# Assessment of Fish Populations in Lake Horowhenua, Levin

## ERI Report 15

Client Report Prepared for Horizons Regional Council
By Grant Tempero

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## EXECUTIVE SUMMARY

Lake Horowhenua (Waipunahau) is of substantial historical, cultural and recreational value to the people of the Horowhenua region. However, water quality and biodiversity within the lake has been in decline for a number of years. As part of lake restoration efforts by Horizons Regional Council and the Lake Horowhenua Trustees, a survey of fish species in Lake Horowhenua was conducted by the University of Waikato using boat electrofishing and fyke netting. A lake restoration plan had previously identified invasive fish species such as koi carp (*Cyprinus carpio*) and European perch (*Perca fluviatilis*) as being potential barriers to rehabilitation of the lake. The purpose of this survey was to determine the abundance and diversity of fish species within the lake and to ascertain if pest fish species were present at biomasses high enough to be negatively impacting on lake ecology. Recommendations would then be made as to the potential methods and necessity for pest fish removal.

A total of 60 10-minute electrofishing transects were conducted on Lake Horowhenua over a four day period of 16-19 April 2013. A total of 1099 fish were collected by boat electrofishing with goldfish (*Carassius auratus*) (325) and perch (301) being the most abundant species. Other species captured included common smelt (*Retropinna retropinna*) (258), common bully (*Gobiomorphus cotidianus*) (203), inanga (*Galaxias maculatus*) (4), grey mullet (*Mugil cephalus*) (1) and koi carp (1). Total density for all species collected by electrofishing was 1.1 fish/100 $m^2$ and total biomass was 374.2 g/100 $m^2$. However, it should be noted that actual fish density and biomass is likely to be significantly higher as eels were not collected during electrofishing. Previous surveys have found that fyke nets have proven more effective in evaluating eel abundance. Therefore, 20 fyke nets were set overnight on 16 April resulting in the capture of 1783 eels (mean 89.1 fish $net^{-1}$) with a total biomass of 341.3 kg. The mean eel weight was 191.4 g and mean fyke net biomass was 17.07 kg $net^{-1}$.

These results suggest that the native fish species richness is slightly below what would be expected for a coastal dune lake. One of the likely causes is the weir on the Hokio Stream outlet reducing upstream migration of lowland species and marine wanders such as flounder (*Rhombosolea retiaria*) and grey mullet (*Mugil cephalus*) into the lake . The abundance of native fish that are not obligatory diadromous, i.e. common smelt and common bully, is equivalent to other eutrophic lakes sampled by boat electrofishing. Fyke netting of eels revealed they were highly abundant in the lake but large specimens (> 1 kg) were nearly absent. This finding is consistent with other eel populations that have been overfished.

Extensive fyke netting and boat electrofishing resulted in no observations of rudd (*Scardinius erythrophthalmus*), tench (*Tinca tinca*), gambusia (*Gambusia affinis*) or brown bullhead catfish (*Ameiurus nebulosus*) and only a single koi carp was captured. Although five suspected goldfish-koi hybrids were also captured, the density of koi carp and associated hybrids appears to be well below the recognised 100 kg $ha^{-1}$ threshold observed to induce negative environmental impacts. Population estimates for perch and goldfish were calculated from mark recaptures. The restricted time-frame and low number of recaptures meant that the error limits for these populations were large. However, the low number of total captures suggests that the Lake Horowhenua populations are not extensive and the densities are likely to be well below the level at which negative environmental impacts would occur.

Currently, pest fish populations in Lake Horowhenua have not reached densities where they are likely to be having a significant impact on the lake. Control or eradication measures would not be cost effective at this stage due to the low population densities and likely impacts on native species. Continued monitoring of the lake is recommended to ensure that no further pest fish invasions occur and that the public are educated on the risk of introducing pest fish to the lake. In addition, an electrofishing survey should be conducted every 5-6 years to monitor any changes in the populations of invasive fish within the lake.

## ACKNOWLEDGEMENTS

Thank you to Nick Ling and Logan Brown for reviewing this document. Warrick Powrie, Steve Woods and Joshua de Villiers provided technical support for the survey work. Population estimates were provided with the assistance of Adam Daniel. Stomach contents analyses of perch were conducted by undergraduate biology students at the University of Waikato under the supervision of Bridget Tulloch. Nicholas Ling and John Tyrrell provided valuable feed-back in the preparation of this report.

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## INTRODUCTION

Lake Horowhenua (Waipunahau) is of substantial historical, cultural and recreational value to the people of the Horowhenua region (MWRC 1998). Prior to European arrival it was one the main food sources for the local Muaupoko iwi and the surrounding catchment was forested with kahikatea (*Dacrycarpus dacrydioides*), pukatea (*Laurelia novae-zelandiae*), rata (*Metrosideros robusta*), totara (*Podocarpus totara*), karaka (*Corynocarpus laevigatus*) and matai (*Prumnopitys taxifolia*) (MfE 2001). Currently, catchment land use is dominated by dry stock or dairy farming (43.3% of catchment), urban development (8.4%) and horticulture (4.9%) (Gibbs 2011).

Lake Horowhenua water quality is currently classed as hypertrophic (Burns et al. 2005) with a mean Trophic Lake Index (TLI) for 2005-2009 of 6.3 (Verburg et al. 2010), classifying it as one of the most degraded lakes in New Zealand. A number of factors were identified by Gibbs (2011) as contributing to the decline in water quality over the past 50 years. These included historical discharge of treated sewage effluent from the township of Levin, nutrient leaching and sediment accumulation from horticultural and agricultural land-use, stormwater discharges, seasonal growth and collapse of the lake weed *Potamogeton crispus* and ecosystem disturbance by invasive pest fish (Gibbs 2011).

Before the 1908 Land Drainage Act, Lake Horowhenua would probably have had extensive stocks of eels (*Anguilla* spp.), black flounder (*Rhombosolea retiaria*), grey mullet (*Mugil cephalous*) and whitebait (*Galaxias* spp.) as well as macroinvertebrate species such as kakahi (freshwater mussels, *Hyridella menziesi*) and koura (freshwater crayfish, *Paranephrops* spp.) (Cunningham et al. 1953; White 1998; MfE 2001; Gibbs 2011). Current opinion and anecdotal evidence is that the lake has become depleted of fish abundance and diversity has significantly decreased (MWRC 1998; MfE 2001). However, there is very little independent evidence to assess this assertion.

The earliest published record of fish species present in Lake Horowhenua comes from Cunningham et al. (1953). In completing a biological survey of 26 dune lakes on the west coast of the North Island, the authors reported longfin (*Anguilla dieffenbachii*) and shortfin (*Anguilla australis*) eels, bully's (*Gobiomorphus* spp.) and brown trout (*Salmo trutta*) being present in the lake in February 1949. Cunningham et al. (1953) also referred to "carp" being present in the lake, however goldfish have been referred to as carp in the past (McDowall 1978) and Cunningham et al. (1953) gave the genus as *Carassius*, which would strongly suggest that goldfish had been introduced to the lake rather than common or koi carp at that time. In addition, koi carp were not officially recorded as present in New Zealand before the 1970s (McDowall 1978). While fish surveys have been conducted on streams entering the lake (Joy and Death 2002) and the Hokio stream (Curtis 1964) which drains the lake, robust assessments of the fish populations in the lake do not exist.

Introduced freshwater fish species such as koi carp (*Cyprinus carpio*), European perch (*Perca fluviatilis*), rudd (*Scardinius erythrophthalmus*) and brown bullhead catfish (*Ameiurus nebulosus*) have been implicated in the decline of New Zealand's aquatic ecosystems (Rowe 2007). Goldfish have also been identified as a potential problem species; however, little research has been conducted on the ecosystem effects (Hicks 2007; Rowe 2007). The effects of these introduced species include sediment disturbance, increased nutrient cycling, disturbance of invertebrate communities and predation on native fish species (Rowe 2007). Control and management of exotic invasive species has become a priority for regional councils around New Zealand as part of their obligations under various legislative acts.

Adult koi carp and brown bullhead catfish (hereafter referred to as catfish) are primarily benthiverous, feeding on aquatic macroinvertebrates living in the soft sediments of lake beds and rivers or opportunistically moving onto flooded areas and feeding on terrestrial invertebrates (Driver et al. 2005; Rowe 2007). The feeding activity of these introduced species has been shown to disturb sediments, thereby reducing water clarity and releasing nutrients such as nitrogen and phosphorus into the water column which then contribute to nuisance algal blooms (Barnes and Hicks 2001; Milstein et al. 2002). While the effects of catfish on aquatic vegetation are relatively unknown, koi carp have been reported to have negative effects on aquatic macrophytes at densities over 100 kg $ha^{-1}$ (Zambrano et al. 1999; Chumchal et al. 2005). Loss of macrophytes appears to be primarily due to uprooting of macrophytes during foraging rather than direct consumption (Crivelli 1981).

