Fish biomass and gonad development in the Rotopiko (Serpentine) lakes

2013

ERI Report Number 20

Prepared for Department of Conservation

By Nicholas Wu, Adam Daniel and Grant Tempero

2013

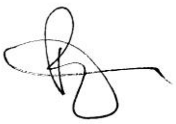
Environmental Research Institute
Te Pūtahi Rangahau Taiao
THE UNIVERSITY OF WAIKATO

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Please cite report as:

Wu, N., Daniel, A. and Tempero, G. 2013. Fish biomass and gonad development in the Rotopiko (Serpentine) lakes. Client report prepared for Department of Conservation. *Environmental Research Institute Report No. 20*, The University of Waikato, Hamilton. 27 pp.

Reviewed by:



Brendan Hicks

Associate Professor

Environmental Research Institute

University of Waikato

Approved for release by:

John Tyrrell

Research Developer

Environmental Research Institute

University of Waikato

Executive summary

The Rotopiko (Serpentine) lake complex is one of the Waikato region's few peat lake systems that contains primarily native aquatic plants. Retaining the natural state of the lakes has been considered a high priority by the Department of Conservation (DOC) and extensive efforts have taken place to prevent nutrient leaching and to control invasive organisms in the lakes. The University of Waikato was contracted to investigate the biomass of introduced and native fish in the Rotopiko lakes in order to determine if the fish removal with rotenone, a chemical piscicide, was required as proposed by DOC. Fish were collected using a variety of traps and nets prior to marking and release. Following a dispersal period, each lake was then fished a second time and fish biomass was estimated using a capture-mark-release-recapture study design; population estimates were derived using the Lincoln-Petersen method (Nichols 1992)

Overall, there was low observed invasive fish biomass (1.37 kg ha^{-1}) and comparatively high native fish (31.9 kg ha^{-1}) biomass in the Rotopiko lakes. The introduced brown bullhead catfish (*Ameiurus nebulosus*) had the highest biomass and the native shortfin eel (*Anguilla australis*) was the species with the highest biomass. Rudd (*Scardinius erythrophthalmus*) are considered the main threat to the aquatic macrophyte community in the Rotopiko lakes, but no rudd were captured during this study. In comparison, rudd were successfully captured using pod traps in Lake Kaituna (mean catch per unit effort (CPUE) 18 fish net^{-1} night^{-1}) at similar water temperatures to those in the Rotopiko lakes. It was therefore concluded that rudd are at very low biomass in the Rotopiko lakes based on the results of this and previous netting surveys.

Based on the low estimated invasive fish biomass (< 2.5 kg ha^{-1}) from mark-recapture data, factors other than invasive fish seem to be responsible for influencing the loss of water quality in the Rotopiko lakes. Treating the lakes with rotenone is not likely to dramatically improve water quality or macrophyte regeneration and would eliminate the native fish community, requiring restocking of native species into the lakes. The current invasive fish reduction programme appears to be sufficient to keep the invasive fish population in check. In addition, implementing both human and physical barriers to prevent future invasions of additional invasive species would be highly recommended. These barriers should include limiting human access and blocking the lake outlet with a fish barrier to restrict movement of invasive species into the lake while allowing passage of native species. Monitoring of sediment and nutrients inputs from inflows to the Rotopiko lakes is currently being conducted by the University of Waikato as part of a contracted research for the Waikato Regional Council; this research may provide insights into the causes of the declining lake water quality.

Table of Contents

List of Figures

List of Tables

1 Introduction

Before human settlement, the Waikato region contained a large number of lowland lakes and vast wetlands including peat formations and floodplains (Collier et al. 2010). During European settlement extensive draining of floodplains and wetlands caused dramatic changes in the Waikato region, draining large areas of peat swamp for agriculture and reducing the number of lowland lakes (Chapman 1996). Water quality of lowland lakes and wetlands has also declined dramatically due to increasing agricultural nutrient leaching from catchments (McDowell et al. 2009). European settlement also amplified the decline of lowland lakes with the introduction of invasive plants and animals; these new species displaced native species and contributed to the decline in water quality (Rowe 2007). Native aquatic macrophytes are important to a healthy lake ecosystem as they provide food, shelter, habitat complexity and enhancement of water quality (Barnes 2001; Collier et al. 2010). Most lakes in the Waikato region have been taken over by invasive aquatic macrophytes or have completely lost their macrophyte populations leading to reduced water quality (Edwards et al. 2005).

The Rotopiko lake complex is one of the few remaining lake systems containing native submerged macrophytes and is listed as a nationally significant wetland in the "Directory of Wetlands in New Zealand" (Cromarty and Scott 1996). The Department of Conservation (DOC) and Waikato Regional Council have made substantial investments into protecting and preserving the high biodiversity values of the Rotopiko lakes. However, water quality and the native macrophyte community have continued to decline over the past two decades (Edwards et al. 2010). At nearby Lake Rotomanuka, native macrophyte communities have collapsed due to declining water quality (Edwards et al. 2005). The cause of the decline in native macrophytes is speculated to be a combination of displacement by invasive macrophytes, consumption by invasive fish and nutrient enrichment (Rowe 2007). Therefore, DOC has taken a catchment wide approach to the restoration by managing invasive fish, the surrounding vegetation and nutrient inputs in the Rotopiko lakes catchment.

Invasive fish are a major threat to aquatic biodiversity in the Waikato region and have been known to dramatically reduce water quality, displace macrophytes and alter ecological communities (Crivelli 1983; Breukelaar et al. 1994; Barton et al. 2000; Rowe 2007; Schallenberg and Sorrell 2009). Rudd (*Scardinius erythrophthalmus*) are a herbivorous species, the adults browse on macrophytes and when in large populations may significantly deplete or even contribute to the total collapse of macrophytes communities (Lake et al. 2002; Nurminen et al. 2003). Brown bullhead catfish (*Ameiurus nebulosus*) and goldfish (*Carassius auratus*) also contribute to lake ecosystem degradation by competing with native fish and causing re-suspension of sediment (Wise 1990). In 2001, a continuing fish removal programme at the Rotopiko lakes was initiated by DOC and the Waikato Regional Council (Neilson et al. 2004). Gill netting was found to be highly effective in catching invasive fish without harming native fish; however, total eradication using netting alone has not been achieved (Neilson et al. 2004; Lake 2010). The use of the piscicide rotenone is currently being considered as an invasive fish eradication option by DOC. Rotenone is a naturally occurring plant compound and is highly toxic to fish as it blocks mitochondrial electron transport. Rotenone has low toxicity to mammals and does not accumulate in the environment due to rapid breakdown by light and heat (Ling 2003). However, rotenone is not species selective and will affect both native and invasive fish species; this will necessitate the restocking of the lakes with native species following rotenone application.

Our objective was to estimate native and invasive fish biomass, determine if the application of rotenone is required to maintain the native charophyte community and recommend a rotenone application period that would give the highest likelihood of invasive fish eradication based on literature review and determination of spawning periods based on gonad analysis.

1.1 *Study site*

The Rotopiko lakes complex is located 20 km south-east of Hamilton, New Zealand (37°56′32”S, 175°19′10”E; Fig. 1). The complex comprises three shallow eutrophic peat lakes (Neilson et al. 2004). All three lakes were once part of a large peat lake formed 17,000 years ago during the last glaciation (Green and Lowe 1985). Drainage during early European settlement separated the three deepest basins into separate lakes. South Lake is the largest (Table. 1), but during low water it can separate into two lakes (South Lake and Winter Lake; Fig. 1). All lakes are fed by groundwater and surface run off from a number of small subcatchments. The main inflow drains from surrounding pastoral land into the southern end of East Lake. Overflow from East Lake results in drainage into South Lake (Fig. 1) which is also fed by North Lake. Outflow from the catchment is from a single drain from South Lake that flows to the east into the Waikato River by way of Mystery Creek.

North and East Lakes are considered to be in pristine condition due to intact native aquatic communities in the lakes based on a 2005 NIWA survey using the Lake Submerged Plant Indicator (Lake SPI; Edwards et al. 2005). The assembly of aquatic vegetation varies with each lake but typically includes pondweeds (*Potamogeton ochreatus*, *Potamogeton cheesmannii*) and charophytes (*Chara coralline, Nitella cristata*) (Edwards et al. 2005; Table 1). Invasive bladderwort (*Utricularia gibba*) was found in South Lake in 2009 and East Lake in 2010 (Edwards et al. 2010).

Table 1. Surface area (ha), depth (m), Lake Submerged Plant Indicator (SPI; %) and number of aquatic vegetation species in the North, South and East lake.

