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Assessment of the eel fishery in the Pouto Lakes in Northern Kaipara

New Zealand Fisheries Assessment Report 2014/21.

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Te Uri o Hau regard tuna (freshwater eel) as a “staple diet of the marae” and an “important aspect of everyday living” (Te Uri o Hau pers. comm.), which is recognised in the Te Uri o Hau Claims Settlement Act 2002 where the Crown agreed to restore Te Uri o Hau’s access to traditional food gathering areas such as the tuna resource located in the Pouto Lakes. Unfortunately, there are no current quantitative assessments of eel populations in the Pouto Lakes that would allow objective decisions to be made in relation to the settlement. The aim of the present study was to examine the distribution, relative abundance, species composition, age structure, growth rate and sex ratio of freshwater eels in a representative range of the Pouto Lakes to provide a reference point for any future monitoring of the population and management of the respective customary fishery.

Eel populations were sampled from seven lakes along the Pouto Peninsula that were selected in consultation with Te Uri o Hau. Four lakes were connected with the ocean allowing continued recruitment of juvenile eels (Lakes Mokeno, Karaka, Whakaneke and Swan Lake) while three lakes were landlocked and have previously been stocked with eels (Lakes Parawanui, Kapoai, Rototuna). Single-night fyke netting was used to sample eels from 52 sites located across the seven lakes. Eels were measured for total length and weight before being returned to the lake. Otoliths from 100 shortfins (*Anguilla australis*) were used to calculate age and growth rates for Lakes Mokeno, Whakaneke, Karaka and Swan Lake (the remaining lakes had insufficient sample sizes). The numbers of migrant eels caught was also recorded for each lake.

Catch-per-unit-effort (CPUE) averaged 5.08 kg/net/night with catches being dominated by shortfins (93%). Lengths of longfins (*Anguilla dieffenbachii*) varied from 391–898 mm with a mean of 550 mm. Weights of longfins varied from 145–2445 g with a mean of 587 g. Lengths of shortfins ranged from 305–1150 with a mean of 570 mm. Weights of shortfins varied from 40–3745 g with a mean of 521 g. Shortfins ages ranged from 6–19 years with a mean of 12 years. Annual increases in shortfin length averaged 42.42 mm/year, while annual increases in weight averaged 30.07 g/year. Swan Lake had the highest abundance of eels, but Lake Parawanui had the highest mean length, mean weight, CPUE and condition factor of all the lakes. CPUE, length and weight of shortfins in landlocked lakes were all higher on average than open lakes, but the numbers of shortfins/net were five-fold higher on average in open lakes.

Eel population structure in the Pouto Lakes was typical of the Northland region being dominated by shortfins, and CPUE was very similar to the mean commercial unstandardised CPUE for Northland of 4.2 kg/lift. The higher proportionate abundances and weight of shortfins compared to longfins in this area is likely to be associated with habitat preferences of the two species and the higher recruitment of shortfins in Northland. Shortfins displayed high growth rates compared to other areas in New Zealand, with growth being roughly twice the national average. The high growth is likely to be associated with the relatively warm water temperatures and consequent longer growing season. Growth rates suggest that a shortfin would take approximately 10 years to reach the minimum commercial weight of 220 g. Stocking landlocked lakes with eels appears to generate low-density populations with high proportions of very large eels. A large proportion of the eels in these landlocked lakes were migrant females and it is recommended that consideration be given to catching migrant eels from any closed systems and releasing them into a freshwater or brackish area connected to the ocean.

1. INTRODUCTION

Te Uri o Hau regard tuna (freshwater eel) as their "main food source" forming a "staple diet of the marae" and an "important aspect of everyday living", being "important not just to Māori, but to everyone" (Te Uri o Hau pers. comm.). Historical notes also exist on the importance of this resource (e.g., McDowall 2011), which is recognised in the Te Uri o Hau Claims Settlement Act 2002 in which the Crown agreed to restore Te Uri o Hau's access to traditional food gathering areas such as the tuna resource located in the Pouto Lakes.

At present, however, there is no quantitative assessment of the current level of harvest for customary purposes or recreational/sustenance use at the level of the stock. The current level of tuna stocks concerns Te Uri o Hau, with one member commenting that his "whānau don't catch the same type of numbers they used to enjoy when I lived with my grandparents" (Te Uri o Hau pers. comm.). The loss of potential habitat for tuna also concerns Te Uri o Hau with members pointing to the fact that "lake levels have dropped considerably" and some lakes have "silted up" (Te Uri o Hau pers. comm.). These concerns have led to the need to carry out a stock assessment, generating information relating to the "protection of their kai mataitai areas".

Since the introduction of North Island eels into the Quota Management System (QMS) on 1 October 2004, allowances have been made for customary Māori purposes (i.e., hui and tangi). For QMA 20 (Northland/Auckland), the customary allowance was set at 40 tonnes, while an allowance for recreational/sustenance use was set at 36 tonnes.

The Te Uri o Hau Claims Settlement Act 2002 (Settlement Act) records an agreement reached by the Crown and Te Uri o Hau Governance Entity. Te Uri o Hau is a hapū of Ngāti Whātua – the rohe for this hapū is based principally around the northern Kaipara Harbour. The purpose of the Settlement Act is to give effect to certain provisions of the Te Uri o Hau Deed of Settlement 2000, being a deed that settles the historical claims of Te Uri o Hau. Under the Settlement Act, the Crown agreed to restore Te Uri o Hau's access to traditional foods and food gathering areas.

One element of the Settlement Act provides that the Minister of Fisheries (MFish) will consider, in accordance with section 186A of the Fisheries Act 1996, temporarily restricting or prohibiting the use of certain eel fishing methods, being fyke net and hīnaki, in respect of the Pouto Lakes. The Pouto Lakes are defined in the deed as being all lakes, named and unnamed, located on the Pouto Peninsula. The Minister may impose such a temporary closure if he/she is satisfied that it will recognise and make provision for the use and management practices of tangata whenua in the exercise of non-commercial fishing rights by improving the availability or size (or both) of a species in the area, or recognising a customary fishing practice in that area.

MFish has provided briefings to the Te Uri o Hau Governance Entity on the management arrangements in place for the eel fishery, and the potential relevance of those arrangements to eel populations within the Pouto Lakes. MFish has signalled to Te Uri o Hau that in assessing whether a section 186A temporary closure should be applied to the Pouto Lakes, or in assessing its success should this measure be implemented, it would be beneficial to obtain information on the current status of the eel resource within the Pouto Lakes. Furthermore, representatives from Te Uri o Hau Governance Entity advised MFish that this information could be used in assessing the on-going status and well-being of the eel resource.

1.1 Project objectives

In January 2011 MFish contracted the National Institute of Water & Atmospheric Research (NIWA) to assess the present status of eel stocks in the Pouto Lakes. The specific objectives of this study were as follows.

1. Assess the distribution, relative abundance, species composition, age structure, growth rate and sex ratio of freshwater eels in a representative range of the Pouto Lakes to provide a reference point for any future monitoring of the population and management of the respective customary fishery.
2. Assess factors that may affect the distribution, relative abundance and condition of eels in the Pouto Lakes, including fish passage, trophic relationships (e.g., extent of forage species), and land management practices (e.g., changes in level of water table from forestry, run-off from adjacent land use), as applicable.

While the present study addressed these specific objectives, two additional aims were also included. The first additional aim was to contrast the population structure between lakes and the second was to contrast population structure between landlocked lakes and lakes with open access to recruitment. These two additional aims were included to help identify the most valuable eel populations for management prioritisation (i.e., largest lengths, weights, condition factors and abundance), and also to generate information on the impacts that stocking eels in landlocked lakes has on population structure.

2. METHODS

2.1 Survey area and design

The Pouto Peninsula is located in the northern Kaipara Harbour and is one of the largest unmodified dune systems remaining in New Zealand (about 600 hectares) (Figure 1). Coastlines along the peninsula are very steep with the highest point being 214 m above sea level, and many areas being over 100 m above sea level. The dune system contains roughly 20 freshwater sand dune lakes with some connected to the ocean while others are landlocked. While these landlocked lakes have restricted access to migrating eels, some contain populations of eels which have been released into the lakes (Greg Hemmingway, Te Uri o Hau pers. comm.). The Pouto Peninsula also contains three threatened plant species and four threatened bird species, and has a unique species of freshwater fish, the dune lake galaxias (*Galaxias gracilis*). Unfortunately, some of these lakes also contain introduced macrophytes (*Egeria densa* and *Ceratophyllum dimersum*), grass carp (*Ctenopharyngodon idella*) and rudd (*Scardinius erythrophthalmus*).

Figure 1: Location of the Pouto Peninsula and approximate location of the lakes sampled. Lakes with black names represent locations with open access to the sea, lakes with red names represent landlocked lakes. NZMS262© sourced from Land Information New Zealand data (Crown Copyright Reserved).

In March 2011, Te Uri o Hau and NIWA representatives met at Waikaretu Marae to discuss this project and identify sampling sites of high customary importance. Seven lakes located on the Pouto Peninsula were identified as having high customary value and were selected for sampling (Figure 2). Aside from the tuna present, these lakes are valued by Te Uri o Hau because of their proximity to their dwellings and ease of access to the lake and to fishing areas (Te Uri o Hau pers. comm.). Of these seven lakes, four had outlet streams that were connected with the ocean (referred to as open lakes) allowing continued recruitment of juvenile eels, while three lakes were not connected to the ocean (referred to as landlocked lakes). These landlocked lakes were selected for inclusion in this study as they have been historically stocked with eels by customary fishers (Mihi Watene, Te Uri o Hau pers. comm.). All the lakes sampled in the present study were shallow with an average depth of between 1 and 3 m. Habitat measurements were generally similar between the lakes, and had either sandy or muddy substrates (Table 1).

Table 1: Mean habitat measurements for the Pouto Lakes.

Lake	Temperature (°C)	Conductivity (µS)	Salinity (ppt)	Maximum depth (m)	Dominant littoral vegetation	Substrate
Kapoai	21.3	446	0.23	–	Toitoi	Sand
Karaka	21.7	384	0.19	6.0	Reeds	Mud
Mokeno	22.1	360	0.18	6.1	Raupo	Mud
Parawanui	21.2	600	0.32	20.0	Raupo	Sand
Rototuna	–	–	–	5.1	Raupo	Mud
Swan	22.0	225	0.11	5.5	Raupo	Mud
Whakaneke	21.6	427	0.22	2.5	Raupo	Sand

Unbaited coarse mesh fyke nets (12 mm stretched mesh, with a 6 m single leader and no escapement tubes) were used to sample eels from 52 locations throughout the seven lakes over 6 days (from 20th-26th March 2011) (Figure 2). One net was set at each of these 52 locations with all nets being at least 50 m apart. All fyke nets were fished overnight and the numbers of individual nets set in each lake varied between 5 and 12 depending on the size of the lake. Fyke nets were all set perpendicular to the bank with the end of the leader staked into the bank, ensuring that the mouth of each net was 6 m from the shore. The sites surveyed were referenced by GPS (Appendix 1).

