The eel (tuna) stocks of Lake Poukawa, Hawkes Bay

NIWA Client Report: CHC2009-172
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Prepared for

Te Ohu Kai Moana
Poukawa 13B Trust

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Summary

In recognition of its importance as a source of mahinga kai for the people of Te Hauke, Lake Poukawa, Hawkes Bay, is designated as a non-commercial eel fishery. The eel stock was surveyed in 1996, after the cessation of commercial eel fishing. A number of recommendations were made at that time about management of the lake and its resources. The present survey (February 2008) was carried out to observe any changes in the well-being of the eel stocks since the previous survey, and consider lake level issues. Comparisons between the two surveys showed that the average size of eels in the lake (all shortfins) had increased, condition (fatness) of the eels has improved, catch rates were similar but growth was slightly slower; diet of eels was also similar. There is ongoing concern about the ability of juvenile eels to negotiate the weir, and this should be addressed. Likewise, the low summer lake levels and associated flow in Poukawa Stream are of concern, although resolution of this would require higher lake levels in winter with implications for the present system of grazing and cropping within the catchment. Willows and raupo are spreading, and unless these are managed, the size of the lake will continue to diminish.

1. Introduction

1.1. Lake Poukawa

Lake Poukawa is a small, shallow lake approximately 15 km south of Hastings. The lake and its eel fishery are of considerable cultural importance to the people of Te Hauke and their hapu Ngai Te Rangikoianake. The lake was extensively fished by commercial eel fishers in the 1960's to mid 1970's, to the extent that Mitchell (1984) recommended that such activity should be prohibited. A survey of the eel stock in 1996 (Jellyman and Bonnett 1996) indicated that eels were in good condition and the stock was showing signs of recovery – at that stage the lake was not closed to commercial eel fishing although there was an informal arrangement that such fishing would not take place. Since then, the lake has been declared a non-commercial fishery, and eels are only harvested by local Tangata Whenua for customary purposes. The present survey was a follow-up to that of 1996, to see whether specific management recommendations from that survey that had been implemented, were having some beneficial effects.

Over recent decades, the Lake Poukawa catchment has been subject to a number of significant changes. The soil of the surrounding land is very fertile, and historically this has led to initiatives to drain much of the low-lying catchment and also to minimise inundation resulting from seasonal rises in lake level. Such development has been to the detriment of wildlife, fisheries, and ecological values in that the once extensive wetland vegetation has declined under the drainage-induced reduction of water levels and continued grazing pressure (Hawkes Bay Regional Council 1988). Today, much of the catchment is leased to BrownRigg Agriculture who maintain an extensive and intensive schedule of cropping and grazing. The lake is shallow, being less than 1 m deep (Hawkes Bay Regional Council 1988). Although not known with certainty, it is likely that the maximum depth would be in the order of 1 m. The bed of the lake is rather indeterminate as it is comprised of very soft substrates overlying extensive peat deposits up to 9 m deep. Margins of the lake are often "springy" as subsoils are inundated by water. The lake is fed by inflowing drains that are extensively lined with flax (*Phormium tenax*) and willow (*Salix* spp.). An aerial photo of the lake (Figure 1, date unknown) shows extensive shallow areas and encroachment by willows, especially along the western shoreline.

The area of the lake varies seasonally, but averages ~ 270 ha , although this area varies both seasonally and from year to year. The lake is drained by Poukawa Stream, a natural outlet that has been extensively modified since drainage and land improvement schemes commenced in the 1920s. The lake level is controlled by a radial arm control gate (Figure 2) approximately three km downstream of the lake outlet. The fall from the lake to the weir is only 20 cm (Environmental Management Services Ltd 1996).

Poukawa Stream runs north through Pekapeka Swamp to enter the Awanui Stream/Karamu Stream at Pakipaki, and finally discharges into the Ngaruroro River.

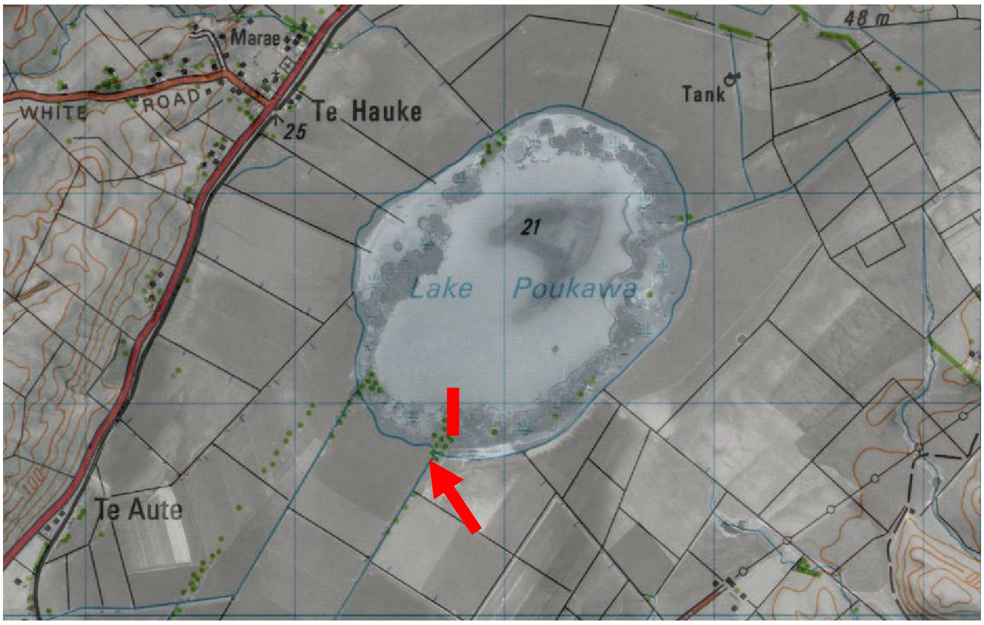

Figure 1: **Lake Poukawa (blended aerial photograph and topographic map) to show areas of lake plant growth (mainly raupo willow), and exposed bed in the centre of the lake. The larger arrow shows the lower section of the drain that was fished and the red line shows the transect at the lake margin that was fished.**

Figure 2: **The weir on Poukawa Stream. The radial gate has been lifted, and lake level is being maintained by the horizontal boards. A small flow can be seen overtopping these boards.**

Inflow to the lake is via a series of man-made drains, with the two major drains stretching for 2.5 km upstream of the lake. These drains are in turn fed by a series of lateral drains. The main drains are up to 1.5 m deep, and extensively lined with scrub and willows – substrate is fine sediment. Cover for eels in the drains is principally the soft sediments, although there are root bases from willows and associated debris clusters, and extensive areas of duckweed (*Azolla*) on the water surface.

1.2. The status of the eel (tuna) resource of the lake

For Te Hauke iwi, the depletion of eels from the lake represents a severely depleted resource - the history of Lake Poukawa is directly related to the eels of the lake and the mana of each chief of Te Wheao is related to control of the lake and its resources (Hawkes Bay Regional Council 1988). In recognition of these high traditional values, the regional council's policy is that water management should not affect the eel fishery (Hawkes Bay Regional Council 1988).

The 1996 survey (Jellyman and Bonnett 1996) made a series of recommendations about management of the lake. Since that time, the Trustees of the lake have been active in implementing a number of these. As a result, in 2007, the Trustees wrote to Te Ohu Kai Moana expressing their desire that some follow-up survey of the tuna population of the lake be carried out to determine the status of the eel population.

The relevant portions of that application to TOKM (16 April 2007) are reprinted below:

It has now been a decade since that research was completed and the recommendations provided the Trustees with a range of challenges to protect our freshwater eel stocks from over exploitation improve the habitat quality and facilitate increased recruitment of juvenile eels.

Set out below are the conclusions and recommendations of the report and after each of the main findings are comments indicating a series of actions undertaken by the Trustees and our community –

***Over-exploitation**: reports (eg. Mitchell 1984) indicate that previous commercial fishing seriously depleted eel stocks in the lake. Given the present growth rates, virtually all eels presently in the lake will have been recruited since the commercial fishing of the late 1960s and mid 1970s, and thus the population can be considered to have recovered. However, because of its sustainability to fyke-netting, and the apparent ease with which large numbers of eels could initially be caught from drains, and no doubt around shorelines during floods, the eel stock would again be vulnerable* *to over-exploitation if unchecked commercial fishing were again permitted. Given the history and present management of the lake, this possibility seems unlikely.*

The Trustees have banned all commercial fishing from taking place within Lake Poukawa. The eel fishery at present sustains customary events primarily located at Kahuranake Marae, Te Hauke and local whanau requirements. We are however anxious to ensure that current levels of eels present within the Lake are not depleted, are in a healthy state and extractions are sustainable.

