Auckland
Regional Council
TE RAUHĪTANGA TAIAO

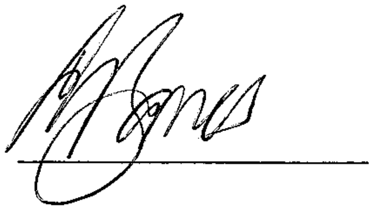
Exotic Fish in ARC Lakes

Implications for Water Clarity Decline and the Development of Restoration Options

June 2003 TR 2008/001

Auckland Regional Council
Technical Report No.001 August 2008
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877483-33-2

Approved for ARC Publication by:



Name: Grant Barnes

Position: Group Manager Monitoring & Research

Organisation: Auckland Regional Council

Date: 11 August 2008

Recommended Citation:

Rowe, D.; Hawes, I.; Smith, J; Taumoepeau, A. (2003). Exotic Fish in ARC Lakes: implications for water clarity decline and the development of restoration options. Auckland Regional Council Technical Report Number 2008/001.

Exotic Fish in ARC Lakes: implications for water clarity decline and the development of restoration options

David Rowe
Ian Hawes
Joshua Smith
Aleki Taumoepeau

Prepared for
Auckland Regional Council

NIWA Client Report: HAM2003-076
June 2003

NIWA Project: ARC03291

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

Contents

Peer Reviewed by: Approved for release by:

Jody Richardson Ian Hawes

1 Executive Summary

Exotic fish may be contributing to the decline in water quality of small ARC lakes. In particular, the recent decline in the water clarity of Lake Wainamu is thought to be related to the introduction of perch, tench, and/or goldfish, whereas the degradation of Lakes Kereta and Kuwakatai is likely to have been caused by rudd and/or koi carp. Such exotic fish are being spread around New Zealand lakes (presumably by coarse fish enthusiasts) and there is growing concern that they will degrade lake environments. Scientific proof of this, and identification of the species responsible, is needed firstly to underpin public education programmes (designed to prevent further introductions), and secondly to develop appropriate control and restoration technologies for the affected lakes.

Fish exclosures were used to see whether foraging by exotic fish disturbed the lake bed of Lake Wainamu during autumn (April-June 2003). Photographic evidence indicated a difference in the lake bed between the inside and outside of the exclosure cages. In particular, algal mats were thicker and formed earlier inside the cages than outside. These results suggest that fish foraging declines in autumn. Further experiments are therefore planned for summer months when fish foraging is maximal. Disturbance of the lake bed results in the re-suspension of fine silt into the water column with a resultant increase in turbidity. Laboratory tests indicated that once suspended, this silt takes 7 days to fully settle, provided there is no further disturbance (e.g., by wave-induced water currents).

A baseline survey was carried out in Lake Ototoa so that any future changes that occur in this lake's food web can be properly attributed to perch. Perch were introduced to this lake around 2001/2002 and their population is expected to increase rapidly over the next few years. At present, the populations of native fish are still abundant, and other exotic fish (e.g., rudd, tench, goldfish) are scarce. This may be because shag numbers are higher in this lake than in other, more turbid lakes, and because shag predation may control the recruitment of species such as rudd, tench, and goldfish. Research is required to test this hypothesis as captive shags may provide a useful bio-control agent in some lakes.

A meta-analysis for a wide range of northern New Zealand lakes revealed a strong correlation between the presence of exotic fish species and low water clarity. This relationship occurred irrespective of variations in lake size, type, depth and location. It

underscores and amplifies international concerns over the spread of exotic fish, and indicates an urgent need to identify the species responsible and how they interact to reduce water clarity. Such information is essential for the future development of restoration technologies and options for affected lakes. Lake degradation related to exotic fish introductions is a growing global concern and exotic fish introductions are the leading cause of reduced biodiversity in lakes. Such problems are now increasing throughout New Zealand but are of major concern in the more northern, warmer waters of the North Island. The species being spread in New Zealand differ from those being spread overseas, but the mechanisms of impact are likely to be similar. The main restoration techniques currently being applied overseas include eradication with rotenone or control by predators.

2 Introduction

Exotic fish species in New Zealand include rudd, perch, tench, catfish, koi carp, and gambusia. Unlike salmonids, these exotic fish all thrive in warm waters. The spread of such warm-water exotic fish into small New Zealand lakes accelerated in the 1970s and is still continuing, particularly in lakes and ponds close to major urban centres. Although information on the impact of these introductions is still being obtained, it is becoming apparent that many of these fish could pose a significant threat to the native fauna, to water quality, and to the recreational use of lake environments. Where such impacts occur, eradication or control over the exotic fish may be required, and under the Biosecurity Act 1993, regional councils now have a statutory role in enforcing such control. The role of regional councils in maintaining biodiversity is also likely to be increased in the near future. Regional councils therefore require strategies for dealing with such issues.

The Auckland Regional Council (ARC) is responsible for the water quality in a range of small lakes, including the dune lakes on the west coast of the Auckland region. In addition, it has management responsibility for recreational use in lakes within reserve areas such as Lake Wainamu. Recreational use of these lakes is important for the Auckland region because they are a scarce resource. High water quality contributes strongly to their recreational use and it needs to be maintained.

The process of eutrophication has progressively degraded water quality in a number of New Zealand and Auckland lakes. This process is now well recognised and is being increasingly managed through controls on land use and nutrient inputs. However, the introduction of exotic plant and fish species now poses a new and growing threat to lake environments. Sala et al. (2000) examined existing and future causes of reductions in biodiversity in a range of global environments, and identified new species introductions as the major threat to lakes. At present, the understanding of how invasions of fish influence water quality, and what species are mainly responsible, is rudimentary. Therefore, it is not yet possible to advise the ARC on which species require control or eradication, let alone the best methods for this.

Such knowledge is more advanced for exotic plants than for fish because plants became a problem in New Zealand lakes after the 1960s and their presence resulted in direct and highly visible problems (e.g., impairment of navigation, swimming, and blocked water intakes). As a consequence, much research has been focused on invasive plants over the past 40 years. In comparison, the spread of exotic (non-salmonid) fish started later, in the 1970s, and, although it has been steadily continuing, the effects of fish introductions on aquatic environments are indirect and therefore much less visible. Furthermore, fish introductions have often involved more than one species, so it is difficult to determine which are responsible for any observed changes.

There is an urgent need to determine the effects of exotic fish on lake water quality and to determine the species and mechanisms responsible. This information is required so that control methods can be developed and targeted at the problem species. Failure to properly identify the problem species will result in failure of control methods, wasted expense, and reluctance by the pubic and by local authorities to pursue any further control or restoration options.

In 2001/2002, the ARC commissioned an investigation to determine whether koi carp could be responsible for the increase in turbidity in Lake Wainamu. This investigation revealed that koi carp were either not present or were so rare as to be undetectable (Rowe & Smith 2001). However, this investigation noted that perch, goldfish, gambusia and tench were all present, with the former 3 species all being relatively abundant (Rowe & Smith 2001). It concluded that one or more of these species could be contributing to the high turbidity level in Lake Wainamu. However, the turbidity could also be related in part to eutrophication. Therefore, before control methods can be identified, investigations are required to isolate the cause(s) of the high turbidity in this lake and to identify the respective roles of the exotic fish species. Such information is needed to determine which, if any, species require control.

The ARC therefore commissioned a further investigation in 2002/2003 to examine the role of exotic fish in the decline of water clarity in ARC lakes, particularly Lake Wainamu and Lake Ototoa. The 2002/2003 investigations were partly supported and extended by NIWA's lake research programme, which is funded by the Foundation for Research Science and Technology. This report presents the results of these investigations and begins the task of determining the role of exotic fish in the decline of lake water quality.