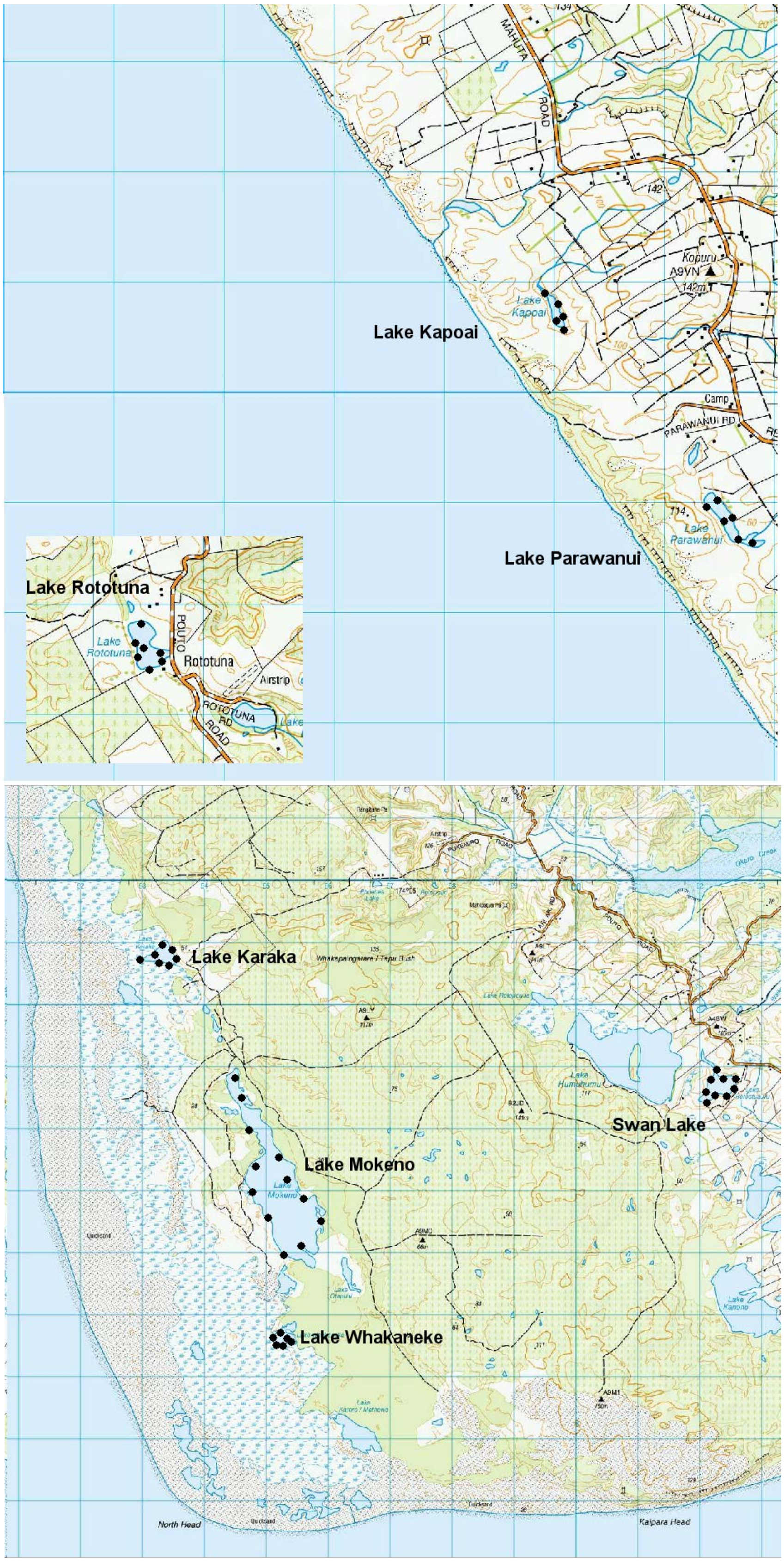

Figure 2: Specific locations of coarse mesh fyke nets set in each lake sampled on the Pouto Peninsula.

Before each use, all nets and other equipment were sanitised by placing them in a solution of 4% sodium chloride (sea salt) and then air dried to minimise the risk of spreading unwanted organisms.

Apart from 100 eels retained for ageing purposes all other fish were returned alive at the point of capture.

2.2 Catch processing

Catch composition

Catches from individual nets were processed separately. Eels captured were anaesthetised in a clove oil based fish anaesthetic, identified by species, measured (to the nearest millimetre) and weighed (to the nearest gram). Data were also collected on the numbers of migrant shortfins captured from each lake. Migrant eels were identified as individuals that displayed a larger eye diameter, dorsally flattened head, slightly chiseled snout, thin lips, prominent lateral line pores, and a metallic silver/gold ventral surface (Todd 1981a) (see Appendix 2 for comparison between migrant and non-migrant shortfin). Gender of migrants was estimated using maximum migrant male lengths reported in Todd (1980), so that any migrant fish smaller than 598 mm were assigned as males while all larger fish were assigned as females.

Age structure, growth rates and sex composition

Otoliths from 100 shortfins were used to calculate the age and growth rates of eels from the Pouto Lakes. To minimise the impacts on the shortfin populations, the numbers of eels taken for ageing from each lake was dependent on the total catch. This resulted in 29 being taken from Lake Mokeno, 21 from Lake Whakaneke, 20 from Lake Karaka and 30 from Swan Lake. Eels were not taken for ageing if they displayed any morphological features indicative of sexual maturity (Todd 1981a). Eels were killed by prolonged exposure to anaesthetic (clove oil) and the bodies were provided to Te Uri o Hau. Otoliths were prepared for ageing using a modified crack and burn technique (Graynoth 1999). The sex and maturity of each shortfin was determined by visual inspection of the gonads using the guidelines in Beentjes & Chisnall (1998).

2.3 Data analysis

Statistical assumptions

A Levene’s test was used to check that data variance was homoscedastic, while a Kolmogorov-Smirnov test was used to check that data were normally distributed. Subsequently, parametric tests were used where appropriate otherwise non-parametric tests were used if data did not meet assumptions. Where necessary data were $\text{Log}_{10}(x+1)$ transformed to help meet assumptions of normality.

Catch per unit effort

To enable stock comparisons among sites, catch data were standardised by converting results into catch-per-unit-effort (CPUE) (kg/net/night). CPUE is a comparable index of abundance that is commonly used to examine and compare the status of eel fisheries (Jellyman & Graynoth 2005; Beentjes et al. 2006). A two-sample t-test was used to compare shortfin numbers/net between lakes and between open and landlocked lakes. Longfin data could not be compared between lakes due to low sample sizes.

Length-weight and condition relationships

Least-squares regression was used to examine length-weight relationships and determine whether significant linear relationships existed between length (mm) and weight (g) for each species after Log_{10} transformation.

The estimated weight for a shortfin of standard length was used to compare the condition of eels in the different lakes using one-way analysis of co-variance (ANCOVA). Lake Rototuna could not be included in these comparisons because of insufficient sample size. A Bonferroni post-hoc test was then used to examine which pairwise comparisons differed. Between lake-comparisons could not be carried out for longfins because of insufficient sample sizes, but total longfin data among all lakes was sufficient to allow an ANCOVA to be completed that compared weight between species. All ANCOVA analyses were completed with length as the covariate.

A nested ANOVA was used to compare length and weight between longfins and shortfins with lake used a nested term. Lengths and weights of both species were compared between lakes using a one-way ANOVA, with Bonferroni post-hoc comparisons used to determine which lakes had different lengths and weights. Condition (K) for all eels was then calculated using the following formula (Ricker 1971) before a one-way ANOVA was used to compare condition between lakes for shortfins only:

- $K = \text{Weight (g)} \times 10^6 / \text{Length (mm)}^3$

A two-sample t-test was used to compare length, weight and condition between open and landlocked lakes for longfins and shortfins.

Age and growth rates

Least-squares linear regression was used to determine whether shortfin age and length were linearly related. Mean growth rates were then calculated for each species and expressed as millimetres and grams of growth per year. Annual freshwater growth in length was determined by subtracting the mean length at entry to freshwater for shortfins [60 mm taken from Jellyman (1977)] from recorded lengths and then dividing by their age (years). Annual freshwater growth in weight was also determined by dividing their weight by their age (years). It was not necessary to subtract weight at entry into freshwater before dividing by age, as this was negligible (about 0.2 g) relative to the weight of the fish (about 200 g). One-way ANOVA was then used to compare age, annual growth in length and weight between lakes Mokeno, Whakaneke, Karaka and Swan Lake. Growth rates (mm/year) from each lake were then used to estimate the average age of migrant male and female shortfins by subtracting the length at entry [60 mm taken from Jellyman (1977)] from recorded lengths and then dividing by the mean growth rate (mm/year) for their respective lake. The average growth rate among all lakes was used to calculate ages for migrants in Lakes Parawanui and Rototuna because no ageing data were collected from these lakes.

Relationships with environmental factors

Only open access lakes were used to examine relationships between eel abundance, condition and environmental factors (e.g., water temperature). Data from landlocked and open lakes could not be pooled, which resulted in insufficient data (i.e., numbers of eels) being available for analysis of landlocked lakes. Similarly, longfin data were insufficient to allow any analysis. Therefore, the relationships between eel sizes (length, weight and condition) and environmental factors could only be examined for shortfins caught from lakes with open access to the sea. Each net was considered as a replicate in the following analyses.

Linear models and Principle Components Analysis (PCA) were used to examine relationships between habitat variables and shortfin condition. PCA was firstly used to summarise multivariate habitat relationships between sites (i.e., data reduction) using normalised values of the water temperature, depth, conductivity, pH and salinity that were recorded for each net. Linear mixed effects models (Crawley 2007) were then used to remove the influence of lake on shortfin size (i.e., length, weight and condition), generating adjusted values of size for each net based on the mean differences between lakes. Linear models were then used to examine correlations between habitat scores on PCA axis 1 and lake adjusted values of shortfin size. Correlations were only carried out in relation to PCA axis 1 as this was the only axis that explained significant amounts of habitat variation in the present data set under the guidelines of the broken stick model (Jackson 1993).

Differences in shortfin and longfin length, weight, and condition between lakes are also discussed in relation to differences in landuse and indicators of ecological status. Landuse information for each lake was generated from the New Zealand Land Cover Database (LCDB) (https://lris.scinfo.org.nz/layer/401-lcdb-v33-land-cover-database-version-33/). The close proximity of Lakes Whakaneke and Mokeno resulted in landcover data being pooled for these two areas. Indicators of ecological condition were also taken from the Northland Lakes Ecological Survey carried out in 2011 (Wells & Champion 2011). This survey reported indices of lake ecological condition (maximum of 100) based on macrophyte composition and the LakeSPI methodology (Clayton & Edwards 2006). The LakeSPI is a measure of the diversity and extent of native submerged vegetation and the extent of invasion by exotic species. This index provides a measure of how close a water body is to its potential or unimpacted (by humans) state, and is very useful for detecting changes in lake condition over time and making comparisons between lakes.

3. RESULTS

3.1 Species composition

Shortfins dominated catches, with a total of 471 shortfins (93%) and only 34 longfins (7%) being captured from all lakes (Tables 2 and 3). Similarly, of the 264 kg of eels caught in the present study, shortfins comprised 93% (246 kg) of the total weight (Table 2).

Table 2: Catch per unit effort (CPUE, number/net/night and kg/net/night) of eels caught in coarse mesh fyke nets from the Pouto Lakes.

		Number						Weight					
		Longfin		Shortfin		All eels		Longfin		Shortfin		All eels	
Lake	No. nets set	Total No.	CPUE	Total No.	CPUE	Total No.	CPUE	Total weight	CPUE	Total weight	CPUE	Total weight	CPUE
Kapoai	5	0	–	0	–	0	–	0	–	0.00	–	0.00	–
Karaka	7	4	0.57	108	15.43	112	16.00	1.40	0.20	27.24	3.89	28.64	4.09
Mokeno	12	1	0.08	79	6.58	80	6.67	0.96	0.08	39.03	3.25	39.99	3.33
Parawanui	6	3	0.50	46	7.67	49	8.17	2.25	0.38	95.06	15.84	97.31	16.22
Rototuna	7	2	0.29	1	0.14	3	0.43	4.55	0.65	2.87	0.41	7.42	1.06
Swan	9	23	2.56	148	16.44	171	19	7.86	0.87	33.78	3.75	41.64	4.63
Whakaneke	6	1	0.17	89	15.00	91	15.17	0.76	0.13	48.19	8.03	48.95	8.16
Overall (across all lakes)	52	34	0.60	471	9.10	505	9.69	17.78	0.34	246.17	4.73	263.95	5.08

Table 3: Characteristics of the longfin and shortfin eel catch sampled from the Pouto Lakes.

			Length (mm)		Weight (g)		Condition (k)	
Species	Total eels caught	% of total catch	Average ± SE	Range	Average ± SE	Range	Average ± SE	Range
Longfin	34	7	550 ± 25	391–898	587 ± 105	145–2445	2.67 ± 0.06	2.15–3.78
Shortfin	471	93	570 ± 30	305–1150	521 ± 8	40–3745	2.07 ± 0.02	0.43–4.07

3.2 Relative abundance and distribution

Total CPUE was 5.08 kg/net/night, which was composed on average of 4.73 kg of shortfins and 0.34 kg of longfin (Table 2). While Swan Lake had the largest total numbers of both longfins and shortfins, the highest CPUE for both species was observed in Lake Parawanui (Table 2).

3.3 Length and weight characteristics

Lengths of the 34 longfins ranged from 391 to 898 mm with a mean ± standard error (s.e.) of 550 ± 25 mm (Table 3). Most longfins were between 400 to 650 mm with only three eels larger than 700 mm (Figure 3). Weights of longfins ranged from 145 g to 2445 g with a mean ± s.e of 587 ± 105 g (Figure 4, Table 3). Most of the longfins were between 100 and 300 g, but there was a small peak around 800 g. Three large eels were markedly heavier than the rest of the catch and weighed between 2200 and 2445 g.