Habitat maintenance: *continued access for eels to marginal flooded habitat is of particular importance to sustain growth rates. Likewise, any further reductions in size and/or depth of the lake will be to the overall detriment of the remaining eel habitat. Mitchell (1984) commented upon the way in which cattle had apparently trampled much of the vegetative margin of the lake, including the fringing raupo beds, during times of low water in dry summers. He noted that the raupo beds provided shelter for eels during such times, and hence any reduction in their extent would impact on the eels. Thus it is important to keep cattle away from the fringe vegetation of the lake, especially during times of low lake level.*

Since the report was completed the Trustees have fenced the entire perimeter of the Lake and planted native vegetation to enhance the fringe of the Lake. We are keen to review the impact this has had on eel levels and whether there are any additional initiatives which could be taken to further enhance the quality of the habitat for our eel stocks.

Recruitment of juvenile eels: *there is some evidence from this study that levels of recruitment of juvenile eels into the lake are less than optimal. Certainly, the radial level-control gate appears to present a substantial impasse to recruitment – it may be that most recruitment over recent years has been due to manual transferral, a situation that is very undesirable as it relies on continuing "a good-will" on behalf of the adjacent landowners. Reinstallation of the elver pass is therefore recommended.*

The Trustees supported the extensive clearing of the Pekapeka Swamp which is located at Pakipaki and is a major passage way for eels recruited to Lake Poukawa. The water level control gate remains in working condition and efforts were made to construct an elver pass with the cooperation of the HB Regional council. Research to assess the contribution of this path to recruitment and identify an appropriate and optimum system to facilitate the passage of elvers will be part of the research programme intended with this application.

From the above, a series of objectives were derived:

(a) Establish present growth rates and relative abundance of shortfin eels

(b) Assess the extent and use of marginal lake habitats

(c) Establish the adequacy of recruitment over the past decade

(d) Review current management practices of the lake, especially water level variability

These objectives formed the basis of an eel survey that was carried out by NIWA during 18 – 20 February 2008. Because of some changes to the Trustees since that time, completion of this report has been delayed. A draft questionnaire was also developed for use by the Trustees (or regular lake users), and although the present lake managers decided not to use it during the present survey, it is attached to this report (Appendix I) so that it could be used in future to provide some benchmark of the importance and usage of the lake to local Tangata Whenua; if repeated at regular intervals, the results would provide an index of perceived changes in the well-being of the lake, and its usage. Such data could be used to advocate improvements to the lake and the way that it is managed.

2. Methods

2.1. Flow and water temperatures

Mean monthly flow data recorded at the Poukawa weir (1977- 2008) were obtained from Hawkes Bay Regional Council. To compare diel water temperatures during the survey period, two Hobo water temperature dataloggers were placed in an inflow drain (200 m above the point of entry into the lake), and at the edge of the lake itself.

2.2. Eel surveys

2.2.1. Survey equipment

For consistency with a previous survey (Jellyman and Bonnett 1996), unbaited fyke nets were used. These nets were a combination of single wings (6 m long) nets, made of 12 mm (stretched) mesh, with an opening height of 0.6 m. No escapement tubes were fitted. Double wing nets were also used – these have two 6 m wings – in small waterways, such nets can effectively seal off the whole stream width. A total of 10 single wing and two double wing nets were set. All nets were set from a 2 metre dinghy which was propelled by rowing as previous experience had indicated that the lake was too shallow to use an outboard motor. Nets were anchored by wooden stakes, set overnight and retrieved the following morning.

During the 1996 survey, we were able to gain access to the outlet of the lake. This enabled setting of nets within both the outlet drain and in the lake itself up to 200 m from the outlet. However, during the present survey we were only able to access the lake via the inflowing drains. In practice though, the lake was particularly low and it was not possible to get beyond 50 m into the lake itself. At this distance, there was less than 15 cm of free water, and because of the very soft sediment of the lake bottom, it was not possible to get out of the boast and pull it through the shallows. Therefore access to the lake outlet may have been of limited use.

Catches from the fyke nets were emptied into mesh keep-bags that were retained in the drain until required for processing. The contents of each keep-bag were emptied into a plastic rubbish-bin containing anaesthetic (2- phenoxyethanol). Once eels were unconscious, they were identified by species, and individually measured; a proportion were weighed on a top-loading electronic balance. Most eels were returned to keep-bags for subsequent release at the point of capture, although a sample of 59 was kept for ageing. These carcasses were given to local Tangata Whenua, who also collected approximately 200 additional eels for customary use. One net had caught so many eels that it was not possible to haul it into the dingy; this net was hauled to the edge of the drain, and eels were released (and counted) back into the drain.

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Electric fishing was carried out both below and above the weir using a battery-powered Kainga EFM300 electric fishing machine. A total of 36 m^2 was fished below the weir and 60 m^2 above the weir. The substrates in these reaches were 80% cobbles, and 20% silt below the weir, and 100% silt above the weir. Two lines of G-minnow traps (Chisnall 1996) were also set, one above and one below the weir. These are small mesh traps (6 mm square mesh) with an entrance at either end. Each line had 10 traps attached and these were baited with Marmite (contained within a perforated container). Traps were left overnight and retrieved the following morning.

2.2.2. Data recording and processing.

The condition factor (k) is a measure of fatness of fish, and is calculated from the relationship between length and weight. Condition factor of those individual eels that were weighed was calculated using:

$$k = weight * 1000000/l^3$$

where weight was in grams and length in mm.

From the sample of eels that were weighed (N = 102), the relationship between length and weight was determined, so that the weight of eels that were not weighed could be estimated from their lengths. In practice, this length-weight relationship was used to estimate individual weights of all fyke netted eels. These weights could then be summed to calculate the total biomass (weight) of eels per net. Catches per net were compared using either the number of eels per net, or the estimated weight of eels per net.

The earbones (otoliths) of eels are used to determine their age (Jellyman 1979). Similar to growth in trees, each year the otolith lays down another annual ring. For ageing, a sample of ~ 10 eels per 10-cm length group was retained. Otoliths from these eels were removed in the field, and stored on waterproof paper (Graynoth 1999). Otoliths were subsequently prepared in the laboratory using the breaking and burning technique (Hu and Todd 1981) i.e. broken otoliths halves were heated and mounted on microscope slides. Age was assessed by counting the number of complete dark (winter) rings. The average annual growth of each eels was estimated as the mean annual length increment. For this, the average length of glass eels at arrival in fresh water (60 mm, Jellyman et al. 2002) was subtracted from the total eel length (mm), and the remaining length divided by the age of that eel.

i.e. annual increase in length per year = (eel length – 60)/age

The stomachs of those eels retained for ageing were removed, injected with formalin, and stored in individually numbered plastic bags. When processed in the laboratory, stomachs were initially assigned a subjective fullness index (0 – 10) where 0 = empty, 4 = half full, 8 = full, and 10 = distended. Contents were then identified to species level where possible, and the number of organisms recorded. For consistency with the previous survey (Jellyman and Bonnett 1996), diet was expressed by both number of food items, and the occurrence of those items across all stomachs.

3. Results

3.1. Discharges and water temperatures

Mean monthly discharge from the lake (1977 – 2008; Figure 3) shows two general flow features – a low flow period (flows < ~ 200 l/s) from October – May, and a period of significantly higher flow from June – September. A crucial time for eel recruitment is the January – March period when juvenile eels move progressively upstream. To explore some of the variability in flows between years, the mean flow for January – March for each year was calculated. The results (Figure 4) show considerable interannual variability, and while there appears to be a general trend towards reduced flows over recent years, this is not statistically significant (linear regression, $P = 0.24 > 0.05$).