Our investigation of the role of exotic fish in the decline of water clarity in Lake Wainamu (and other ARC lakes) included three components. Firstly, exclosure cages were trialed in Lake Wainamu to exclude fish from areas of the lake bed. This study was designed to see whether the exclusion of benthic fish would result in less bed disturbance and so less silt re-suspension from wind-driven, water movements.

The second study was a baseline survey in Lake Ototoa. This lake is still relatively pristine. It is one of the few lakes still dominated by native fish (both galaxiids and eleotrids are abundant) and it supports a major rainbow trout fishery (Wilson 2002). Its water quality is high and no exotic plants are present (Gibbs et al. 1999). However, perch were first reported from this lake in 2002, and both rudd and tench are present in the lake (Wilson 2002). As the proliferation of perch may impact on this lake and produce similar changes to those seen in Lake Wainamu, a baseline survey was required so that future changes in this lake can be properly quantified and attributed to the perch introduction.

A third component involved the collation of data on the water clarity and exotic fish species present in other Auckland lakes, and a meta-scale analysis of the effects of such fish introductions on water clarity. This analysis was designed to see whether any general correlations occurred, and whether a cause-and-effect relationship might exist between exotic fish introductions and a decline in water clarity.

3 Exclosure cages in Lake Wainamu

3.1 Introduction

Exclosure cages are used to exclude the browsing effects of benthic fish on the lake bed and to determine whether these fish could be contributing to the maintenance of an easily disturbed, suspendible layer of fine silt. Where there is no fish disturbance, and light can penetrate down to the lake bed, the sediment provides a substrate for plant growth. This plant growth then covers the lake bed and prevents silt re-suspension. In deeper waters, where light levels are too low for plant growth, fungal mats often provide a surface cover that could help prevent the re-suspension of silt. However, if fish browsing continually disturbs the lake bed, then plant propagules and fungal mats may fail to develop, benthic invertebrate populations can be low or composed of different species, the surface of the sediment can become broken, and silt re-suspension can occur when wind action creates lateral water movements.

In general, fish disturbance is likely to be caused by the adult stage of the larger, exotic fish species such as koi carp, tench, goldfish, and catfish. These species are mostly benthic and feed on plant material, small invertebrates, and detritus on the lake bed. However, rudd and perch, which are schooling fish, and which generally feed in the littoral zone, may switch to benthic feeding when littoral foods become scarce. They could also contribute to sediment disturbance in lakes where littoral macrophytes decline, such as Lake Wainamu.

Exclosure cages need to be monitored over a relatively long period, firstly to ensure that no large fish enter the cages, secondly to determine changes in both the appearance and composition of the sediment, and thirdly to identify any biotic changes such as plant growth or invertebrate community changes. Where fish browsing is believed to inhibit plant growth, cages are placed in shallow waters were there is sufficient light to support the germination of seedlings. Such sites are very limited in Lake Wainamu because of its relatively steep sides and are restricted to the southern end of the lake.

3.2 Methods

Two exclosure cages were constructed of stainless steel frames (800 x 800 x 600 cm high) and covered with 20 mm plastic mesh on all sides, including the hinged top. They were placed over a bare area of the lake bed in the southern end of Lake Wainamu by SCUBA divers on 10th April 2003. They were positioned in approximately 1.6-1.8 m of water so that some light was able to penetrate to the lake bed and allow plant growth. These cages excluded fish from the part of the lake bed enclosed by the cage, and observations and measurements of the lake bed, both inside and outside the cages were used to reveal differences related to fish disturbance. However, as the mesh tops and sides of the cages may inhibit light penetration and restrict silt settlement on the lake bed, and as these effects could compound the effects of fish exclusion, two further cages were set up as controls. One of these had mesh sides but no top. This cage allowed fish access, but it restricted lateral movement of silt and produced edge effects. The other cage had a mesh top but no sides allowing fish access, but restricting light and the vertical settlement of silt. The 2 exclosure cages and the 2 controls were placed in the same general area, and the lake bed in each cage was photographed to determine its surface structure. Sediment samples (n = 2) were also taken from each cage for later analysis of invertebrate composition as, over the long term, this could be expected to increase in the cages that excluded fish. The cages were re-inspected, photographed and further sediment samples taken on 15th May and 4th June 2003.

A sample of the sediment from the bed of Lake Wainamu was obtained and placed in a 500 ml beaker and mixed with pure clean water to create a turbid suspension. This turbid water was then placed in the dark, and in a fridge (to inhibit plankton growth and biological production), and the silt was allowed to settle. The turbidity level was measured with a Hach turbidometer at approximately 66, 90 and 120 hrs, and then after 7 days, to determine how quickly the silt would settle in the absence of any further disturbance.

3.3 Results

When the exclusion cages were first installed (10th April), the lake bed was composed of a layer of silt overlying fragments of plant debris (Fig. 1). An algal mat was present in places, but was thin and sparse. By 15th May (4 weeks after installation), larger patches of a green algal mat were observed on the lake bed, but they were both thicker and more prevalent within the fish exclosures (Fig. 2). By 4th June, the algal mat had become more extensive and covered much of the lake bed outside the cages (Fig. 3), whereas there was little apparent change inside the cages.

The exclusion cages successfully excluded browsing by large fish (perch, tench, goldfish, mullet), so the changes within them can be attributed primarily to a lack of fish. However, sediment sampling produced localised disturbance within each cage.

Figure 1:
Appearance of the lake bed on 10th April, at the start of the exclusion trials.

Figure 2:
Thicker 'plates' of algal mat growing; (A) inside the cages versus, (B) outside the cages on 15th May 2003.