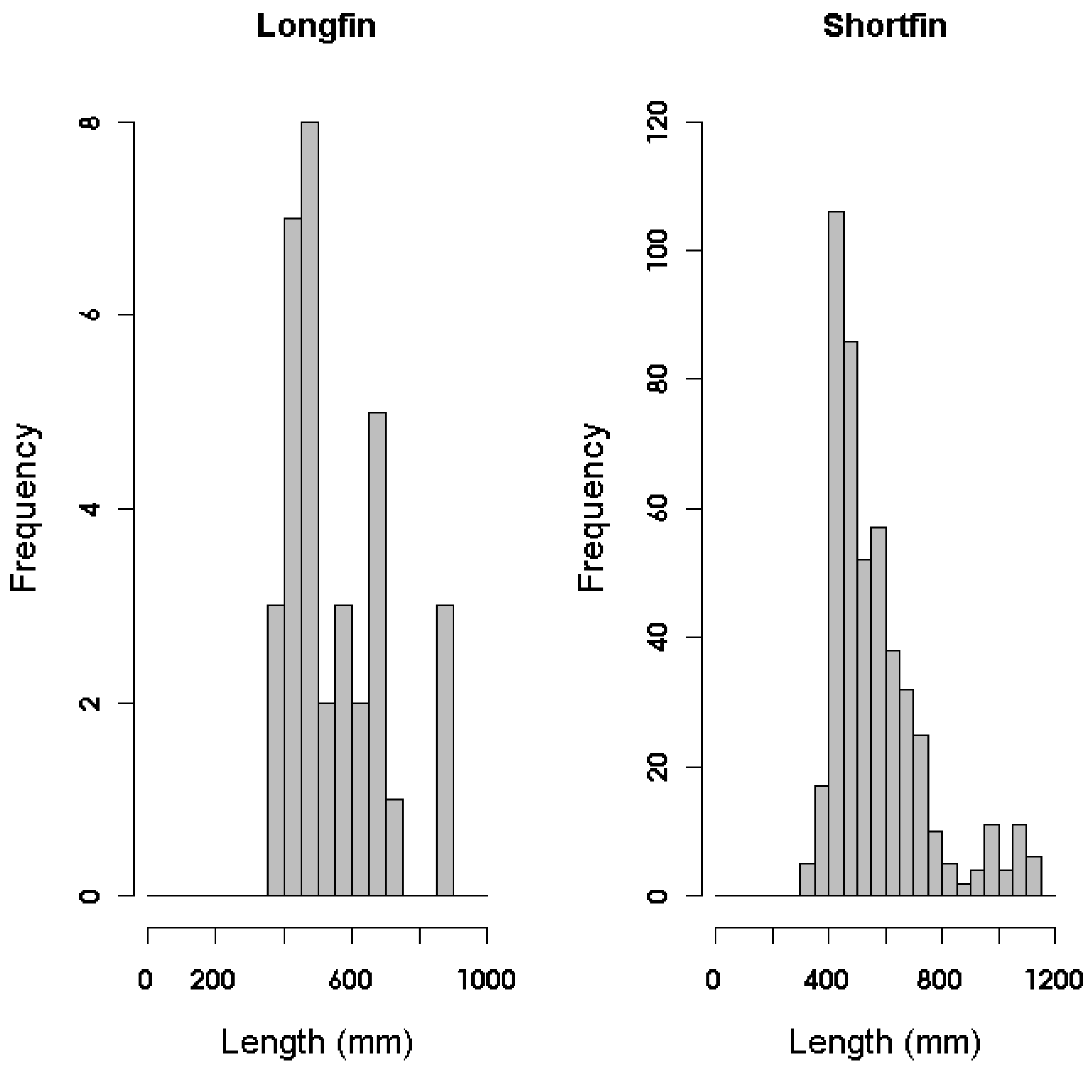

Figure 3: Length-frequency distribution of longfin and shortfin eels captured from the Pouto Lakes.

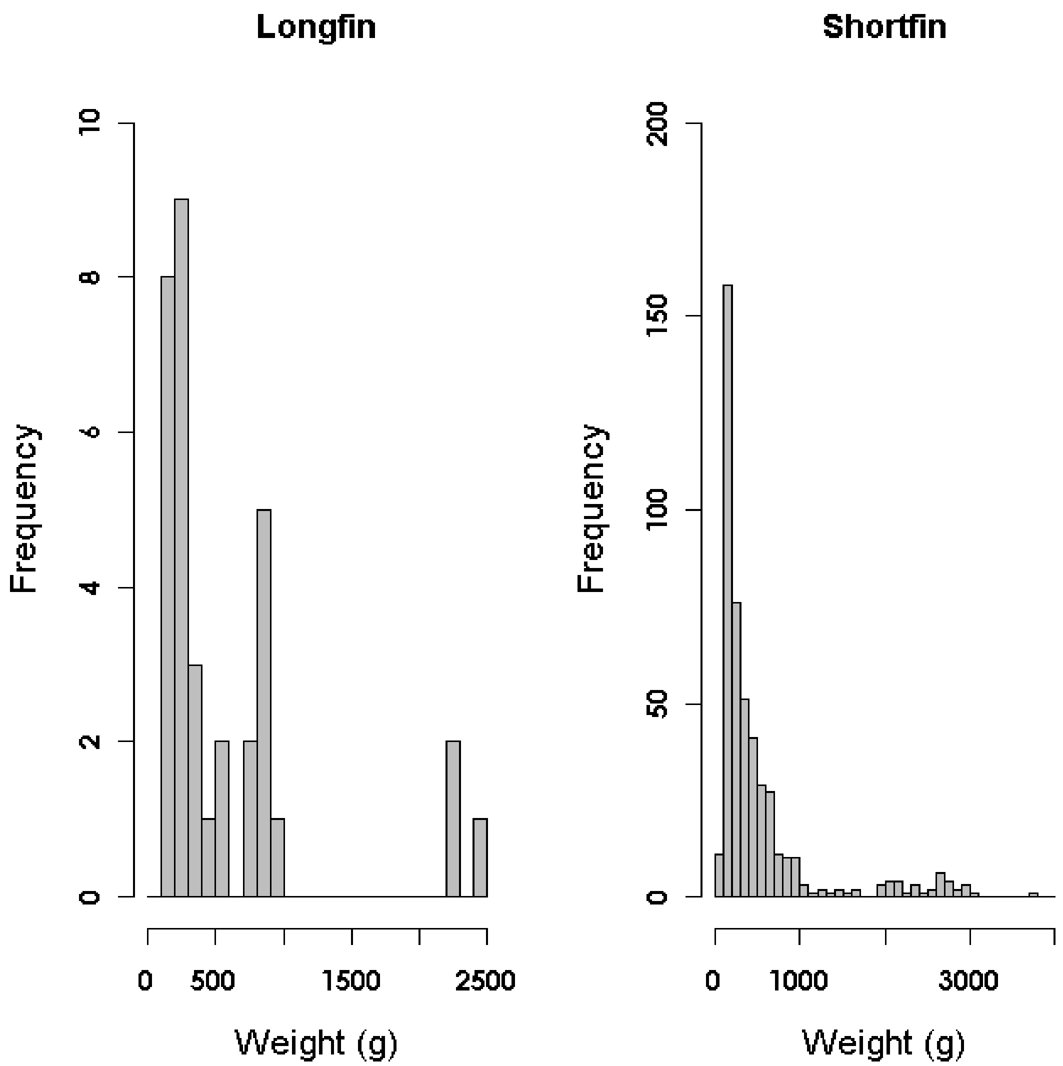

Figure 4: Weight-frequency distribution of longfin and shortfin eels captured from the Pouto Lakes.

The length of the 471 shortfins ranged between 305 and 1150 mm with a mean ± s.e of 570 ± 30 mm (Table 3), and there was a strong peak around 400–500 mm (Figure 3). The proportions of eels declined steadily with increasing size until 850 mm. There were a number of shortfins larger than 850 mm, with similar numbers present in each of these categories. Weights of shortfins ranged between 40 and 3745 g with a mean ± s.e of 521 ± 8 g (Table 3). A very strong peak was observed at 100–150 g (Figure 4). The numbers of shortfins in each category steadily declined until 1000 g. There were similar numbers of eels in each of the large categories up to 3000 g, with the largest shortfin weighing 3745 g.

Although shortfins were significantly longer on average (DF=9, F=79674, P<0.001), longfins were significantly heavier (DF=9, F=6714, P<0.001) (Table 3). Log_{10} transformed length and weight data formed significant linear relationship for longfins (R^2=0.981, DF=1, F=2681, P<0.001) and shortfins (R^2=0.914, DF=1, F=6913, P<0.001). ANCOVA analysis revealed that the weight of longfins was significantly higher than shortfins when standardised by length (DF=1, F=7.937, P=0.005).

Shortfin length-frequency distributions were very similar in Lakes Karaka, Mokeno and Swan Lake (Figure 5). Length categories in all three of these lakes was highest for the 400–500 mm categories, but Lake Mokeno showed a slightly higher peak around 550 mm. Lake Whakaneke had a higher proportion of lager eels compared to Lakes Mokeno, Karaka and Swan Lake, with eel abundance peaking between 600–700 mm. Lake Parawanui size distributions were biased towards the larger categories, peaking between 1000–1200 mm. Only a single shortfin in the 1100 mm category was caught from Lake Rototuna. Longfin data were insufficient to allow length-frequency plots to be generated. Average shortfin length was significantly higher in Lake Parawanui compared to all other lakes (Figure 6). Shortfin length was the same in Lakes Mokeno and Whakaneke, but length in these two lakes was significantly higher than lakes Karaka and Swan Lake. Length in Karaka and Swan Lake were not significantly different.

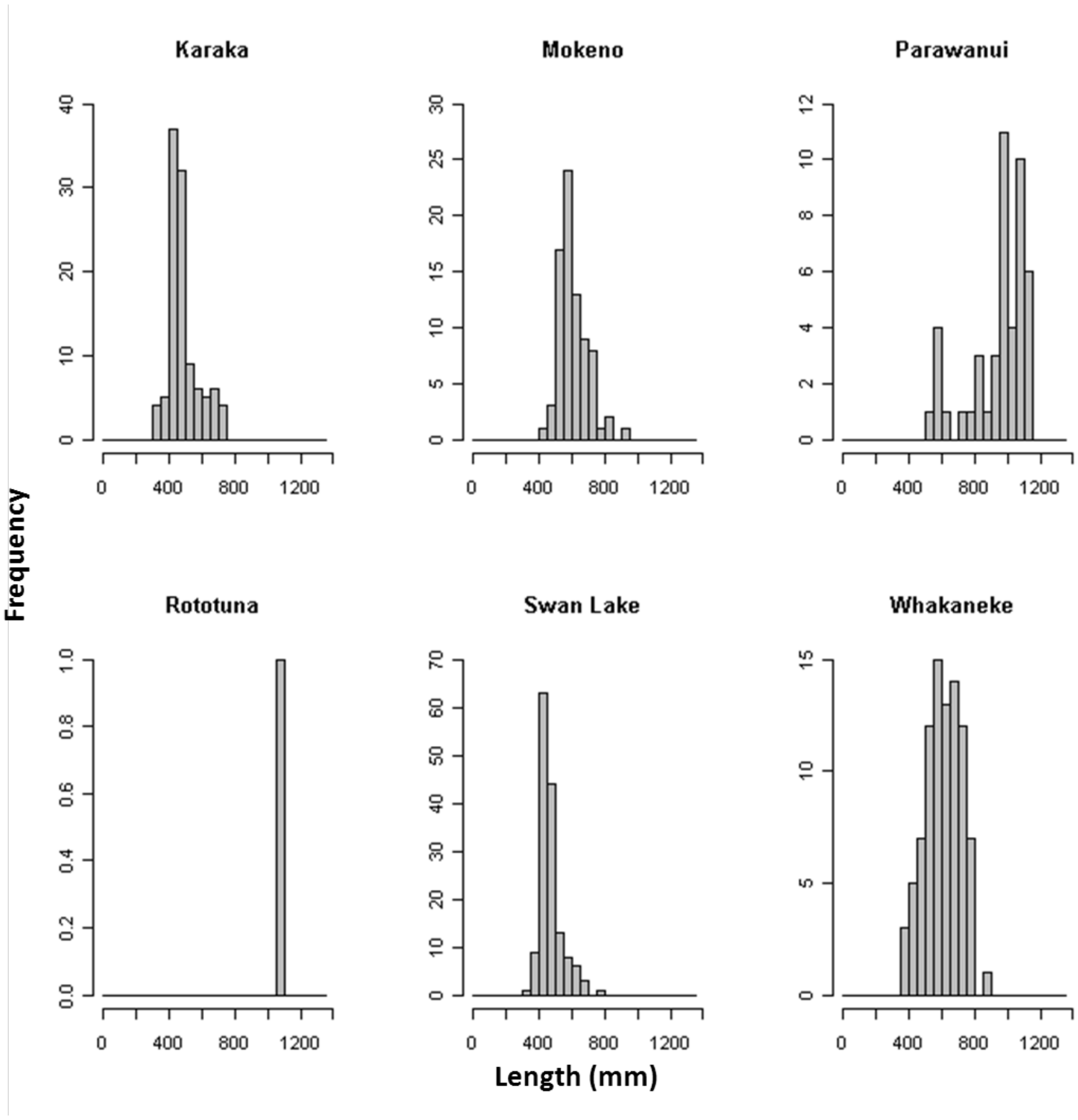

Figure 5: Length-frequency distributions of shortfins caught from each lake.