Adult rudd feed directly on submerged macrophytes, and at high densities are capable of removing all submerged aquatic macrophytes from an aquatic ecosystem (Hicks 2001; Dugdale et al. 2006). For example, Lake Rotoroa in the Waikato region has experienced significant variability in submerged macrophyte cover associated with rudd population fluctuations (Dugdale et al. 2006). As with other juvenile cyprinids, rudd are zooplanktivorous, and at high fish densities this can lead to a significant loss in zooplankton biomass which in turn releases the grazing pressure on planktonic algae exacerbating algal blooms (Hicks 2001; Rowe 2007).

Juvenile European perch (hereafter referred to as perch) are also zooplanktivorous (Hicks et al. 2007), but of more concern is that adult perch switch to piscivory at approximately 110-160 mm total length (Mittelbach and Persson 1998). Adult perch have been observed to prey extensively on smaller native fish species such as common bully (*Gobiomorphus cotidianus*) and common smelt (*Retropinna retropinna*) (Griffiths 1976). Given the right conditions, perch can dominate an aquatic ecosystem, seriously impacting native vertebrate and invertebrate communities to the point where the perch population is dominated by a few cannibalistic large fish and extensive numbers of zooplanktivorous young-of-the-year (Closs et al. 2001; Hicks et al. 2007).

The paucity of information regarding the status of fish populations in Lake Horowhenua has meant that assumptions have had to be made as to the condition of the native fish populations within the lake. In addition, information regarding the extent of pest fish populations such as koi carp and perch is needed to assess whether they are having a significant impact on the lakes' ecology. If extensive populations of pest fish were present in the lake it would require control and eradication programmes to be initiated if progress was to be made on restoring the lake. The University of Waikato was contracted by Horizons Regional Council to perform a survey of fish species and a population assessment of koi carp, perch and goldfish in Lake Horowhenua in April 2013. The objective was to quantify the condition of native fish populations within the lake and provide population estimates for pest fish species. Based on these data, recommendations as to the necessity and potential avenues for pest fish control programmes would be made. These survey data would also provide a valuable reference point for future restoration programmes planned for Lake Horowhenua.

## METHODS

### Site Description

Located adjacent to the township of Levin, Lake Horowhenua is a small (2.9 $km^2$), shallow (< 2 m deep), highly eutrophic coastal dune lake on the west coast of the North Island (Gibbs and White 1994) (Figure 1). The Lake has a catchment area of 61 $km^2$ dominated by agricultural land use. The lake is fed by groundwater and a number of surface inflows including storm-water discharges from Levin. Outflow is by way of the Hokio Stream on the far western side of the lake which has a mean annual flow of 0.8 $m^3 s^{-1}$. A weir is sited on the outlet and maintains the lake level at a near constant 9.1 m above mean low water spring tides at Foxton Heads, as set out in the "Reserves and Other Lands Disposal Act, 1956" (Gibbs 2011). The lake margin has been fenced from livestock and the riparian margin extensively planted.

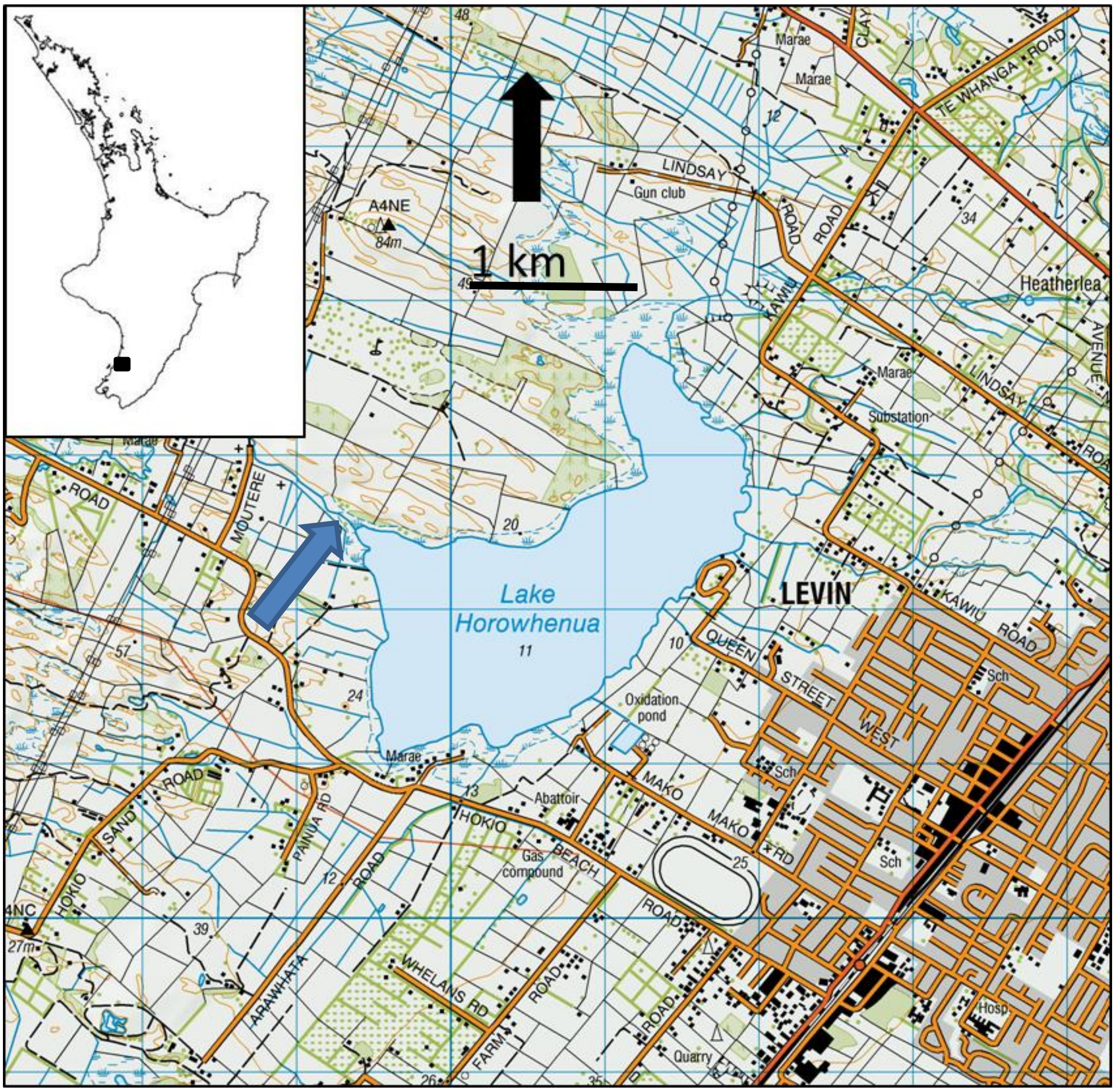


Figure 1. Location of Lake Horowhenua (Waipunahau), North Island, New Zealand. Lake outlet and approximate location of weir indicated by blue arrow. Map Source: Topomap.co.nz

### Survey Methods

Boat electrofishing was conducted using a 4.5-m long, custom-made aluminium electric fishing boat equipped with a 5-kilowatt gas-powered pulsator (GPP, model 5.0, Smith-Root Inc, Vancouver, Washington, USA) which was powered by a 6-kilowatt custom-wound generator. Two anode poles, each with an array of six electrode droppers, created the fishing field at the bow, with the boat hull acting as the cathode. We assumed from past experience that an effective fishing field was developed to a depth of 2-3 m, and about 2 m either side of the centre line of the boat. It was assumed that the boat fished transects approximately 4 m wide, which was generally consistent with the behavioural reactions of fish at the water surface. This assumption was used to calculate area fished from the linear distance measured with the boat's global positioning system. Past experience has proven that separate 10-minute electroshocking events covering a variety of habitats have produced a good representation of fish species within similar aquatic systems (Hicks and Tempero 2011).