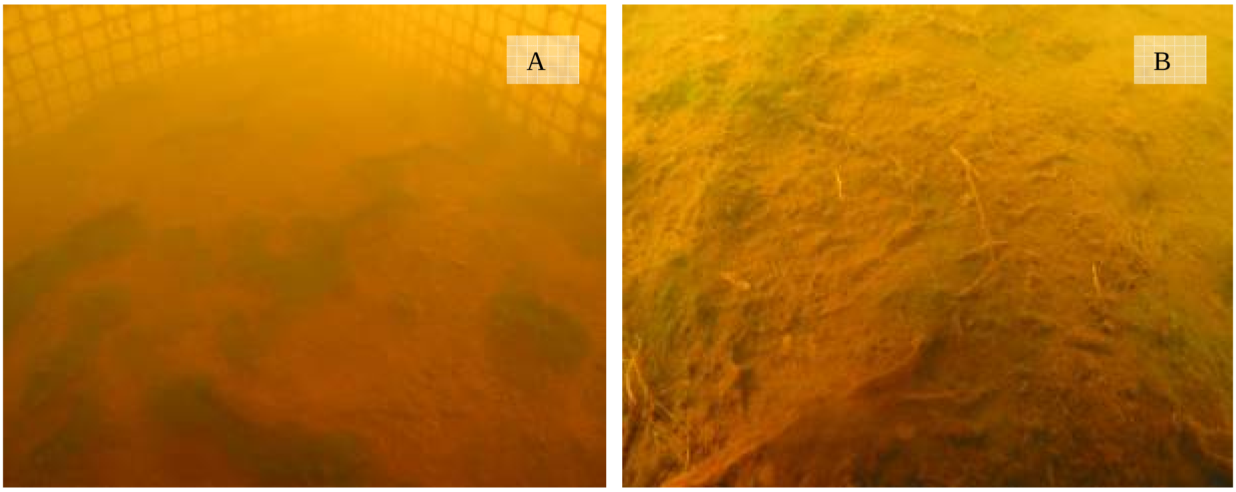
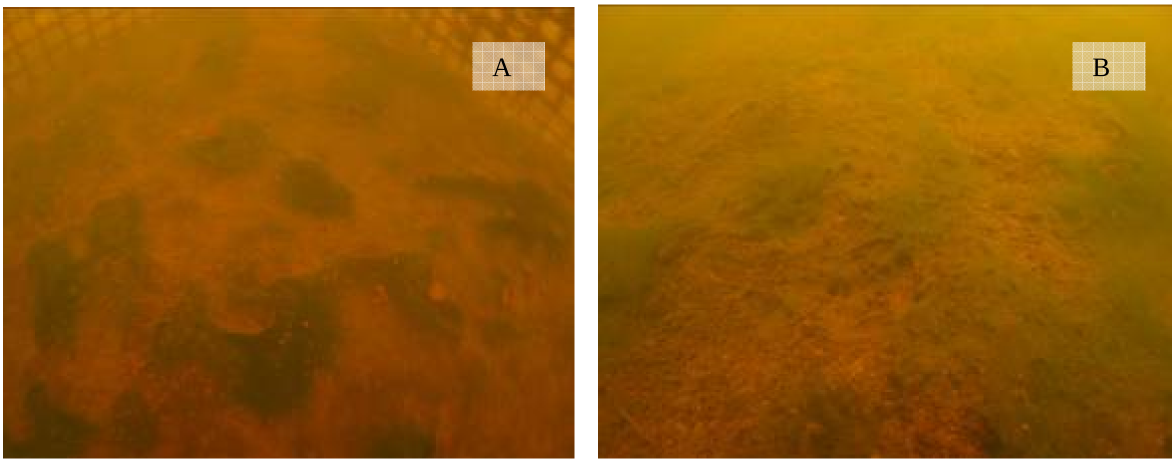
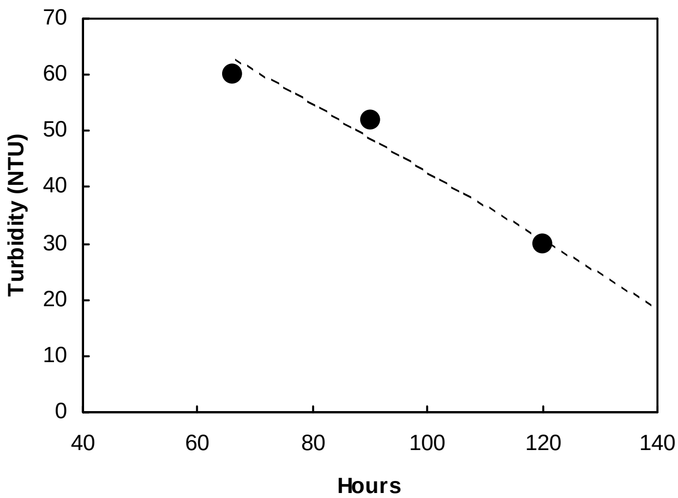


Figure 3:
More extensive growth of the 'thick plates' of algal mat; (A) inside the cages versus, (B) outside the cages, on 4th June 2003.



Sediment from the bed of Lake Wainamu had a turbidity of 60 NTU after 66 hours. This is relatively high. It prevents objects 5 cm away from being seen, and it is 3 times greater than the level resulting in reduced feeding by sensitive native fish species (Rowe & Dean 1998). By 90 hours the turbidity level had only dropped to 52 NTU and by 120 hours it was 30 NTU (Fig. 4). Seven days after mixing, the water was relatively clear and the turbidity level was less than 5 NTU.

Figure 4:
Decline in turbidity over time for silt from Lake Wainamu.



3.4 Discussion

The algal mat that covered much of the lake bed less than 2 m deep by 4th June would have prevented re-suspension of fine silt by wind-driven wave action and lateral water movements. Its complete absence in April, and presence over much of the shallow lake bed by June, indicates a seasonal growth effect. However, such algal growth would be expected more in spring and summer when water temperatures are rising and light levels are increasing, than in autumn, when temperatures are dropping and light levels are declining. The autumnal growth of algae on the lake bed may therefore represent a general reduction in browsing pressure and lake bed disturbance by the exotic fish present. The faster growth of the algal mat in the exclosures is consistent with the absence of fish browsing and disturbance in these microcosms, and it reinforces this hypothesis.

Autumn is not the best time of year to test the effects of fish browsing on lake bed disturbance, so the exclosures will be left in for a further month to monitor any further changes. They will then be removed and re-established in December 2003, when fish browsing is likely to be maximal.

The data on silt settling rates indicated that, in a 15 cm deep beaker, it took approximately 7 days for the turbidity caused by silt re-suspension to drop to less than 10 NTU (i.e., relatively clear water). In Lake Wainamu, silt settlement over the deeper depth range present between the surface waters and the lake bottom (i.e., 1-2 m) would take much longer, and this assumes that no re-suspension caused by wave-induced water movements would occur within this period.

There are no data on water movements and currents in Lake Wainamu, but given its narrow shape, 800 m fetch, and susceptibility to south-westerly winds, subsurface lake-wide currents can be expected at reasonably frequent intervals. The re-suspension of silt from the bottom of Lake Wainamu into the water column of this lake could therefore contribute to its high turbidity.

4 Lake Ototoa fish survey

4.1 Introduction

Perch were the main exotic fish species present in Lake Wainamu (Rowe & Smith 2001). As they are a top-predator, they may be responsible for a number of faunistic and food-web changes in this lake that combine to increase algal (phytoplankton) turbidity and/or silt re-suspension from lake-bed disturbance. At present it is not possible to test this hypothesis in Lake Wainamu, as data prior to the introduction of perch are lacking. However, the recent introduction of perch into Lake Ototoa provides an ideal opportunity to test it and to identify the role of perch on dune lake ecosystems. In this sense, changes in Lake Ototoa are expected to provide a model for the impact of perch in Lake Wainamu, and so help identify the role of this species in this and other dune lakes.

The recent introduction of perch to Lake Ototoa also has implications for the regionally significant trout fishery in this lake (Wilson 2002) as well as for the DOC conservation strategy covering the rare and threatened galaxiid (*Galaxias gracilis*, commonly called dwarf inanga). Perch can be expected to proliferate in Lake Ototoa and to compete with the stocked trout for food. In addition, large perch are voracious piscivores so they can be expected to reduce the galaxiids, especially the dwarf inanga, which is a major prey for trout, and the land-locked population of banded kokopu (*Galaxias fasciatus*). If so, this top-predator will not only reduce the trout fishery, but will also significantly reduce the conservation and biodiversity values of this lake. This is apart from its potential role in restructuring the lake's food-web, which could result in a decline in water clarity as has occurred in Lake Wainamu.

Because perch can be expected to change the abundance and distribution of other exotic fish species as well as the native fish species in Lake Ototoa, a general fish survey was required to provide baseline data on the relative abundance of each species. Future monitoring, using the same methods, can then be used to quantify any significant changes in fish abundance and/or in species dominance.

4.2 Methods

A survey was carried out in Lake Ototoa to measure the relative abundance of native fish species (common bully and dwarf inanga) and to determine the relative abundance of exotic fish, particularly perch, rudd and tench. The standard survey, as used in Lake Wainamu (Rowe & Smith 2001), was repeated in Lake Ototoa between 1st-4th April, 2003. Thirteen sites were selected around the lake to cover the different habitat types (e.g., shallow vs. deep, sheltered vs. exposed shores), as well as all margins and quadrants (i.e., N, S, W, E) of the lake (Fig. 5). Sampling was restricted to waters shallower than 16 m as a preliminary acoustic survey across the lake revealed that hypolimnetic deoxygenation was present (Fig. 6). This was confirmed by recent ARC field studies (Hawes & Haskew 2003) and it restricts fish to waters shallow than this.