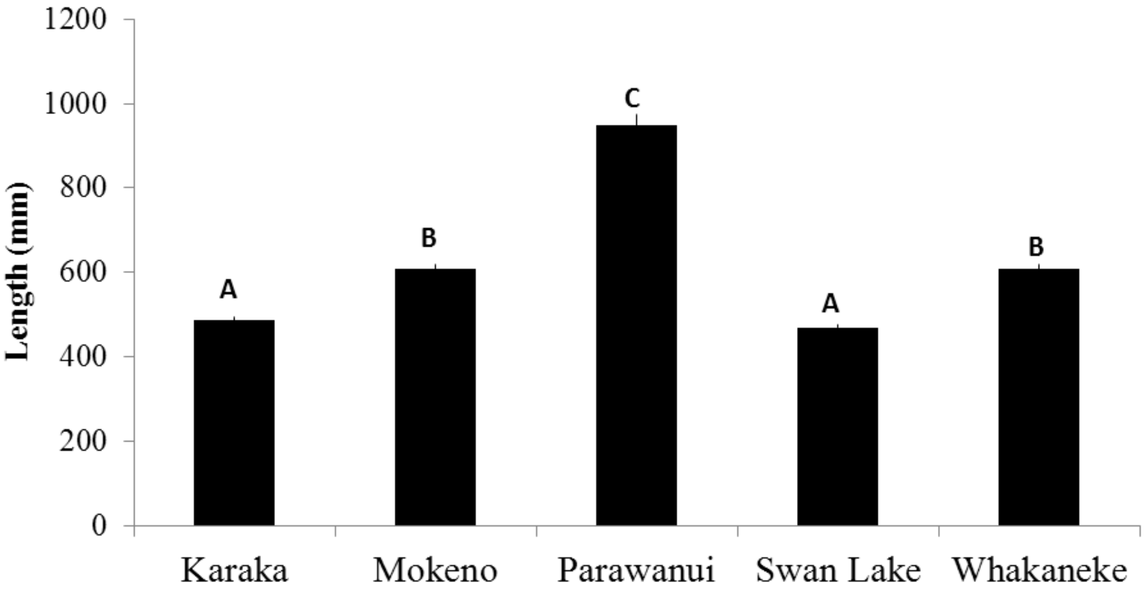

Figure 6: Mean length of shortfins caught from each lake. Letters denote ANOVA post-hoc comparisons between lakes at the *P*<0.05 significance level. Comparisons with Lake Rototuna could not be carried out due to insufficient sample sizes from this lake. Results for Lake Kapoai are not shown as no eels were caught.

Weight frequency distributions showed similar inter-lake patterns to the length-frequency data (Figure 7). Weight categories in Lake Karaka and Swan Lake showed a strong peak around 200 g. Lake Mokeno showed a peak between 300–400 g, while the population in Lake Whakaneke was dominated by fish from 400 to 600 g. Lake Parawanui contained very large eels, with most fish weighing 2000–3000 g. Average shortfin weight was significantly higher in Lake Parawanui compared to all other lakes (Figure 8). Shortfin weight was the same in Lakes Mokeno and Whakaneke, but weight in these two lakes was significantly higher than lakes Karaka and Swan Lake. Weight in Karaka and Swan Lake were not significantly different.

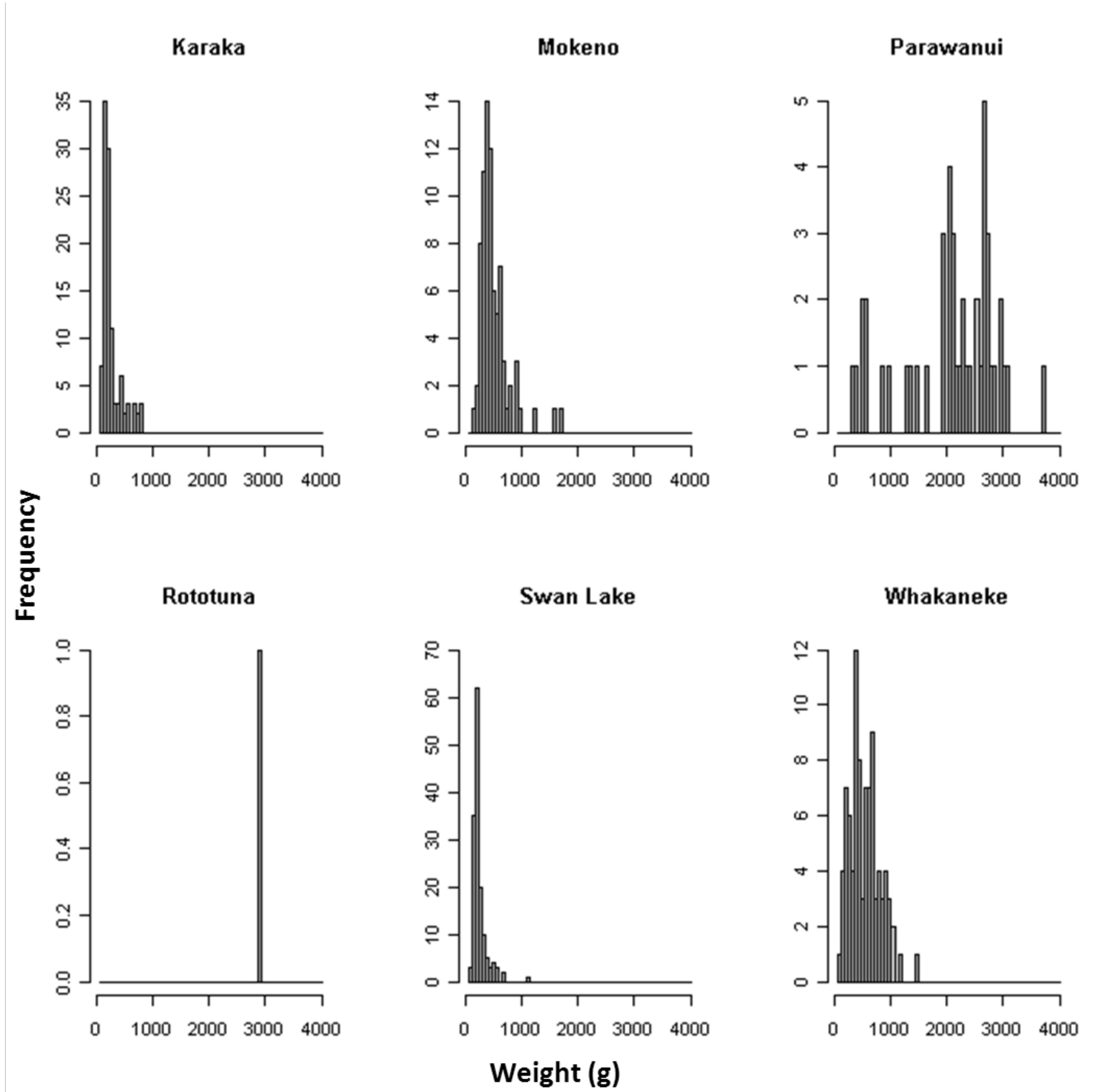

Figure 7: Weight-frequency distributions of shortfins caught from each lake.

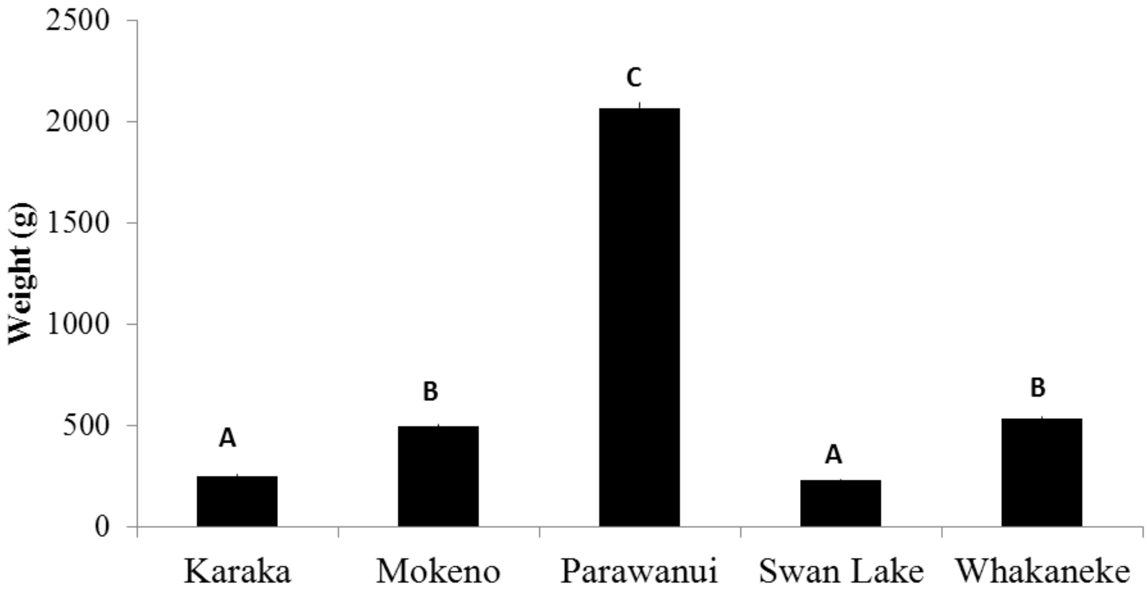

Figure 8: Mean weight of shortfins caught from each lake. Different letters denote significant ANOVA post-hoc comparisons between lakes at the *P*<0.05 significance level. Comparisons with Lake Rototuna could not be carried out due to insufficient sample sizes from this lake. Results for Lake Kapoai are not shown as no eels were caught.

3.4 Condition

The condition factors for longfins and shortfins were 2.67 ± 0.06 (mean ± s.e.) and 2.07 ± 0.02 respectively (Table 3), with longfin condition being significantly higher than shortfin condition (*DF*=9, F=2248, *P*<0.001). The condition of shortfins from Lake Karaka was the lowest for the area, significantly differing from all lakes except Lake Mokeno (Figure 9). Condition factor in Lakes Mokeno and Swan Lake did not differ, but condition in these two lakes was significantly lower than the highest condition factors that were found in Lakes Parawanui and Whakaneke. ANCOVA analysis showed that length-standardised weight differed between lakes (*DF*=4, *F*=8.075, *P*<0.001). Post-hoc comparisons revealed that this was because length-standardised weight in Lake Karaka was significantly lower than all other lakes except Lake Mokeno (Table 4). Weight of fish did not differ between the remaining lakes. No comparisons between lakes could be carried out for longfins because of insufficient sample sizes.

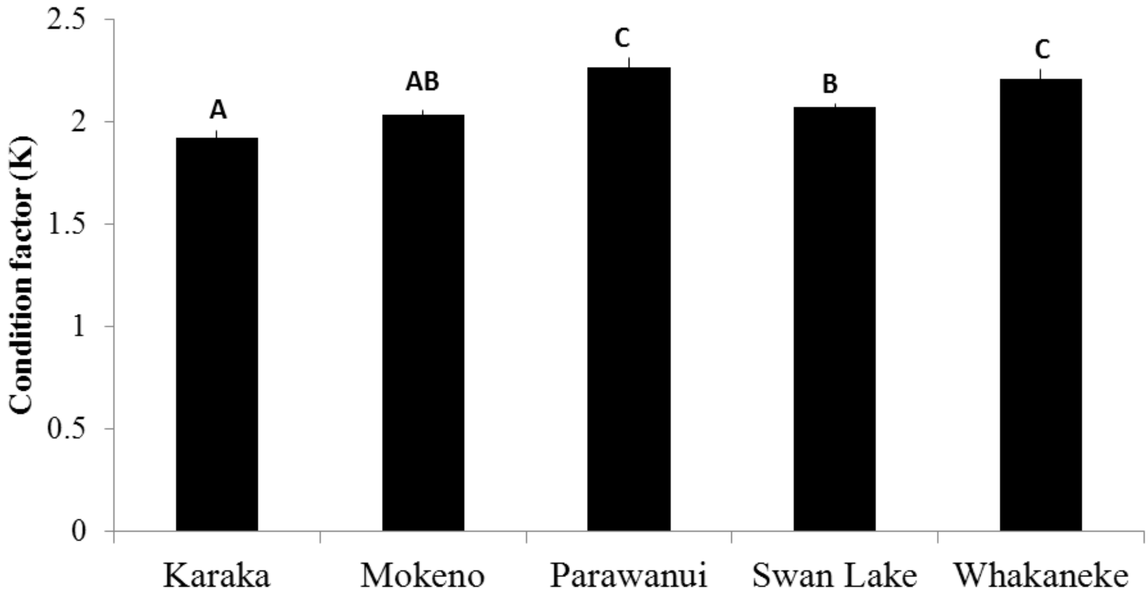

Figure 9: Mean (+ standard error) condition of shortfin sampled from each Pouto Lake. Different letters denote significant ANOVA post-hoc comparisons between lakes at the *P*<0.05 significance level.