A total of 60 10-minute boat electrofishing transects were conducted over a period of 4 days from 16-19 April 2013; of these, 16 transects were conducted at night (Figure 2). Night electrofishing was conducted because previous boat electrofishing surveys of perch dominated systems had found this approach more effective for collecting juvenile perch (Hicks unpublished data). Night fishing was conducted on 18 April between 6:00 pm and 10:15 pm and 19 April between 5:00 pm and 7:00 pm. Eels were excluded from capture by electrofishing as fyke netting has proven to be more effective at evaluating eel abundance (A. Daniel unpublished data). Narcotised fish were collected by netting and then transported to a shore-base for processing. Captured fish were held in aerated plastic fish-bins before being anaesthetised with Aqui-S (Aqui-S New Zealand Ltd; Lower Hutt, New Zealand) at the manufacture's recommended dose rate. Fish were then identified, measured (± 1 mm) and those greater than 100 mm were weighed (± 1g). Weights for fish < 100 mm were back calculated from length-weight regression as this has been found to be more accurate than weights obtained in the field. Following weighing, the right pectoral fin was removed from all perch and goldfish before they were returned to an aerated plastic fish-bin to recover. Following recovery, the fish were released back into the lake; any fish that failed to recover were euthanized and frozen for later disposal. Fin clipping was conducted as part of a mark-recapture programme to provide estimates of the size of the pest fish populations in the lake. Marking (fin clipping) was conducted on the first three days (16-18 April) and recapture was implemented on 19 April. Mark-recapture data was analysed using the Bailey modification of the Lincoln-Petersen model as described in White et al. (1982).

Assessment of eel biomass was carried out using fyke nets. Twenty fyke nets (4 mm mesh size) were deployed around the periphery of Lake Horowhenua (Figure 3) on 16 April and recovered on 17 April. The number of eels caught exceeded expectations, therefore, rather than anaesthetising, identifying species and recording length and weight, eels from each fyke net were collectively weighed and then counted before being returned to the lake. This approach was taken as it was assumed that attempting to hold and individually process such a large number of eels would have resulted in significant eel mortaility. In addition, planned deployment of gill nets was not undertaken due to the entanglement risk presented to the large number of waterfowl on the lake.

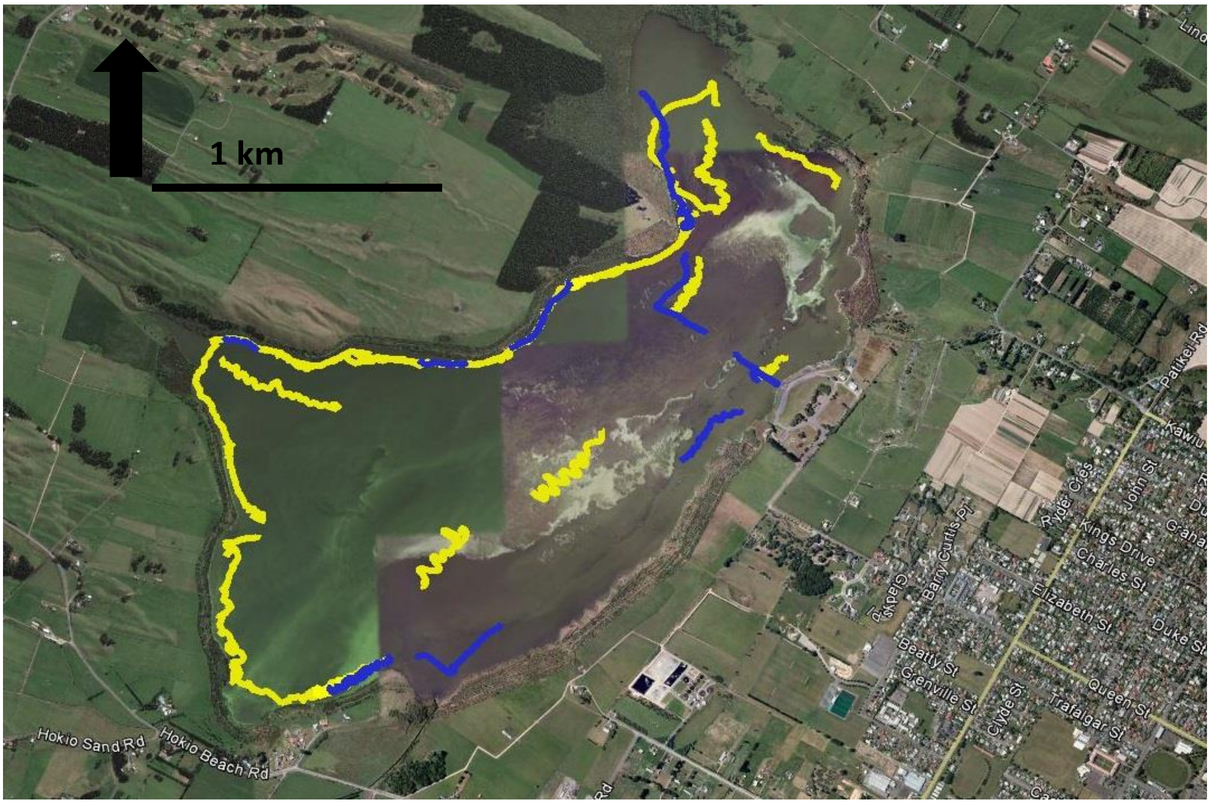


Figure 2. Boat electrofishing transects of Lake Horowhenua Levin, undertaken 16-19 April 2013. Yellow transects were conducted during the day, blue transects were conducted at night. Map source: Google Earth.


Figure 3. Locations of the 20 fyke nets set overnight on 16 April 2013. Map source: Google Earth

## RESULTS

### Boat Electrofishing

Total boat electrofishing time was 600 minutes, covering 23.7 km with an area of 9.88 ha fished. This resulted in the capture of 1099 fish by electrofishing; in addition, a further 12 individuals were recaptured following fin clipping. The number of fish collected in each transect, transect area fished and fish density for each transect can be viewed in Table 1. Three introduced species were detected including 325 goldfish, 301 European perch and a single koi carp (Figure 4). In addition, 6 suspected koi-goldfish hybrids were collected; these fish typically have the olive-green colouring of wild goldfish but have a single pair of mouth barbels, have a more downward facing mouth and can grow significantly larger (> 2 kg) than goldfish. No rudd, catfish, tench (*Tinca tinca*), gambusia (*Gambusia affinis*) or salmonids were detected in the lake. Four native fish species were collected by boat electrofishing; these included 258 common smelt, 203 common bully, 4 inanga *(Galaxias maculatus*) and 1 grey mullet (Table 1).

Figure 4. Introduced pest fish species from Lake Horowhenua Levin, collected by boat electrofishing. A single koi carp (bottom) with an unusual pink colouration was collected late on the last day. Numerous large European perch (centre and left) and goldfish (top 3 right) were also present. Several potential koi-goldfish hybrids were also detected (lower 4 right).

Table 1. Number of fish, area fished and fish density for Lake Horowhenua 16-19 April 2013.