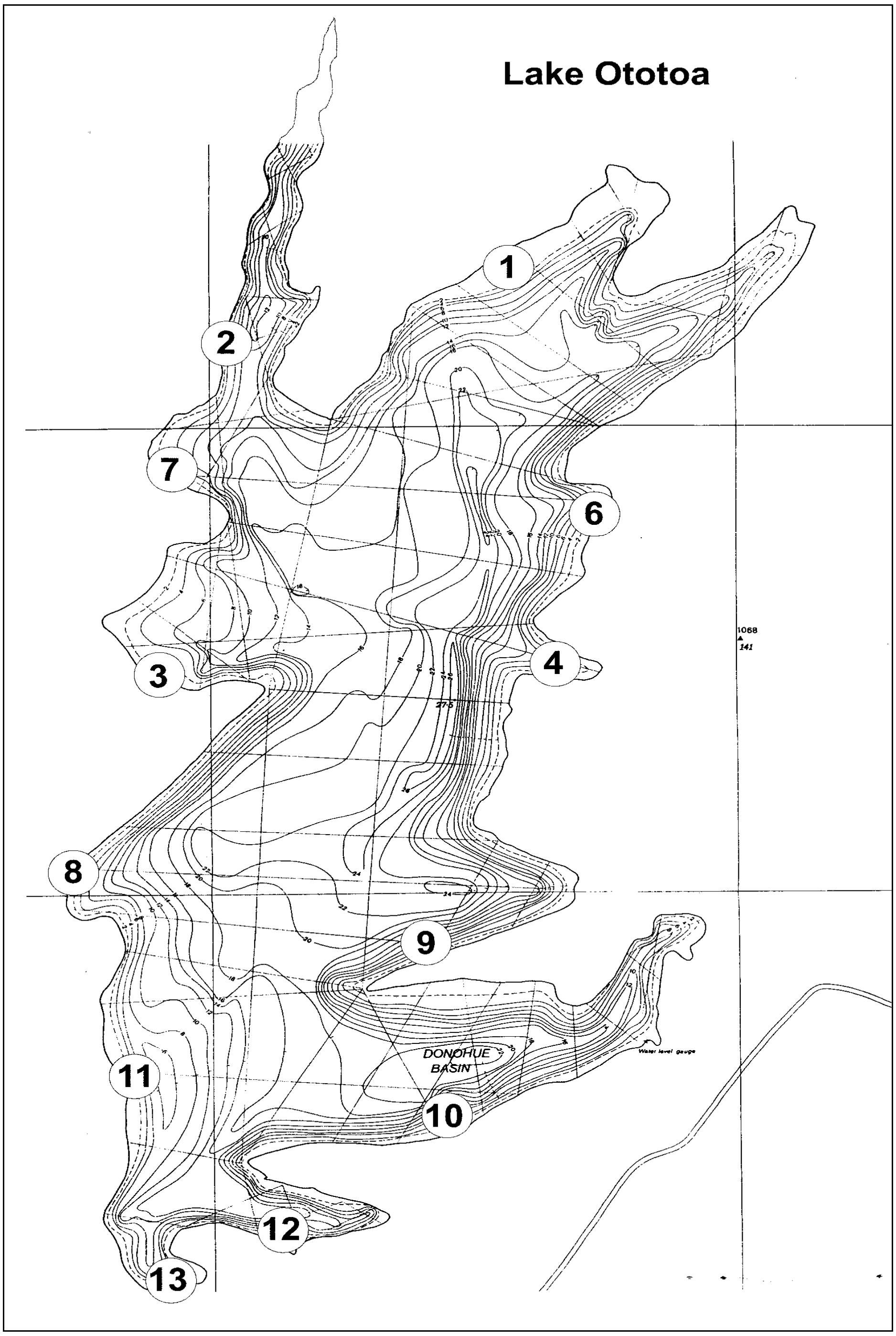
At each site, we placed a 30 m long by 1.5 m deep monofilament nylon, sinking, gill net perpendicular to the lake edge. The three 10 m long panels in the net contained meshes of 60, 90 and 115 mm respectively. Each net was set with the smallest mesh onshore in water depths of 1-2 m and the largest mesh offshore at depths of 5-15 m. In addition, a small (unbaited) fyke net (mesh size 5-6 mm) was set in shallow waters (0-2 m) at each site, and a string of 4 baited minnow traps (5 mm mesh) set from the shoreline out to a depth of approximately 5 m. The approximate depth (± 0.5 m) of each trap was noted. These traps and nets were set during the late afternoon and lifted in the early morning, so were fished for approximately 16 hours over the dusk, night and dawn period.

The number and species of each fish (including crayfish) caught by each method was recorded for each site. The length of fish was also recorded for all the larger fish species and for subsamples of common bullies (*Gobiomorphus cotidianus*) and dwarf inanga.

Gambusia (*Gambusia affinis*) were observed in very shallow water in the southern end of the lake, but not in the northern end. Visual surveys were therefore carried out at a number of sites in the southern end of the lake to determine its presence/absence and hence the extent of its distribution.

Figure 5:

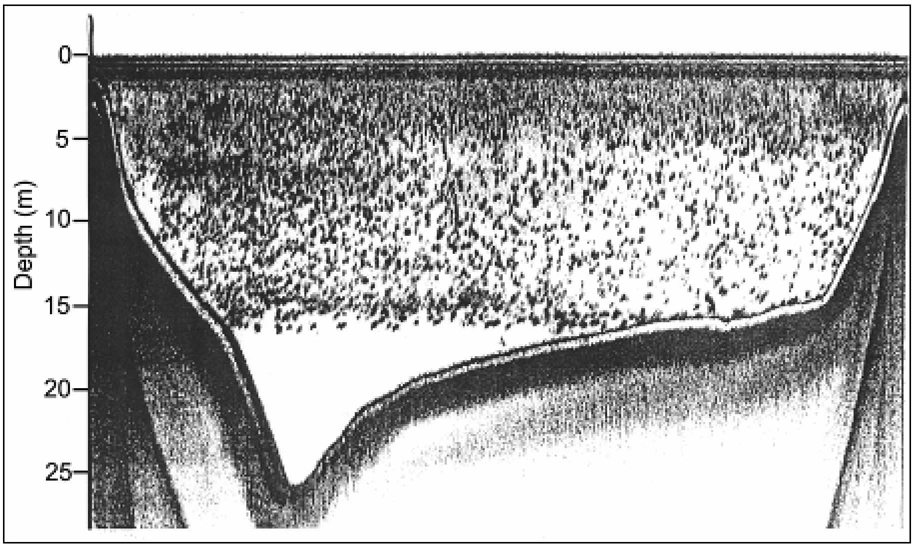
Sampling sites in Lake Ototoa, 1st-3rd April, 2003.



4.3 Results

The acoustic profile for this lake taken on 1st April 2003 revealed the absence of fish echoes below about 16 m (Fig. 6).

Figure 6:
Acoustic profile of fish depth distribution in Lake Ototoa taken with a high frequency (200 kHz) JMC echosounder across the middle of the lake.



Overall, 3271 fish were caught and processed from Lake Ototoa in April 2003 (Table 1). All native species, including crayfish, were returned to the lake alive. This was not possible for the larger exotic fish species, as they were damaged in the gill nets.

Nine species of fish were found in Lake Ototoa (3 native, and 6 exotic), however, rainbow trout cannot be considered a true resident species as it cannot breed in this lake. Annual stocking is required to maintain its population.

