/cm (specific, i.e., temperature adjusted to 25°C). This is similar to conductivity measured in 1976 and 1977 (116±13 µS/cm, mean± 1 standard deviation: Taranaki Catchment Commission 1980); it is not clear whether the 1976 and 1977 measurements are ambient or specific conductivity. In 2013, water clarity in the middle of the lake was measured by black disc distance (1.42 m) and Secchi disc depth (1.95 m). These were very similar to measurements in summer 1980 (mean 1.93 m on 30 Jan 1980, *N* = 4, Fig. 4).

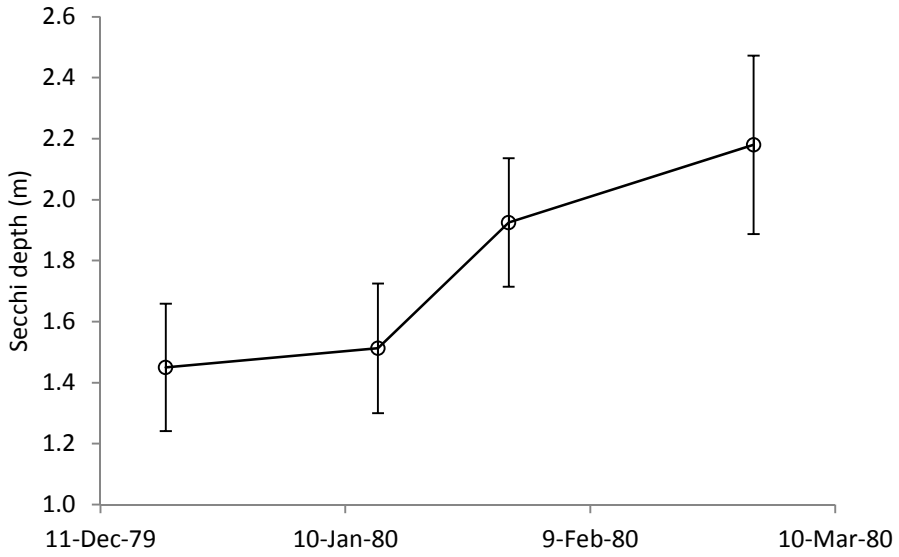

Figure 4. Mean Secchi depth measured at four sites in Lake Rotokare in summer 1980 (source: Taranaki Catchment Commission 1980). Errors bars are 95% confidence interval).

Dissolved oxygen

The dissolved oxygen (DO) and temperature profile with depth at site 7 (Fig. 3), the deepest part of the lake (11 m), showed that the lake was strongly stratified on 9 February 2013, with 20-30% DO from 7 to 11 m depth (Table 3). In 2013, the thermocline, as defined by the point where temperature changes >1°C over 1 m of depth, occurred between 6 and 7 m. DO was 21-25% of saturation below the thermocline. In contrast, the stratification in 1977 was more severe and the thermocline was shallower at 3 and 4 m, and DO below the thermocline (3%, Table 3, Fig. 5) was much lower than in 2013.

The black colouration of the water below the thermocline in 2013 (Fig. 6) is due to particulate manganese oxide, which accumulates in response to the low DO conditions. On 9 September 1976 the water column was fully mixed with a DO concentration of 80%.

Table 3. Dissolved oxygen and temperature profile data for Lake Rotokare on 2 February 1977 at site 5 (Fig. 2) and between 1130 and 1345 h on 9 February 2013 at site 7 (Fig. 3) (source of 1977 data: Taranaki Catchment Commission 1980).

	2 Feb 1977			9 Feb 2013		
	Dissolved oxygen		Temperature	Dissolved oxygen		Temperature
Depth (m)	%	mg/L	(°C)	%	mg/L	(°C)
0.0	104	9.3	20.4	96.2	8.5	21.6
0.5	105	9.5	20.0			
1.0	98	9.0	19.6	98.2	8.6	21.4
2.0	83	7.7	19.0	81.9	7.4	20.9
3.0	80	7.4	18.8	78.1	7.0	20.8
4.0	73	6.8	18.7	64.7	5.8	20.5
5.0	59	5.5	18.7	44.6	4.0	20.1
6.0	3	0.3	16.9	39.9	3.6	19.3
7.0	3	0.3	15.7	30.1	2.9	17.4
8.0	3	0.3	15.6	26.7	2.6	16.3
9.0				25.0	2.4	15.8
10.0				25.0	2.5	14.9
11.0				21.4	2.1	14.9