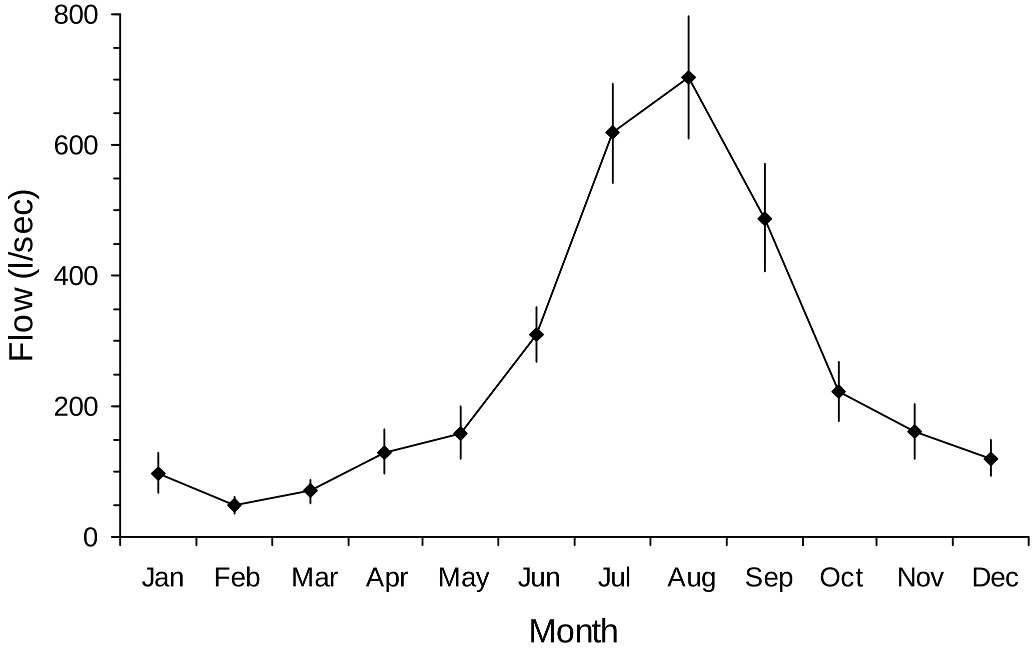

Figure 3: **Mean monthly flows (and 1 SE) at Lake Poukawa weir, 1978 – 2008**

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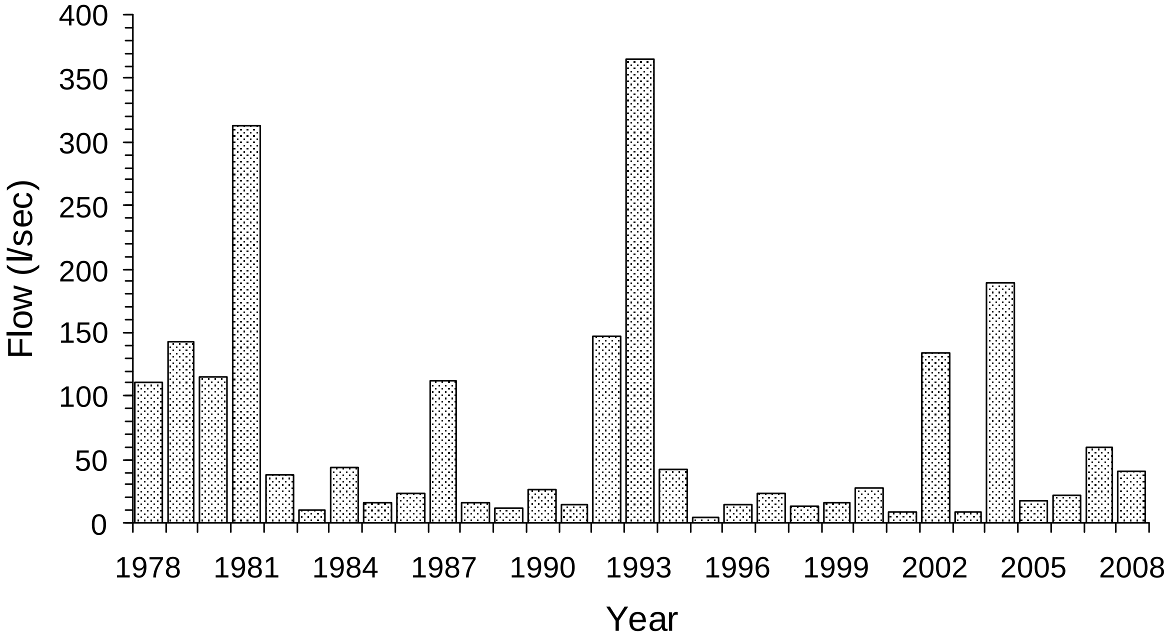

Figure 4: **The mean flow, January – March at Lake Poukawa weir, 1978 - 2008**

The suggested minimum flow of 20 l/s (Hawkes Bay Regional Council 1988) is often unable to be achieved during summer. For example, for the above years, the monthly average over January – March was less than 20 l/s for 36 of the 87 months of record (41% of time).

Water temperatures over a 24 h period in the lake and the drain were almost identical (Figure 5). The drain had a slightly smaller range (19.2 – 22.8 °C) than the lake (19.0 – 23.7 °C), probably because of the cooler groundwater entering the drain. Conductivity in the drain was 600 µS/cm.

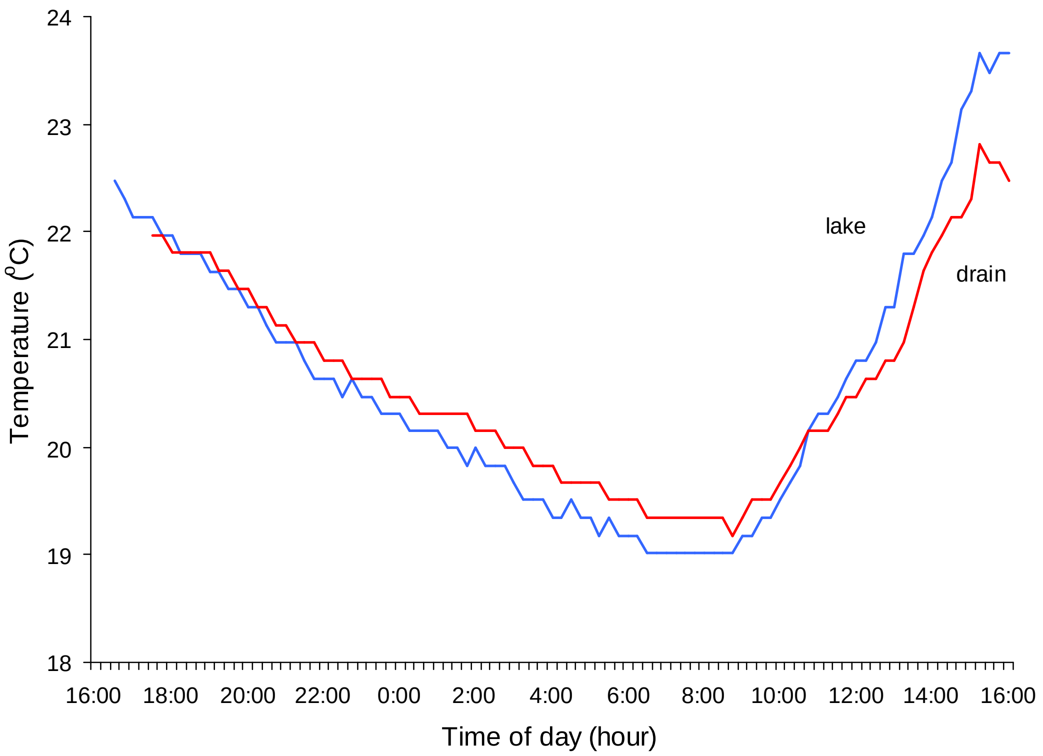

Figure 5: **Water temperatures recorded from the drain and the edge of Lake Poukawa, 1600 h 18 February 2008 – 1600 h 19 February 2008.**

3.2. 2008 Eel survey

Figures 6 – 10 show various aspects of the fyke net sampling, and processing of eels.

3.2.1. Species proportions

Fyke netting was used exclusively within the lake and drain, and all eels caught were shortfins (Table 1). Both electric fishing and G-minnow traps were used in the outlet stream, and while G-minnow traps caught only shortfins (n = 16), electric fishing caught both species (92 % shortfins, 8% longfins).

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Figure 6: **Fyke nets set in the lake. Note the lack of depth as the outermost net is only in 15 cm of water (just sufficient for water to cover the valves within the net).**

Figure 7: **Fyke net (double wing) full of eels retrieved from the main drain (395 eels)**

Figure 8: A fyke net (single wing) full of eels, from the main drain (n = 222 eels).

Figure 9: Keep net of eels prior to being anaesthetised.