	Surface area (ha)[1]	Depth (m)[1]	Lake SPI (%)[2]	Aquatic vegetation[1]	
				Native	Invasive
North Lake	5.3	4	90	4	0
South Lake	8.3	3.6	70	1	1
East Lake	1.6	4.4	90	4	1

[1] Neilson et al. (2004); [2] Edwards et al. (2005)

All three lakes contain native fish species including shortfin eel (*Anguilla australis*), longfin eel (*Anguilla dieffenbachii*), common bully (*Gobiomorphus cotidianus*), and common smelt (*Retropinna retropinna*). In addition, three invasive species rudd, goldfish and brown bullhead catfish are found in the lake. Gambusia (*Gambusia affinis*) has not been previously reported, but has recently been observed in the lakes in the lake by the authors.

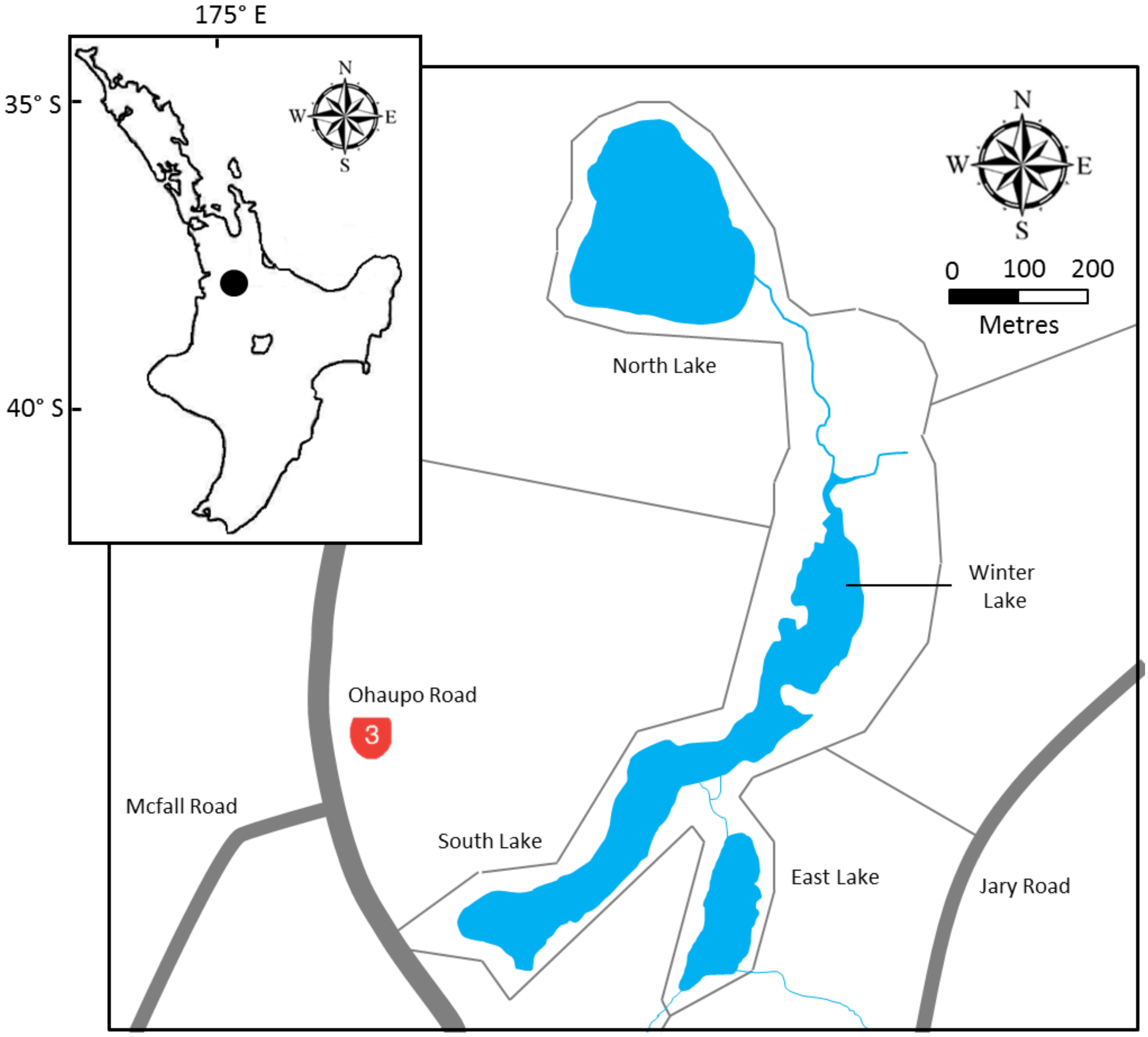


Figure 1. Position of the North, South (including Winter Lake) and East lakes, Rotopiko lakes complex, Waikato, New Zealand. Top left box indicates relative location of the complex in the North Island.

1.2 Invasive fish control programme

A review of the Rotopiko lakes invasive fish control programme by Lake (2010) looked at the effectiveness of monofilament gill nets at removing invasive fish. There were four phases in the programme. The first was the experimental phase where DOC and Waikato Regional Council (WRC) documented the effectiveness of capture rate of rudd and determined the most effective net spacing and orientations within the lakes (Neilson et al. 2004). The experiment was conducted twice yearly around March and September from spring 2001– spring 2003. The success at reducing rudd numbers spurred the continuation of netting in each of the lakes. The control phase from autumn 2003- spring 2004 looked at more standardised methodology in order to compare catch per unit effort (CPUE) between years. Lastly, the adaptive management phase, from March 2007 – present, allocated different managements and netting efforts based on additional data such as vegetation conditions and fish densities. Netting effort was decreased to once annually in spring (September) from 2007. Overall, there has been a decrease in invasive fish numbers since the experimental phase but each lake has had fluctuations in CPUE for catfish, rudd and goldfish (Table 2).

Table 2 Annual mean catch per unit effort (fish net^{-1} night^{-1}) for catfish, rudd and goldfish for each of the Rotopiko lakes (Lake 2010).

Lake	Species	2001	2002	2003	2004	2005	2006	2007	2008	2009
North										
	Rudd	1.26	0.32	0.41	0.80	1.49	0.40	2.08	1.48	4.62
	Catfish	0.00	0.00	0.00	0.01	0.03	0.24	1.26	1.95	1.50
	Goldfish	0.51	0.37	0.76	0.56	0.34	0.11	0.18	0.12	0.45
South										
	Rudd	4.22	0.61	0.09	0.20	0.16	0.12	0.01	0.07	0.20
	Catfish	0.00	0.03	0.06	0.53	0.91	0.91	0.56	0.59	0.35
	Goldfish	0.36	0.48	0.21	0.30	0.39	0.70	0.26	0.14	0.16
East										
	Rudd	0.15	0.07	0.02	0.04	0.01	0.01	0.00	0.01	0.01
	Catfish	0.54	0.18	0.13	0.15	0.48	0.13	0.08	0.16	0.17
	Goldfish	0.01	0.03	0.05	0.07	0.15	0.12	0.12	0.19	0.14

2 Methods

A capture-mark-release-recapture population estimate was undertaken on fish populations in the Rotopiko lakes over a 3 month period from April to June 2012. Equipment included 10-12 collapsible minnow traps (Fig. 2A), 10 Gee minnow traps (Fig. 2B), 12 fine mesh fyke nets (4-mm mesh), 1 trout line (20-m line with 20 corn baited hooks) and 5 pod traps. Fyke nets were approximately 3 m in length with a 5 m wing in front of the net opening. The net opening was semi-circular shaped (200 mm height and 650 mm width). Gee minnow traps and collapsible minnow traps were set with and without floats, some baited and some unbaited, on a long line with a weight and buoy at each end for ease of retrieval. Baited minnow traps contained corn and cat biscuits.

Pod traps were constructed with 3-m fibreglass legs connected to tripod header (Fig. 2). An automated feeder (Model 6VDSU, Spintech Outdoor Products Texas, USA) was suspended from the tripod and connected to a 20-L plastic bucket filled with 50% chicken feed (Peck N Lay, NRM Auckland, New Zealand) and 50% cracked corn. The automated feeder was set for 16 feed cycles spread evenly throughout the day. The trap (6-mm netting) was built to connect to the pod trap on the top and bottom using bungee cords for ease of dismantling. One of the top corners was zipped for easy access to the fish inside. Openings were made near the bottom of the net with one-way entrance doors that allow fish to enter but prevented escape. The bottom of the net was chained for extra weight.