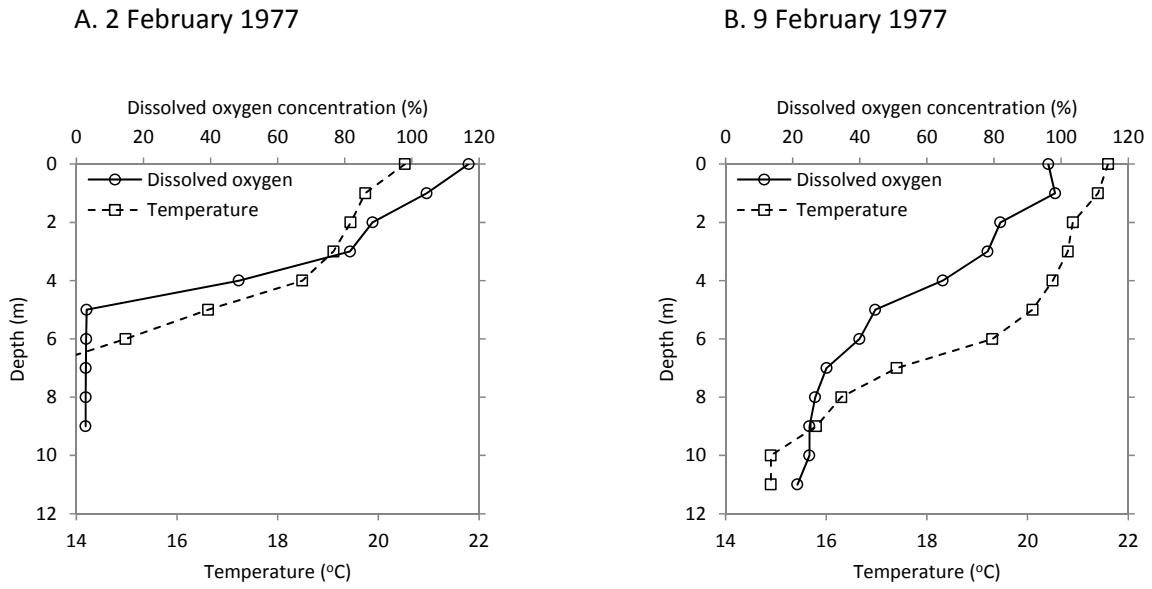

Figure 5. Depth and temperature profiles for Lake Rotokare for A. 2 February 1977 at site 5 (Fig. 2) and B. 9 February 2013 at site 7 (Fig. 3) (see Table 3 for data).

Figure 6. Water from 10-m depth showing the black colouration caused by manganese oxide that accumulates as a precipitate under anaerobic conditions.

Dissolved nutrients

In 2013, concentrations of phosphate (PO_4) were 59-121 mg/m^3. Nitrate and nitrite ($N0_x$ and $N0_2$) were negligible (≤5 mg/m^3, Table 4), but ammonia (NH_4) was present in extremely high concentrations below the thermocline (up to 1342 mg/m^3). Nitrogen release as ammonia is a classic response of nitrogen-rich sediments to deoxygenation. Phosphorus concentrations, expressed as dissolved reactive phosphorus (DRP), were much greater in 1976 (Table 5) than PO_4 in 2013. PO_4 and DRP, although not identical, measure broadly similar species of phosphorus so are reasonably comparable for this purpose.

Unfortunately, NH_4 was infrequently measured between 1976 and 1980 and samples were taken mostly from the surface water (Taranaki Catchment Commission 1980) where NH_4 concentrations are typically low (Table 4), so cannot be compared directly with the 2013 results. Measurements made in 7 December 1977 and July and August 1979 ranged between 18 and 56 mg/m^3, much less than our highest measurements from below the thermocline (1173-1342 mg/m^3; Table 4).

Table 4. Dissolved nutrient concentrations measured in Lake Rotokare on 9 February 2013.

Depth (m)	Dissolved nutrient concentration (mg/m^3)			
	NH_4	NO_2	NO_x	PO_4
0.2	43	1	5	59
5.0	248	1	1	88
9.0	1173	<0.1	<0.1	121
9.0	1274	<0.1	<0.1	98
9.0	1342	<0.1	<0.1	97

Table 5. Dissolved nutrient concentrations measured in Lake Rotokare on 2 Sep 1976 and 1 Feb 1977 (source: Taranaki Catchment Commission 1980).

