Potential effects on smelt of diverting Ohau Channel water out of Lake Rotoiti

NIWA Client Report: HAM2006-116
November 2006

NIWA Project: BOP06205

Potential effects on smelt of diverting Ohau Channel water out of Lake Rotoiti

Rowe, D.K.
Richardson, J.
Boubée, J.A.T.
Dunford, A.
Bowman, E.

Prepared for

Environment Bay of Plenty

NIWA Client Report: HAM2006-116
November 2006

NIWA Project: BOP06205

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

Reviewed by:

Dr Cindy Baker

Approved for release by:

Dr David Roper

Formatting checked

Executive Summary

In order to reduce future nutrient additions to Lake Rotoiti, the flow of the Ohau Channel into Lake Rotoiti is to be diverted out of the lake and into the Kaituna River. Although this diversion will help prevent further deterioration in the lake's water quality and hence in its trout fishery, it may restrict fish movements between Lakes Rotorua and Rotoiti and reduce the recruitment of trout or smelt into Lake Rotoiti. Eastern Fish & Game are concerned about the effects of the diversion on trout in Lake Rotoiti and will monitor angler catch rates to determine effects on the fishery. However, smelt are an important forage fish for trout and may also be affected. In this report we describe the movements of larval, juvenile and adult smelt in the Ohau Channel as these may be affected by the diversion wall. We also establish the methodologies and baseline data sets needed to monitor smelt populations in the Channel and in Lake Rotoiti in accordance with the conditions in the resource consents for the diversion wall.

The monthly transport of larval smelt from Lake Rotorua into the Ohau Channel was relatively low compared with that from the Ohau Channel into Lake Rotoiti (i.e., peak of 1.5 larvae.s^{-1} compared with 33 larvae.s^{-1}). However, the production of smelt in the Ohau Channel was minimal compared with the number of smelt being carried out of Lake Rotoiti by the flow at Okere. A major loss (i.e., 357 larvae.s^{-1}) occurred during April 2006 and a second loss (166 larvae.s^{-1}) occurred in September 2006. The order of magnitude difference between larval smelt numbers being transported into Lake Rotoiti from the Ohau Channel and those being transported out of the lake at Okere indicates that the production of larval smelt in the Ohau Channel is minor compared with that from this lake. However, we were unable to measure larval smelt production from the delta of the Ohau Channel.

The seasonal timing and extent of upstream movements by juvenile and adult smelt from Lake Rotoiti into the Ohau Channel were also measured on a monthly basis. A large migration of juvenile smelt into the Ohau Channel occurred in January and February 2006 (10–35 smelt.min^{-1}) and is consistent with the summer migration of juvenile smelt reported in other studies. However, one of these studies also reported large numbers of juveniles in the Channel in March and April indicating that some variation in seasonal timing of juveniles can be expected. The upstream migration of these fish is analogous to the migrations of whitebait into river mouths as juvenile fish seek habitats for growth. These juvenile smelt in the Ohau Channel are therefore expected to move up the Channel and, provided the weir across the mouth of the Channel does not prevent further movement into Lake Rotorua. The downstream movement of smelt in the Ohau Channel was also determined by trapping, but high water velocities at the weir restricted sampling to 9 of the 16 occasions. The maximum rate of downstream movement of juvenile smelt of 1.4 fish.min^{-1} occurred in January 2006 and was minor compared with the peak upstream movement of 35 fish.min^{-1} at this time.

A large migration of adult smelt from Lake Rotoiti into the Ohau Channel occurred during August and September 2006, but not in September 2005. Other studies have reported high concentrations of adult smelt in the Channel as late as October and November. Thus, the late winter/spring seasonal timing of

the migration of adult smelt into the Channel may also vary between years. The smelt in the Channel in August 2006 were all ripe and some had spawned so this was a spawning migration, but relatively little spawning occurred in the Ohau Channel because larval drift here in late September 2006 was only 20 larvae.s^{-1}. The rate of movement of adult smelt into the Ohau Channel in August and September 2006 was much smaller than expected from the large number of smelt actually observed at this time. It was our impression that these smelt were 'milling' around in the Channel rather than moving upstream into Lake Rotorua. This may be because high water velocities around the weir at this time inhibited their upstream movement. These smelt disappeared from the channel in late September.