Figure 2. Experimental pod trap design (top) and measurements of A) collapsible minnow trap and B) Gee minnow trap.

2.1 Mark-recapture

Unbaited fyke nets (n = 12) were evenly distributed around perimeter of each lake (Fig. 3). Nets were checked three times a week from mid-April to the end of June 2012. Pod traps were set in the shallowest areas (1.5 m maximum depth) of South and North lakes. The depth of East Lake made it impractical to use pod traps. The marking phase for all three lakes had a combined total fishing effort of 528 net nights for fyke nets and 150 net nights for pod traps. During the removal phase a total of

276 net nights for fyke nets and 65 net nights for pod traps were set. Gill nets were not used as the primary objective was to conduct a population estimate, which required release of live fish.

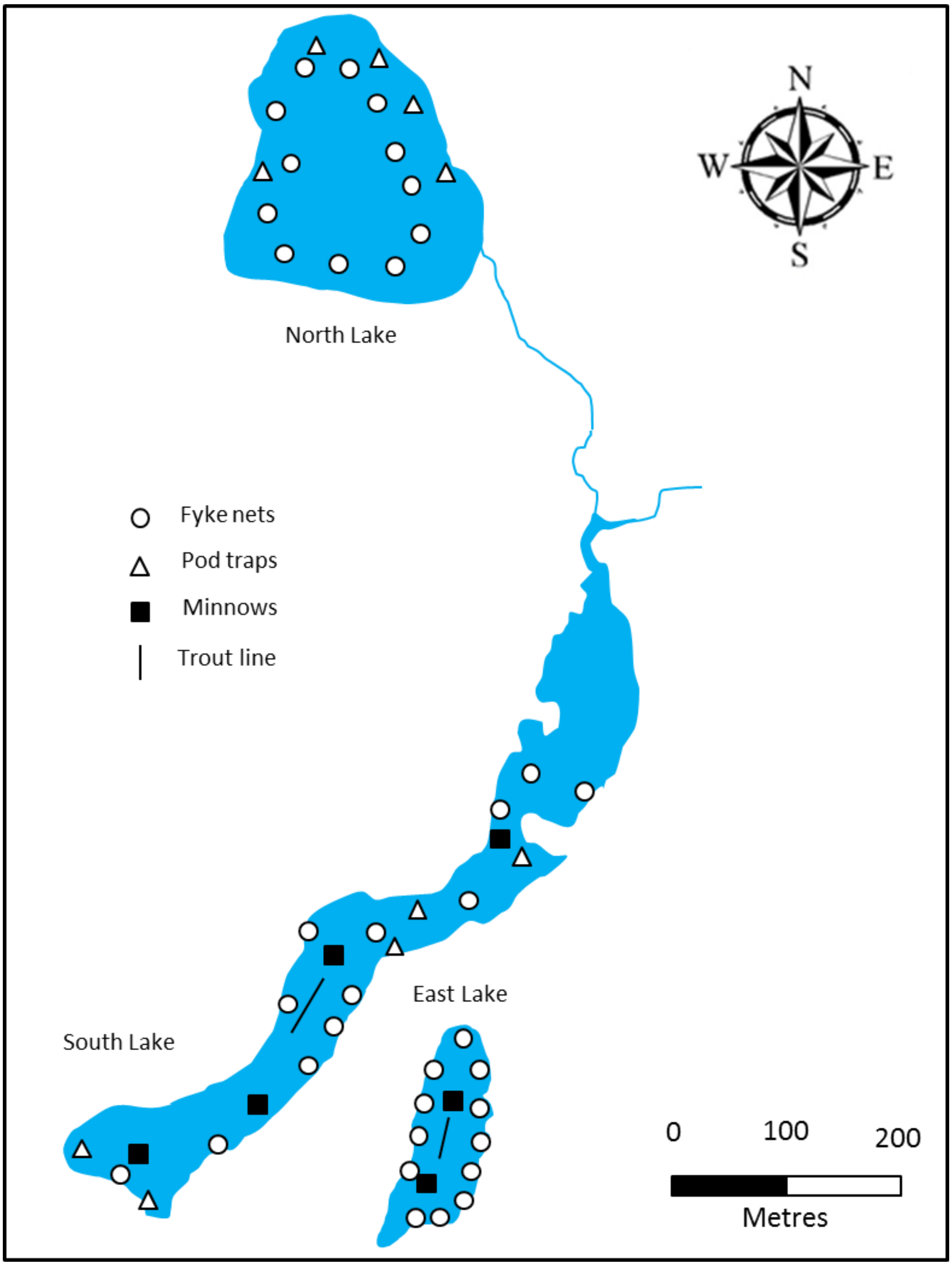


Figure 3. Locations of fyke nets, pod traps, minnow traps and trout lines set in each lake.

All fish collected were anaesthetised in fish bins with Aqui-S (Aqui-S New Zealand Ltd; Lower Hutt, New Zealand) at the recommended dose rate. Fish were marked using left pectoral fin clips (eels; Fig. 4) or dorsal spine removal (catfish, goldfish and rudd). All marked eels and invasive fish were weighed (g) and fork length measured (mm). All non-native fish recaptured were removed from the lake and euthanized. Recaptured eels were retained in holding pens within the lake to allow for an accurate population estimate and then released back into the lake of capture at the end of the study. All marking and handling procedures were under the provisions of the University of Waikato Animal Ethics Committee Standard Operating Procedure number 6.

Figure 4. A large longfin eel (*Anguilla dieffenbachii*) from South Lake in the Rotopiko lakes complex. Length = 1.07 m, weight = 4.55 kg. Photograph by Jeremy Garrett-Walker.

2.2 Gonad analysis

Gonads were extracted from 20 individuals of each species (rudd, goldfish and catfish) to determine the potential for late season spawning at the Rotopiko lakes as late summer spawning events have been detected in some New Zealand rudd populations (unpublished data A. Daniel). Due to the low number of fish captured from the Rotopiko lakes fish were also collected from Lake B and the Whangamarino Wetland. All fish were held at the University of Waikato in fish holding tanks (unless noted as Rotopiko) and kept at a relative water temperature of 17^{o}C. Following euthanasia, total weight and fork length was measured for each individual. Gonads were extracted using tweezers and the gonad weight was taken. Gonads were classified into one of 6 distinctive developmental stages following De Vlaming and Vodicnik (1978). The gonadosomatic index (GSI) (Crim and Glebe 1990) for each individual was calculated as:

$$GSI = \frac{gonad\ weight}{total\ body\ weight} \times 100.$$

2.3 Data analysis

The Lincoln-Petersen method (Nichols 1992) was used to estimate population size of each species. To satisfy the assumptions of the Lincoln-Petersen population estimate populations were considered to be closed. Eels were held in temporary holding pens to avoid recapture and non-native fish were removed from the lake when recaptured. Population estimates were calculated based on the formula

$$N = \frac{S1 \times S2}{M},$$

where N = estimate of total population size, $S1$ = total number of animals marked on first visit, $S2$ = total number of animals captured on second visit and M = number of marked recaptures on second visit.

2.4 Spawning timing and literature review

Spawning periods for rudd, brown bullhead catfish and goldfish were collected from various international and national studies to determine potential spawning periods in the Rotopiko lakes. The recommended timing of rotenone treatments were interpreted based on the effectiveness of rotenone with environmental variables (e.g., temperature) and biology of target fish species via literature review (Finlayson et al. 2000; Ling 2003). Monthly surface water temperature and dissolved oxygen for North Lake were obtained from Waikato Regional Council. During the experiment, temperature loggers, maintained by DOC, were used to log daily temperatures.

3 Results

3.1 Population and biomass estimates

Large populations of native fish (mean 31.9 kg ha^{-1}) and low densities of invasive fish (mean 1.37 kg ha^{-1}) were detected in all three lakes. The rudd population in the Rotopiko lakes is assumed to be low as no rudd were captured during this study. Shortfin eel comprised the majority of the total fish biomass for each lake (East = 98%, South = 91% and North = 95%). East Lake had the highest shortfin eel biomass per hectare (44.5 kg ha^{-1}; Fig.5A), but South Lake had the highest estimated population (Fig. 6B). Longfin eel biomass was low compared to the shortfin eel biomass but was highest in the South Lake (1.4 kg ha^{-1}). Catfish biomass was highest (2.2 kg ha^{-1}) in North Lake (Fig. 7A) compared to South and East lakes. Goldfish biomass (0.7 kg ha^{-1}) was low in South Lake (Fig. 6A).