Figure 10: **Eels in anaesthetic**

Table 1. **The number and size of both species of eel caught by different fishing methods. The number measured is shown in italics within brackets.**

Location	Method	Species	Number caught	Mean length (range)	SE
Inflow drain and lake					
	Fyke nets	Shortfin	1574 (*410*)	578 (314 – 849)	5.3
Outlet					
	Electric fishing	Shortfin	102 (*102*)	284 (90 – 693)	16.1
	Electric fishing	Longfin	9 (*9*)	191 (122 – 298)	19.4
	G-minnow traps	Shortfin	16 (*16*)	412 (302 – 512)	15.5

3.2.2. Size

The average size of shortfins caught by fyke nets exceeded sizes caught by the other two methods. Length-frequency distributions of eels caught by the various methods (Figure 11) showed a skewed distribution of juvenile eels from below the weir, with the majority being 200 mm or less. Above the weir, there was a greater size range, and the dominance of the smaller sizes was less pronounced. For fyke netted eels from the lake and drain, the length – frequency distribution was very close to a normal distribution, although there was a slight skew in favour r of larger eels. The rapid truncation at sizes < 400 mm is normal and is a result of the size selective nature of fyke nets.

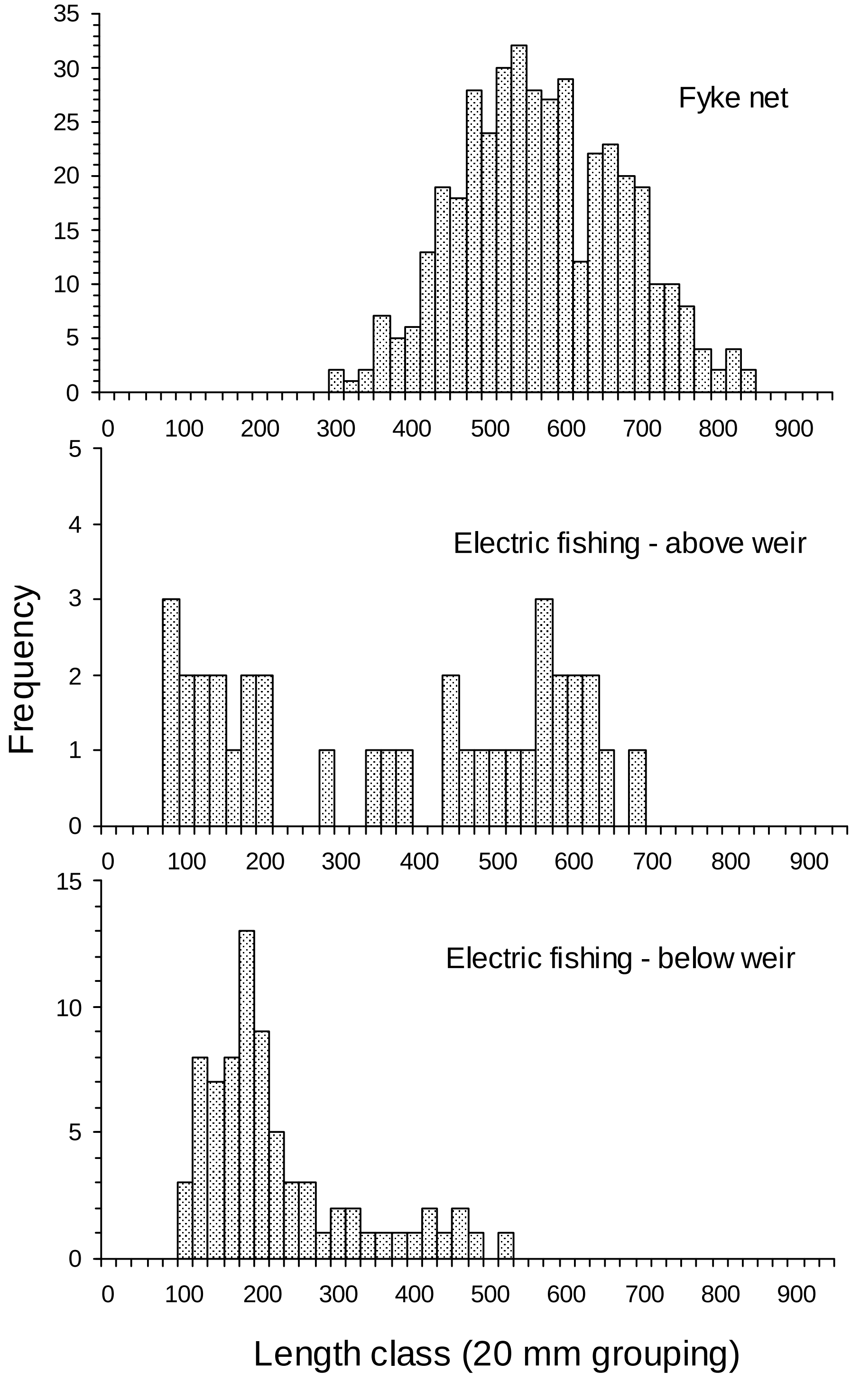

Figure 11: **The length distributions of shortfin eels caught in the lake and drain by fyke nets (top), and electric fished from above and below the weir**

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When the average size of fyke-netted eels caught in the drain (115 measured) was compared with that of eels caught in the lake (295 measured), there was no significant differences (mean lengths: drain 578.3 mm, lake 578.1 mm; *t* – test, P = 0.99 > 0.05). Both electric fishing and G-minnow traps were used to sample eels below and above the weir. For both methods, the average size of shortfins from below the weir was smaller than shortfins from above the weir (Table 2); differences were significant (*t* – test, P< 0.05) for electric fished eels (P = 0.001), but not for the much smaller sample from G-minnow traps (P = 0.19).

Table 2: Comparison of sizes of shortfin eels caught below and above the weir

	Below weir		Above weir	
Method	Number measured	Mean length (SE)	Number measured	Mean length (SE)
Electric fishing	67	238.2 (13.4)	35	372.4 (17.1)
G-minnow traps	4	380.8 (22.3)	12	422.9 (18.8)

All 9 longfins caught by electric fishing were from below the weir, and their mean length (190.9 mm, SE 19.4) was smaller than that of shortfins from the same area (t-test, p = 0.002 < 0.05).

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3.2.3. Length-weight relationship and condition

Because weight varies according to the cube of the length, the relationship between length and weight was log-transformed. The resulting length-weight relationship (where ln weight = log of weight, and ln length = log of length) was:

$$\ln(\text{weight}) = 3.162(\ln \text{length}) - 14.125 \qquad N = 102, R^2 = 0.98$$

Thus a 500 mm shortfin would average 251 g, with equivalent weights for a 600 mm and 700 mm shortfin being 447 and 727 g respectively.

Condition (k) ranged from 1.43 - 2.79, with an average of 2.02 (SE 0.02). There was a slight tendency for condition to increase with increasing size of eel (Figure 12), and the relationship was significant (P = 0.006< 0.05).

3.2.4. Catch-per-unit-effort (CPUE)

Numbers of eels per net ranged from 0 to 395 eels (weight 206.6 kg). The average number of eels per net was 131 (67 kg). As the zero catch was for a double wing net facing downstream (set across the whole width of the drain) compared with a catch of

395 eels for the equivalent net set facing upstream, it was apparent that eels were migrating out of the drain at night and were intercepted by the upstream-facing net. When the downstream facing net is excluded, the average catch was 143 eels (75 kg) per net.

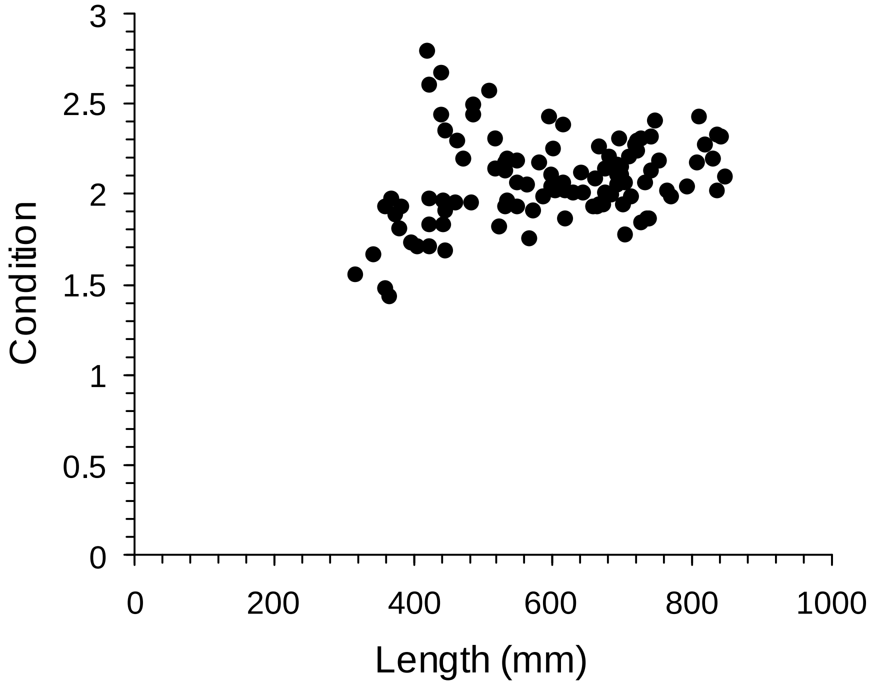

Figure 12: Relationship between length and condition of shortfin eels

3.2.5. Age and growth

The plot of length at age (Figure 13) shows a linear relationship, with relatively little scatter. The regression was;

$$\text{length} = 29.565\,(\text{age}) + 156.639 \quad (n = 59,\ R^2 = 0.87,\ P < 0.001)$$

This linear relationship meant that, on average, eels grew at the same rate in length (29.6 mm/year) throughout their life.