The relative abundance of perch, as measured by gill net catches, was 1.8 (SE 0.6) perch net-1 night-1. This is very similar to the mean of 1.7 perch net-1 night-1 (SE 1.7) for the same nets in Lake Wainamu. The size range of perch in these lakes was also similar. In Lake Ototoa, most perch were between 180-305 mm compared with 195-260 mm in Lake Wainamu. However, a few large perch (FL 360 and 450 mm) were present in Lake Ototoa. None of the smaller size classes (FL 90-105 mm) of perch that were present in Lake Wainamu were caught in Lake Ototoa.

Table 1:

Species of fish and crayfish present in Lake Ototoa.

No.	Species	Common name	Number caught	Size range (mm)
	Native			
1	*Gobiomorphus cotidianus*	Common bully	2282	20-65
2	*Galaxias gracilis*	Dwarf inanga	787	32-74
3	*Galaxias fasciatus*	Banded kokopu	1	80
4	*Paranephrops planifrons*	Crayfish	145	30-130
	Exotic			
5	*Perca fluviatilis*	Perch	25	195-445
6	*Oncorhynchus mykiss*	Rainbow trout	19	365-490
7	*Scardinius erythrophthalmus*	Rudd	6	195-370
8	*Tinca tinca*	Tench	4	400-490
9	*Carassius auratus*	Goldfish	1	170
10	*Gambusia affinis*	Gambusia	--	15-25
	Total fish		**3271**	

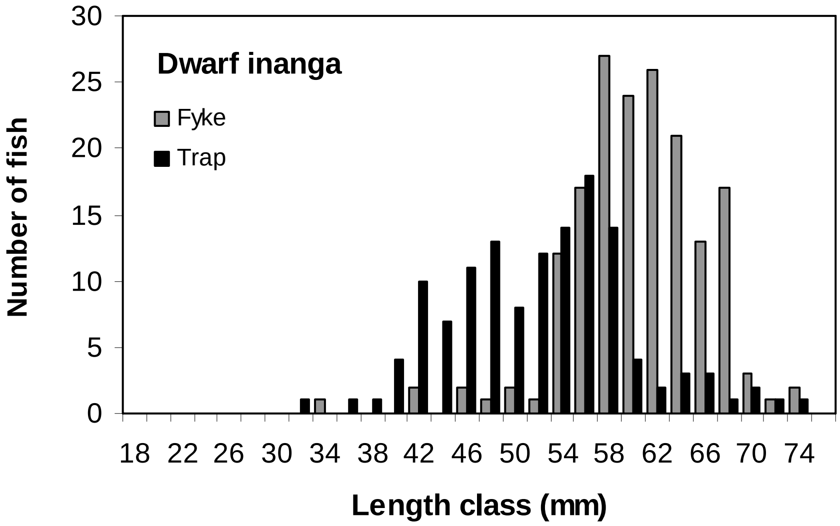
Goldfish, rudd and tench were all comparatively rare in Lake Ototoa. Only 1 goldfish (170 mm long) was caught compared with 26 in Lake Wainamu. The 4 tench were all between 400-490 mm long, and the 6 rudd were between 190 and 370 mm long. The size frequency distribution of rudd included two size classes.

The mean catch per unit of effort (CPUE) for dwarf inanga was 27.8 fish net-1 night-1 (SE 5.7). Fyke net data on this species' relative abundance in other North Island west coast lakes indicates that they are 'abundant' if the mean CPUE exceeds 20 fish net-1 night-1, are 'common' if the mean CPUE is between 10-20, and are 'rare' if it is less than 10 (Rowe & Chisnall 1997). Dwarf inanga were therefore abundant in Lake Ototoa in April 2003.

Minnow traps also caught dwarf inanga, but they were present mainly in traps set in the shallows (0.5-1.5 m), and were rarely caught in traps set in deeper (>2 m) waters. The size range of the dwarf inanga caught was the same for both fyke nets and minnow traps, but the fyke nets caught more larger fish than the traps (Fig. 7).

Common bullies were also abundant in Lake Ototoa. Their mean CPUE in the fyke nets was 104.8 fish net-1 night-1 (SE 16.4). This figure compares well with the predicted range of 70-80 fish net-1 night-1 from the regression of bully abundance on secchi disc depth for other small North Island lakes (Rowe 1999). The mean is lower than the range of 500-1000 typically occurring in eutrophic lakes and higher than the 10-50 range for oligotrophic lakes.

Figure 7:
Differences in the size distribution of dwarf inanga caught in fyke nets and trap nets in Lake Ototoa.



Minnow trapping also indicated that the abundance of bullies was relatively high in Lake Ototoa. Trap catches of common bullies in lakes vary with depth, with the maximum abundance usually occurring between depths of 10-12 m (Rowe et al. 2001, 2003). However, minnow traps in Lake Ototoa were restricted to depths above 5 m. There was no significant relationship between catch rates and depth (ANOVA, F = 1.44, P = 0.22), so catches were pooled for all depths, and the overall mean was 70.7 fish trap^{-1} night^{-1} (SE 13.6). This value is above the range of 10-15 bullies trap^{-1} night^{-1} for water depths of 0-5 m in other lakes (Rowe et al. 1999a, 2001), and well above the mean of 0.5 bullies trap^{-1} night^{-1} (SE 0.5) for Lake Wainamu. Therefore, common bullies are still relatively abundant in Lake Ototoa, but are comparatively scarce in Lake Wainamu.

Crayfish were also relatively common in Lake Ototoa. Mean catches in fyke nets were 10.2 (SE 2.4) fish net-1 night-1 and in minnow traps were 12.0 (SE 0.3) fish trap-1 night-1. The fyke net catches of crayfish in Lake Ototoa compare well with mean catch rates of 3-7 fish trap-1 night-1 in Lake Taharoa and 7-20 fish trap-1 night-1 in Lake Waikere, which are both relatively pristine, west coast, dune lakes in Northland (Rowe et al. 1999b).

4.4 Discussion

Perch are clearly breeding in Lake Ototoa. At least two year classes were found in the autumn 2003 survey, and a recently hatched juvenile (35 mm) was caught during a summer survey in December 2002 (B. Wilson, pers. comm.). The abundance of 'adult' perch, as assessed by gill net CPUE, was no different to that in Lake Wainamu, indicating that the adult population is already large. However, the relative abundance of juveniles is unknown.

Similarly, rudd, tench and goldfish are all likely to be breeding in this lake, despite their relatively low abundance. Goldfish were thought to be present in Lake Ototoa as early as 1952 (Cunningham et al. 1953) and have been reported sporadically since 1979 (Wilson 2002). Rudd and tench were illegally introduced into the lake between 1970-1974, and a few large adults have been caught in the lake over the past 30 years (Wilson 2002). The absence of juvenile fish and the very low numbers of these three species in this lake might suggest that they are not breeding, and that regular stocking is occurring (Wilson 2002). However, breeding by all three species readily occurs in other similar lakes, and periodic stocking over a period of 30 years, without breeding becoming established, seems unlikely. An alternative hypothesis is that these species are breeding in Lake Ototoa but that their juvenile mortality is very high, resulting in a low population density. Evidence that breeding is occurring is provided by the capture of goldfish over many years without any stocking; by the capture of a relatively young (165 mm long) tench in December 2002 (B. Wilson, pers. comm.), and by the capture of rudd from two year classes in April 2003 (this survey).

Mortality rates of rudd and tench were closely related to shag predation in Lake Parkinson (Rowe 1984). Shags were present at Lake Ototoa, where water clarity is high, but were absent at Lake Wainamu, where it is low. A difference in the relative abundance of shags between these two lakes may account for differences in the abundance of certain exotic fish species between these lakes. For example, high shag predation in clear waters may partly explain the low numbers of rudd, and goldfish in Lake Ototoa, whereas the scarcity of shags in the more turbid Lake Wainamu could account for the high abundance of goldfish in this lake. This hypothesis needs to be explored further as, if shags can control exotic fish in clear lakes, 'captive' shags may provide a useful means of control for some exotic fish species in more turbid lakes.