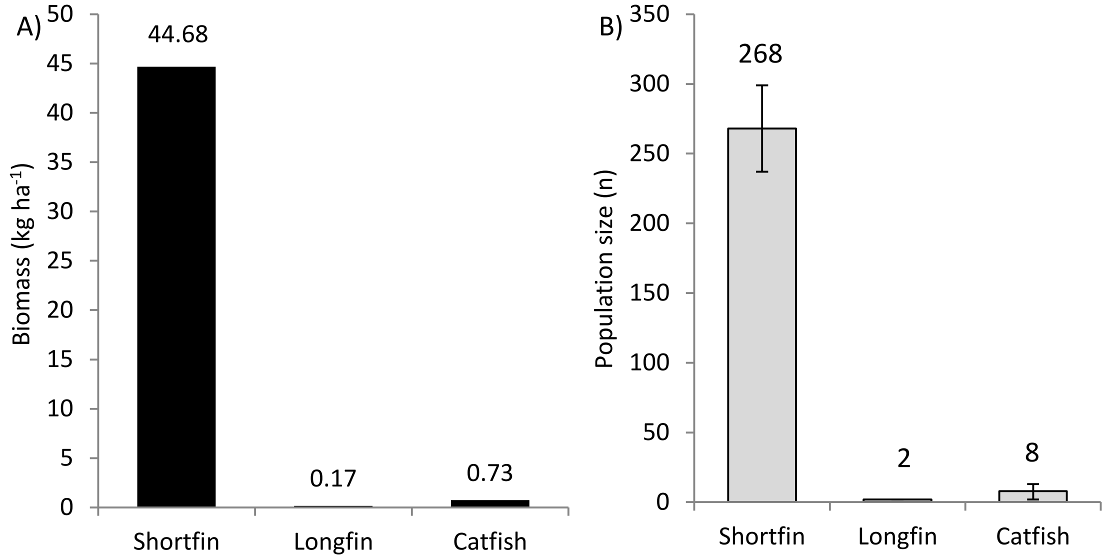


Figure 5. A) Biomass (estimated kg ha^{-1} listed on top of each bar) and B) population estimate (n) of each fish species in Rotopiko East Lake. Error bars equal to 95% confidence interval (CI).

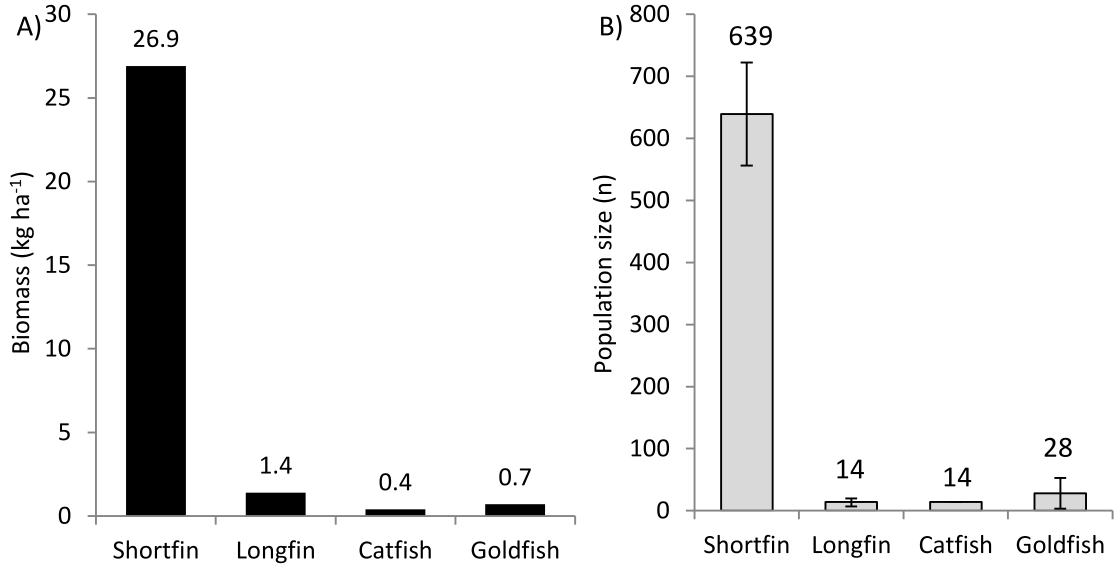


Figure 6. A) Biomass (estimated kg ha^{-1} listed on top of each bar) and B) population estimate (n) of each fish species in Rotopiko South Lake. Error bars equal to 95% confidence interval (CI).

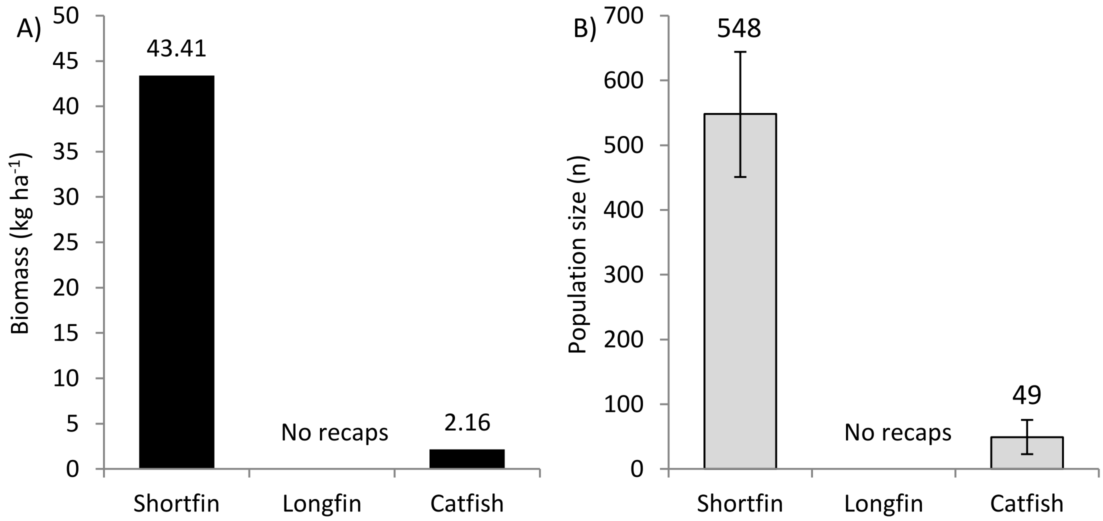


Figure 7. A) Biomass (estimated kg ha^{-1} listed on top of each bar) and B) population estimate (n) of each fish species in Rotopiko North Lake. Error bars equal to 95% confidence interval (CI).

3.2 Native fish

North Lake had larger shortfin eels (mean 590 mm) than South and East lakes (Fig. 8A). East Lake had comparatively small shortfin eels, with no eels larger than 800 mm. Large longfin eels were present in the Rotopiko Lakes with individuals reaching 1070 mm in the South Lake (Fig. 8B). Mean CPUE of common bully for East Lake and South Lake are presented in Fig. 9. Mean common bully CPUE (Fish net^{-1} night^{-1}) was greater in East Lake (7.58 Fish net^{-1} night^{-}1) compared to South Lake (2.42 Fish net^{-1} night^{-1}). However, trapping in East Lake was done approximately one month after trapping in South Lake, therefore no direct comparison between lakes could be made.