As this is an average value across all eels aged, the annual length increment for individual eels was also estimated. The mean value was 37.02 mm (range 27.50 – 58.90, SE 0.73). There was no relationship between the average length increment and fish length (R^2 = 0.023, P = 0.256, > 0.05), meaning that the mean value was indicative of annual growth over the length range of eels i.e small eels grew at the same rate as large eels.

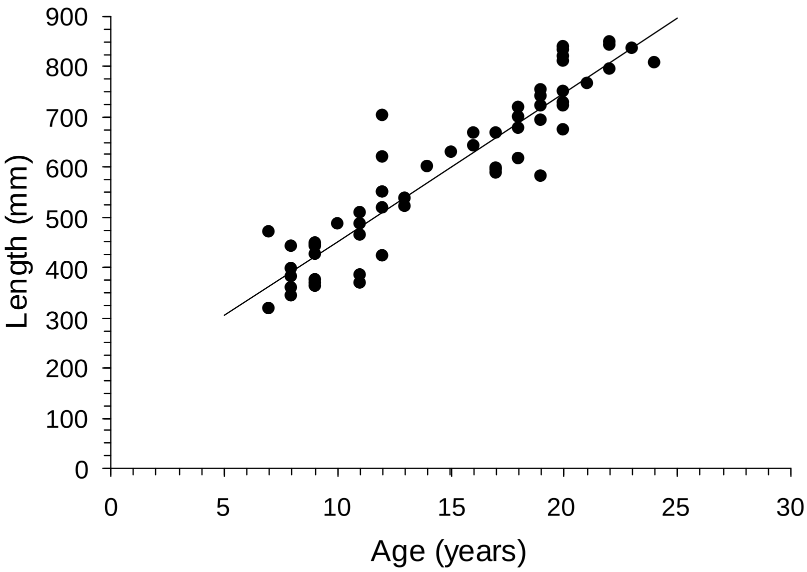

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Figure 13. The distribution of lengths for given ages, and the average growth rate.

The relationship between length and weight increment (the annual increase in weight expressed as g/year) was:

weight increment = 0.096 (length) – 24.019 (n = 59, R^2 = 0.88, P < 0.001)

Using this relationship, the average annual increase in weight for a 300 mm eel was 4.8 g, compared with 24.0 g for an eel of 500 mm, and 43.2 g for a 700 mm eel.

There was also a strong linear relationship between weight and age i.e.

weight = 70.505 (age) – 494.58 (n = 59, R^2 = 0.80, P < 0.001).

Using this relationship, an eel would be just over 10 years old by the time it was 220 g (the minimum commercial size); a 0.5 kg eels would be 14 years old, and a 1 kg eels would be 21.2 years old.

3.2.6. Diet

Of the 56 stomachs examined, only 18 (32%) contained food (Table 3) The fullness index ranged from 0 (empty) to 8 (full), but the average was only 0.71, which equated to approximately 1/8 full. Numerically, snails dominated, and comprised half of all food items recorded, followed by midges (26% of all food items), and ostracods (11%). The "fullest" stomach was from an 807 mm eel that contained a shortfin eel of 201 mm in its stomach, with this stomach being classified as being "full" (an index of 8).

Table 3: **The diet of 56 shortfins eels. Number = absolute number of organisms recorded; occurrence = the number of eel stomachs where that food item was recorded.**

		Number		Occurrence	
		Number	%	Number	%
Aquatic food					
Mollusca	*Potamopyrgus* (snail)	96	49.8	7	12.5
	Physastra (snail)	1	0.5	1	1.8
	Gyraulus (snail)	1	0.5	1	1.8
Insecta	*Sigara* (water boatman)	7	3.6	5	8.9
	Chironomis (midge) larvae and pupae	51	26.4	6	10.7
	Trichoptera (caddis larvae)	4	2.1	2	3.6
Ostracoda	"Water flea"	22	11.4	3	5.4
Amphipoda	"Water hopper"	1	0.5	1	1.8
Oligochaete	Aquatic worm	2	1.0	1	1.8
Arachnida	*Dolomedes* (water spider)	1	0.5	1	1.8
Pisces	Eel	2	1.0	2	3.6
	Bully remains	2	1.0	1	1.8
Terrestrial food					
Aves	Bird feathers	3	3.1	3	14.3
		193	100		
Number of empty stomachs		38			
Number of stomachs containing food		18			
Mean fullness index		0.71			

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3.3. Comparisons between 1996 and 2008 data (main outcomes are indicated in italics)

3.3.1. Species proportions

For both years, all eels caught in the lake or drains, were shortfins (Table 4). The only longfins caught were in the outlet stream, near the weir (5 and 7% of the total eels caught here in 1996 and 2008 respectively).

Main outcome: no changes over time

Table 4: **Comparison of the numbers, species proportions, and average lengths of eels caught in 1996 and 2008.**

	Lake			Outlet					
	Shortfins			Shortfins			Longfins		
Year	N	%	Mean length	N	%	Mean length	N	%	Mean length
1996	1701	100.0	510.5	43	95.5	434.0	2	4.5	-
2008	1574	100.0	578.2	118	92.9	301.6	9	7.1	190.1

3.3.2. Size

For fyke-netted eels, the average size in 2008 was significantly larger (578.2 mm) than in 1996 (510.5 mm) (ANOVA, d.f.1, 813, $F = 100.17$, $P < 0.001$). Comparison of the length frequencies of fyke netted eels from the lake (Figure 14) shows that the 1996 data were strongly unimodal (500 mm), and length classes ≥ 600 mm were not well represented (11 % of total), whereas in 2008, the size groups 520 – 600 mm were more strongly represented, and the % of eels ≥ 600 mm was substantially greater (41 %).

Main outcome: the 2008 eels had a larger average size than in 1996, and the length distribution showed a much higher proportion of bigger eels present, indicating a population that had recovered from the substantial harvest that had occurred prior to 1996.

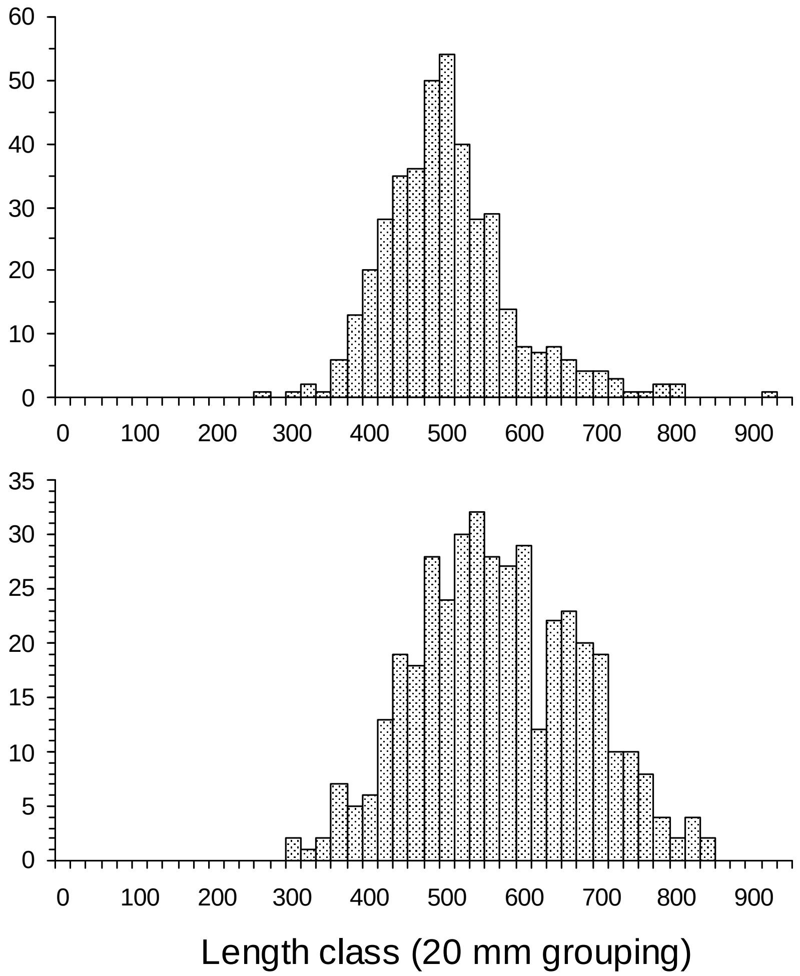

Figure.14: Comparison of the length frequencies of eels caught by fyke nets in Lake Poukawa in 1996 (top) and 2008 (bottom).