| Transect Number | Goldfish | European perch | Goldfish-koi hybrid | Koi carp | Common smelt | Common bully | Inanga | Grey mullet | No fish | Area fished ($m^2$) | Fish/100 $m^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Horo 1 | | | | | | 10 | | | | 1212 | 0.825 |
| Horo 2 | | | | | | | | | 1 | 1896 | 0.000 |
| Horo 3 | | | 1 | | 4 | | | | | 2796 | 0.179 |
| Horo 4 | 25 | 2 | | | | 2 | | | | 1148 | 2.526 |
| Horo 5 | 9 | 6 | | | 1 | 3 | | | | 1236 | 1.537 |
| Horo 6 | 1 | 3 | | | | | | | | 1972 | 0.203 |
| Horo 7 | | 3 | | | 4 | 1 | | | | 1844 | 0.434 |
| Horo 8 | | 4 | | | | | | | | 1692 | 0.236 |
| Horo 9 | | 3 | | | 4 | | | | | 1672 | 0.419 |
| Horo 10 | | 6 | | | 3 | | | | | 2828 | 0.318 |
| Horo 11 | | 6 | | | 5 | | | | | 1972 | 0.558 |
| Horo 12 | 7 | | | | 5 | | | | | 1536 | 0.781 |
| Horo 13 | 2 | 1 | | | 19 | 7 | | | | 1684 | 1.722 |
| Horo 14 | | | | | 32 | 2 | | | | 1724 | 1.972 |
| Horo 15 | | | | | 9 | | | | | 2792 | 0.322 |
| Horo 16 | 1 | | | | 4 | | | | | 2800 | 0.179 |
| Horo 17 | 5 | | | | 3 | 4 | | | | 2016 | 0.595 |
| Horo 18 | 6 | | | | 2 | | | | | 1744 | 0.459 |
| Horo 19 | | 3 | | | | | | | | 1868 | 0.161 |
| Horo 20 | | 19 | | | | | | | | 864 | 2.199 |
| Horo 21 | | | | | | | | | 1 | 3196 | 0.000 |
| Horo 22 | | | | | | | | | 1 | 2872 | 0.000 |
| Horo 23 | 2 | 14 | | | | | | | | 944 | 1.695 |
| Horo 24 | 5 | 17 | | | | | | | | 1188 | 1.852 |
| Horo 25 | | 1 | | | | | | | | 3560 | 0.028 |
| Horo 26 | | | | | | | | | 1 | 2724 | 0.000 |
| Horo 27 | | | | | | | | | 1 | 2752 | 0.000 |
| Horo 28 | 1 | 12 | | | | | | | | 1024 | 1.270 |
| Horo 29 | 14 | 13 | | | | | | 1 | | 1468 | 1.907 |
| Horo 30 | | 3 | | | | 6 | | | | 1944 | 0.463 |
| Horo 31 | 17 | 5 | | | | 1 | | | | 1420 | 1.620 |
| Horo 32 | 20 | 7 | | | 6 | 8 | | | | 1088 | 3.768 |
| Horo 33 | 13 | 2 | | | 58 | 37 | 2 | | | 1260 | 8.889 |
| Horo 34 | 5 | 5 | | | 1 | 2 | | | | 992 | 1.310 |
| Horo 35 | 2 | 9 | | | 1 | | | | | 1184 | 1.014 |
| Horo 36 | 4 | 1 | | | 69 | 7 | 2 | | | 1908 | 4.350 |
| Horo 37 | 27 | | | | 22 | 19 | | | | 1820 | 3.736 |
| Horo 38 | 58 | | | | | 21 | | | | 980 | 8.061 |
| Horo 39 | 30 | | | | | | | | | 840 | 3.571 |
| Horo 40 | | | | | 5 | | | | | 1912 | 0.262 |
| Horo 41 | 45 | | | | 1 | 73 | | | | 856 | 13.902 |
| Horo 42 | | 8 | | | | | | | | 1872 | 0.427 |
| Horo 43 | | 2 | 4 | 1 | | | | | | 2008 | 0.349 |
| Horo 44 | 2 | 6 | | | | | | | | 1420 | 0.563 |
| Horo 45 | 1 | 7 | | | | | | | | 1088 | 0.735 |
| Horo 46 | 3 | 10 | | | | | | | | 1332 | 0.976 |
| Horo 47 | 2 | 13 | | | | | | | | 2680 | 0.560 |
| Horo 48 | | 9 | | | | | | | | 1388 | 0.648 |
| Horo 49 | | 13 | | | | | | | | 852 | 1.526 |
| Horo 50 | | 25 | | | | | | | | 1368 | 1.827 |
| Horo 51 | 1 | 9 | | | | | | | | 1072 | 0.933 |
| Horo 52 | | 24 | | | | | | | | 908 | 2.643 |
| Horo 53 | | | | | | | | | 1 | 1152 | 0.000 |
| Horo 54 | 16 | 6 | | | | | | | | 1376 | 1.599 |
| Horo 55 | | 7 | | | | | | | | 908 | 0.771 |
| Horo 56 | | 2 | | | | | | | | 1396 | 0.143 |
| Horo 57 | | 2 | | | | | | | | 1240 | 0.161 |
| Horo 58 | 1 | 3 | | | | | | | | 1020 | 0.392 |
| Horo 59 | | 7 | | | | | | | | 844 | 0.829 |
| Horo 60 | | 3 | 1 | | | | | | | 1640 | 0.244 |
| Total | 325 | 301 | 6 | 1 | 258 | 203 | 4 | 1 | 6 | 98792 | |

Population and biomass densities for species collected by boat electrofishing in Lake Horowhenua are presented in Table 2. Total population density for all species collected by electrofishing was 1.1 fish/100 m$^2$ and total biomass was 374.2 g/100 m$^2$, however it should be noted that actual fish density and biomass is significantly higher because eel biomass is not included in electrofishing density estimates.

Table 2. Population density and biomass of introduced and native species collected by boat electrofishing of Lake Horowhenua 16-19 April 2013.

| | Species | Number | Biomass (g) | Fish/100 m$^2$ | Biomass g/100 m$^2$ |
|---|---|---|---|---|---|
| **Introduced** | | | | | |
| | Goldfish | 325 | 75,263 | 0.329 | 76.18 |
| | European perch | 301 | 266,822 | 0.305 | 270.08 |
| | Goldfish-koi hybrid | 6 | 18,242 | 0.006 | 18.47 |
| | Koi carp | 1 | 5,447 | 0.001 | 5.51 |
| | **Total** | 633 | 365,774 | 0.641 | 370.25 |
| **Native** | | | | | |
| | Common smelt | 258 | 580 | 0.261 | 0.59 |
| | Common bully | 203 | 286 | 0.205 | 0.29 |
| | Inanga | 4 | 12 | 0.004 | 0.01 |
| | Grey mullet | 1 | 3,066 | 0.001 | 3.10 |
| | **Total** | 466 | 3,944 | 0.472 | 3.99 |

The mean weights and lengths of fish species collected by boat electrofishing are presented in Table 3. Analysis of length-frequency data of goldfish revealed a bimodal population, with smaller fish in the 75-125 mm length range being the most prevalent group (Figure 5). In contrast, the perch population is dominated by large adult fish and a secondary age class of maturing fish. No young-of-the-year perch are represented in the data (Figure 6). Length-frequency plots from common smelt and common bully are presented in Figure 7 and Figure 8, respectively. There were insufficient captures of koi carp, goldfish-koi hybrids, inanga and grey mullet to determine population structure. However, captured specimens of these species were comparatively large (Table 3) and were all likely to be mature adult specimens.

Table 3. Mean lengths and weights of fish species collected by boat electrofishing of Lake Horowhenua 16-19 April 2013.

| Species | Mean length (mm) | Mean weight (g) |
|---|---|---|
| Goldfish | 134.5 | 231.6 |
| European perch | 315.7 | 886.5 |
| Goldfish-koi hybrid | 465.0 | 3,040.3 |
| Koi carp | 580.0 | 5,447.0 |
| Common Smelt | 67.4 | 2.2 |
| Common bully | 47.6 | 1.4 |
| Inanga | 98.5 | 3.1 |
| Grey mullet | 600.0 | 3,066.0 |

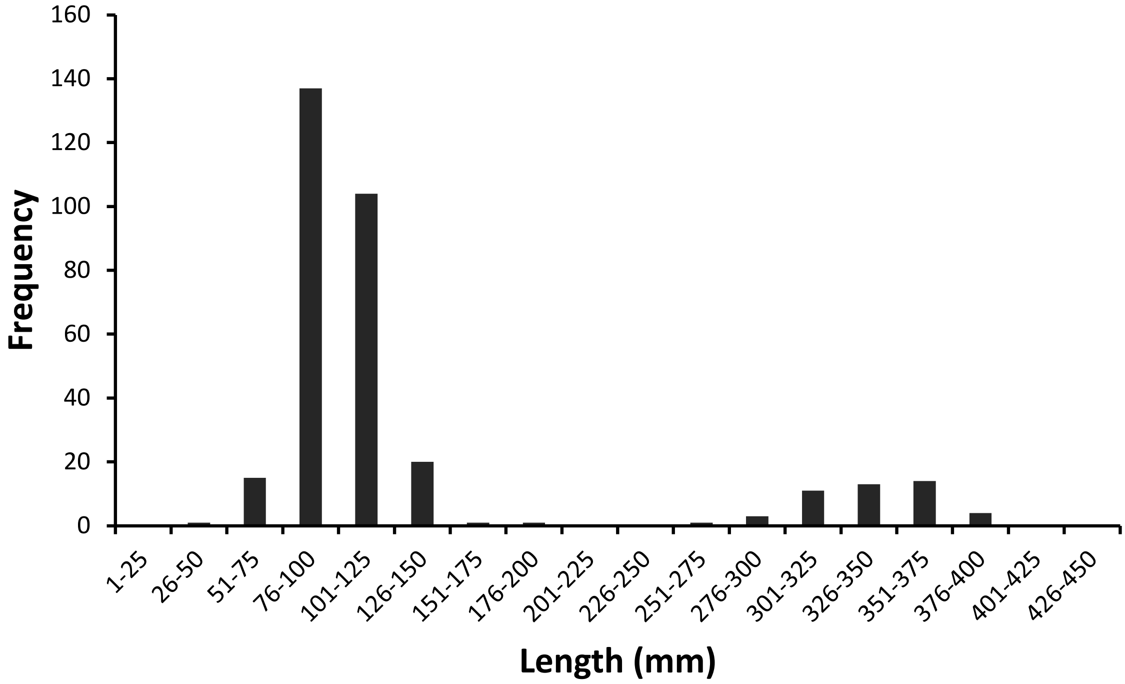


Figure 5. Length-frequency of goldfish from Lake Horowhenua captured by boat electrofishing 16-19 April 2013 (*n* = 325).