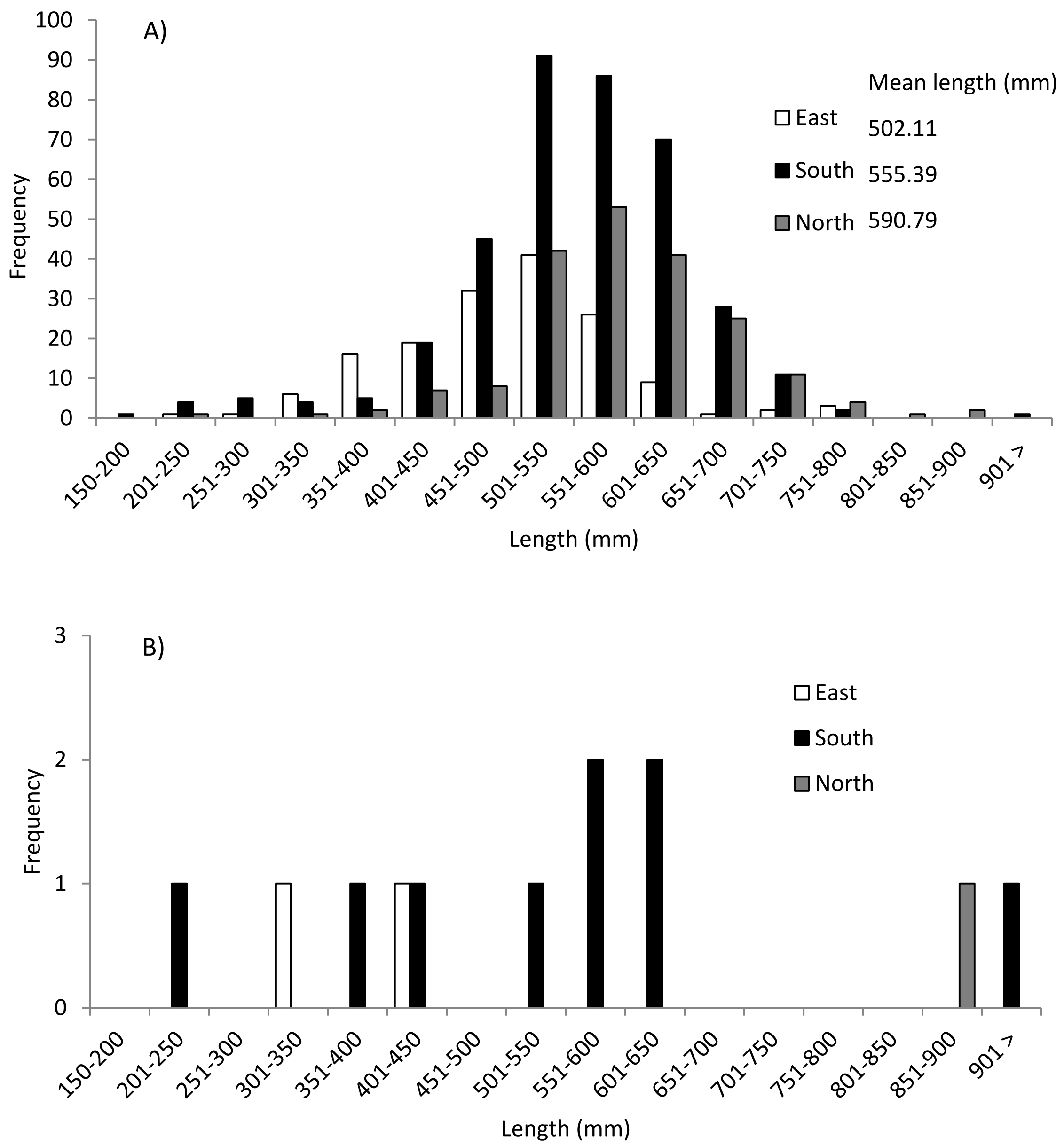


Figure 8. Size-class frequency distribution of A) shortfin eels (*A. australis*) (*n* = 720) and B) longfin eels (*A. dieffenbachii*) (*n* = 12) in North, South and East lake, Rotopiko lakes complex.

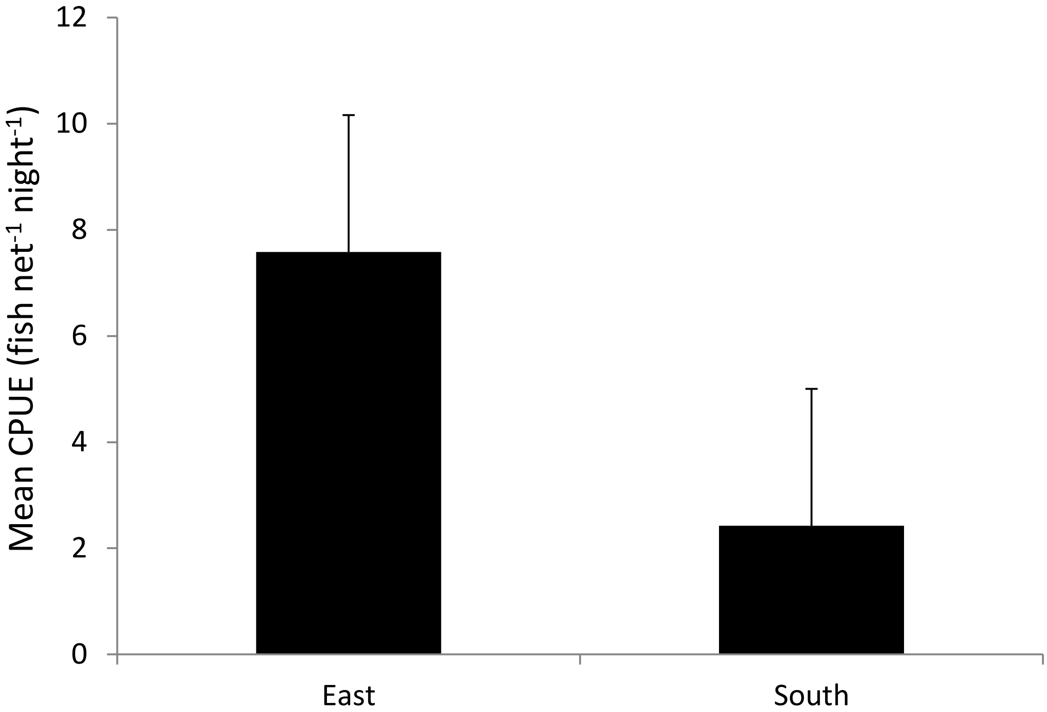


Figure 9. Mean catch per unit effort for common bully (*Gobiomorphus cotidianus*) at Rotopiko East and Rotopiko South. Error bars indicate standard error.

3.3 Catch per unit effort

Fyke nets caught six species in total, with catches dominated by shortfin eels. Common smelt were only found in fyke nets, and most were dead or regurgitated from eel predation; other methods of surveying the smelt populations were deemed impractical (Table. 2). North Lake had the highest number of common smelt captured and no smelt were caught in East Lake. The CPUE of catfish captured in fyke nets was highest in the North Lake (3 fish net^{-1} night^{-1}) followed by South Lake (1 fish net^{-1} night^{-1}) and East Lake (0.66 fish net^{-1} night^{-1}). One catfish was also caught on a trout line in the South Lake (Table 3). The CPUE of goldfish was low overall and no goldfish were captured in East and North Lake. The CPUE of goldfish captured in pod traps (0.85 fish net^{-1} night^{-1}) was higher than fyke nets (0.61 fish net^{-1} night^{-1}) and the trout line (0.25 fish net^{-1} night^{-1}). One gambusia was found in a minnow trap in the South Lake but several were also observed in the South and East Lake shore.

Table 3. Mean CPUE (fish net^{-1} night^{-1}) of each species caught from different capturing methods during the project. (*) CPUE excluding recaptures. "Present" indicates fish numbers not counted. - = zero catch.

			Fishing method				
	Species	**Lake**	**Fyke nets**	**Pod traps**	**Collapsible minnow trap**	**Gee minnow trap**	**Trout line**
Native							
	Shortfin eel	North	42.0*	-	-	-	-
		South	32.2*	0.1	2.8	-	-
		East	25.1*	-	-	4.2*	0.2*
	Longfin eel	North	0.9*	-	-	-	-
		South	0.8*	-	-	-	-
		East	0.1*	-	-	0.1*	-
	Common bully	North	Present	Present	-	-	-
		South	Present	Present	89.8	-	-
		East	Present	-	48.2	156.5	-
	Common smelt	North	2.6	-	-	-	-
		South	0.2	-	-	-	-
		East	-	-	-	-	-
Invasive							
	Brown bullhead catfish	North	3.0*	-	-	-	-
		South	1.0*	-	-	-	0.2*
		East	0.7*	-	-	-	-
	Goldfish	North	-	-	-	-	-
		South	0.6*	0.8*	-	-	0.2*
		East	-	-	-	-	-
	Gambusia	North	-	-	-	-	-
		South	-	-	0.1	-	-
		East	-	-	-	-	-

3.4 Gonad analysis

Gonads were extracted on 7 June 2012 when water temperature was 17°C. Female rudd showed stage 1-2 gonad development with a mean GSI 2.81. Male gonads only revealed different colouration and gonad stage was difficult to morphologically distinguish. Goldfish from the Rotopiko lakes (12.7°C at the time of capture) had smaller gonads and about half the weight compared to goldfish kept in the laboratory (Table 4). Close examination revealed stage 4 gonads of laboratory goldfish (kept at 17°C), while Rotopiko goldfish had yet to develop eggs. Catfish gonads were more difficult to distinguish due to relatively small gonad size compared to other fish. Catfish were found with two different gonad stages: 1) small, stage one gonads (mean weight 0.02 g) with blood vessels still present and no eggs developed, and 2) stage 3 – 4 gonads that were relatively larger (mean weight 4.19 g) with developing eggs.