	Depth	DRP (mg/m^3)		NO_3-N (mg/m^3)		pH	Alkalinity	Total hardness
Site	sampled	2-Sep-76	1-Feb-77	2-Sep-76	1-Feb-77	1-Feb-77	(g/m^3 as $CaCO_3$)	(g/m^3 as $CaCO_3$)
Outlet		405		1500				
Ramp		350		1120				
A			950		1220	7.3	80	63
1	surface	260	100	240	80	6.9	30	32
1	middle	50	10	250	70	6.8	20	31
1	bottom	245	10	330	310	6.5	40	31
2	surface	255	0		90	7.1	30	27
2	middle	70	25	310	90	7.1	30	29
2	bottom	260	15		100	6.8	30	29
3	surface	195	15		70	7.3	30	28
3	middle	120	335	330	80	7.2	30	28
3	bottom	40	10		70	7.2	30	27
4	surface	175	10		70	8.8	40	27
4	middle	195	135	270	70	8.5	30	28
4	bottom	320	1		50	8.3	20	28
5	surface	165	135		10	7.3	30	27
5	middle	50	40	260	60	7	30	28
5	bottom	170	425		310	5.3	30	34
6	surface	260	160		70	8.3	60	27
6	middle	175	80		70	8.1	40	29
6	bottom	45	15		50	8	20	28

Fish

Perch and eels

Boat electrofishing for 80 mins caught 234 fish (217 perch, 16 shortfin eels, and 1 longfin eel). Night fishing on 9 February 2013 at site 6 (Fig. 3) showed a 16-fold increase in the catch rate of perch (125 fish/10 min of fishing) compared to fishing during the day (8 fish/10 min of fishing at site 1 (Fig. 3; Table 6).

Figure 7. A wide size range of perch caught by boat electrofishing at night.

Figure 8. Longfin eel (1126-mm long, 45-cm girth, 2.582 kg calculated weight) caught by boat electrofishing at night at site 6 (Fig. 3) in Lake Rotokare on 9 Feb 2013.

Table 6. Number of fish caught by boat electrofishing in Lake Rotokare on 9 and 10 February 2013. Blank cells indicate zero catch.

	Length	Area			Number of fish/10 min fishing			
Site	fished (m)	fished (m^2)	Date	Time (h)	Perch	Shortfin eel	Longfin eel	Total
1	142	568	9-Feb-13	1515	8	1		9
2	234	936	9-Feb-13	1600	48	2		50
3	296	1184	9-Feb-13	1640		1		1
4	316	1264	9-Feb-13	1700	1			1
5	161	644	9-Feb-13	2020	23	6		29
6	131	524	9-Feb-13	2100	125	2	1	128
1	142	568	10-Feb-13	1100	9	1		10
6	234	936	10-Feb-13	1130	3	3		6
Total	1656	6624		Average	217	16	1	234

Table 7. Density of fish caught by boat electrofishing in Lake Rotokare on 9 and 10 February 2013. Blank cells indicate zero catch.

	Length	Area			Fish density (number/100 m^2)			
Site	fished (m)	fished (m^2)	Date	Time (h)	Perch	Shortfin eel	Longfin eel	Total
1	142	568	9-Feb-13	1515	1.41	0.18		1.58
2	234	936	9-Feb-13	1600	5.13	0.21		5.34
3	296	1184	9-Feb-13	1640		0.08		0.08
4	316	1264	9-Feb-13	1700	0.08			0.08
5	161	644	9-Feb-13	2020	3.57	0.93		4.50
6	131	524	9-Feb-13	2100	23.85	0.38	0.19	24.43
1	142	568	10-Feb-13	1100	1.58	0.18		1.76
6	234	936	10-Feb-13	1130	0.32	0.32		0.64
Total	1656	6624		Average	4.49	0.29	0.02	4.80

Table 8. Total weight of fish caught by boat electrofishing in Lake Rotokare on 9 and 10 February 2013. Blank cells indicate zero catch.