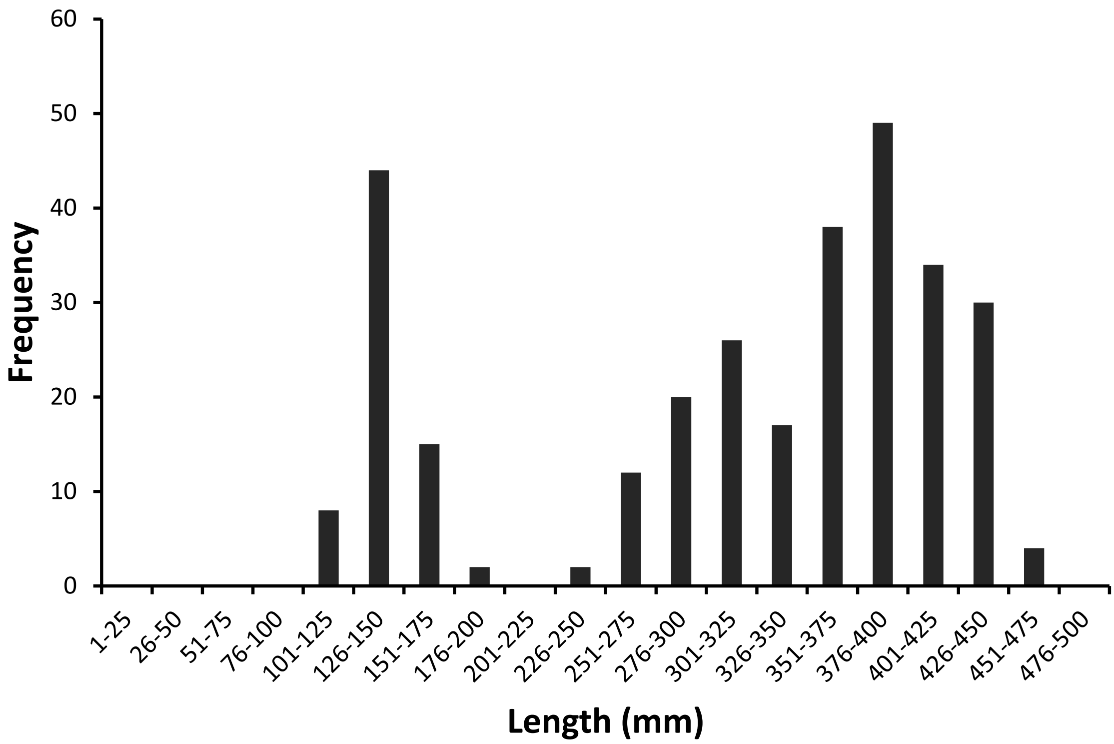


Figure 6. Length-frequency of perch from Lake Horowhenua captured by boat electrofishing 16-19 April 2013 (*n* = 301).

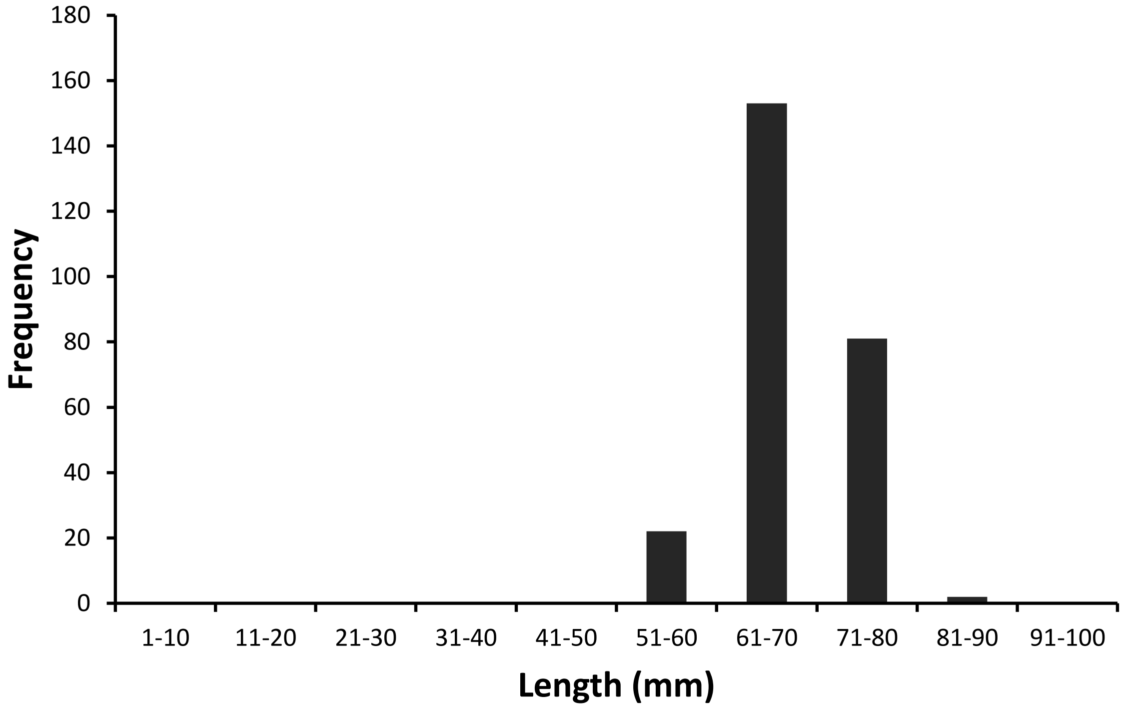


Figure 7. Length-frequency of common smelt from Lake Horowhenua captured by boat electrofishing 16-19 April 2013 (*n* = 258).

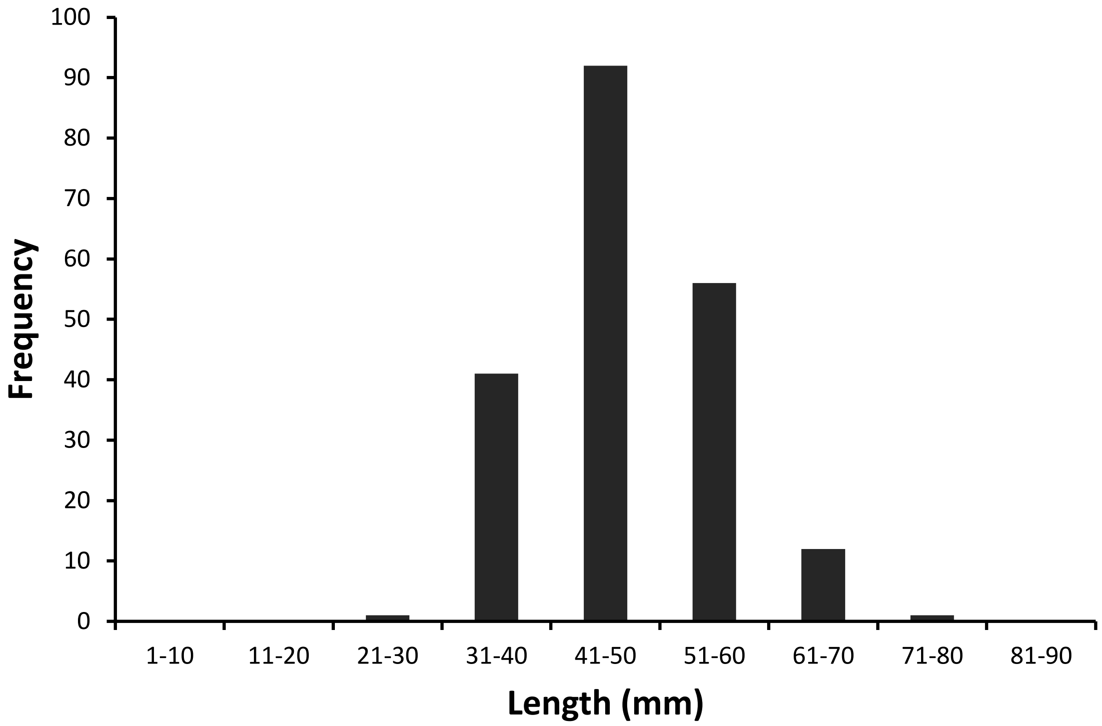


Figure 8 Length-frequency of common bully from Lake Horowhenua captured by boat electrofishing 16-19 April 2013 (*n* = 203).