Table 4. Mean length (mm), weight (g), gonad weight (g) and gonadosomatic index (GSI) for each invasive fish species. (Rotopiko) indicate fish caught in Rotopiko lakes. - = no data.

Species	Sex	Mean length (mm)	Mean weight (g)	Mean gonad weight (g)	Gonad stage	GSI (%)
Rudd	M	221.9	195.6	3.2	-	-
	F	226.3	208.4	5.9	1-2	2.8
Goldfish (lab.)	M	200.0	140.0	4.9	-	-
	F	206.6	159.6	10.1	4	6.4
Goldfish (Rotopiko)	M	Not collected	Not collected	Not collected	-	-
	F	195.0	151.5	5.6	3	3.7
Catfish	M	254.9	205.8	0.02	-	-
	F	236.7	184.3	4.2	3-4	2.4

3.5 Spawning

The surface water temperature of North Lake varied seasonally with a peak during summer (January) reaching 25^{o}C, decreasing to < 10^{o}C mid-winter (July) (Fig. 12). Dissolved oxygen levels showed similar seasonal variation. The theoretical spawning water temperatures of rudd (20 – 21^{o}C; Hicks 2003), goldfish (20^{o}C; Kucharczyk et al. 1997) and catfish (14 - 29 ^{o}C; Blumer 1985; (Tucker and Robinson 1990) are roughly similar. For all species, estimated spawning period for Rotopiko lakes is during the spring, and again in early autumn (Fig. 13). Based on the theoretical spawning temperature range of invasive fish, rotenone treatment would be most effective in March to May (Chadderton et al. 2001; Ling 2003). However, late season spawning, presumably second spawning events, of rudd have been observed in highly productive New Zealand lakes (Lake Kuwakatai; unpublished data, A. Daniel) so it would be prudent to sample fish and check the GSI of target species two weeks prior to application.

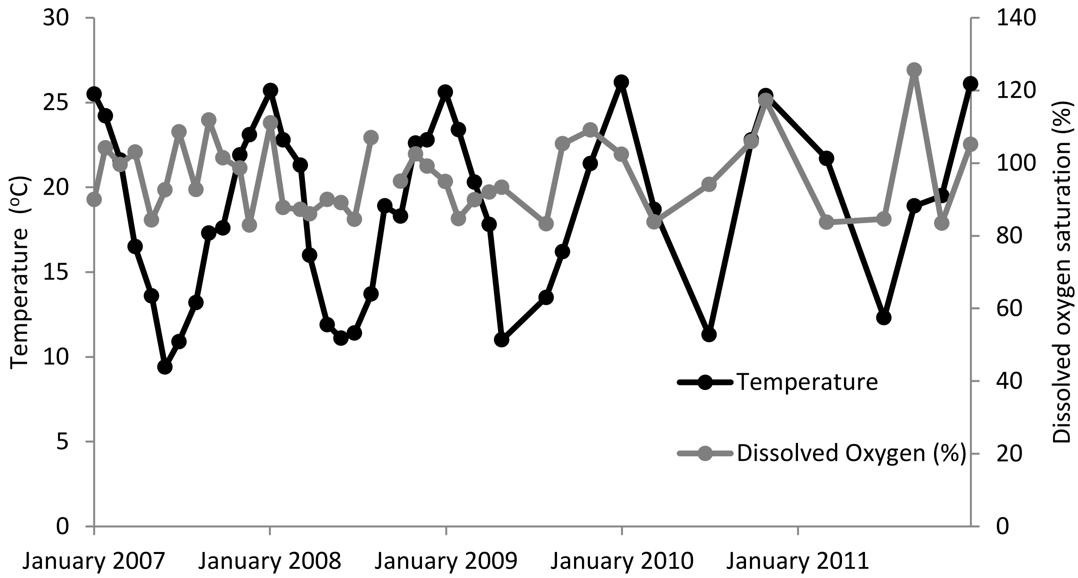


Figure 10. Monthly records of dissolved oxygen saturation and water temperature in North Lake in the Rotopiko lakes complex for the period January 2007 to January 2012.

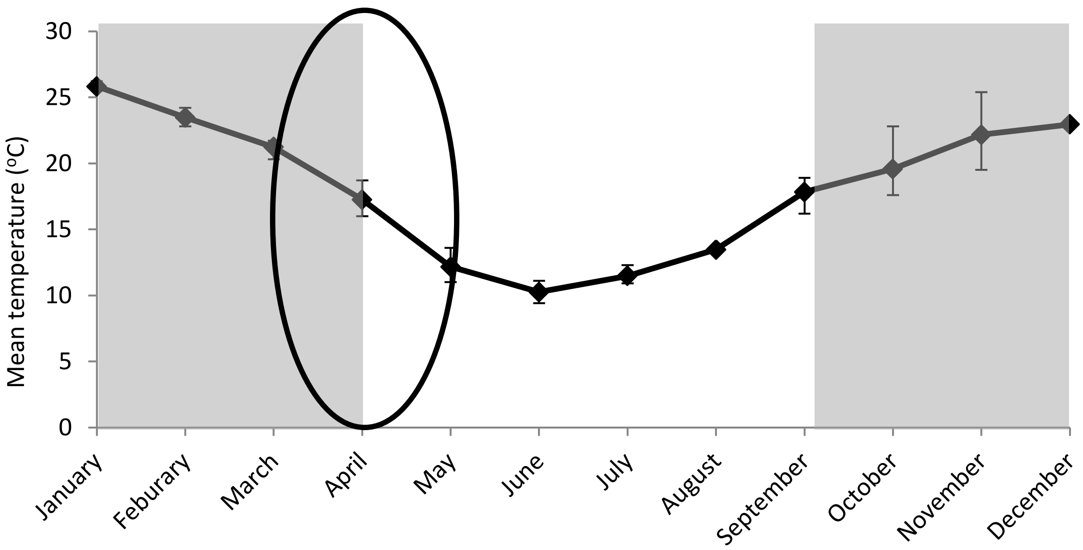


Figure 11. Average water temperature in North Lake in the Rotopiko lakes complex over a 5-year period (January 2007 to January 2012). Bars represent maximum and minimum temperatures recorded. Grey area indicates possible spawning period for rudd, catfish and goldfish based on a literature review. The circle represents the optimal period for rotenone treatment based on acceptable water temperatures and reduced likelihood of recent spawning events.

4 Discussion

4.1 Invasive fish population estimate

Invasive fish populations in the Rotopiko Lakes are low overall and unlikely to be a key factor in declining water quality. The total estimated non-native fish biomass in the Rotopiko lakes is likely less than <5 kg ha^{-1} and is well below the 92-282 kg ha^{-1} observed in similar peat lakes in the Waikato region (A. Daniel unpublished data 2012). A review of the fish removal programme in Rotopiko revealed rudd, catfish and goldfish were present in all of the lakes (Lake 2010).

This study used pod traps due to the need for live release to conduct mark-recapture population estimates. Although pod traps did not capture rudd in the Rotopiko lakes, they were highly effective at catching rudd in Lake B during the same time period, so the absence of rudd in pod traps indicates a very low abundance. It is possible that the rudd biomass and water temperatures were too low for bait to be an effective attractant in the Rotopiko lakes and a method such as intensive gill netting may have been more effective but risked fish deaths and compromising population estimation. Modified fyke nets (19-mm mesh size) have been shown to be successful for catching rudd (Blackwell et al. 2009) as lake depth and shape allows the net wings to effectively guide the fish into the trap. Similarly, minnow traps were shown to be effective at catching juvenile rudd at Lake Kuwakatai (A. Daniel unpublished data) (Fig. 15). However, significant numbers of common bullies and eels were caught in the minnow traps set in the Rotopiko lakes, which resulted in high loss rates of bullies due to consumption by eels (Table 2).

The low catch rates of rudd in this study and the low CPUE of the DOC-administered annual netting programme over the past 8 years (Lake 2010) are evidence that the current removal programme has been highly effective. However, catfish and goldfish numbers have been increasing in the North and South lakes from 2005 to 2011. The dynamics of this ecological shift from rudd dominance to catfish and goldfish dominance is not well understood and may not have any impact on aquatic vegetation community considering the biomass of both species are still comparatively low. Using fyke nets to control catfish may be necessary if catfish numbers continue to increase but this method will have high by-catch of eels, requiring a substantial amount of labour to clear traps. Although the CPUE of pod traps for goldfish was not high it was the best method tested in this study. The presence of gambusia in the lakes is concerning as they have not previously been reported in the Rotopiko Lakes and indicate introductions continue to occur despite having limited access and signage.