	Length	Area			Total weight (g)			
Site	fished (m)	fished (m^2)	Date	Time (h)	Perch	Shortfin eel	Longfin eel	Total
1	142	568	9-Feb-13	1515	1,086	306		1,391
2	234	936	9-Feb-13	1600	2,622	1,272		3,894
3	296	1184	9-Feb-13	1640		76		76
4	316	1264	9-Feb-13	1700	12			12
5	161	644	9-Feb-13	2020	356	1,154		1,509
6	131	524	9-Feb-13	2100	4,933	435	2,582	7,951
1	142	568	10-Feb-13	1100	677	903		1,580
6	234	936	10-Feb-13	1130	244	219		463
Total	1656	6624		Average	9,930	4,365	2,582	16,877

Table 9. Biomass of fish caught by boat electrofishing in Lake Rotokare on 9 and 10 February 2013. Blank cells indicate zero catch.

Site		Length fished (m)	Area fished (m^2)	Date	Time (h)	Biomass (g/m^2)			
						Perch	Shortfin eel	Longfin eel	Total
	1	142	568	9-Feb-13	1515	1.91	0.54		2.45
	2	234	936	9-Feb-13	1600	2.80	1.36		4.16
	3	296	1184	9-Feb-13	1640		0.06		0.06
	4	316	1264	9-Feb-13	1700	0.01			0.01
	5	161	644	9-Feb-13	2020	0.55	1.79		2.34
	6	131	524	9-Feb-13	2100	9.41	0.83	4.93	15.17
	1	142	568	10-Feb-13	1100	1.19	1.59		2.78
	6	234	936	10-Feb-13	1130	0.26	0.23		0.49
Total		1656	6624		Average	2.02	0.80	0.62	3.43

Two clear cohorts were apparent in the perch population (Fig. 9A). These are most likely to be age 0 (modal size class 80-90 mm fork length) and age 1 (modal size class 140-150 mm fork length). Shortfin eels were not sufficiently numerous to see cohorts, but the size distribution suggests that recruitment is still occurring (Fig. 9B).

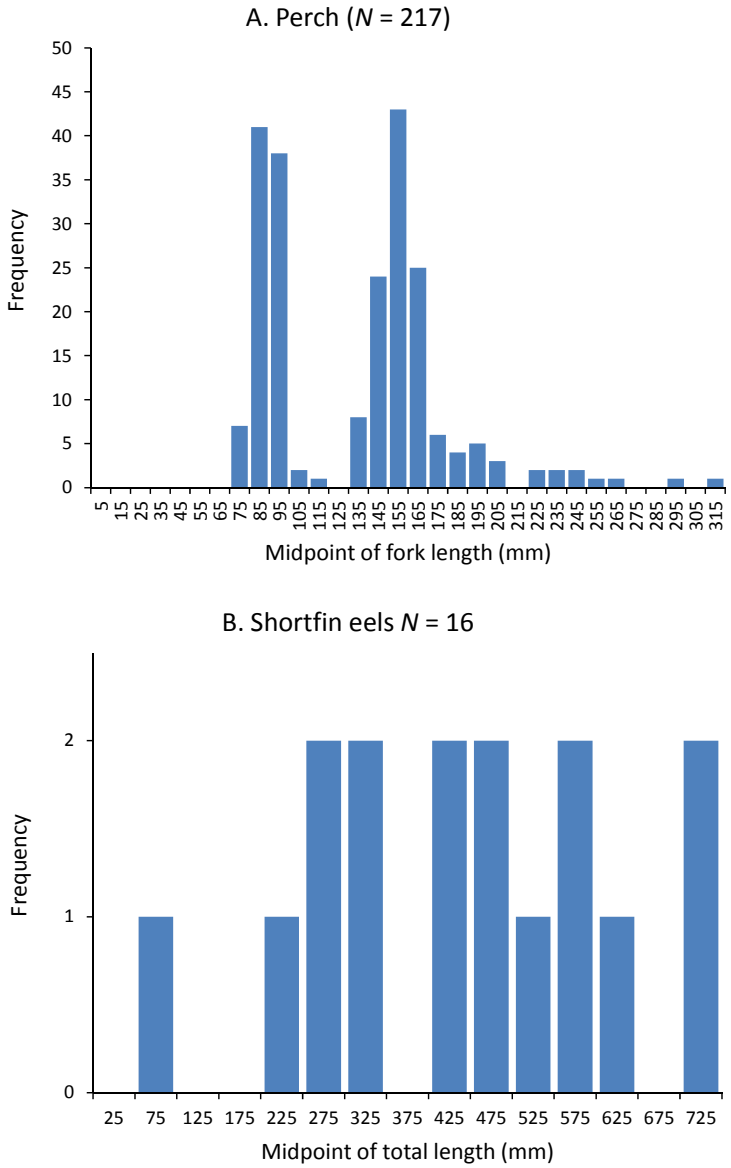

Figure 9. Length-frequency distribution of A. perch and B. shortfin eels in Lake Rotokare on 9-10 February 2013.