The absence of fish echoes in the bottom waters of lakes during summer months is common in small lakes that stratify, and occurs because of low oxygen levels. The lower limit for fish generally occurs where oxygen concentrations are below 2.5 mg l-1 (Rowe & Chisnall 1995, unpubl. data), because fish cannot survive below this concentration for any length of time. Hypolimnetic deoxygenation therefore reduces the volume and depth of fish habitat in lakes during summer months. Hawes & Heskew (2003) found that the depth of anoxic water ranged from 12-19 m in Lake Ototoa during the 2003/2004 summer. This indicates that the volume of fish habitat in this lake is restricted in summer months and that the presence of benthic invertebrates and hence fish foraging may be confined to waters above 12 m for much of the year.

Oxygen depletion of bottom waters in lakes (i.e., hypolimnetic deoxygenation) occurs when they stratify and the cooler layer of deeper water (hypolimnion) receives little or no oxygen. The extent of hypolimnetic deoxygenation increases as lakes become more enriched or eutrophic. Therefore, a decrease in the depth of fish echoes indicates that the lake has become more enriched, that a larger zone of oxygen depleted water is now present, and that the conditions are being created which could soon lead to the release of nutrients bound up in lake sediments. When this occurs, a positive feedback cycle for nutrient increase can occur and, in shallow lakes, this can lead to lake decline. The additional nutrients released from the lake bed by hypolimnetic deoxygenation produce more planktonic algae, and this results in a greater hypolimnetic deoxygenation. In turn, increased hypolimnetic deoxygenation covers a greater area of lake bed and releases more nutrients from the sediments. The increasing levels of nutrients in the water column can eventually lead to algal blooms and increased lake turbidity. This process can eventually result in macrophyte collapse, which produces a further influx of nutrients and a further decline in water clarity. Avoidance of any increase in hypolimnetic deoxygenation is therefore critical for small dune lakes such as Ototoa. Catchment control over nutrient inputs is a key to this, however, control over exotic fish (which are thought to enhance internal nutrient cycling and increase lake turbidity) may also be important.

5 Analysis of data on exotic fish and water clarity in small lakes

5.1 Introduction

High densities of warm-water, cyprinid fish have been recently implicated in the decline of water quality in many small European lakes. As yet, the mechanisms for such impacts are unknown, but are thought to be related to a combination of top-down predatory effects on plankton communities, bio-perturbation of sediments, and/or greater nutrient recycling (e.g., Richardson et al. 1995; Tatrai et al. 1996, 1997; Berg et al. 1997; Bergman et al. 1999; Perrow et al. 1999; Hamrin 1999). The overseas evidence for the impact of such fish on water clarity is therefore strong, and control of such fish by either predators (e.g., pike), pond drainage, or by chemical methods (rotenone) has resulted in significant improvements to the water clarity of affected lakes (i.e., Van Donk 1987; Giussani et al. 1990; Annadotter et al. 1999).

A number of warm-water cyprinid species are now present in New Zealand (e.g., koi carp, rudd, tench, goldfish), whereas other large, exotic species (e.g., catfish, perch) are capable of contributing to the mechanisms that result in water quality decline in lakes. More importantly, all of these species are invaders, and they have the ability to change the food web structures within New Zealand lakes, just as terrestrial invaders introduced to New Zealand have impacted both the native fauna and flora of forests.

At present, there is little direct evidence that exotic fish can degrade the water clarity of New Zealand lakes. However, the overseas experience with such fish, and a biomanipulation study carried out in New Zealand (Rowe & Champion 1994) indicate the potential for this. Given the recent spread of exotic fish in New Zealand, it is timely to take an overview of the effects of such fish on small New Zealand lakes, and to determine whether these environments could be affected by exotic fish introductions.

Such an investigation could be achieved by a before-and-after study as is now being set up for Lake Ototoa (see previous section). However, biotic changes can take many years (>5) to occur. Therefore, a faster study design is needed. Comparative studies that substitute space for time can provide this. In this approach, a small group of similar environments containing exotic fish species is compared with a group of comparable environments lacking these species. However, this approach is impractical when applied to New Zealand lakes, as most differ markedly in character as well as in location and fish species composition. Therefore, a broader-scale approach is warranted in which a very large group of lakes with exotic fish species is compared with an equally large group without exotic species. A potential problem with this design is that the wide variation among lakes can overwhelm and obscure any effects of exotic fish, unless the fish effects are both widespread and major (i.e., unless exotic fish are a significant ecological problem). However, this limitation is useful if the aim of the study is to see whether the effects of exotic fish are a significant and widespread issue, and therefore of concern. This design was therefore adopted to determine whether exotic fish could influence the water clarity of small lakes in the top half of the North Island.

5.2 Methods

The presence/absence of breeding populations of exotic fish species (i.e., one or more of: koi carp, rudd, tench, perch, catfish, and goldfish) was determined for lakes in the Auckland region and for lakes in the top half of the North Island (north of Hamilton) using the NZ Freshwater fish database and the various reports on these lakes produced over the past 50 years by MAF Fisheries, Acclimatisation Societies, Fish & Game Councils, Catchment Boards and Regional Councils. A database was created to record these data and now includes 72 lakes. Gambusia was excluded from this list, as although it may impact on small native fish, its effect on lake water quality is limited to small ponds and/or small, shallow lakes lacking predators.

The maximum depth and the most recent secchi disc data (measuring the water clarity of these lakes) were also collated and added to the database. Secchi disc data were restricted to summer measurements because water clarity can vary seasonally, and summer values more accurately reflect the impact of exotic fish on lake ecosystems.

Analysis of the data involved comparing the water clarity of lakes lacking exotic fish with those containing exotic fish. As lake depth can play an important role in moderating water clarity in lakes (i.e., shallow lakes are more prone to increased turbidity than deep lakes), depth was included as a co-factor in the analysis to reduce some of the variability among the lakes. Analysis of covariance was therefore used to determine significant differences in water clarity between the two groups of lakes (with and without exotic fish), irrespective of differences in lake depth.

5.3 Results

Of the 72 lakes for which some data were available, the presence/absence of exotic fish could be confirmed in 61, and recent data on water clarity was available for 49. Twenty two of these lakes do not contain exotic fish, whereas 27 do.

An initial analysis of the entire data set indicated that water clarity was positively correlated with lake depth ($r = 0.52$, $P < 0.01$), but that the presence of man-made reservoirs confounded the separation of lakes with and without exotic fish species. When reservoirs were excluded because their water clarity is influenced by factors that don't apply to lakes (i.e., much lower water residence times), overlap between the lakes with and without exotic fish species declined markedly and a clear separation became apparent (Fig. 7). As reservoirs constitute a separate type of water body, they would need to be analysed separately. In this respect, the 3 reservoirs lacking exotic fish all had a higher secchi disc depth, and therefore clearer water, than the 3 reservoirs containing exotic fish. But they were also deeper.

The water clarity of the lakes lacking exotic fish ($n = 18$) was positively and strongly correlated with lake depth ($r = 0.81$, $P < 0.001$). This positive relationship between lake depth and water clarity also held for lakes containing exotic fish ($n = 25$), but was weaker ($r = 0.60$, $P < 0.001$).

The slope of the regression for water clarity on lake depth was over 6 times higher for lakes lacking exotic fish than for lakes containing exotic fish (Fig. 7, Table 2). The difference was highly significant (ANCOVA, $F_{interaction} = 33.4$, $P < 0.001$) and indicates that water clarity was much higher in the lakes lacking exotic fish, especially the deeper lakes.