Table 4: ANCOVA post-hoc comparisons of shortfin weight between the Pouto Lakes sampled with length as a covariate. Column labelled "Difference" shows the value of the mean for Lake 2 subtracted from the mean of Lake 1. Figures in bold indicate a significant difference.

Lake 1	Lake 2	Difference	*P* value
Karaka	Mokeno	-0.026	0.161
Karaka	Parawanui	-0.065	**0.003**
Karaka	Swan	-0.037	< **0.001**
Karaka	Whakaneke	-0.054	< **0.001**
Mokeno	Parawanui	-0.039	0.083
Mokeno	Swan	-0.011	0.854
Mokeno	Whakaneke	-0.028	0.072
Parawanui	Swan	0.028	0.515
Parawanui	Whakaneke	0.011	0.948
Swan	Whakaneke	-0.017	0.494

Age and growth

Shortfin ages ranged between 6 and 19 years across all of the lakes sampled, with a mean of 12 years. Age did not differ significantly between lakes (*DF*=3, *F*=2.197, *P*=0.093) (Figure 10). Annual increases in length averaged 42.42 mm/year among all lakes and growth significantly differed between lakes (*DF*=3, *F*=10.05, *P*<0.001) (Figure 11). Post-hoc comparisons revealed that the difference in annual length increase between lakes was generated by a significantly higher growth rate in Lakes Mokeno and Whakaneke compared to Lake Karaka and Swan Lake. Annual increases in weight averaged 30.07 g/year among all lakes with annual increases differing between lakes (*DF*=3, *F*=17.07, *P*<0.001) (Figure 11). Post-hoc comparisons revealed that the difference in annual weight increase between lakes was generated by a significantly higher growth rate in Lake Whakaneke compared to all other lakes. Also Lake Mokeno had a higher mean annual increase in weight than Lake Karaka and Swan Lake. The average (± s.e) ages of migrant male and female shortfins were 10.6 ± 0.1 and 14.1 ± 0.4 years respectively (Table 5). The oldest migrant eels were found in Lake Parawanui, which were all female with an average age of 22.4 years.

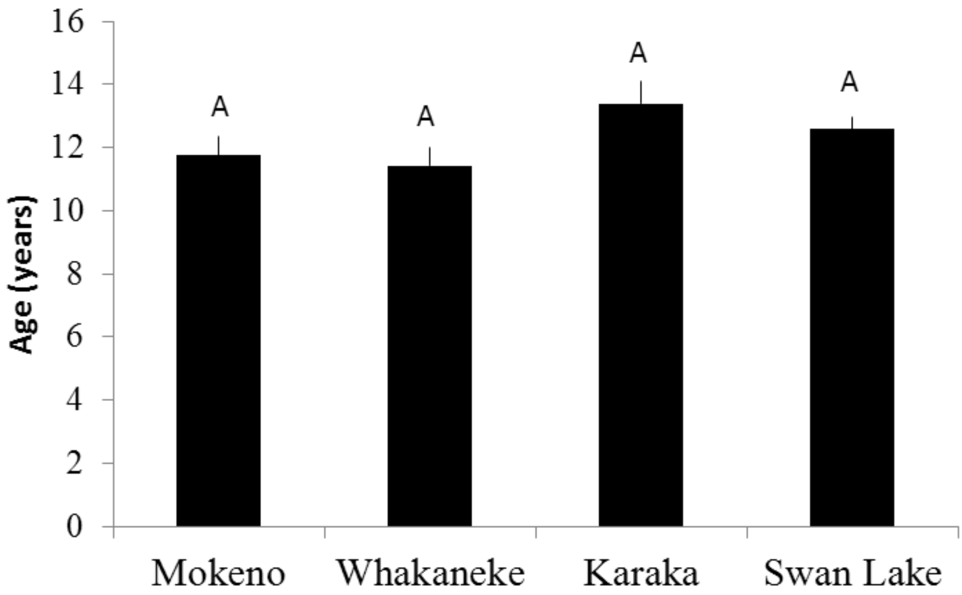

Figure 10: Mean (+ standard error) age of shortfin eels sampled from Pouto Lakes. Different letters denote significant ANOVA post-hoc comparisons between lakes at the *P*<0.05 significance level

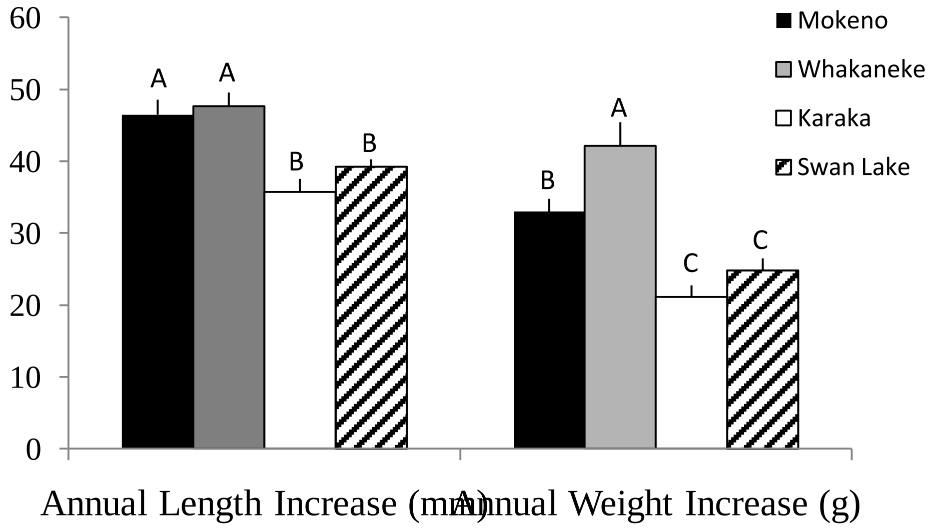

Figure 11: Mean (+ standard error) annual length and weight increases for shortfin eels collected from each lake. Different letters denote significant ANOVA post-hoc comparisons between lakes at the *P*<0.05 significance level.

Table 5: Numbers, lengths and ages of migrant eel captured form each lake.

Lake	Sex	Number of eels	% total shortfin catch	Mean length (mm)	SE Length (mm)	Mean age	SE Age
Kapoai	F	-	-	-	-	-	-
	M	-	-	-	-	-	-
Karaka	F	11	10	644	19.1	16.3	0.5
	M	23	21	454	4.5	11.0	0.1
Mokeno	F	15	19	688	25.5	13.5	0.5
	M	-	-	-	-	-	-
Parawanui	F	21	46	1007	30.2	22.4	0.7
	M	-	-	-	-	-	-
Rototuna	F	1	100	898	-	19.9	-
	M	-	-	-	-	-	-
Swan Lake	F	10	7	592	20.5	13.5	0.5
	M	33	22	458	4.5	10.1	0.1
Whakaneke	F	18	20	687	19.4	13.2	0.4
	M	-	-	-	-	-	-
Total	F	76	16	645	16.4	14.1	0.4
	M	56	12	456	4.5	10.6	0.1

3.5 Sex composition

Of the 100 shortfin gonads visually examined, only one fish was male. This male measured 427 mm and was found in Swan Lake. A total of 132 migrant shortfin eels (27% of the total shortfin catch) were caught in total, with 76 of these fish being classified as female and 56 as male (Table 5). Of the total shortfin catch, migrant females and males accounted for 16% and 12% respectively. Migrant eels from Lake Parawanui were all females and accounted for 46% of the total shortfin catch in this lake. Male migrants were only present in Lake Karaka and Swan Lake, where they made up 21% and 22% of the total shortfin catch.

3.6 Relationship between eel sizes and environmental factors

Habitat

Recognising that the method used in the current survey did not sample eels smaller than about 250 mm, no significant statistical relationships were observed between habitat variables and shortfin length, weight or condition (Table 6) (Figure 12), with linear models explaining less than 1% of the variation.

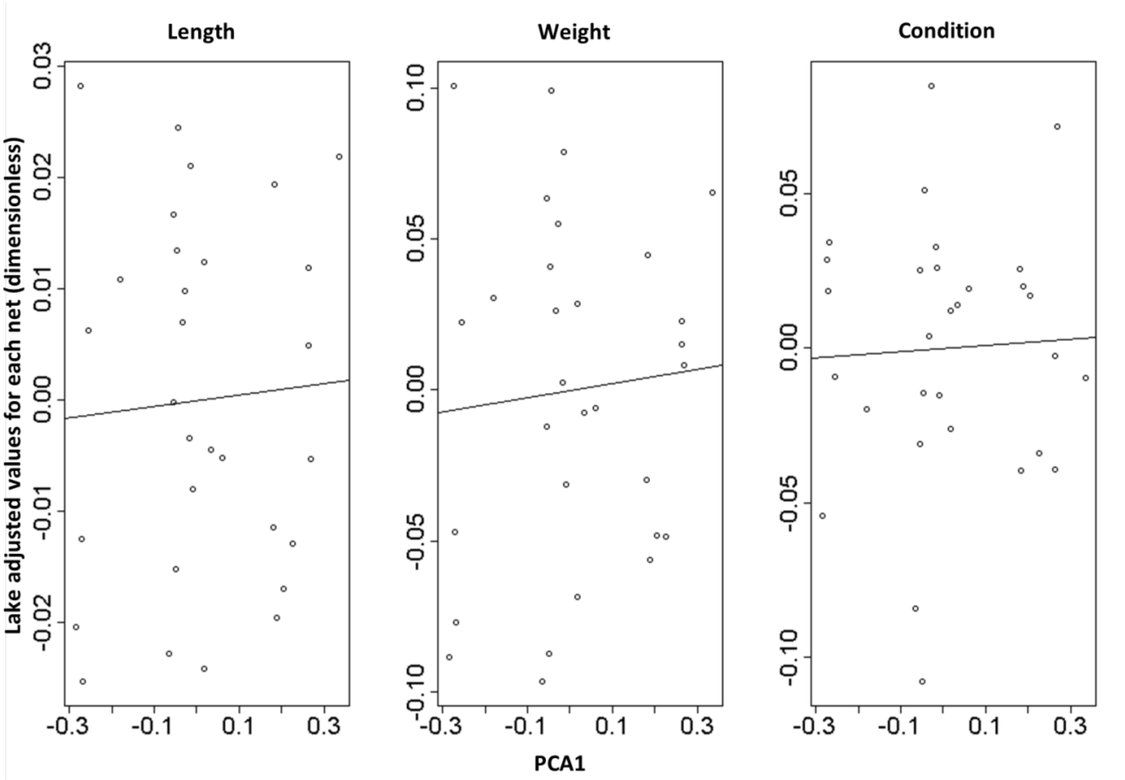

Figure 12: Relationship between habitat (PC1) and shortfin length, weight and condition.

Table 6: Linear model results for the relationship between habitat variables (i.e., PCA 1 of all habitat variables) and shortfin length, weight and condition (K).

	R^2	DF	F	P
Length	0.003	28	0.093	0.763
Weight	0.005	28	0.163	0.689
K	0.002	28	0.048	0.830

Access to the sea

Length frequency distributions differed markedly between landlocked lakes and open lakes. Length frequency distributions of longfins in open lakes predominantly contained eels below 550 mm, whereas landlocked lakes only contained eels over 600 mm (Figure 13). On average, the length of longfins was significantly higher in landlocked lakes (*DF*=32, *t*=3.596, *P*=0.001) (Figure 14). Shortfin catches in open lakes were dominated by smaller eels between 450 and 550 mm (Figure 13), with none larger than 950 mm. In contrast, shortfins from landlocked lakes were all larger than 500 mm, with most fish caught being 1000 mm. The average length of shortfins was significantly larger in landlocked lakes (*DF*=469, *t*=19.19, *P*<0.001) (Figure 14).