Banded kokopu

Twenty-four banded kokopu between about 8 and 25 cm in length were observed in 16 m of stream length. As the stream was on average about 1 m wide, the banded kokopu density was about 150/100 m^2. Some of these fish were large for the species (e.g., Fig. 10).

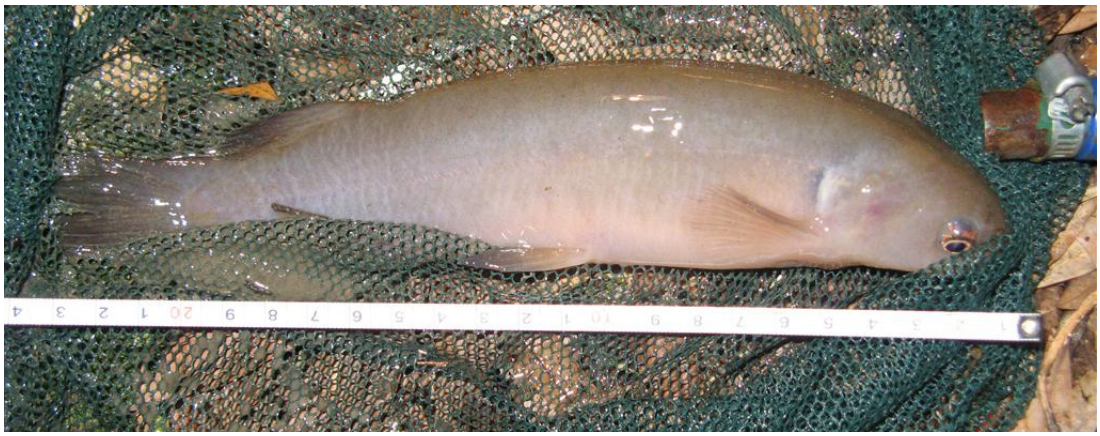

Figure 10. Banded kokopu (225-mm total length) that was caught by hand netting in a small stream at the northern end of Lake Rotokare on 9 February 2013.

Phytoplankton

Planktonic phytoplankton sampled by vertical plankton net hauls were identified to genus by Susie Wood, Cawthron Institute (Table 10). The dominant species in the planktonic phytoplankton sampled by vertical plankton net hauls were the potentially toxic cyanobacteria *Anabaena circinalis* and *Microcystis* sp. (Susie Wood, Cawthron Institute). The green filamentous alga *Oedogonium* sp. occurred as an epiphyte on the submerged macrophytes.

Table 10. Phytoplankton in Lake Rotokare sampled by vertical plankton net hauls on 9 February 2013.

Chlorophyta
Botryococcus sp.
Closterium sp.
Cosmarium sp.
Eudorina sp.
Nephrocytium sp.
Oocystis sp.
Sphaerocystis sp.
Staurastrum sp.
Volvox sp.
Unidentified large filamentous species (only one filament)
Euglenophyta
Trachelomonas sp.
Euglena sp.
Euglena texta
Diatoms
Asterionella sp.
Aulacoseira sp.
Fragilaria sp.
Navicula sp.
Dinoflagellates
Ceratium sp.
Ankyra sp.
Cyanobacteria
Anabaena planktonica
Anabaena circinalis
Aphanocapsa sp.
Microcystis sp.
Pseudanabaena sp.
Pseudanabaenaceae (could not be identified below Family level - very small < 1 um)

Zooplankton

The zooplankton in Lake Rotokare, determined from a bulked sample taken from three vertical tows from a depth of 10 m to the surface, were all very common species in North Island lake assemblages (Table 11). The community was dominated by a North American invader, *Daphnia galeata*, which is a very efficient grazer that can be associated with clear water because of its ability to remove phytoplankton.

Table 11. Zooplankton in Lake Rotokare sampled on 9 February 2013.

Cladocerans:
Daphnia galeata: North American invader
Ceriodaphnia dubia
Copepods:
Calamoecia lucasi
Mesocyclops sp.
Rotifers:
Trichocerca similis
Asplanchna priodonta
Synchaeta pectinata
Polyarthra dolichoptera
Keratella procurva
Pompholyx complanata
Water mites (Acari: Hydrachnidae):
Unidentified water mites, most likely *Piona* sp.