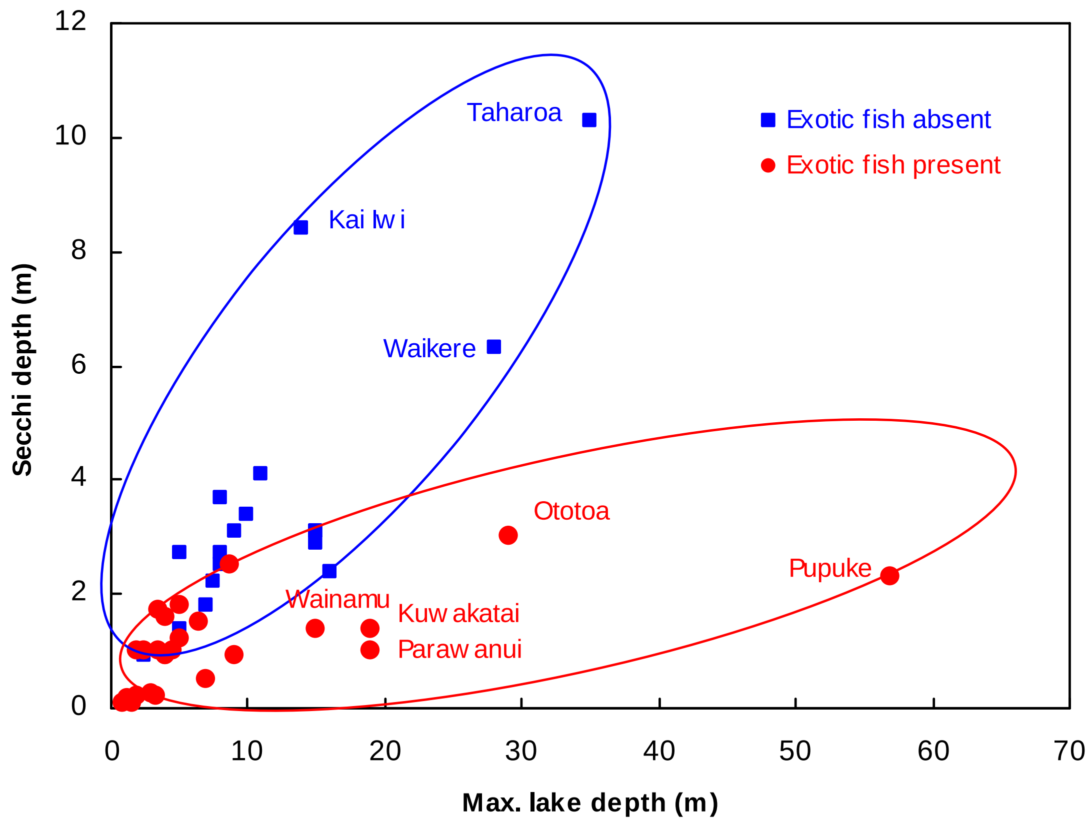
Table 2:

Results of regression analysis for water clarity on lake depth for lakes with and without warm-water exotic fish species, and for reservoirs.

Water body type	N	Slope (b)	Intercept (a)	R^2
Lakes with no exotic fish	19	0.24	0.61	0.67
Lakes with some exotic fish	24	0.04	0.77	0.36
Reservoirs	6	0.06	0.92	0.70

These results could arguably be influenced by an effect of exotic fish in the few deep lakes present. However, when the data set was restricted to lakes less than 10 m deep, there was still a highly significant difference in water clarity between them (ANOVA, $F = 27.7$, $P < 0.001$). Overall, the mean secchi depth of lakes with no exotic fish was 3.6 m compared with 1.1 m for lakes with exotic fish (i.e., a 69% reduction).

Figure 7:
The water clarity and maximum depth for lakes with and without exotic fish species. Ellipses enclose all data points for all lakes with and without exotic fish respectively.



5.4 Discussion

Incorporation of lake depth into the analysis of the effects of exotic fish on lake water clarity removed much of the variability in this relationship and revealed a strong correlation between the presence of such fish and reduced water clarity. This effect is more marked in the deeper lakes than in the shallower ones. However, even when the data set was restricted to lakes less than 10 m deep, the effect of exotic fish on water clarity was still marked.

Although these results strongly suggest the existence of a cause-and-effect relationship between exotic fish and a decline in lake water clarity, such an association may be coincidental. For example, exotic fish may only survive in turbid lakes and not in clear ones. Alternatively, they may only be stocked into the more turbid lakes. While such possibilities present theoretical limits to the interpretation of these data, field data on the distribution of these fish in New Zealand indicates that such limits are not particularly plausible, nor convincing. The spread of exotic fish has been widespread in the top half of the North Island and they have been introduced to large and small lakes, as well as to eutrophic and oligotrophic lakes. Nevertheless, uncertainty remains because the mechanisms for such effects are unknown. This uncertainty underscores the need for a before-and-after study to provide more conclusive results, and/or a bio-manipulation experiment to remove all exotic fish from a lake. The latter technique has been recently adopted in European lakes to confirm the deleterious role of exotic fish on water clarity and to restore lakes. In this respect, a biomanipulation study, such as that successfully carried out in Lake Parkinson in 1980 to remove all exotic fish species (Rowe & Champion 1994), could be used to both confirm the role of exotic fish in lake water clarity decline, and to restore an already degraded lake. However, future monitoring in Lake Ototoa will also be important.

Lake Kuwakatai is a small, somewhat isolated lake on the North Kaipara Head south of Lake Ototoa. It contains exotic fish (including rudd, tench, koi carp, goldfish and gambusia) as well as invasive plants and is now characterised by low water quality and high levels of suspended solids (Gibbs et al. 1999). It is therefore well suited for a biomanipulation study designed to eliminate exotic fish and to measure the expected improvement in water clarity. The same methods used to eradicate the exotic plant (*Egeria densa*, Argentinean pond weed) and exotic fish (carp, rudd and tench) from Lake Parkinson (Rowe & Champion 1994) could be readily applied to this lake to eradicate its exotic fish. However, a preliminary feasibility study would be required to present arguments for and against such a proposal, to examine other issues or problems that may arise, and to detail the methods required, the logistics involved, the timing, and the likely costs. A feasibility study, framed within the context of exotic fish impacts on lakes, would provide a basis and catalyst for the various management agencies involved in exotic fish control in the Auckland region (e.g., ARC, DOC, Fish & Game) as well as stakeholders (e.g., Landcare groups, property holders, iwi, angling groups) to consider both strategies and specific actions for dealing with the problem of exotic fish.

6 Summary and Recommendations

1. Exclosures on the bed of Lake Wainamu excluded all large fish during autumn and allowed a faster growth of mat-forming filamentous green algae. It is recommended that a further exclusion experiment be carried out in summer, when browsing activity by the exotic fish in this lake will be greatest.
2. Perch have not yet reduced the abundance of native fish in Lake Ototoa, but will do so if their numbers increase over the next few years. As top predators, they may precipitate changes in the food web of this lake, resulting in reduced water clarity, increased survival of other exotic fish species, and eventually macrophyte collapse, algal domination, and a decline in both water quality and amenity value. It is imperative that the future biotic and water quality changes in this lake are carefully monitored so that; (1) managers have advance warning of any sudden deterioration, (2) the mechanisms by which exotic fish degrade lakes can be better understood, and (3) the role of perch in water clarity decline can be clarified. The information gained will be important for the development of targeted fish control and restoration technologies. Monitoring of both fish numbers (2 yearly) and water quality (quarterly) is strongly recommended, along with research to identify the current links in the food web of this lake.
3. Shag numbers appear to be very low in Lake Wainamu and high in Lake Ototoa. Shag predation may be important in maintaining low densities of some exotic fish species, especially in clear lakes. The role of shags as a control agent for exotic fish therefore needs to be explored further. Collection of data on shag numbers in small North Island lakes varying in fish community composition and water clarity would help reveal any significant differences in predation patterns related to such variables. A study along such lines is therefore recommended in principle.
4. Bio-manipulation of Lake Kuwakatai to remove all exotic fish species would help confirm the negative effect of exotic fish on the water clarity of small North Island lakes. In the process, it would restore this lake and gain experience for the restoration of other larger lakes (e.g., Kereta). Preparation of a feasibility study would assist the various management agencies (e.g., ARC, DOC, Fish & Game) and stakeholders to assess the issues, costs and benefits of such a proposal and to develop a coordinated strategy for dealing with exotic fish in the Auckland region.