### Fyke Netting

A total of 1783 eels with a total biomass of 341.3 kg were caught in the 20 fyke nets set overnight on 16 April. The mean eel weight was 191.4 g and mean fyke net biomass was 17.07 kg net$^{-1}$. A wide range of eel sizes were observed from fyke catches during release ranging from ~5 g to > 3 kg. Due to the unexpectedly high number of eels from the fyke nets, eel species identification and individual length-weights were not recorded. However, individual net counts and catch weights are presented in Table 4 below. In addition to the eels, four perch, two goldfish and two inanga were captured in these fyke nets (Table 5). Of the total fish biomass (713.9 kg) captured by fyke netting and electrofishing, eels accounted for 47.8% of the biomass.

Table 4. Number and total weight of eels captured in 20 fyke nets set overnight in Lake Horowhenua 16 April 2013.

| Fyke | Number | Weight (g) |
|---|---|---|
| Hf1 | 46 | 14,590 |
| Hf2 | 126 | 32,175 |
| Hf3 | 110 | 21,254 |
| Hf4 | 154 | 38,178 |
| Hf5 | 54 | 8,455 |
| Hf6 | 67 | 11,345 |
| Hf7 | 94 | 15,833 |
| Hf8 | 83 | 18,986 |
| Hf9 | 20 | 3,350 |
| Hf10 | 18 | 4,148 |
| Hf11 | 11 | 1,473 |
| Hf12 | 479 | 73,234 |
| Hf13 | 99 | 21,533 |
| Hf14 | 45 | 8,284 |
| Hf15 | 31 | 9,552 |
| Hf16 | 203 | 31,814 |
| Hf17 | 8 | 3,549 |
| Hf18 | 93 | 19,140 |
| Hf19 | 18 | 1,898 |
| Hf20 | 24 | 2,518 |
| Total | 1,783 | 341,309 |

Table 5. Additional species caught in 20 fyke nets set overnight in Lake Horowhenua 16 April 2013.
* Indicates weight was back calculated from length measurements.

| Fyke # | Species | Count | Length (mm) | Weight (g) |
|---|---|---|---|---|
| Hf7 | Goldfish | 1 | 77 | 10* |
| Hf8 | Perch | 1 | 444 | 1,808 |
| Hf8 | Perch | 1 | 297 | 500 |
| Hf9 | Inanga | 1 | 97 | 2.2* |
| Hf9 | Inanga | 1 | 103 | 2.2* |
| Hf11 | Perch | 1 | 106 | 180 |
| Hf12 | Perch | 1 | 264 | 349 |
| Hf16 | Goldfish | 1 | 113 | 26 |

### Population Estimates

A total of 299 goldfish were marked and released on the first three days and 28 were captured on the final survey day, two of which were recaptures. This gives a population estimate for goldfish of 2691 ±2486 95% CI and a biomass estimate of 2.14 kg $ha^{-1}$ ±1.98 kg $ha^{-1}$ 95% CI. A total of 145 perch were marked and released on the first three days and 161 were captured on the final day, five of which were recaptures. This provides a perch population estimate of 3915 ±2846 95% CI and a biomass estimate of 11.96 kg $ha^{-1}$ ±8.70 kg $ha^{-1}$ 95% CI. No catfish, rudd or tench were detected in the lake and only a single koi carp was collected by electrofishing late on the final day. However, five suspected goldfish-koi hybrids were collected, which is unusually high given the very small number of koi carp likely to be present in the lake.

### Pest Fish Densities

Densities of perch and goldfish captured during boat electrofishing were categorised according to density and then plotted using Google Earth. The categorised transects were then interpolated to give comparative densities of fish. Relative densities of perch and goldfish are presented in Figure 9 and Figure 10.

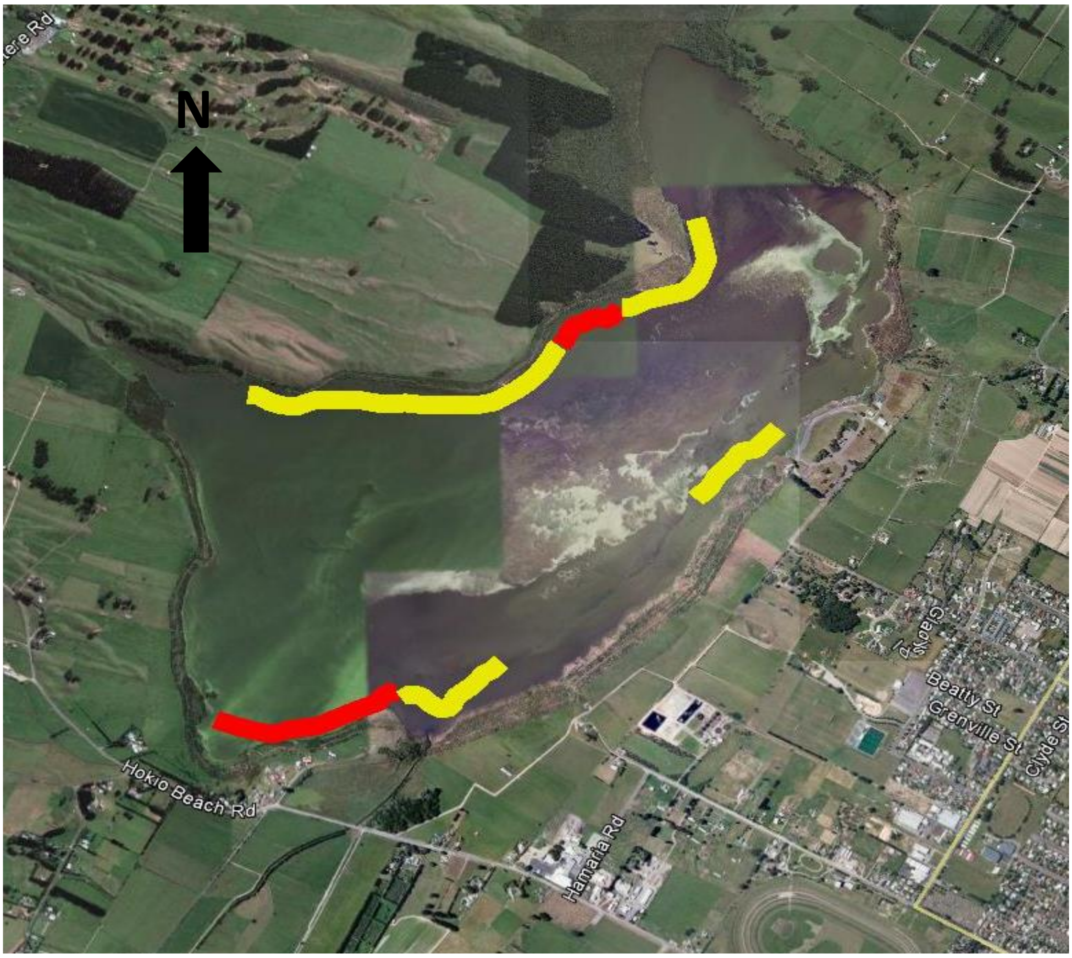


Figure 9. Comparative densities of European perch in Lake Horowhenua. Areas marked in red represent areas where perch density was >1 fish/100 $m^2$, yellow areas 0.1-1 fish/100 $m^2$ and all other areas of the lake (unmarked) < 0.1 fish/ 100 $m^2$.