Discussion

Water quality

The most important finding from our comparison with the surveys of 1976-1980 is the reduction of phosphorus in the lake waters, which is most likely a response to the catchment restoration that has occurred. Some caution should be exercised in this conclusion given the differences in sampling and analytical methods, but the difference is compelling. Mean water-column phosphate (PO_4) concentration was 93±31 mg/m^3 (± 95% confidence interval) in 2013, signicantly less than the dissolved reactive phosphate DRP was greater in September 1976 (190±50 mg/m^3) than mean $p < 0.05$, Kolmogorov-Smirnov two-sample test). Seasonal sampling of inorganic phosphate using the sites in Fig. 2, especially in early September, would be useful to compare current conditions to previous sampling.

It is not possible to compare dissolved nitrogen concentrations because of the lack of systematic measurements of ammonia (NH_4) between 1976 and 1980. This nitrogen species was clearly the most abundant in our survey because of the stratification and consequent deoxygenation, and it is reasonable to assume the same would have been true during stratification

events between 1976 and 1980. What we can conclude is that nitrogen stored in the sediments continues to be released during periods of low dissolved oxygen in the bottom waters and will continue to fuel algal blooms. The apparent reduction of phosphorus to about half its previous concentration does suggest that algal blooms should be less intense now than between 1976 and 1980.

The cause of the reduced concentration of phosphorus is most likely to be the fencing of the Rotokare Scenic Reserve and exclusion of grazing animals. In 1981, a report by BR Clarkson and BD Clarkson on the Rotokare Domain noted intense browsing pressure by sheep and cattle, particularly near the reserve margins. Browsing pressure was so intense that the forest condition was categorised as “degraded”, with depleted understorey and ground cover layers (p231-233 in Clarkson and Boase 1982). Application of fertiliser to the land might also account for some of the high values of nutrients (Taranaki Catchment Commission 1980). Re-establishment of intact forest and exclusion of stock will have had the effect of both reducing sediment run-off into the lake and removing a contribution of dung and urine from browsing animals to lake-water nutrients.

Modelling nutrient release is possible once the temperature and oxygen profiles are known. Accurate bathymetry would be required, but as a starting point the eight transects showing lake bed profiles that are available in Taranaki Catchment Commission (1980) could be used for this purpose. Alternatively, a vessel with side-scan sonar could be used to map the lake bed.

Algal blooms

Regular state-of-the-environment monitoring for cyanobacteria has been carried out since 2009, and the predominant genus has always been *Anabaena*, occasionally with low levels of *Microcystis*, e.g., in mid-January 2011. Peak abundance usually occurs between late January and mid-February (Table 12), although in 2012-2013 and 2013-14 the peaks in abundance occurred in December (27,000 and 61,900 cells/mL respectively). Algal blooms have reduced in intensity and duration since monitoring began in 2009-2010, and in 2011-2012 did not exceed the health warning guideline of 15,000 cells/mL (Taranaki Regional Council 2012). Cell counts in 2013 and 2014 again exceeded the guidelines in mid-December, with *Anabaena* as the dominant alga. In late March *Microcystis* was common with the *Anabaena*, and in April, *Oscillatoria* dominated the bloom with *Anabaena* also present (Table 12).

Table 12. Cyanobacterial cell counts for Lake Rotokare from 2009-2012 (source: Taranaki Regional Council 2010, 2011, 2012, 2013, 2014).

Cyanobacterial cell count									
2009-2010		2010-2011		2011-2012		2012-2013		2013-2014	
Date	cells/ml	Date	cells/ml	Date	cells/ml	Date	cells/ml	Date	cells/ml
9.07.09	2350								
		15.11.10	8,800			08.11.12	1,025	12.11.13	260
19.11.09	650	24.11.10	7,500	21.11.11	3,200	22.11.12	15,400		
27.11.09	0	30.11.10	12,600			29.11.12	8,250		
10.12.09	7150	15.12.10	33,000	12.12.11	8,750	10.12.12	27,000	13.12.13	61,900
21.12.09	12,550	23.12.10	25,500	05.01.12	3,100			19.12.13	10,800
12.01.10	66,700	13.01.11	33,000	18.01.12	8,300	10.01.13	23,300	23.12.13	27,830
19.01.10	105,900					23.01.13	9,450	14.01.14	16,850
26.01.10	202,250	31.01.11	16,500	01.02.12	13,600				
08.02.10	210,650	15.02.11	18,200	16.02.12	9,600	07.02.13	6,300	11.02.14	2,100
23.02.10	45,900	28.02.11	10,200	28.02.12	1,200	20.02.13	55	24.02.14	2,010
09.03.10	63,550	08.03.11	6,100			07.03.13	1,700	11.03.14	330
		15.03.11	10,400	15.03.12	200	22.03.13	10,100		
26.03.10	8,650			30.03.12	0			24.03.14	4,600
						11.04.13	13,900	03.04.14	920
10.05.10	7,050	12.04.11	815			29.04.13	5,050		