7 References

Annadotter, H.; Cronberg, G.; Aagren, R.; Lundstedt, B.; Nilsson, P.; Stroebeck, S. (1999). Multiple techniques for lake restoration. Hydrobiologia 395/396: 77-85.

Berg, S.; Jepperson, E.; Sondergaard, M. (1997). Pike (Esox lucius L.) stocking as a biomanipulation tool 1. Effects on the fish population in Lake Lyng, Denmark. Pp. 311-318, In Kufel, L.; Prejs, A.; Rybak, J.I. (eds.). Shallow Lakes '95: Trophic cascades in shallow freshwater and brackish lakes. Proceedings of a conference held in Mikolajki, Poland, 20-26 August 1995.

Bergman, E.; Hansson, L-A.; Persson, A.; Strand, J.; Romare, P.; Enell, M.; Graneli, W.; Svensson, J.M.; Hamrin, SF.; Cronberg, G.; Andersson, G.; Bergstrand, E. (1999). Synthesis of theoretical and empirical experiences from nutrient and cyprinid reductions in Lake Ringsjoen. Hydrobiologia 404: 145-156.

Cunningham, B.T.; Moar, N.T.; Torrie, A.W.; Parr, P.J. (1953). A survey of the western coastal dune lakes of the North Island of New Zealand. Australian Journal of Marine and Freshwater Research 4: 343-386.

Gibbs, M.; Boothroyd, I.; Champion, P.; Green, J.; Duggan, I. (1999). ARC lakes monitoring programme review. NIWA Client report ARC00256.

Giussani, G.; De Bernadi, R., Ruffoni, T. (1990). Three years of experience in biomanipulating a small eutrophic lake: Lago de Candia (Northern Italy). Pp. 357-366, In Gulati, R.D.; Lammens, E.H.H.R (eds.). Biomanipulation – tools for water management. Hydrobiologia: 200-201.

Hamrin, S.F. (1999). Planning and execution of fish reduction in Lake Ringsjoen. Hydrobiologia 404: 59-63.

Hawes, I.; Haskew, R. 2003. Summer oxygen depletion in Lakes Pupuke and Ototoa. NIWA Client report HAM20003-088.

Perrow, M.R.; Jowitt, A.J.; Stansfield, J.H.; Phillips, G.L. (1999). The practical importance of the interactions between fish, zooplankton and macrophytes in shallow lake restoration. Hydrobiologia 395/396: 199-210.

Richardson, M.J.; Whoriskey, F.G.; Roy, L.H. (1995). Turbidity generation and biological impacts of an exotic fish Carassius auratus, introduced into shallow seasonally anoxic ponds. Journal of Fish Biology 47: 576-585

Rowe, D.K. (1984). Some effects of eutrophication and the removal of aquatic plants by grass carp (Ctenopharyngodon idella) on rainbow trout (Salmo gairdnerii) in Lake Parkinson, New Zealand. New Zealand Journal of Marine and Freshwater Research, 18: 115-127.

Rowe, D.K. (1999). Factors influencing the abundance of the common bully, Gobiomorphus cotidianus McDowall, in small, North Island, New Zealand lakes. Fisheries Management and Ecology 6: 377-386.

Rowe, D.K; Champion, P.D. (1994). Biomanipulation of plants and fish to restore Lake Parkinson: a case study and its implications. Pp. 53-65. In: Restoration of Aquatic Ecosystems. (ed.) Collier, K.J. Department of Conservation, New Zealand.

Rowe, D.K.; Chisnall, B.L. (1995). Effects of oxygen, temperature and light gradients on the habitat and depth distribution of adult rainbow trout (Oncorhynchus mykiss) in two central North Island lakes, New Zealand. New Zealand Journal of Marine and Freshwater Research 29: 421-434.

Rowe, D.K.; Chisnall, B.L. (1997). Distribution and conservation status of dwarf inanga (Galaxias gracilis McDowall), an endemic fish of Northland dune lakes. Journal of the Royal Society of New Zealand 27: 223-233.

Rowe, D.K.; Dean, T. (1998). Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. New Zealand Journal of Marine and Freshwater Research 32: 21-29.

Rowe, D.K.; Konui, G.; Christie, K. (1999a). Koaro (Galaxias brevipinnis) in Lake Rotoaira. NIWA Client Report ELE90232/2. 31 p.

Rowe, D.K.; Champion, P.; de Winton, M. (1999b). Lake management trials for dwarf inanga (Galaxias gracilis) and a rare plant (Hydatella inconspicua) in Northland Dune lakes. NIWA Client Report DOC90202. 73 p.

Rowe, D.K.; Nichols, S.; Kelly, G. (2001). Depth distribution and abundance of the common bully, Gobiomorphus cotidianus (Eleotridae), in three oligotrophic New Zealand lakes, one of which is turbid. Environmental Biology of Fishes 61: 407-418.

Rowe, D.K.; Smith, J. P. (2001). The role of exotic fish in the loss of macrophytes and increased turbidity of Lake Wainamu, Auckland. NIWA Client Report ARC02286.

Rowe, D.K.; Graynoth, E.; James, G.; Taylor, M.; Hawke, L. (2003). Influence of turbidity and fluctuating lake levels on the abundance and depth distribution of small benthic fish in alpine, New Zealand lakes. Ecology of Freshwater Fish 12: 000-000.

Sala, O.E.; Chapin, F.S.; Armesto, J.J.; Berlow, E.; Bloomfield, J.; Dirzo, R.; Huber-Sanwald, E.; Huenneke, L.F.; Jackson, R.B.; Kinzig, A,; Leemans, R.; Lodge, D.M.; Mooney, H.A.; Oesterheld, M.; Poff, N.L.; Sykes, M.T.; Walker, B.H.; Walker, M.; Wall, D. (2000). Global biodiversity scenarios for the year 2100. Science 287: 1770-1774.

Tatrai, I.; Olah, J.; Jozsa, V.; Kawiecka, B.J.; Matyas, K.; Paulovits, G.; Pekar, F.; Szabo, P. (1996). Regulation of plankton and benthic communities and water quality by cyprinid fish. Lakes & Reservoirs: Research and Management 2: 3-4.

Tatrai, I.; Olah, J.; Paulovits, G.; Matyas, K.; Kawiecka, B.J.; Pekar, F. (1997). Changes in the lower trophic level as a consequence of the level of fish manipulation in the ponds. International Revue der Gesamten Hydrobiolgie 82: 213-224.

Van Donk, E.; Gulati, R.D.; Grimm, M.P. (1987). Restoration by biomanipulation in a small hypertrophic lake: first-year results. pp. 285-295. In Biro, P.; Talling, J. F. (eds.), Trophic relationships in inland waters. Hydrobiologia 191.

Wilson, B. (2002). Lake Ototoa: July 2003 netting survey. Unpublished report. Auckland/Waikato Fish & Game Council, Hamilton.