3.3.3. Length-weight relationship and condition

In 1996, the average condition of 1.90 (SE 0.01), was less than in 2008 (mean = 2.07, SE 0.02); these differences were significant (ANOVA, d.f. = 1, 380, F = 41.37, P = < 0.001). When expressed as differences in weight for a given length, at 300 mm, an eel in 2008 (49.9 g) was an average of 1.4 g heaver than an eel of that length would have been in 1996, a 500 mm eel (251.0 g in 2008) was 13.1 g heavier than in 1996, and a 700 mm eel (727.4 g in 2008) was 49.5 g heavier than in 1996.

Main outcome: in 2008, eels were in better condition (fatter) than in 1996.

3.3.4. CPUE

Comparisons were made of catches between the 2 years, using both the number of eels per net and the biomass per net. Results (ANOVA, d.f.= 1,23) were similar for both dependant variables (number or biomass) and year had no effect ((F = 0.90, P = 0.352 for numbers, F = 1.48, P = 0.236 for biomass), but there was a significant site (drain versus lake) effect (P< 0.001 for either numbers (F = 21.21, P = < 0.001) or biomass (F = 121.30, P = 0.002). The interaction effect (year*site) was just significant for numbers (F = 4.39, P = 0.047) but not for biomass (F = 0.45, P = 0.507).

Main outcome: drain catches in both years were much greater than lake catches, but there were no differences in catch rates (numbers or biomass) between the two years.

3.3.5. Age and growth

Distributions of mean annual length increments for both years (1996: mean = 43.1 mm/year, SE 1.3; 2008: mean = 37.0 mm/year, SE 0.7) were significantly different (ANOVA, d.f. = 1,121, F = 16.98, P < 0.001).

Main outcome: although eels in 2008 were larger (longer and heavier) than in 1996, and in better condition, their growth rate was slightly slower.

3.3.6. Diet

Of the 61 stomachs examined in 1996, 47 (77 %) contained food, which was a much higher proportion than in 2008 (32 % of the 56 stomachs examined). Likewise the fullness index was twice as high in 1996 (1.48) than in 2008 (0.71). In 1996, a total of ten aquatic taxa and four terrestrial taxa were recorded, compared with 12 aquatic and one terrestrial taxa in 2008. In both years, the numerically dominant food item was snails (54% and 51% , 1996 and 2998 respectively), followed by chironomids (30%

and 26% respectively). Fish were relatively uncommon, being recorded from only five eels in 1996 (8%) and three in 2008(5%).

Main outcome: diets were very similar between the two years with snails and midges dominating, although the proportion of empty stomachs in 2008 was much greater.

4. Discussion

The discussion is focused around answers to the objectives posed earlier

- Establish present growth rates and relative abundance of shortfin eels
- Assess the extent and use of marginal lake habitats
- Establish the adequacy of recruitment over the past decade
- Review current management practices of the lake, especially water level variability

4.1. Growth rates and relative abundance of shortfin eels

As indicated in the previous section, the size of eels, growth rates, and relative abundance are all favourable. Relative to other North Island shortfin populations (Table 5), the average size of shortfins in Lake Poukawa in 1996 was relatively small (exceeded by nine other locations in Table 5), but by 2008 the mean length had increased significantly and exceeded the average lengths in nine of the locations listed.

CPUE was very high during both surveys, but this was partly because many eels were intercepted as they apparently made a daily migration from the drain to the lake. Hence the data are not comparable with catches in other locations. However, the high catch rates in the lake (average of 85 eels/net, = 44.5 kg/net/night), were indicative of a large population, although an extensive mark-recapture programme would be needed to verify this.

4.2. Extent and use of marginal lake habitats

Unfortunately we were unable to study the extent of use of the lake margins relative to other parts of the lake, as water was too shallow to be navigable by boat. The 4 nets set near the edge of the lake all caught good numbers of eels (Appendix II), and it would be expected that eels will forage extensively among lake shallows at night. The vegetation around the lake margin, especially raupo and flax, will provide a diversity of habitats of invertebrates and also small fish (although no other fish species were caught in the nets during the present survey, common bullies and small goldfish were electric fished from above the weir).

Table 5: Comparison of sizes of shortfin eels from North Island rivers and lakes.

Region	Location	No.	Mean length	SE	Range in length	Reference
Waikato	Lake Waikare	88	570	1.0	450 - 990	Chisnall and Kemp 2000
Waikato	Lake Whangape	14	629	2.4	510 – 770	Chisnall and Kemp 2000
Waikato	Lake Ngaroto	316	533	0.4	370 - 800	Beentjes & Chisnall 1998
Waikato	Lake Harihari	87	532		350 – 990	Chisnall and Ruru 2008
Waikato	Lake Rotoroa	148	507		280 – 755	Chisnall and Ruru 2008
Waikato	Lake Numiti	151	485		325 – 687	Chisnall and Ruru 2008
Waikato	Lake Taharoa	276	534		220 - 740	Chisnall and Ruru 2008
Wellington	Lake Horowhenua	782			117 - 780	Chisnall & Jellyman 1999
Hawkes Bay	Waipaoa River	128	615		330 - 1030	Maumahara Consultants 2007
Hawkes Bay	Wairoa River	100	565	0.6	480 - 790	Chisnall and Kemp 2000
Hawkes Bay	Lake Repongaere	400	565	0.3	440 – 820	Chisnall and Kemp 2000
Hawkes Bay	Lake Repongaere	833			295 - 762	Ruru and Chisnall 2004
Hawkes Bay	Lake Purimu	553	541	0.3	390 - 840	Beentjes & Chisnall 1998
Hawkes Bay	Lake Poukawa	423	511	4.2	279 - 930	Jellyman & Bonnett 1996
Hawkes Bay	Lake Poukawa	410	578	5.3	314 - 849	this study

During periods of higher lake levels, shortfins will forage extensively in newly inundated shoreline and pasture (Jellyman 1991), when their diet will include terrestrial invertebrates, especially earthworms and insects (Jellyman 1989). Shoreline vegetation provides both stability to the shoreline (reduces erosion during windy periods, with associated ingress of silt and nutrients into the lake), and also increased habitat diversity and area where terrestrial food can be found. Both features are advantageous for eels, especially in spring when eels feed regularly following reduced feeding in winter, or cessation of feeding if water temperatures fall below 5 – 6^{o} C (Jellyman 1991, 1997). As well as seasonal changes in lake levels and margins, short-term pasture inundation from floods also provides periodic access to insects and worms, and can provide significant feeding benefits for eels.

Aquatic snails typically make up a high proportion of eel diets (Jellyman 1989; this study), and snails prefer firm substrates or vegetation to silt. Thus increased vegetation will provide additional grazing areas for snails, and hence more food for eels. Willows will also provide some habitat for aquatic invertebrates, while their root bases provide cover for adult eels; while these are favourable features, willows also have a significant negative impact by trapping sediment and removing water through their metabolism (see later comments).

4.3. Adequacy of recruitment over the past decade

There was a good representation of small eels during both the 1996 and present study, indicative of regular recruitment. During the present study, there was some indication of increased numbers of eels below the weir (average density of 2.8/m^2 versus 0.6/m^2 above the weir, but there was also better habitat below the weir which would partly account for this difference. There was certainly no accumulation of eels in the immediately downstream of the weir that would have indicated that the weir was acting as a substantial barrier.