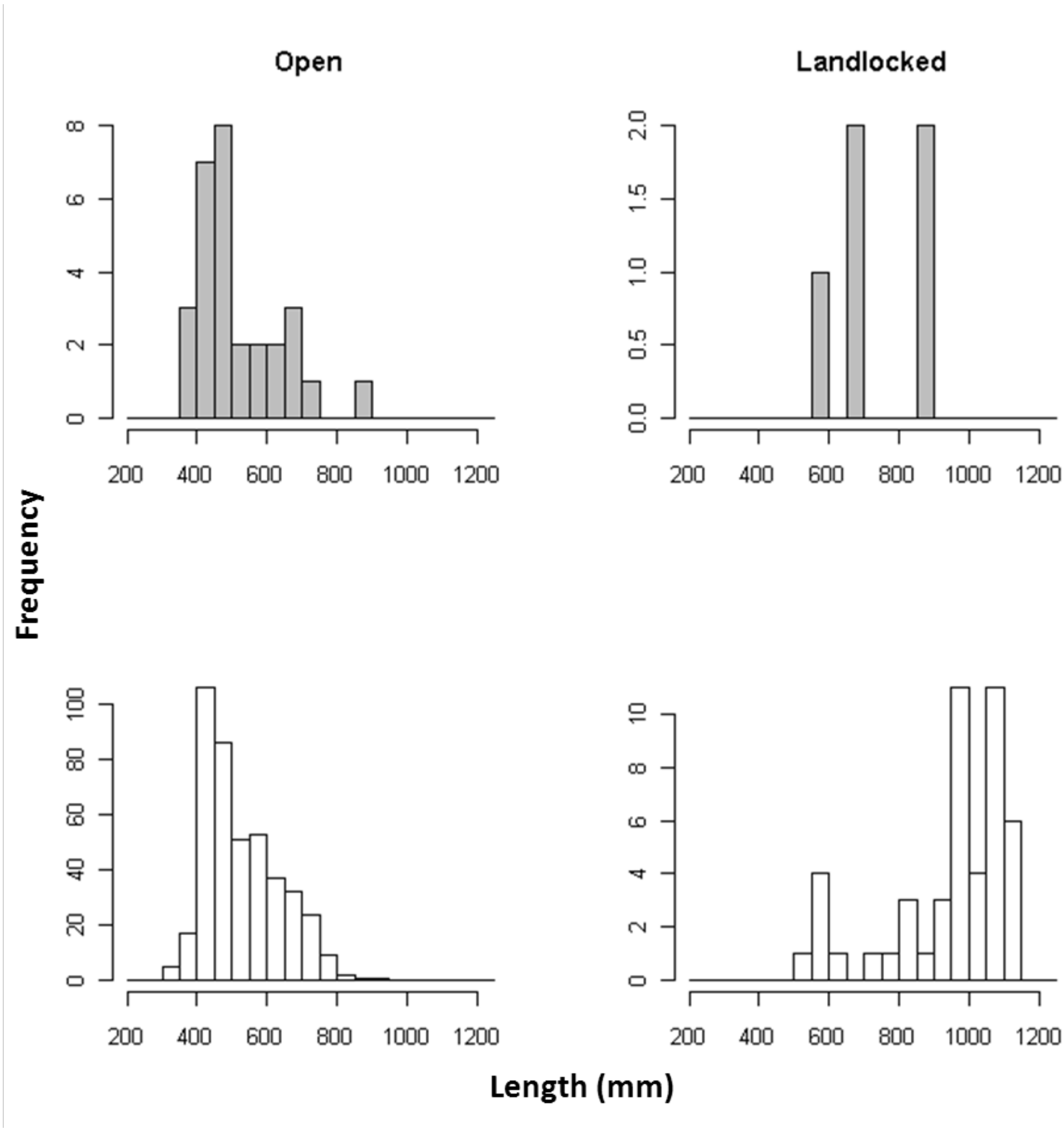

Figure 13: Length-frequency distributions of longfins (grey) and shortfins (white) in landlocked lakes and lakes with open access to fish.

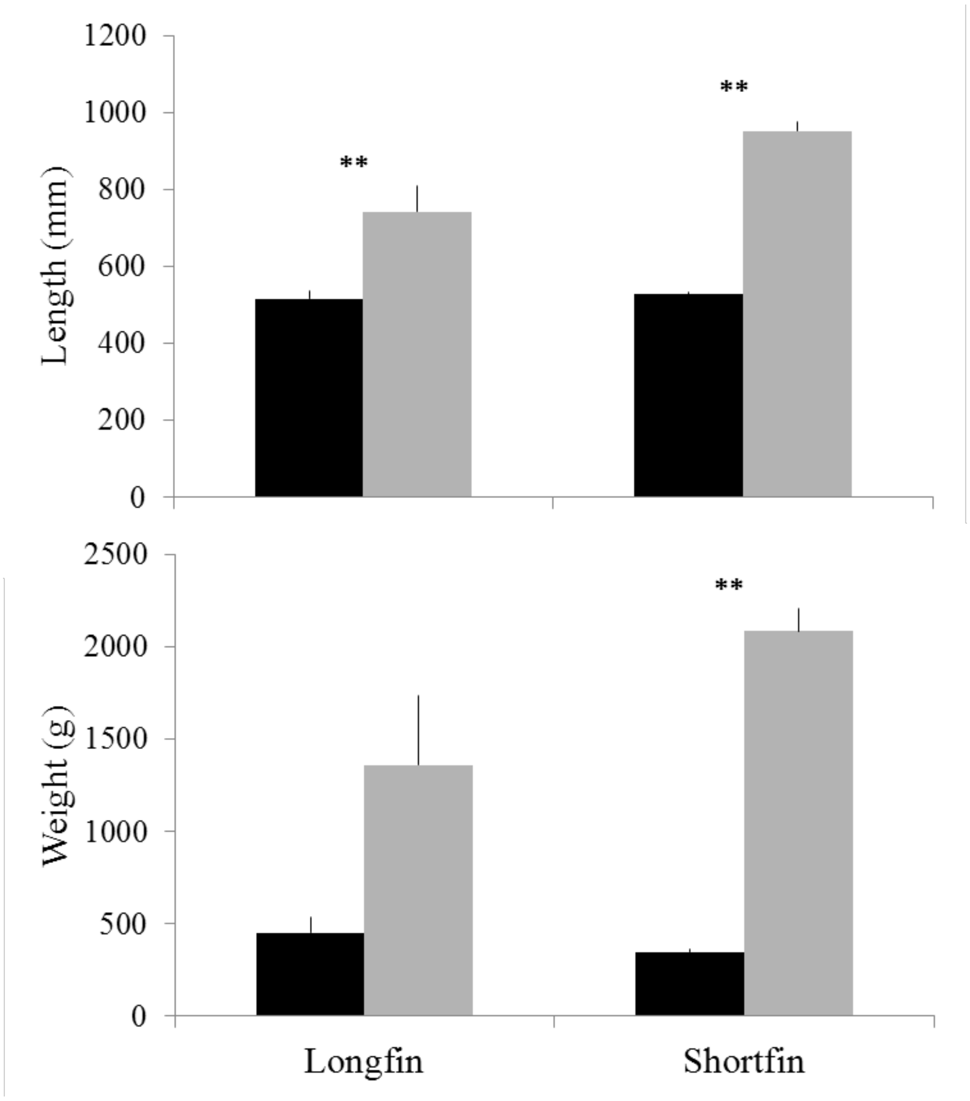

Figure 14: Mean (+ standard error) weight and length of longfin and shortfin eels from landlocked (grey) and open lakes (black). ** indicate statistical differences at the *P*<0.001 significance level.

The contrasting population structure in open and landlocked lakes was even more marked with respect to weight distributions (Figure 15). Longfins in open lakes mostly weighed around 300–400 g, while longfins in landlocked lakes all weighed more than this. The average weight of longfins, however, did not differ between open and landlocked lakes (*DF*=32, *t*=1.87, *P*=0.071) (Figure 14). Shortfins in open lakes predominantly weighed less than 400 g, whereas shortfins in landlocked lakes weighed more than four times this (i.e., 2–3 kg) (Figure 15). The average weight of shortfins was significantly higher in landlocked lakes (*DF*=469, *t*=19.07, *P*<0.001) (Figure 14). Mean condition factor was also significantly higher in landlocked compared with open lakes for shortfins (*DF*=469, *t*=4.117, *P*<0.001) and longfins (*DF*=32, *t*=2.116, *P*=0.042) (Figure 16).

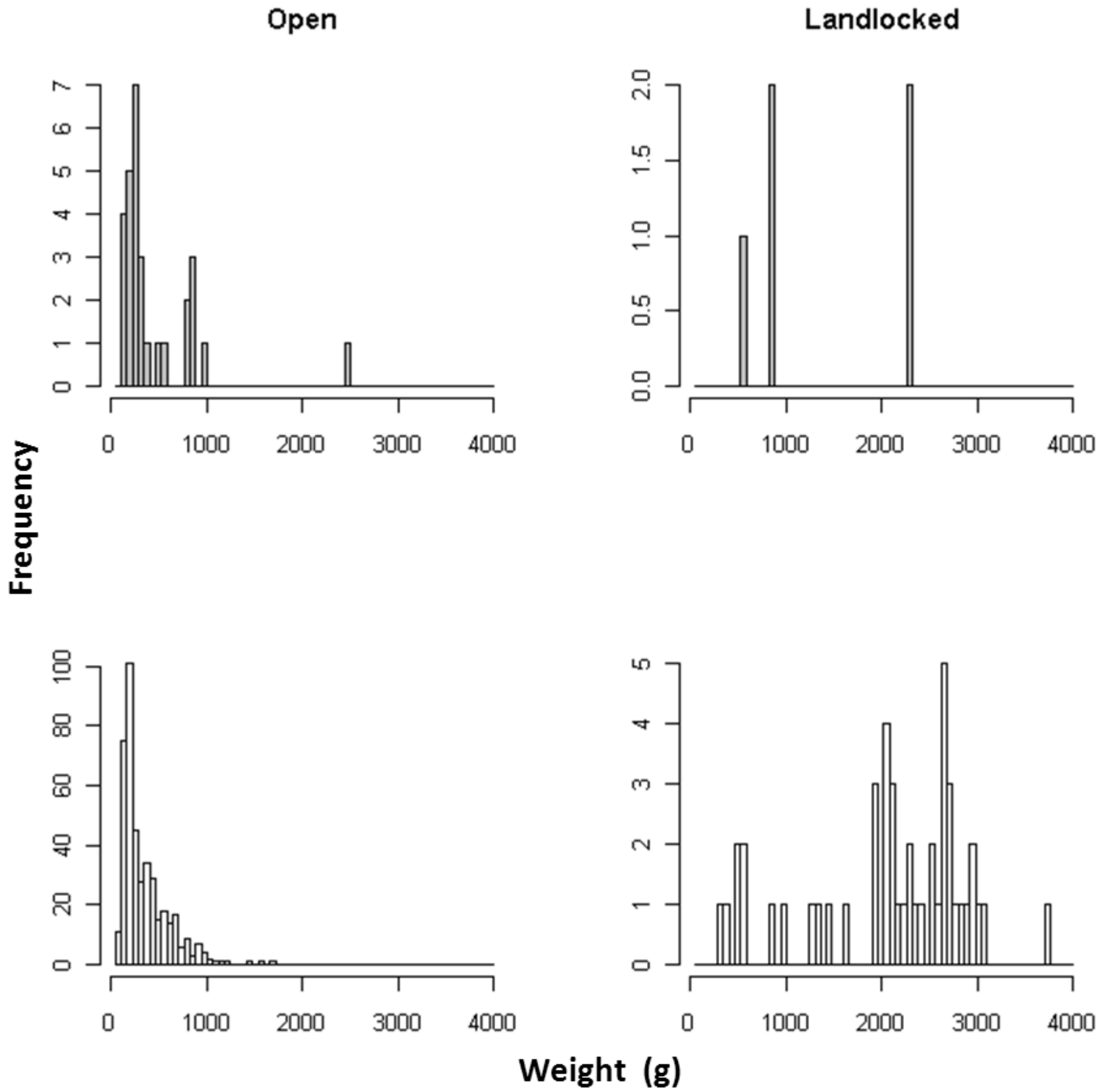

Figure 15: Weight-frequency distributions of longfins (grey) and shortfins (white) in landlocked lakes and lakes with open access to fish.

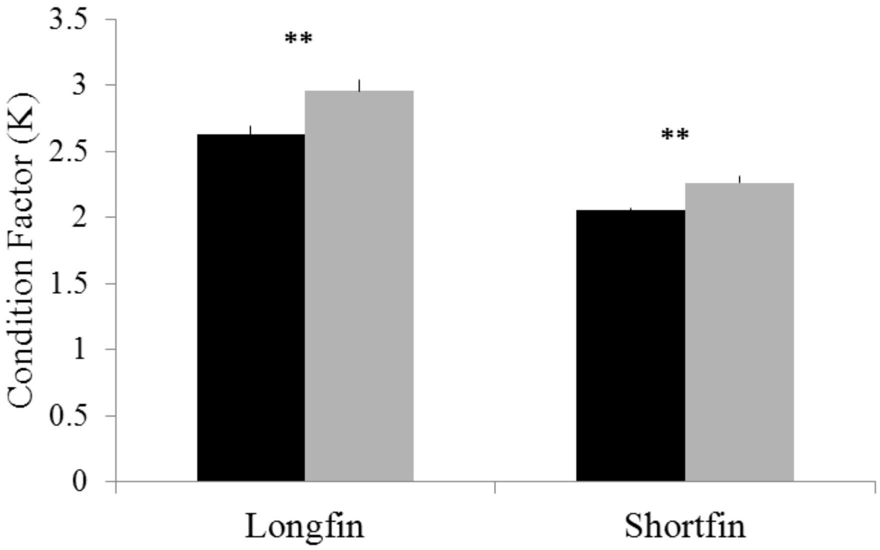

Figure 16: Mean (+ standard error) condition of longfins and shortfins caught from open (black) and landlocked (grey) lakes. ** indicate statistical differences at the *P*<0.001 significance level.