Figure 12. Collapsible minnow trap with juvenile rudd at Lake Kuwakatai.

4.2 Native fish

Fish biomass in the Rotopiko lakes was dominated by shortfin eels (Figs 5, 6, 7), which is a native species. Common bullies were also comparatively abundant with minnow traps being highly effective at capturing this species (Fig. 9). Smelt were caught in low numbers in all the lakes similar to previous studies (McDonald and Lake 2006). However, an accurate assessment of the smelt population is difficult because methods typically used for smelt surveys such as seine netting and trawling are not practicable in these lakes. The smelt population in the Rotopiko lakes is throught to have been introduced (J. Gumbley pers. com.; May 2012) and are likely a closed population as suggested by Northcote and Ward (1985).

There has been very little change in the eel populations between 2001 and 2012. McDonald and Lake (2006) found that the North Lake had the highest shortfin eel mean length (610 mm; cf 590 mm) and the East Lake with the lowest mean length (584 mm; cf 502 mm) which correlates with the results of this study (Fig. 8A). The average shortfin eel length for all the lakes was slightly lower than the 2006 study. The length frequency distribution of shortfin eels supports the fact that the lakes have not been commercially or recreationally fished (Fig. 8).

Fyke nets were highly efficient at capturing eels at the Rotopiko lakes despite a depth ranging from 4-5 m. Although baited fyke nets have been shown to catch significantly more fish than unbaited (Jellyman and Graynoth 2005)nets, they were still highly effective. More than 98% of the shortfin eels caught were larger than 200 mm (Fig. 8) which may be due to cannibalism or failed recruitment.

4.3 Spawning

A review of available literature showed the timing of rudd, catfish and goldfish spawning largely depended on temperature. Rudd could spawn in spring and summer when water temperatures exceed 18^{o}C and they are able to lay about 100,000 - 200,000 eggs per kg of body weight (McDowall 2000). The gonad staging of rudd from Lake B had a typical developmental stage 1- 2 (Table. 3), which indicates rudd did not spawn in May that year. A study conducted on Rotoroa (Hamilton) Lake rudd showed gonad GSI was highest around October during spawning season (Wise 1990). Rudd are known to have multiple spawning events in New Zealand and have been observed spawning in January (A. Daniel pers. obs.).

Brown bullhead catfish are capable of multiple spawning events in a single year including spring and summer spawning at temperatures ranging from 14 - 19^{o}C (Blumer 1985). Gonads were difficult to distinguish due to the size of the gonads (mean weight 0.02 g; Table. 3). Catfish do not lay large quantities of eggs and breed with only one mate during a breeding season, guarding a nest (Blumer 1985), unlike cyprinids, which are broadcast spawners (McCrimmon 1968).

Goldfish have no defined spawning season, although spring spawning at approximately 17^{o}C has been observed in the Waikato region (A. Daniel pers. obs.). Goldfish are capable of multiple spawning events during spring and summer (Yamazaki 1965). Goldfish from the Rotopiko lakes had smaller GSI (3.73%) compared to the laboratory goldfish (6.37%) suggesting that fish captured in May were not capable of a second spawning event during the year of this study. Long photo periods stimulated goldfish reproductive function (De Vlaming and Vodicnik 1978) which could account for the higher GSI of lab fish with artificial lighting and water temperature (17^{o}C) in the University holding facility that stimulated faster gonad development. A multiyear study of Rotopiko Lakes would need to be conducted to determine if late summer spawning events were possible.

4.4 Rotenone treatment

Based on lake water temperatures and likelihood of spawning, the optimal time for application of rotenone to the Rotopiko lakes would be late March. Rotenone does not persist in the environment and is degraded by light, heat, and oxygen (Ling 2003). The ideal temperature range would be around 10 to 15^{o}C. Spring and summer would not be recommended for rotenone treatment as high water temperatures (>23^{o}C) and long day lengths quickly degrade rotenone, requiring repeated treatments every 2 days (Ling 2003). The Rotopiko lakes also have strong a thermocline in the summer (Collier et al. 2010), which could prevent rotenone from properly mixing in deeper areas (Rowe 2001).

Winter treatments are also unsuitable for rotenone as it does not degrade as quickly and is less toxic to fish due to the fish's metabolism being lower in the colder temperatures and uptake being reduced. In addition, a large proportion of the rotenone would become bound in the bottom sediment and vegetation and quickly become unavailable (Gilderhus et al. 1986). In summer, rotenone would degrade more rapidly and would be less likely to be bound to the sediment. During the summer dense aquatic vegetation in the Rotopiko lakes is likely to inhibit mixing and create pockets of untreated water (Rowe 2001; Rayner and Creese 2006). The Rotopiko lakes have the added complexity of a thick peat margin (Barnes 2001) that will likely inhibit mixing and provide refugee for invasive fish. During spawning, fish eggs are not affected by rotenone as it does not diffuse past the egg membrane (Marking and Bills 1976). Juveniles are more sensitive to rotenone than adults hence rotenone application would work best in autumn (March) after spawning (Raimondo et al. 2008) and before water temperatures fall below 10^{o}C. Rudd and gambusia are very sensitive to rotenone; however catfish, goldfish and eels are more resistant to rotenone (Chadderton et al. 2001; Ling 2003).

4.5 Recommendations

Based on low numbers of invasive fish, high numbers of native fish species and the complexity of applying piscicide in a peat lake, rotenone application is not likely to eradicate all invasive fish in a single application. We recommend continuing the gill-netting methodology of Neilson et al. (2004) to maintain low invasive fish numbers and maintain the recruitment of eels as a biological control for invasive juveniles. This recommendation is based on the assumption that rudd are not significantly impacting native aquatic vegetation in the Rotopiko lakes due to current low rudd biomass estimates (Edwards 2010). Installing simple exclosures to exclude invasive fish would be a cost effective means of confirming the findings of this study that rudd are currently having a limited impact on submerged macrophytes in the Rotopiko lakes. Exclosure experiments conducted in Lake Rotoroa (Dugdale et al. 2006) have shown charophyte re-establishment and growth when fish were excluded; however, these experiments were conducted at a far higher invasive fish biomass than is present in the Rotopiko lakes.

Introduction of invasive fish through connecting waterways from neighbouring lakes (Lake Ngaroto and Lake Rotomanuka) is likely. Gambusia have now been found in the Rotopiko lakes and this introduction raises concerns of other invasive fish making their way through drains or via deliberate or accidental introduction. Controlling fish migration through the drainage system with barriers will allow native fish to migrate into the lakes while excluding large invasive fish which are already present in neighbouring lakes such as koi carp (*Cyprinus carpio*), tench (*Tinca tinca*) and perch (MacGibbon and Etheridge 2011). The recent installation of a fish barrier on the North Lake outlet drain should greatly reduce the chance of further introductions via this route.

In conclusion, low numbers of invasive fish species in the Rotopiko lakes suggest other factors are involved in the declining lake water quality. Continuing the fish removal programme will keep invasive fish biomass low and will likely keep the impact on macrophytes by invasive fish at a negligible level. If rotenone is used, we would recommend an autumn application (water temperature 10 to 20^{o}C) to minimise the possibility of viable invasive fish eggs being present in the lake. Test fishing the lakes three weeks prior to rotenone application to check for stage of gonad development would also be prudent. Maintaining barriers and managing human activities to prevent future invasions of fish are also advised. Research into the causes of the decline in lake water quality is currently being conducted by the University of Waikato. This research includes monitoring of sediment and nutrient inflows into the lakes as part of contracted work for the Waikato Regional Council and investigations into the effectiveness of detainment bunds to reduced sediment inputs into the lakes.

5 Acknowledgements

This study was funded by the New Zealand Department of Conservation (DOC). We would like to thank Jeremy Garrett-Walker and Matthew Prentice for assisting with fieldwork. We would also like to acknowledge Amy McDonald and John Gumbley (DOC) for valuable insight about the lakes. We also acknowledge Associate Professor Brendan Hicks for his helpful comments when reviewing this report.