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Discussions with the farmer whose property the weir is on, Mr Bill Buddo, indicated that in most years he sees elvers at the weir, and notices heavy predation by larger eels. He has transferred several "hatfulls" in past years, but thought that there were fewer elvers arriving at the weir over the past decade. He also mentioned that he saw few juvenile eels in the area immediately upstream of the weir (confirmed by electric fishing during the present survey), probably because that area had little flow and he assumed low levels of dissolved oxygen. Most flow came from the adjacent small waterfall that used to provide the water source to operate the fish ladder. However, the ladder pipes and water piping got broken by successive draglining "many years ago" - the ladder was broken prior to the 1996 survey, and appears to have not operated since then.

Mr Buddo didn't think that the elvers could climb the weir, and he has observed elvers in grass alongside the weir, trying to get upstream. However, he did consider that most elvers could negotiate a submerged pipe ("2 inches in diameter") that passed some flow below the crest of the weir (Table 6). While we were unable to measure velocities passed by the pipe during the present survey, we did estimate diameter and depth below the surface on the downstream side. From these data, the flowing velocities were estimated for varying head differences.

Flume swimming trials for small shortfins (55 – 80 mm length) showed that their maximum burst swimming speed (the maximum swimming speed they could maintain for short periods, often only 4-5 sec) was 0.57 m/s (Mitchell 1989), which is less than any of the above velocities. So, in theory, if the head difference on either side of the weir was only 5 cm, the velocity through the tap (0.85 m/s) would still be greater than small eels could negotiate. These calculations raise serious doubt then whether small eels are able to swim through the pipe, in which case their access is reduced to climbing around splash zones of the weir, an undesirable situation. Larger eels have greater swimming ability, and European eels of 40 – 60 cm have been recorded as having swimming speeds of 0.51 – 0.83 m/s (DWA 2005), meaning that larger eels might be able to negotiate the pipe at low head differences, but eels of this size are too large to climb vertical surfaces and splash zones.

Table 6: The estimated velocity for given differences in water level (head) on either side of the Lake Poukawa weir

Head (m)	Estimated velocity m/s
0.05	0.85
0.1	0.98
0.15	1.10
0.2	1.23
0.25	1.35
0.3	1.48
0.35	1.60
0.4	1.73
0.45	1.85
0.5	1.98

The present weir has a series of dam boards to maintain the water level. Prior to installation of these boards, the radial arm was used to control levels, and in these circumstances it was possible for elvers to swim under the radial gate when it was raised. Velocity measurements under the gate (Hawkes Bay Regional Council 1988) ranged from 0.37 – 1.18 m/s, meaning that elvers could have negotiated the lower velocities found at the bank edges.

Overall it seems very likely that the weir does provide at least a partial barrier to small eels. The preferred solution would be the reinstallation of a small fish ladder. When the radial gate is open (as it presumably is most of the summer), there is potential for installing a small ramp on the downstream side of the weir crest (from top of weir sill to downstream water level) along either side; there is already a notch in the sill which produces small flow at this point, and could be diverted down a small ramp. If so, some reduction in flow to the point of intake would be required to cope with varying (especially higher) flows when elvers are most likely to attempt to migrate upstream. Regional Council engineers may be able to provide a better and more permanent solution.

4.4. Current management practices of the lake, especially water level variability

4.4.1. History

- The issue of lake level is a complex one with a long history of investigation and recommendation. The report of Williams Consultants Ltd. (2000) provides a useful overview of the history and issues relating to lake management. Significant points are:

- peat land around Lake Poukawa was extensively drained in the 1930's

- drainage has caused shrinkage of the peat with associated adverse effects for flooding of marginal land (the range in water level within which flood storage can occur without affecting farmed land is now effectively about 0.20 m, a very small amount)

- intensive horticultural development between Lake Poukawa and Pekapeka Swamp has lead to increased demand for irrigation water which is obtained directly from Poukawa Stream, groundwater bores, and dam storage on tributary streams - all these takes potentially affect flows in Poukawa Stream

- because of potential conflicts between land and water uses, and protection or enhancement of wetlands, over the past two decades there have been a number of technical investigations of the water and soil resources of the catchment and associated management plans

- major issues that have been identified are:

  - the continued shrinkage of the peat lands within the basin by drainage and agricultural use

  - the importance of maintaining water levels as high as possible over summer months to minimise further settlement ("shrinkage") of land

  - the importance of the flood detention and storage provided by Lake Poukawa and the Pekapeka Swamp for the Heretaunga Plains

  - the very small flows in Poukawa Stream over summer, and the possibility of using controlled storage in the Poukawa Basin to supplement these summer flows

- the significance of the Lake Poukawa and Pekapeka Swamp wetlands and the threat to such wetlands from reduced summer water levels

- the continued encroachment of willows into Lake Poukawa

- the importance of Lake Poukawa to the Maori owners, and it's status as a reserve under the Maori Reserved Land Act (1955), and as a non-commercial eel fishery

- the suggested minimum flow of 20 l/s in Poukawa Stream is often unachievable during summer, and low flow augmentation from the lake is not feasible

- the sill and adjustable radial gate were added to the outlet in 1981 to modify the storage of water and the basin by allowing a faster dewatering of floodwaters while retaining water in spring to supplement summer low flows down Poukawa Stream

- in practice, the operation of the gate has had only minor effect on stream flows and the large evapo-transpiration losses in summer mean that the scheme is now considered unlikely to have been effective in enhancing summer flows

- the water right to operate the radial gate at the outlet control lapsed in 1991-although Hawkes Bay Regional Council has applied for a consent under the RMA to operate the gate, no consent has been obtained mainly because of difficulties in defining appropriate maximum and minimum water levels for operation of the gate

- a review of five management options for the lake (Willams Consultants Ltd 2000) suggested that the "do nothing" option was the preferable one. This option was to abandon the drainage scheme (not maintain the drains) and allow low-lying land to revert to wetland again. The consequent siltation and vegetation growth would result in higher lake levels of about 30.0 – 30.5 m (the outlet sill level is 29.4 m, although water ceases to flow from the lake at a level of 29.7 m, Williams Consultants Ltd 2000). Cropping of present farm land would have to cease almost immediately, although pastoral use could continue intermittently (in summer) for some time.

4.4.2. Present situation

Lake levels are maintained by manipulating the control gate and weir boards. Historically the lake has been managed to keep water levels high prior to summer to maximise habitats for wildlife, including fish – this regime also provides a store of water for downstream irrigators with property between the lake and Pekapeka Swamp (Jellyman 1996). A minimum flow of 20 l/s in the stream has been recommended as part of the irrigators water rights (Hawkes Bay Regional Council 1988). However, as flow augmentation from Lake Poukawa is not feasible in summer under the present regime (of minimising winter storage to reduce land inundation) , flows in summer are often less than 20 l/s.

A problem associated with drainage is oxidation and compaction of peat deposits (which are up to 9 m deep). Subsidence is a major problem for farming as it means the land is increasingly susceptible to flooding and more difficult to free drain (Environmental Management Services Ltd 1996). For example, during the first summer that the operating level of 30.35 metres was set in 1980, higher lake levels would have resulted in inundation of 150 ha of land beyond the lake, but in 1996, that the same level would inundate 500 ha of land. This tendency for inundation is partly offset by increased evaporation associated with a larger area, but an outcome of inundation of shallow marginal areas is a more dramatic decline in lake level as summer progresses.

It is undesirable for the lake to enter summer at a low level. Reduced volume of water will increase the likelihood of increased water temperatures – a maximum temperature of 27.7 ^{o} C has been recorded (Hawkes Bay Regional Council 1988); shortfin eels can cope with such temperatures, although their upper lethal limit is about 35^{o}C (Richardson et al. 1994). However, accompanying increased temperatures in Lake Poukawa will be reduced dissolved oxygen, meaning that the combination of these two stressors could be lethal at temperatures below the lethal limit of 35 ^{o}C. Warm summer temperatures are often accompanied by phytoplankton blooms, including blue-green algae. During the daytime, such algae contribute oxygen to the lake, but during the night, and especially during early-morning hours, these plants use oxygen which leads to significantly reduced levels of dissolved oxygen in the lake water. Any die-off of such blooms will also reduce oxygen, exacerbating conditions for aquatic life. In all likelihood, regular circulation of the lake by wind is particularly important for keeping the lake aerated, and a period of several days of calm weather during the peak summer period, could produce a chronic oxygen deficit in the lake. To date, there are no records of fish kills, but this is always a possibility n shallow, warm lakes dominated by phytoplankton.

Maintaining the lake as high as possible during summer provides some insurance against the possible effects of such conditions. Unfortunately, in a normal summer, it is very likely that the evapotranspiration rate will exceed the inflows into the lake, meaning that the lake will continue to become lower throughout the summer. Unless the lake is maintained at a higher level prior to summer, there is little likelihood of an increased outflow, and the volume of this outflow is one of the major attractants to promote upstream migration of juvenile eels from Pekapeka Swamp.