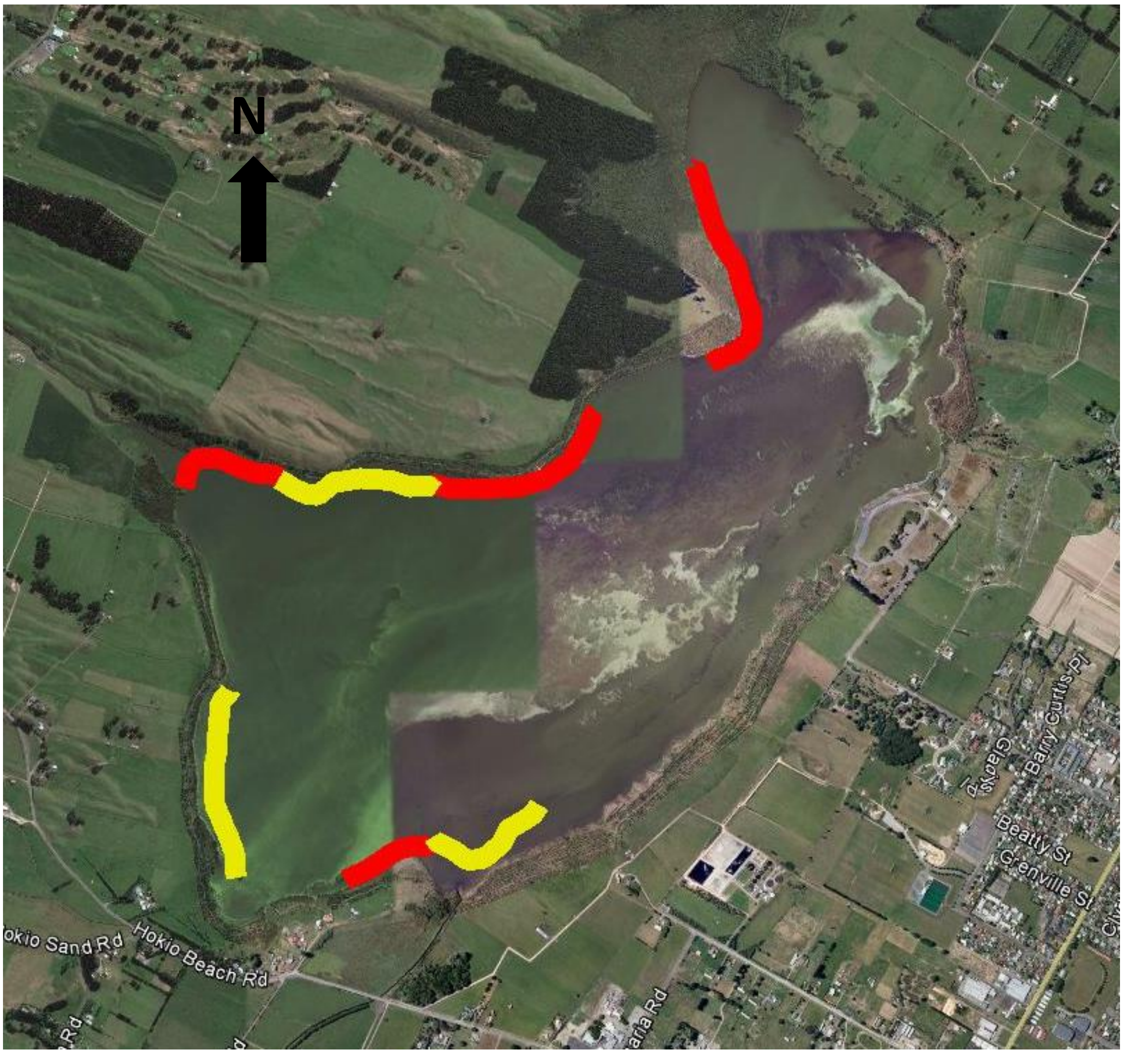


Figure 10 Comparative densities of goldfish in Lake Horowhenua. Areas marked in red represent areas where goldfish density was >2 fish/100 $m^2$, yellow areas 0.05-2 fish/100 $m^2$ and all other areas of the lake (unmarked) < 0.05 fish/ 100 $m^2$.

## DISCUSSION

Lake Horowhenua has experienced significant declines in water quality and biodiversity in its recent history (Verburg et al. 2010; Gibbs 2011). An electrofishing boat survey was carried out on the lake over 16-19 April 2013 to evaluate the state of fish populations in the lake and determine the size of pest fish populations present in the lake. Fyke nets were also set overnight as they have proven more effective than boat electrofishing when surveying eel and catfish populations.

### Native species

A combined total (fyke netting and electrofishing) of 2890 fish were caught over the four days the survey was conducted. However, fish diversity was comparatively low for a lowland lake only 5 km from the sea. Only nine fish species (assuming both longfin and shortfin eels were present) were detected, six of which were native and of those only a few specimens of inanga (6) and grey mullet (1) were collected. Native fish diversity was slightly greater than that reported by Cunningham et al. (1953) (4 species). This is not unexpected given the amount of fishing effort and improved techniques used in the current survey. However, marine wanders such as black flounder (*Rhombosolea retiaria*) and yelloweyed mullet (*Aldrichetta forsteri*) were noticeably absent from the species detected.

The most obvious explanation for the poor native fish species diversity in Lake Horowhenua is the weir on the Hokio Stream which was installed on the lake outlet in 1956 and stabilises the lake water level. The weir likely restricts the movement of native fish into the lake in all but extreme high water conditions. Limited fish migration into the lake must still occur as evidenced by the fact that a grey mullet were collected in the lake, as their life histories dictate a marine life-stage (McDowall 2000). Suggestions that the poor water quality of Lake Horowhenua is responsible for reduced native fish biodiversity (MWRC 1998; MfE 2001) appear to be overstated. While suspended sediment, hypoxia and increased water temperatures are known to have negative impacts on many of New Zealand's native fish species such as torrentfish (*Cheimarrichthys fosteri*), banded kokopu and other galaxiids (Richardson et al. 1994; Dean and Richardson 1999; Rowe et al. 2000) these species have habitat preferences for fast flowing, shaded, and well oxygenated streams. Water quality requirements for coastal and lake species such as mullet, bully's and shortfin eels have been less well studied. Numerous boat electrofishing surveys of lakes and rivers have often found extensive populations of common bully, common smelt, eels, mullet and inanga in water bodies with higher TLI's than Lake Horowhenua such as Lake Whangape and Lake Waikare (Verburg et al. 2010; Hicks unpublished data). In fact, Hayes et al. (1992) found no difference in fish communities between two turbid and clear lakes in the Waikato region.

Perceptions of a lack of native fish in Lake Horowhenua also appear to be overstated (MfE 2001). Comparisons of abundance of small fish such as common bully and common smelt collected by boat electrofishing are difficult, as the electrical field is optimised for larger fish and small fish often avoid its influence. In addition, stunned small fish are often difficult to see and retrieve in aquatic systems with low water clarity. Benthic species such as common bully and catfish are also difficult to survey as, when stunned, they often lie on the bottom beyond sight and retrieval. However, when the Lake Horowhenua results are compared to results from previous boat electrofishing surveys, the densities of common bully (0.29 fish/100m$^2$) and common smelt (0.59 fish/100m$^2$) are equivalent with those collected in other eutrophic systems such as the Whangamarino wetland (Brijs et al. 2008), Lake Ngaroto (Hicks and Brijs 2009), Lake Ohinewai (Daniel and Morgan 2011) and Lake Waahi (Hicks and Tempero 2011). Unfortunately, these densities are still well below those found in less eutrophic systems such as Lake Rotoiti in the Rotoura region where densities of common smelt and common bully were ten times those of Lake Horowhenua (Hicks and Ring 2004).

There also appears to be an abundance of eels in Lake Horowhenua with an average catch per unit effort of nearly 90 eels net$^{-1}$ night$^{-1}$. This compares favourably with the 1.82 net$^{-1}$ night$^{-1}$ for Lake Wainamu, Auckland (Rowe and Smith 2001), 4-10 net$^{-1}$ night$^{-1}$ for Lake Wairarapa (Hicks 1993), 40.8 net$^{-1}$ night$^{-1}$ for Lake Whangape (West et al. 2000) and 56-85 eels net$^{-1}$ night$^{-1}$ for Lake Waahi (Chisnall and West 1996; Jellyman and Chisnall 1999). While eels are abundant in Lake Horowhenua, mean eel weight was only 191.4 g, well below the minimum commercial size limit of 220 g set by the Ministry for Primary Industries. In fact, from observations during the release of trapped eels following processing, only five eels were likely to have been heavier than 1 kg and only one greater than 3 kg. The abundance of small eels is most likely related to overfishing (Beentjes et al. 2006), however, further research into the population structure and biomass is recommended.

The common smelt population structure was equivalent to other boat electrofishing surveys conducted in the Ohau channel (Brijs et al. 2008) and Lake Rotoiti (Blair 2012) in the Rotorua region. While no juvenile smelt were detected (<45 mm FL), the large population of adult fish in the lake suggests that the population is not being significantly influenced by perch predation. This is supported by the fact that examination of stomach contents of 90 perch taken from Lake Horowhenua found no evidence of extensive predation of smelt. Preliminary analysis of vertebrae numbers and otolith chemical signatures from Lake Horowhenua smelt show no evidence of a marine life-stage supporting the fact that the smelt population is fully lacustrine (Tana et al. 2013).

Length-frequency data of captured common bully suggests that the population in Lake Horowhenua is composed mainly of two-year-old fish with few three-year old-fish (Stephens 1982). As with the common smelt, analysis of perch stomach contents provides little evidence of extensive predation of common bully by perch.

### Introduced species

No catfish, rudd or tench were observed during the survey of Lake Horowhenua. Given the amount of fishing effort, it is highly unlikely these species are present in the lake. A single adult koi carp and five suspected goldfish-koi hybrids were captured; however, the density of these fish is below that of any reported negative ecological effects.