6 References

Barnes, G. (2001). *Aquatic and Marginal Vegetation of Lake Serpentine North*. Enviromental Waikato Technical Report TR 2001/03. Hamilton, New Zealand

Barton, D. R., N. Kelton and R. I. Eedy (2000). The effects of carp (*Cyprinus carpio* L.) on sediment export from a small urban impoundment. *Journal of Aquatic Ecosystem Stress and Recovery (Formerly Journal of Aquatic Ecosystem Health)* **8**: 155-159.

Blackwell, B. G., T. M. Kaufman and W. H. Miller (2009). Occurrence of Rudd (*Scardinius erythrophthalmus*) and dynamics of three populations in South Dakota. *Journal of Freshwater Ecology* **24**: 285-291.

Blumer, L. S. (1985). Reproductive natural history of the brown bullhead *Ictalurus nebulosus* in Michigan. *American Midland Naturalist* **114**: 318-330.

Breukelaar, A. W., E. H. R. R. Lammens, J. G. P. K. Breteler and I. Tatrai (1994). Effects of benthivorous bream (*Abramis brama*) and carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll *a*. *Freshwater Biology* **32**: 113-121.

Chadderton, L., S. Kelleher, A. Brow, T. Shaw, B. Studholme and R. Barrier (2001). Testing the efficacy of rotenone as a piscicide for New Zealand pest fish species. In: Managing Invasive Freshwater Fish in New Zealand. Munro, R. ed. Department of Conservation, Hamilton, New Zealand

Chapman, M. A. (1996). Human impacts on the Waikato River system, New Zealand. *GeoJournal* **40**: 85-99.

Collier, K. J., D. P. Hamilton, W. N. Vant and C. Howard-Williams (2010). *The Waters of the Waikato: Ecology of New Zealand's Longest River*. Hamilton, New Zealand, Environment Waikato and the Centre for Biology and Ecology Research, The University of Waikato. Hamilton, New Zealand

Crivelli, A. J. (1983). The destruction of aquatic vegetation by carp. *Hydrobiologia* **106**: 37-41.

Cromarty, P. and D. A. Scott (1996). *A Directory of Wetlands in New Zealand*. Department of Conservation Wellington. 395.

De Vlaming, V. and M. J. O. Vodicnik (1978). Seasonal effects of pinealectomy on gonadal activity in the goldfish, *Carassius auratus*. *Biology of Reproduction* **19**: 57-63.

Dugdale, T. M., B. J. Hicks, M. De Winton and A. Taumoepeau (2006). Fish exclosures versus intensive fishing to restore charophytes in a shallow New Zealand lake. *Aquatic Conservation: Marine and Freshwater Ecosystems* **16**: 193-202.

Edwards, T., J. Clayton and M. de Winton (2005). *The Condition of Lakes in the Waikato Region Using LakeSPI*. Hamilton, New Zealand, NIWA Hamilton.

Edwards, T., M. de Winton and J. Clayton (2010). *Assessment of the Ecological Condition of Lakes in the Waikato Region using LakeSPI - 2010.* Prepared for Environment Waikato. NIWA Client Report: HAM2010-065.

Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay, C. W. Thompson and G. Tichacek (2000). *Rotenone use in Fisheries Management: Administrative and Technical Guidelines Manual*. American Fisheries Society.

Gilderhus, P., J. Allen and V. Dawson (1986). Persistence of rotenone in ponds at different temperatures. *North American Journal of Fisheries Management* **6**: 129-130.

Green, J. D., and Lowe, D. J., 1985. Stratigraphy and development of c. 17,000 year old Lake Maratoto, North Island, New Zealand, with some inferences about postglacial climatic change. *NZ Journal of Geology and Geophysics* **28**: 675-699.

Hicks, B. J. (2003). Biology and potential impacts of rudd (*Scardinius erythrophthalmus* L.) in New Zealand. In: Managing Invasive Freshwater Fish in New Zealand. Munro, R. ed. Department of Conservation, Hamilton, New Zealand.

Jellyman, D. and E. Graynoth (2005). The use of fyke nets as a quantitative capture technique for freshwater eels (*Anguilla* spp.) in rivers. *Fisheries Management and Ecology* **12**: 237-247.

Kucharczyk, D., M. Luczynski, R. Kujawa and P. Czerkies (1997). Effect of temperature on embryonic and larval development of bream (*Abramis brama* L.). *Aquatic Sciences-Research Across Boundaries* **59**: 214-224.

Lake, M. (2010). *Review of the Rotopiko (Serpentine) Lakes Exotic Fish Control Programme*. Department of Conservation DOCDM-455123. Hamilton, New Zealand.

Lake, M. D., B. J. Hicks, R. Wells and T. M. Dugdale (2002). Consumption of submerged aquatic macrophytes by rudd (*Scardinius erythrophthalmus* L.) in New Zealand. *Hydrobiologia* **470**: 13-22.

Ling, N. (2003). *Rotenone: A Review of it's Toxicity and use for Fisheries Management*. Science for Conservation Report No. 211. Department of Conservation, Hamilton, New Zealand 1-40.

MacGibbon, R. and N. Etheridge (2011). *Assessment of the Restoration Potential for East Lake Serpentine and the Feasibility of Constructing a Pest Exclusion Fence Around the Reserve*. Opus International Consultants Limited 1- 68.

Marking, L. L. and T. D. Bills (1976). *72. Toxicity of rotenone to fish in standardized laboratory tests*. Investigations in fish control. Washington, D. C., US Fish and Wildlife Service 20.

McCrimmon, H. R. (1968). *Carp in Canada*. Fisheries Research Board of Canada. Bulletin 165. Ottowa, Canada.

McDonald, A. and M. Lake (2006). *Rotopiko Lakes Fish Surveys, 2006.* Department of Conservation QLDDM-293435. Hamilton, New Zealand.

McDowall, R. M. (2000). *The Reed Field Guide to New Zealand Freshwater Fishes*, Reed Publishing (NZ) Ltd.

McDowell, R., S. Larned and D. Houlbrooke (2009). Nitrogen and phosphorus in New Zealand streams and rivers: control and impact of eutrophication and the influence of land management. *New Zealand Journal of Marine and Freshwater Research* **43**: 985-995.

Neilson, K., R. Kelleher, G. Barnes, D. Speirs and J. Kelly (2004). Use of fine-mesh monofilament gill nets for the removal of rudd (*Scardinius erythrophthalmus*) from a small lake complex in Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research* **38**: 525-539.

Nichols, J. D. (1992). Capture-recapture models. *BioScience* **42**: 94-102.

Northcote, T. and F. Ward (1985). Lake resident and migratory smelt, *Retropinna retropinna* (Richardson), of the lower Waikato River system, New Zealand. *Journal of Fish Biology* **27**: 113-129.

Nurminen, L., J. Horppila, J. Lappalainen and T. Malinen (2003). Implications of rudd (*Scardinius erythrophthalmus*) herbivory on submerged macrophytes in a shallow eutrophic lake. *Hydrobiologia* **506**: 511-518.

Raimondo, S., D. N. Vivian, C. Delos and M. G. Barron (2008). Protectiveness of species sensitivity distribution hazard concentrations for acute toxicity used in endangered species risk assessment. *Environmental Toxicology and Chemistry* **27**: 2599-2607.

Rayner, T. S. and R. G. Creese (2006). A review of rotenone use for the control of non-indigenous fish in Australian fresh waters, and an attempted eradication of the noxious fish, *Phalloceros caudimaculatus*. *New Zealand Journal of Marine and Freshwater Research* **40**: 477-486.

Rowe, D. K. (2001). Rotenone-based approaches to pest fish control in New Zealand. In: Managing Invasive Freshwater Fish in New Zealand. Munro, R. ed. Department of Conservation, Hamilton, New Zealand.

Rowe, D. K. (2007). Exotic fish introductions and the decline of water clarity in small North Island, New Zealand lakes: a multi-species problem. *Hydrobiologia* **583**: 345-358.

Schallenberg, M. and B. Sorrell (2009). Regime shifts between clear and turbid water in New Zealand lakes: environmental correlates and implications for management and restoration. *New Zealand Journal of Marine and Freshwater Research* **43**: 701-712.

Tucker, C. C. and E. H. Robinson (1990). *Channel catfish farming handbook*, Springer.

Wise, G. (1990). The biology of three exotic freshwater fish species in Hamilton Lake. MSc Thesis MSc, University of Waikato. Hamilton, New Zealand

Yamazaki, F. (1965). Endocrinological studies on the reproduction of the female goldfish, Carassius auratus L., with special reference to the function of the pituitary gland. *Memoirs of the Faculty of Fisheries Hokkaido University* **13**: 1-64.