Fish

Perch numerically dominated the fish community in Lake Rotokare and the biomass and density of eels is low, which is unusual for Taranaki water bodies. This may be the result of impaired access for eels or predation by perch on migrant juvenile eels. Boat electrofishing is biased towards pelagic species such as perch and can be less effective for benthic species such as eels. However, mean catch rate of shortfin eels in Lake Rotokare was 0.24 eels/100 m^2 (biomass 0.8 g/m^2), compared to the range of means in the Waikato River (0.7-1.3 eels/100 m^2, biomass 0.8-2.6 g/m^2; Hicks et al.

2005) and shallow Waikato lakes such Lake Rotokaeo (0.4 eels/100 m^2, biomass 2.6 g/m^2; Hicks et al. 2009). These comparisons suggest that the eel population in Lake Rotokare is limited by recruitment.

A previous report indicated that inanga (*Galaxias maculatus*) was present (Taranaki Catchment Commission 1980), but this is unlikely given the distance from the coast. These fish were probably young banded kokopu, which appear similar to inanga as juveniles.

Zooplankton

There have been major changes in the zooplankton community since 1980. In February 1980, the zooplankton was dominated by *Boeckella* sp., *Ceriodaphnia dubia*, and *Bosmina meridionalis*. Cyclopoid copepods were also abundant, and there were a few mites (*Piona* sp., Taranaki Catchment Commission 1980). The North American invader *Daphnia galeata* was found in 2013 but not in 1980, and appears to have replaced *Bosmina meridionalis* and *Boeckella* sp. However, the diverse rotifer community found in our survey compared to 1976-1980 sampling is probably more attributable to the experience of the person doing the zooplankton identification (Ian Duggan) than to any changes in zooplankton community, as rotifers can be challenging to identify. The water mites found in our survey are likely to be *Piona* sp. as these were previously found in 1980.

Management options

High density of zooplanktivorous fish such as juvenile perch can remove the larger cladocerans that normally control algal blooms. Perch removal would have the added benefit of reducing the abundance of a non-native animal inside the Rotokare Scenic Reserve. Boat electrofishing can only catch fish in water less 2-3 m deep, so the number of perch in the deeper areas of the lake is unknown, although given the littoral densities, is very probably quite high. There are several possible management solutions for the lake that might reduce the frequency and duration of phytoplankton blooms, and thereby reduce the need for lake closure. The options for perch control include:

1. Assessment of the perch population by hydroacoustic methods, followed by successive perch removals by netting, which could be achieved by volunteers. Follow-up hydroacoustic surveys would establish the success of perch removal. Fishing will not eradicate the perch, but could achieve an improvement in water quality by reducing predation on the zooplankton, thereby allowing zooplankton to effectively graze the phytoplankton.

2. Fish aggregation devices could be trialled to improve capture rates of young-of-the-year perch, which congregate around brushy cover in lakes.

3. Eels can be effective predators of other fish, but their density is currently too low to control perch densities. Stocking longfin eels into Lake Rotokare could increase their density, which appears at the moment to be recruitment-limited. These long-lived predators could control perch recruitment by eating juvenile perch and, at maturity, the eels would leave the lake to spawn at sea. Closing Lake

Rotokare to eel fishing to allow the eel populations to increase, assuming eels can migrate into the lake.

4. Understanding the conditions under which algal blooms establish is a key to their management. Continued monitoring of depth profiles of dissolved oxygen and temperature would show if the trend of reducing intensity and duration of blooms is real or simply a response to normal environmental fluctuations. A lake monitoring buoy would be a good way to achieve real-time monitoring without the need for field visits. These buoys are now routinely used around New Zealand and the world to monitor lakes (http://www.lernz.co.nz/lake/realtimedata.html).

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