The last resource consent for management of lake levels expired in May 1991 (Jellyman 1996). Since then, all management decisions have been made through an informal committee representing interested and effected parties, including the Tangata Whenua through the lake trustees. At present though, there is no legal authority for operation of the control gate, and hence management of lake levels is somewhat ad hoc. Despite the lack of agreed management protocols, there is general recognition that it is desirable to retain the lake as high as possible when entering summer (Bill Buddo, pers. comm.).

A further aspect of lake management is recognition that the inflowing drains provide some short-term temperature refuges, enabling eels to move into drains and experience slightly cooler and flowing water during the day, before migrating downstream to feed in the lake at night. Therefore, it is important that the volume of the water in these drains does not reduce substantially, and that they be shaded as much as possible to decrease the likelihood of warming up too much during the day. The excessive growth of plants like duckweed (*Azolla*) should be discouraged, as this plant blankets the water surface and reduces the uptake of oxygen to the water column.

Restoration of Pekapeka Swamp ~ 8 km downstream, is a high priority for Hawkes Bay Regional Council, and a huge effort has been put into removal of willows and fencing (Hawkes Bay Regional Council 2005). All of the wetland has been purchased by Hawkes Bay Regional Council. A report on the wetland (Hawkes Bay Regional Council 2005) commented that “During prolonged low flow periods the flow from Lake Poukawa virtually ceases”. Also, the wetland was described as being in “poor condition” in terms of native fish fauna, with only shortfin eels, common bullies and inanga present. A subsequent survey (Hawkes Bay Regional Council 2008) found only shortfin eels, although many mosquito fish and some goldfish were found. Goldfish are already present in the outlet stream of lake Poukawa, but mosquitofish are not known from the lake. It is especially important that this species not be transferred upstream into Lake Poukawa where they would compete with eels for invertebrate food and be of little ecological benefit. The 2005 report mentioned a “constructed barrier which may inhibit fish migration”; although a fish pass has since been installed it needs to be monitored to ensure it is effective (Hawkes Bay Regional Council 2008).

Regular monitoring of the ecological conditions and trends is a requirement of the planned management of Lake Poukawa by Hawkes Bay Regional Council. To date, two surveys have been carried out in December 1999 and December 2001 (Walls 2000; Walls 2002). An important observation from these surveys is that during the intervening two years there has been a significant encroachment of willows and raupo "both willows and raupo have bulked up right around the lake margin, advancing significantly both into the lake and landwards. This has large management implications. The willows will keep spreading and will dominate the entire lake margin if not controlled….the raupo will keep thickening and advancing now that stock are fenced out…" (Walls 2002). Differences recorded in aquatic plants between the two surveys were not great – water net (*Hydrodicton reticulatum*), a highly undesirable species, was present during both surveys, and overall the native submerged macrophytes have become displaced by exotic species. To control the spread of willows (crack and grey willows), Walls (2002) advocated a manual cutting and poisoning programme, and noted that the perimeter fencing had resulted in some improvement in the conditions and regeneration of the native wetland vegetation around the lake margins, especially raupo, sedges and rushes, but there had also been a proliferation of exotic vegetation -he advocated a planting programme of natives in the areas of former pasture from which stock are now excluded.

It is not the intention or place of the current report to attempt to solve the convoluted issue of tradeoffs between lake levels and landuse practices. However, from a fisheries perspective, there is concern about the continued reduction in the size of the lake (through drainage and willow encroachment), the limited winter water storage options (as higher lake levels reduce landuse options), and consequently the low summer lake levels and reduced minimum flows. Improvement of the status of the lake, and flows in Poukawa Stream would only be possible at the expense of loss of farming opportunities. Ultimately, such decisions will need to be made by the lake trustees, who will need to weigh up reduced farming production and income from present leases against the need to manage the lake more effectively through control of willows and maintaining higher winter lake levels. Additionally, there are ongoing fish passage problems at the outlet weir, and some improved facility is required here. It is recommended that a small study should be implemented to look at the potential for re-establishing the previous native fish pass, or should that option not be viable, the alternative of a catch-and-carry system whereby the juvenile eels are trapped below the weir and manually transferred upstream.

5. Conclusions and recommendations

- The shortfin eel population has recovered substantially since the 1996 survey, and indicators from the present survey (sizes, condition, growth rates, relative abundance) were all favourable, and indicative of a healthy shortfin eel population.

- The weir is considered to provide a partial barrier to juvenile eels, although significant numbers must be able to negotiate it. Installation of a permanent elver pass (or a catch-and-carry trapping system as operated at a number of hydro dams and weirs throughout the country) is recommended

- A significant effort should be directed towards control of willows (and raupo to some extent), to reduce the rate of sediment trapping and infilling of the lake.

- Although unproven, it is likely that shoreline planting and fencing have benefited the lake by providing more habitat for invertebrate food for eels, reducing shoreline erosion and the input of more sediment into the lake, intercepting runoff (sediment and nutrients)

- Management of the lake should be such that summer levels are kept as high as possible to reduce high temperature and low dissolved oxygen effects, and provide the minimum residual flow of 20 l/s down Poukawa Stream. Achievement of these outcomes would require some additional water storage in winter with implications for present farming operations.

- Inflowing drains should be shaded as much as possible (although the benefits of this would need to be considered relative to the increased uptake of water by trees)

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Appendix I: Draft questionnaire

Lake Poukawa Cultural Health Indicator Project

INDIVIDUAL QUESTIONAIRRE

GENERAL STATISTICAL INFORMATION

1. Your name? ____________________

2. Your age on your last birthday? ______ **3. Are you?** ☐ Female ☐ Male

Personal values and site specific historic and contemporary associations with Lake Poukawa

Q1. What is your relationship to Lake Poukawa and why is this lake important to you?

Q2 How was this lake used in the past? What sites were used? Can you still use each of these sites today?

Q3 **How is this lake used today? What sites are still used?**

MAHINGA KAI QUESTIONS

Q4 **What mahinga kai sites did you use in the past in this lake? What was gathered from these areas? What mahinga kai sites do you still use today? What is gathered from these areas?**

Q5 **For each species identified in the response to Question 4, how important was the species in the past?**

- **How abundant was the species in the past (relative assessment)**
- **What was used in the past?**

CHANGES OVER TIME AND INDICATOR QUESTIONS

Q6 **What changes have taken place within the catchment that have affected your traditional sites?**

Q7 **What are the main changes you have seen in this lake over the years?**

Q8	**List the most important things that tell you about the health of Lake Poukawa. What do you see when you think about Poukawa as a healthy lake**

Are there any issues, questions and comments you would like to make?

Appendix II: Total catches of eels from Lake Poukawa, 2008 and 1996. Non-standard nets used in 1996 not included. DwU = double wing net set facing upstream; DwD = double wing net set facing downstream.

	Method	Location	Net	No of eels Shortfin	Longfin	Weight (kg)
2008	Fyke	Lake	S	21	0	11.0
	Fyke	Lake	S	136	0	71.1
	Fyke	Lake	S	129	0	67.5
	Fyke	Lake	S	54	0	28.2
	Fyke	Drain	S	222	0	116.1
	Fyke	Drain	S	93	0	48.7
	Fyke	Drain	S	303	0	158.5
	Fyke	Drain	S	48	0	25.1
	Fyke	Drain	S	68	0	35.6
	Fyke	Drain	S	105	0	54.9
	Fyke	Drain	DwU	395	0	206.6
	Fyke	Drain	DwD	0	0	0
	G-minnow traps	Above weir		12	0	
	G-minnow traps	Below weir		4	0	
	Electric fishing	Above weir		35	0	
	Electric fishing	Below weir		67	9	
	2008 Total			1692	9	
1996	Fyke	lake	S	147		42.6
		lake	S	114		33.0
		lake	S	63		18.2
		lake	S	71		20.6
		lake	S	23		6.7
		lake	S	13		3.8
		lake	S	11		3.2
		lake	S	9		2.6
		lake	S	13		3.8
		lake	S	11		3.2
		lake	S	20		5.8
		lake	S	26		7.5
		drain	DwU	246		71.2
		drain	DwD	181		52.4
		drain	S	312		90.3
		drain	DwU	409		118.4
		drain	DwD	0		0.0
	Electric fishing	Above weir		25		
	Electric fishing	Below weir		18	2	
	1996 Total			1712	2	