Numbers of shortfins/net were five-fold higher in open lakes compared to landlocked lakes (mean=2.4 and 11.15 shortfins/net respectively) (*DF*=55.51, *t*=4.26, *P*<0.001). Similarly, total eels/net were five-fold higher in open lakes (mean = 2.6 and 12.0 eels/net respectively) (*DF*=54.97, *t*=3.443, *P*<0.001), but numbers of longfins did not differ statistically between open and landlocked lakes (*DF*=45.19, *t*=1.696, *P*=0.097).

4. DISCUSSION

4.1 Species composition

Catches (by weight and number) from the Pouto Lakes were dominated by shortfin eels. The eel population structure in the Pouto Lakes was typical of lakes in the Northland region and appears to be comparable to other studies done in this area. Shortfins are reported as the dominant species from 1990–2007 commercial catch in Northland, comprising 59% of the commercial catch weight (Beentjes & Dunn 2010). However, 22% of the eels in the commercial catch were classed as unidentified, and if these eels are apportioned pro-rata to a species, then the percentage of each species increases to 76% and 24% for shortfins and longfins respectively. Catches from nearby Lakes Taharoa and Hariari in the lower Waikato also reflect the species composition observed in the present study with 99% of the catch from these lakes being shortfin (Chisnall 1998). Similarly, catches from two other Northland lakes, Lake Owhareiti and Lake Kaiwai were comprised of 100% and 66% shortfins (by number) respectively (Williams et al. 2011).

4.2 Relative abundance and distribution

The total observed CPUE averaged 5.08 kg/net/night, but this did include fish below the minimum weight of 220 g because the fyke nets did not have any escapement tubes. The equivalent total commercially harvestable CPUE was 4.5 kg/net/night, which was very similar to the mean commercial unstandardised CPUE for Northland of 4.2 kg/lift reported from commercial catches covering the years 1990–1999 (Beentjes & Bull 2002). Northland commercial catches over the period 1990–2007 did, however, average around 5 kg which was slightly higher than that observed in the Pouto Lakes (Beentjes & Dunn 2010). Similarly, the total CPUE in the Pouto Peninsula was slightly lower than the mean unstandardised North Island CPUE of 5.5 kg over the period 1990–2007

(Beentjes & Dunn 2010). CPUE in the present study was higher than the mean CPUE of 2.1 kg/net/night caught with the same fyke net mesh size in the nearby Kawakawa (Taumārere) River catchment (Table 6, Williams et al. 2011).

The higher abundance and biomass of shortfins compared to longfins in this area is likely to be associated with habitat preferences of the two species. Recruitment is dominated by shortfins in the North Island (Jellyman et al. 1999; Martin et al. 2009), and the higher abundance of juvenile shortfins will be further favoured by the high proportion of areas that contain the preferred habitat of adult shortfins. Shortfins typically prefer slow flowing water bodies and lowland lakes with high turbidity (McDowall 1990; Jellyman et al. 2003). This type of habitat is predominantly what is available around the Pouto Peninsula, with very few small fast flowing streams present which provide ideal longfin habitat (McDowall 1990; Jellyman et al. 2003). Longfin eels do, however, live in lakes and can dominate lake catches, e.g., Crow & Jellyman (2010), but lowland lakes like those around the Pouto Peninsula are usually dominated by shortfins. For example, lowland turbid lakes in the South Island contain much higher proportions of shortfins (over 75%) than longfins (Beentjes & Bull 2002; Jellyman & Cranwell 2007). Similarly, catches from other Northland lakes and lowland lakes in the Waikato have also been shown to be dominated by shortfins (Chisnall 1998; Williams et al 2011).

4.3 Population structure

Average eel lengths and weights observed in the present study were similar to other North Island water bodies, but catches from the Pouto Peninsula did contain very high proportions of large eels (i.e., over 1000 mm). Average longfin length in the present study was 550 mm, which was similar to the average longfin length of 539 mm recorded from coarse mesh fyke net catches in the Pātea River (Crow & Jellyman 2009). Mean length in the present study, however, was smaller than the mean length of 627 mm recorded from the Motu River (Jellyman et al. in press), but this system was noted as having a lot of large eels in the population of longfins by the authors.

Average shortfin length in the present study was 570 mm, which was slightly higher than the mean length of 539 mm caught from the Pātea River (Crow & Jellyman 2009) and 100 mm higher than the mean length of shortfins caught from the Kawakawa catchment (Williams et al. 2011). Length frequency and weight frequency distributions of shortfins in the present study showed that roughly 10% of shortfins caught weighed over 1 kg and 3% measured over 1000 mm. For comparison, of 690 shortfins caught from the Pātea River by Crow & Jellyman (in press), only 0.14% of the individuals weighed over 1 kg and measured more than 1000 mm. Similarly, no shortfins exceeded 1000 mm out of 1849 eels caught in South Canterbury (Jellyman 2010) and only one shortfin exceeded 1000 mm out of 945 shortfins caught from a highly productive fishery in Lake Wairewa.

The large individuals in the present study predominantly came from one landlocked lake where fish had been stocked in the past (Greg Hemmingway and Te Uri o Hau, pers. comm.) and are therefore unlikely to be representative of the eel sizes found from the majority of lakes in the Pouto Peninsula that have open access to fish recruitment or are unstocked. Most of these very large individuals were migrants and appeared to have reached this size because they were unable to migrate out to sea over the roughly 20 m bank that is blocking access to the sea. Similar dune lakes in the Waikato that have inhibited recruitment have also been noted to contain a high proportion of large individuals (Chisnall 1998). The large individuals found in these lakes, therefore, suggests that landlocked lakes may generate populations that have high proportions of large individuals.

The seven lakes sampled had significantly different population structures. Catches from Lakes Kapoai and Rototuna had zero and only three fish respectively, while all other lakes had significantly higher numbers. Swan Lake had the highest numbers of longfins and shortfins, but the highest CPUE, length and weight for both species was found in Lake Parawanui. Lake Parawanui also contained an exceptionally high proportion of large fish that had been previously released into this landlocked lake. It is unknown how long these fish have been present in the lake, but there was an abundance of a potential prey species in the lake, which may have contributed to the large sizes of eels. In two of the fyke nets there were catches of more than 100 juvenile (less than 60 mm) rudd, which may provide an abundant food source for eels larger than 300 mm and able to be piscivorous (Kelly & Jellyman 2007). This lake also contains common bullies, but the abundance of this prey species alone is unlikely to explain the larger sizes of eels because bully densities are similar to other Pouto Lakes (Rowe 1999). The introduced rudd were only found in Parawanui, although Rowe & Chisnall (1997) recorded them in Rototuna also. This coarse fish can proliferate rapidly in the absence of any predators (McDowall 1990), which suggests that the presence of larger eels may play an important regulatory role on rudd populations. Rudd are regarded as a noxious fish, and have few benefits apart from providing a forage species to larger fish, and being of interest to a select group of anglers. Once established, they are difficult to eradicate, so some form of biological control like predation may be a preferred option. Continued stocking of eels greater than 300 mm into Lake Parawanui may therefore help control the rudd population. Continued stocking of eels would be necessary to replace any mortality in the lake and maintain predation levels on rudd.

4.4 Growth rate

Shortfins displayed high growth rates compared to other areas in New Zealand, which may be associated with the warmer climate in Northland. Growth rates of shortfins averaged 42 mm/year in the present study, which is twice the national average of 20 mm/year reported by Jellyman (2009). High growth rates in another nearby Northland catchment have also been reported by Williams et al. (2011), who found that the average shortfin growth rate at each site ranged from 29–38 mm/year with the exception of one site that averaged 99 mm/year. The higher growth rates observed in the Northland region are likely to be due to the higher temperatures in the area, which has been shown to influence growth rates (Kearney et al. 2008). Higher temperatures also mean that eels are active all year round, compared with more southerly regions where activity and growth are seasonal (Jellyman 1997). The growth rates in the study area suggest that a shortfin would take roughly 10 years to reach the minimum commercial weight of 220 g, which is roughly five years faster than in other areas of the North Island (Chisnall & Kemp 2000).

Shortfin growth in mm/year and g/year significantly differed between the four lakes where ageing was carried out. Lakes Mokeno and Whakaneke had the highest annual increase in length, with Swan Lake and Lake Karaka having the lowest. Annual weight increase was highest in Lake Wakaneke followed by Lakes Mokeno, Karaka and Swan. These data suggest that eel biomass and mean length would recover faster after harvesting in Lake Whakaneke (both length and weight) compared to the other three lakes where ageing data were collected.

4.5 Condition and maturation

Lake Whakaneke had the highest condition factor for shortfins. This lake may be of particular interest to Te Uri o Hau, with one member stating that they “would target the fat males” during their fishing trips. Given the high condition factor of eels in Lake Wahaneke, the preferred fish are most likely to be found in this lake. The higher condition factor seen in Lake Whakaneke was likely to be associated with the high propotion of migrants present (20%). Sampling was carried out during March 2010, which is when the proportions of migrant shortfins in the population are at their highest (Todd 1981b). This is approaching the harvest timing of some whānau from Te Uri o Hau who “would harvest them when the tuna was at its fattest during the months of July and August”.

4.6 Relationship with environmental factors

No statistical relationships were found between shortfin sizes (length, weight or condition) and habitat. Other potential explanations for differences in eel structure between lakes can be discussed in relation to the values of ecological health found in each lake and relevant literature. Although no direct causes can be conclusively stated given these data, linkages between eel population structure and lake health/catchment use can still be informative.

Lakes Mokeno and Whakaneke had the highest growth rates, which may be associated with the higher amount of cover available to fish in these lakes. Both lakes had a very high biodiversity value with a high proportion of native macrophytes present and significant coverage (Table 7). Lakes Mokeno and Whakaneke had a much higher proportion of the catchment covered by pine plantation and manuka-kanuka (Figure 17). Riparian cover such as that generated by pine and manuka-kanuka is an important factor associated with freshwater fish presence (Bonnett & Sykes 2002). Similarly, macrophyte coverage in Lakes Mokeno and Whakaneke provide direct "in-lake" cover for eels, which is also of primary importantance to habitat selection in fishes (Crow et al. 2010). Lake Mokeno also had high LakeSPI values indicating excellent ecological health, which may also be associated with growth rates in this area. Both these lakes had common bullies present (S. K. Crow, NIWA, pers. obs.), which form an important component of shortfin diet (Kelly & Jellyman 2007). But common bully abundance is unlikely to explain higher growth in these lakes as bully abundance is similar (if not slightly lower) than in other Pouto Lakes in the area (Rowe 1999). Although temperature does influence growth (Jellyman 1997), this was unlikely to explain higher growth in these two lakes as spot temperatures did not differ between lakes in the present study, and given the proximity of the lakes, it was considered that longer term temperature regimes would also be similar.