In New Zealand, freshwater systems dominated by perch have a characteristic population structure with very few adult fish and large numbers of juveniles (0+ and 1+ year old fish). Typically, these systems are depauperate in native fish species due to predation by the expanding perch population following introduction. Once food resources have been depleted the perch population becomes cannibalistic with adult fish spawning every year, juveniles feeding on zooplankton and the adults predating on the juveniles (Treasurer 1993; Closs et al. 2001; Hicks et al. 2007). The perch in Lake Horowhenua do not exhibit this type of population structure. Three distinct age classes can be observed in the length-frequency data (Figure 6) and while there is a significant proportion of juvenile fish (<200 mm F.L.) they are not the numerically dominant proportion of the population. Juvenile perch tend to be more active at night and night boat electrofishing surveys have successfully targeted them (Hicks et al. 2013; Hicks unpublished data). Night electrofishing in Lake Horowhenua failed to significantly increase juvenile perch catch rates, suggesting that large numbers of juveniles are not present in the lake. Research into the effects of perch introductions in New Zealand began in the late 1960s when Duncan (1967) examined the diet and population structure of perch in Lake Mahinerangi near Dunedin. Perch were found to prey almost entirely on chironomid larvae and pupae, and ate only small numbers of common bully and juvenile perch. Other studies by Barr (1968), Griffiths (1976), Closs et al. (2001) and McEwan (2009) reported extensive predation on New Zealand native fish species, in particular common bully and common smelt. Perch have also been associated with reductions in water quality through 'top-down' predatory effects on zooplankton (Rowe and Smith 2001; Rowe 2007; Smith and Lester 2007). While comparisons in fish densities are difficult to make, estimated perch density in Lake Horowhenua (0.135 fish/100m$^2$) is an order of magnitude less than those given in reports of adverse ecological effects on native fish and zooplankton by perch i.e. Treasurer (1993), Smith and Lester (2007) and Closs et al. (2001).

The effect of goldfish on aquatic ecosystems in New Zealand is relatively unknown. While they do reach densities comparable to those of koi carp, their biomass is considerably less (Hicks 2007). Wild goldfish can reach weights up to 2 kg as was found in this survey, but specimens this large are typically rare. Lake Horowhenua is a highly productive system and potential invertebrate prey for fish is prolific within the lake. The vast numbers of lake flies (chironomids) that swarm from the lake in the evening are well known in the area. Large numbers of backswimmers (*Anisops* sp.) and water boatmen (*Sigara* sp.) were observed in the lake and most of the fish caught during the survey were in excellent condition, indicating that food was abundant. It would not be unexpected that goldfish would be able to reach weights in excess of 1 kg in this system. However, koi-goldfish hybrids are known to reach sizes in excess of 2 kg (Tempero 2004) and five suspected goldfish-koi hybrids were captured from the lake during this survey. Identification of goldfish-koi hybrids can be complicated by cryptic hybridisation and while F1 male goldfish female koi carp offspring are infertile, male koi carp female goldfish offspring are fertile (Haynes et al. 2012). Given that koi carp were introduced to Lake Horowhenua approximately 40 years ago this is certainly sufficient time for a strain of fertile goldfish-koi hybrids to have arisen, as has occurred in Australia (Haynes et al. 2012). The large proportion (39/325) of goldfish in excess of 1 kg in Lake Horowhenua is unusual and may warrant further investigation if it continues to expand.

## CONCLUSION

Currently, Lake Horowhenua contains two recognised pest fish species, koi carp and perch. The population densities of both these species are well below the known threshold levels where they are like to cause ecological disturbance. Control and eradication programmes for pest fish are typically expensive and usually exceed $10,000 per ha depending on the species and method of control. Associated losses of non-target species and unforeseen ecological effects also add an unquantifiable cost. Initiation of control programmes for pest fish in Lake Horowhenua would not be cost effective at this time and would result in little benefit in increased water quality. Monitoring of the fish populations would be the most effective strategy as indications of increasing perch or koi carp populations could then be quickly responded to, preventing population densities reaching levels where impacts on the lake would become evident. Provided accidental bird capture can be avoided regular monitoring using gill netting for perch will give a simple catch per unit effort measure that will indicate changes in population density. Unfortunately, koi carp are not as susceptible to gill netting, but the low initial population density means that a boat electrofishing survey conducted every 5-6 years will be able to detect significant changes in the population. If control measures were initiated, the most effective option would be gill netting at locations of high perch density as identified in Figure 9. There are currently no known methods for controlling koi carp at their present low densities in Lake Horowhenua. But of note is one low cost approach to pest fish control currently being trialled by the Department of Conservation in Lake Whangape which is the closing of the eel fishery. The theory is that if eels in the catchment are not harvested they will become large enough to prey on pest fish species, thereby helping to control their numbers. The current effectiveness of this approach is unknown and is likely to be only anecdotal as the Department of Conservation is not currently monitoring the trial.

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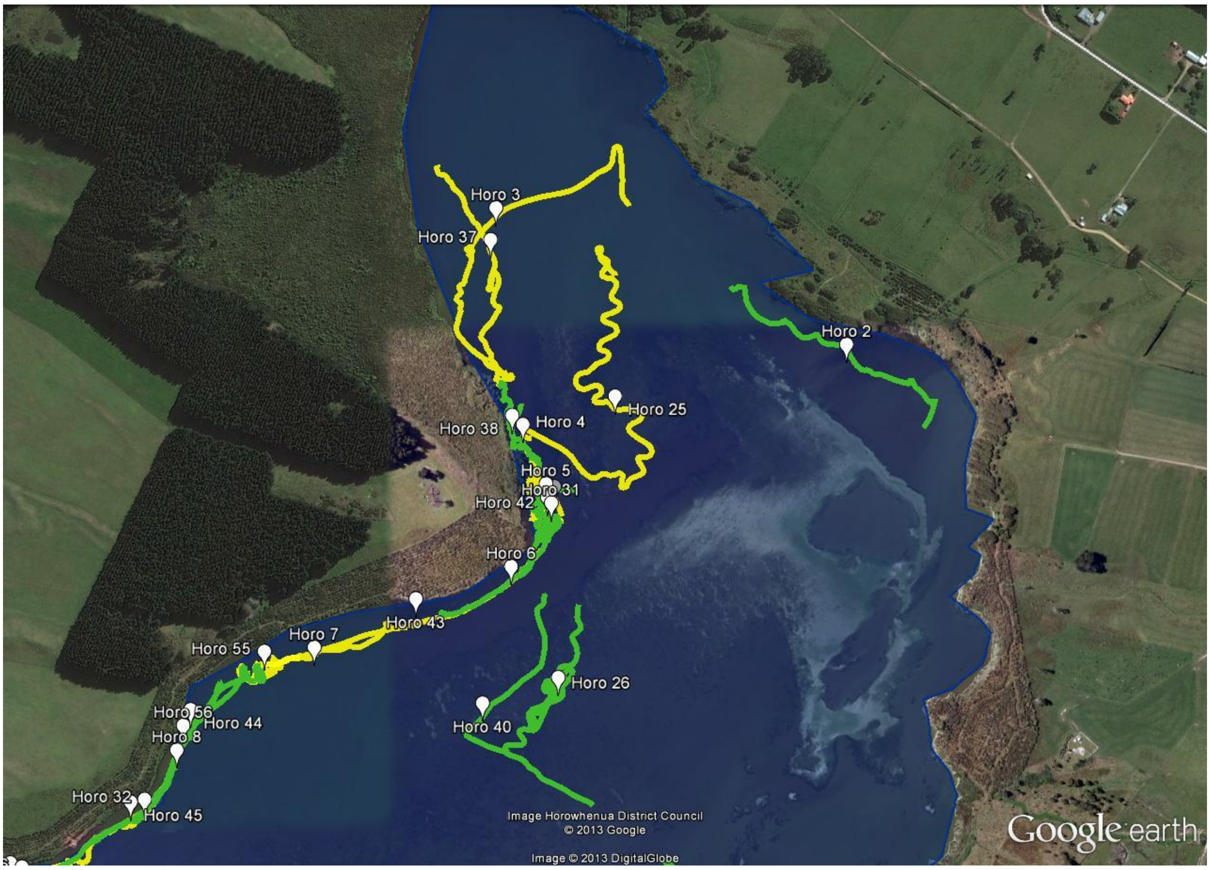
**APPENDIX 1**

Boat electrofishing transects conducted on Lake Horowhenua 16-19 April 2013. Green and yellow lines are used to differentiate transects.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Horo 60
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Horo 30
Queen St
Horo 21
Lakewood Grove
Barry Curtis Pl
Horo 22
Horo 36
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