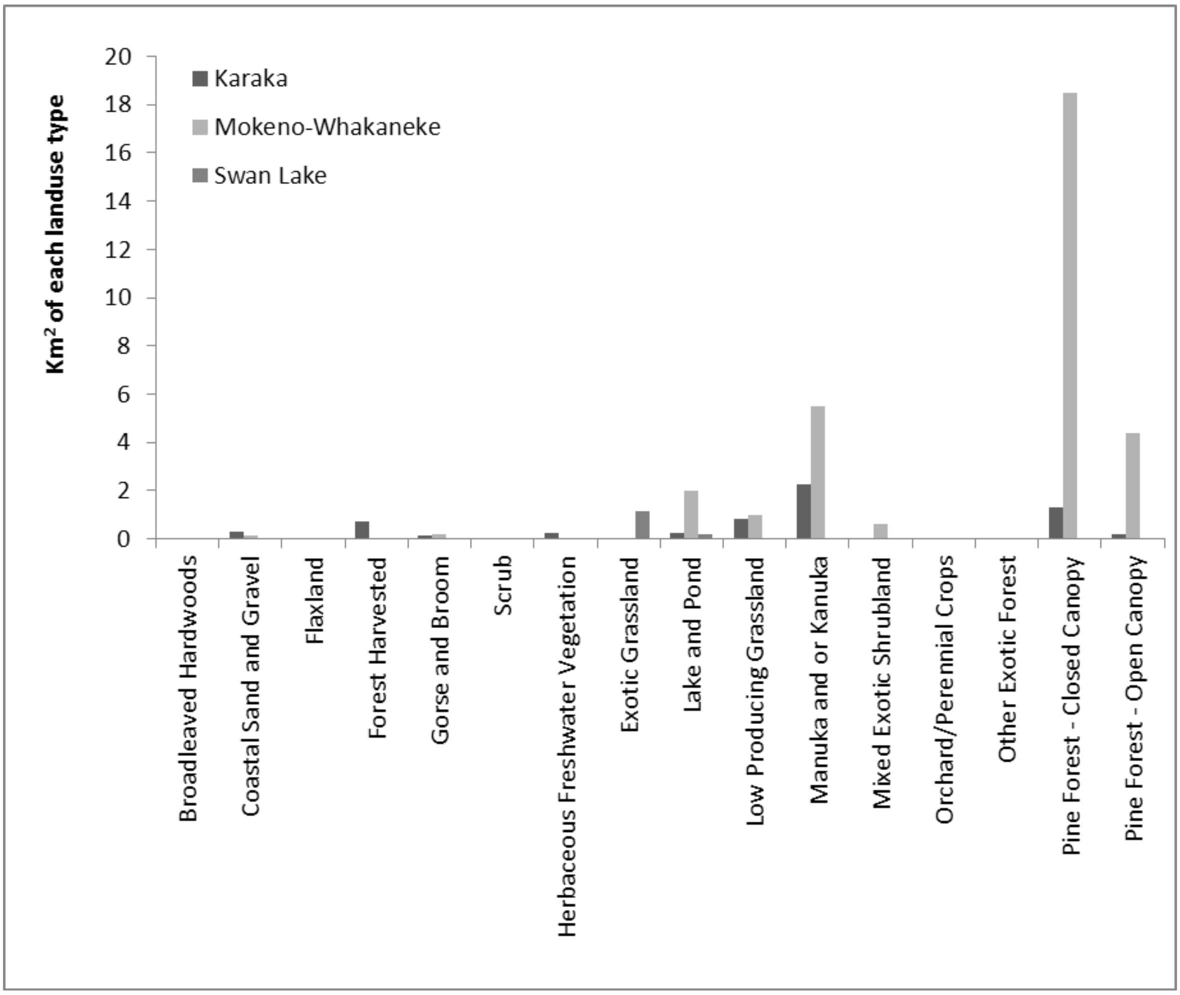

Figure 17: Total area (km^2) of each Pouto Lake catchment that is covered by each landuse type. Data from the New Zealand Land Cover Database (LCDB).

Table 7: Table showing highest eel values for each lake and a summary of the ecological health for each lake taken from Wells & Champion (2011). Values for LakeSPI (Clayton & Edwards 2006) indicate ecological health while values for native and invasive are indices of native condition and invasive impacts (maximum of 100). Lake names in red represent landlocked lakes. Column labelled eel value shows which lakes had the highest values for growth, size, abundance and condition in the present study.

Lake	Eel value	Biodiversity rank	Area (ha)	Macrophytes	Lake SPI value	Native	Invasive	Fish	Invasive plants threat
Kapoai		Moderate-low	1.6	nil	no plants			Common bully, shortfin eel, rudd, tench, goldfish	Low as isolated
Karaka		High	11.1	lots	81	62	0	Common bully, shortfin, longfin,giant kokopu	Low as isolated
Mokeno	Highest growth	Outstanding	148.3	Lots, to 5.3 m	90	80	0	Common bully, inanga, smelt, shortfin	Low as isolated
Parawanui	Largest eels	Low – degraded, poor water quality	5.8	little	Not done			Rudd, koi, orfe, shortfin, cb	Pest fish liberated
Swan Lake	Highest abundance	Moderate – invasive plants	17.4	*Egeria, Ceratophylum*	21	37	86	Dwarf inanga, Common bully, shortfin grass carp	Grass carp introduced in May 2009 to control exotic weeds
Rototuna		High	6	Lots	86	70	0	Dwarf inanga, Common bully, mosquitofish, rudd	Pest fish; *Glyceria* (reed sweet grass) threatens margins
Whakaneke	Highest growth and condition	High	20.5	Little	Not done			Common bully	Low as isolated

Lake Parawanui had the population with the largest eels, but this does not appear to be associated with values of ecological health or landuse. As mentioned above, this population was likely to have been generated by the landlocked nature of the lake combined with higher prey species abundance generated by the presence of rudd, but it is interesting to note that this lake is classed as being a low quality degraded lake (Table 7). This lake was surrounded by farmland which may also contribute to the larger sizes of eels as this is one of the most productive landuse types for eel biomass (Hicks & McCaughan 1997).

The higher abundances of eels found in Swan Lake cannot be explained in relation to ecosystem health values directly, but may be associated with the indirect effects of a grass carp introduction. The only unique aspects of this lake that could be linked to higher eel abundance were the presence of invasive macrophytes (*Egeria densa* and *Ceratophyllum dimersum*) and introduced grass carp (*Ctenopharyngodon idella*) (Table 7). The presence of these exotic macrophytes led to the introduction of grass carp in 2009, which has subsequently resulted in the almost complete removal of these exotic macrophytes (Wells & Champion 2011). Weed control in other lakes has led to an increase in bully size and condition (Mitchell 1986), which was associated with higher chironomid abundance (Hofstra & Rowe 2008). Because common bullies are a preferred prey item (Kelly & Jellyman 2007), the biological control grass carp may have indirectly led to higher abundances of eels by increasing prey species biomass. Similarly, juvenile grass carp may have acted as an additional prey species in this Lake. Lake Parawanui was, however, shown to have low abundances of common bullies in 1999 (Rowe 1999), but this was before grass carp were introduced. Grass carp removal is likely to occur in Swan Lake over the next few years now that exotic macrophytes are nearly removed, which will provide an interesting before-after study situation for examining any changes in eel abundance as a result of the presence of grass carp.

5. MANAGEMENT IMPLICATIONS

5.1 Future surveys

It is recommended that any future eel population surveys in the Pouto Peninsula be completed with the same methodology used in the present study. Consistency in methodologies between studies would ensure that data can be directly compared, and that the effects of management decisions initiated between studies could be examined. Representatives from Te Uri o Hau Governance Entity have already identified their desire to MFish that the information in the present study could be used in assessing the on-going status and well-being of the eel resource, an objective which is supported by the authors of the present study.

Future studies could also use fine mesh fyke nets and G-minnow traps, in addition to the equipment used in the present study, to sample smaller eels (less than about 250 mm). The potential impacts that fine mesh fyke nets could have on the dune lake galaxias (e.g. predation by larger eels within the nets), should be discussed with Te Uri o Hau and the Department of Conservation before their use. Electric-fishing is an alternative technique that provides quantitative data on all size classes of eels and non-target species, but this is not able to be utilised at any locations in the Pouto Lakes because the conductivity levels are too high for the equipment to operate effectively.

Past levels of commercial and customary harvesting could also influence eel population structure in the Pouto Lakes. Unfortunately, no information on previous customary harvesting in these lakes was available from the interviews and commercial catch data is currenlty not available for individual lakes. The impacts of harvesting on eel population sturcture in the Pouto Lakes could be further examined in relation to customary and commercial fishing pressure in each of these lakes.

5.2 Stocking of juvenile eels

Stocking landlocked lakes with eels appears to generate low-density populations with high proportions of very large eels. On average only 2.6 eels (both species) were caught from landlocked lakes in each net, while 12 eels were caught on average from each net in open lakes. It should be noted that these catches are only an indication of relative abundance. In contrast to the lower numbers caught from landlocked lakes, mean length and weight of eels were 2–3 fold larger than from open lakes. Similarly, condition factor was higher in landlocked lakes for both species. However, high condition will be associated with food not being limiting for the population and the inability for migrants to emmigrate, but if lakes were stocked to excess, growth rates could be expected to decline.

Stocking rates for each lake are difficult to recommend because the appropriate numbers of eels to release would depend on productivity and available habitat within each lake. Further work would be required to address stocking rates and subsequently avoid any unnecessary mortality, which should be completed before stocking eels in any areas. Alternatively, stocking guidelines could be inferred from Chisnall (1998) who stocked a similar recruitment inhibited dune lake in the lower Waikato. Chisnall (1998) released approximately 6000 juvenile eels (under 220 g) into a total lake area of 2.46 km^2, which equals a stocking rate of approximately 2400 eels/km^2. This stocking rate could be used as a guideline for the Pouto Lakes based on the area of the specific landlocked water body to be stocked. This stocking rate is also consistent with the population size estimated in a similar sized lowland lake in Canterbury (NIWA unpubl. data). Chisnall (1998) sourced juvenile eels with the assistance of the commercial fishery, which is an option that could also be pursued with respect to stocking the Pouto Lakes. Alternatively, eels could be sourced from Swan Lake as this had the highest numbers of eels in the present study.

The high proportions of large eels in the population may be associated with a lack of stocking with smaller fish over the last four to five years or more (Greg Hemmingway, pers. comm.). It is anticipated that eels roughly 400–600 mm were released into these landlocked lakes, because this is the minimum size that would allow fish to reach the mean observed length of 930 mm within five years since the last observed stocking was carried out (Greg Hemmingway, pers. comm.). This assumes that growth in these stocked lakes is similar or slightly higher than that observed in the four open access lakes of 43 mm/year. Stocking of eels larger than 300 mm will ensure that released fish are able to predate on any small fishes present in the lake (Kelly & Jellyman 2007). Stocking eels larger than 300 mm may also minimise avian predation, although avian predators capable of catching eels up to 500 mm have been shown to have a minimal impact on eel populations (Carpentier et al. 2009).

5.3 Improving escapement of migrant eels

It is recommended that consideration be given to catching and releasing migrant eels in landlocked lakes. All of the landlocked migrant shortfin eels caught in Lake Parawanui were large females (N=21). Using the linear relationships between feccundity and size suggested by Todd (1981a), these fish could hold roughly 107 million eggs. Fishing for migrants should be carried out during the months of January–June when the proportion of the population composed of migrants peaks for both species (Todd 1981b). To ensure that eels have sufficient time to adjust to the different osmoregulatory requirements associated with saltwater (Cutler & Cramb 2000), it is recommended that migrant eels be released into a nearby freshwater or brackish waterbody connected to the ocean rather than directly into the sea.

6. ACKNOWLEDGMENTS

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APPENDIX 1

Locations of the fyke nets set in the present study.

Lake	NZMG East	NZMG North
Rototuna	2603956	6549384.7
Rototuna	2603932.7	6549514.1
Rototuna	2603986.3	6549688.7
Rototuna	2604015.1	6549468
Rototuna	2604088	6549301
Rototuna	2604193	6549356
Rototuna	2604218	6549451
Mokeno	2605801.5	6537819.7
Mokeno	2606087.3	6537958
Mokeno	2606401.7	6538364.8
Mokeno	2606130.7	6538716.3
Mokeno	2605557.3	6538411.3
Mokeno	2605306.4	6538826
Mokeno	2605861.1	6539034.3
Mokeno	2605730.3	6539390.6
Mokeno	2605358	6539242.5
Mokeno	2605244.7	6539833.3
Mokeno	2605124.3	6540345.8
Mokeno	2605027.6	6540666.9
Karaka	2604083.3	6542590.5
Karaka	2603954.7	6542492.9
Karaka	2603800.9	6542530.4
Karaka	2603495.7	6542584.3
Karaka	2603734.4	6542667.2
Karaka	2603853	6542820.7
Karaka	2604015	6542735.8
Whakaneke	2605626.1	6536477.8
Whakaneke	2605746.2	6536564.8
Whakaneke	2605858.6	6536463.1
Whakaneke	2605915	6536411.9
Whakaneke	2605792.5	6536351.8
Whakaneke	2605683.1	6536365
Swan Lake	2613081.6	6540474.8
Swan Lake	2612954.9	6540361.2
Swan Lake	2612777.8	6540379.6
Swan Lake	2612637.7	6540252.7
Swan Lake	2612623.7	6540434.2
Swan Lake	2612709.1	6540625.9
Swan Lake	2612795.4	6540781.9
Swan Lake	2612902.4	6540647.2

Swan Lake	2613106.2	6540636.9
Parawanui	2587266.8	6570574.3
Parawanui	2587395.4	6570537.6
Parawanui	2587137.1	6570735.6
Parawanui	2586981.6	6570870.5
Parawanui	2587078.6	6570928.5
Parawanui	2587218.4	6570765.3
Kapoai	2585691	6572475.3
Kapoai	2585620.9	6572562.4
Kapoai	2585514.7	6572813
Kapoai	2585634	6572713.7
Kapoai	2585677.8	6572595.7

APPENDIX 2

Photograph of migrant male shortfin eel (top) and non-migrant shortfin eel. On the migrant shortfin, note the enlarged eye, dorsally flattened head, slightly chiseled snout, thin lips, prominent lateral line pores behind the eye, and a metallic silver/gold ventral surface.