Although there are large annual migrations of both juvenile and adult smelt from Lake Rotoiti through the Ohau Channel and, when not impeded by the weir, into Lake Rotorua, there was no evidence that there is a corresponding downstream movement of smelt from Lake Rotorua to Lake Rotoiti. These migrations could therefore represent a net loss of smelt from Lake Rotoiti to Lake Rotorua, except when high flows at the weir impede the upstream migrations and result in the return of many fish back downstream to Rotoiti. At present too little is known about smelt migrations or smelt behaviour to predict whether these fish will find the new entrance to the Ohau Channel created by the diversion wall, or not. Monitoring in the Ohau Channel after the wall is in place will therefore be required to determine whether smelt find the new entrance. If they do not, then monitoring to detect smelt aggregations around the outside of the wall will be required to identify the best location for providing a fish pass (as per the consent conditions). This might be readily achieved by using a multi-beam, acoustic, swathe sounder to provide a three-dimensional picture of fish schools around the outside of the wall. This sounder has been used to detect schools of small marine fish (e.g., anchovies) in shallow waters at sea, but has not been used for detecting smelt schools close to vertical structures in lakes. The feasibility of using this sounder to monitor smelt aggregations around the wall therefore needs to be investigated as a monitoring tool.

If smelt migrations are disrupted by the diversion wall and this results in a reduction in smelt densities in Lake Rotoiti, then trout production may be reduced. It will therefore be important to monitor smelt densities in Lake Rotoiti as well as in the Ohau Channel. Monitoring of smelt densities in this lake depends on the establishment of pre-wall databases and the development of appropriate methodologies. Because densities of larval smelt were measured in 1994/95, the density of larval smelt in Lake Rotoiti was determined in 2005/06 to compare with the 1994/95 data and to establish a pre-wall baseline. Measurement of larval smelt densities throughout Lake Rotoiti during the 2005/2006 summer showed that there had been a 78% decline since 1994/1995 and that this decline was consistent with the decline in lake water quality since 1994/95. The relationship between larval smelt density and lake water transparency for the Rotorua lakes allows the effect of water quality changes to be accounted for in estimating larval smelt densities so that any decline over and above this can be detected. Because annual variations in smelt recruitment can be expected as a result of annual variations in climate factors, we recommend that larval smelt density also be measured in a control lake. Densities were measured in Lake Okataina in 2005/2006 to provide baseline data for this lake.

Acoustic data on fish in Lake Rotoiti were collected in September 2000 and provided an opportunity to determine adult smelt abundance at this time using hydro-acoustic analysis. Further acoustic surveys were therefore carried out throughout the lake in both September 2005 and September 2006 to estimate the abundance of adult smelt in the lake and to provide a robust as possible pre-wall baseline. The abundance of adult smelt as assessed by acoustic methods declined by about 70% between 2000 and 2005. This result is consistent with the 78% decline in larval smelt densities between 1994/95 and 2005/06, so the results of these two monitoring methods are in good agreement. The density of adult smelt in September 2005 was no different to that in September 2006, but studies of adult smelt abundance in other lakes indicated that abundance can be expected to vary by a factor of up to four between years because of natural variations in factors influencing egg mortality and larval growth rates. Thus, we could expect smelt abundance in Lake Rotoiti to fall naturally by up to a quarter of the 2005 and 2006 levels. If smelt abundance was to drop below this threshold and to remain at this low level for at least two years in a row after installation of the diversion wall, then, all other factors being equal, it can be concluded that the wall is having an effect on smelt abundance in the lake.

If trout or smelt abundance in Lake Rotoiti does decline as a consequence of the diversion wall, we have identified some preliminary options for remediation that can be explored to complement trout stocking. These include improvements to juvenile trout rearing habitats of major spawning streams in Lake Rotoiti, and the identification of some key issues for improving smelt spawning habitat in Lake Rotoiti by way of a PhD study.

1. Introduction

The landscape around Rotorua is renowned for the variety of natural lakes that provide a wealth of angling and recreational opportunities. In recent years some of the lakes have suffered from reduced water quality, and in particular blooms of toxic algae that prevent safe contact with the water. In order to improve water quality in Lake Rotoiti, Environment Bay of Plenty is proposing to construct a wall to divert the flow from the Ohau Channel down the Kaituna River (Figure 1). This is because the Ohau Channel conveys nutrient-rich water from Lake Rotorua into Lake Rotoiti. If this 'external' supply of nutrients to Lake Rotoiti continues, then the trophic status of the lake will increase and the trout fishery will eventually decline (Rowe 2005).

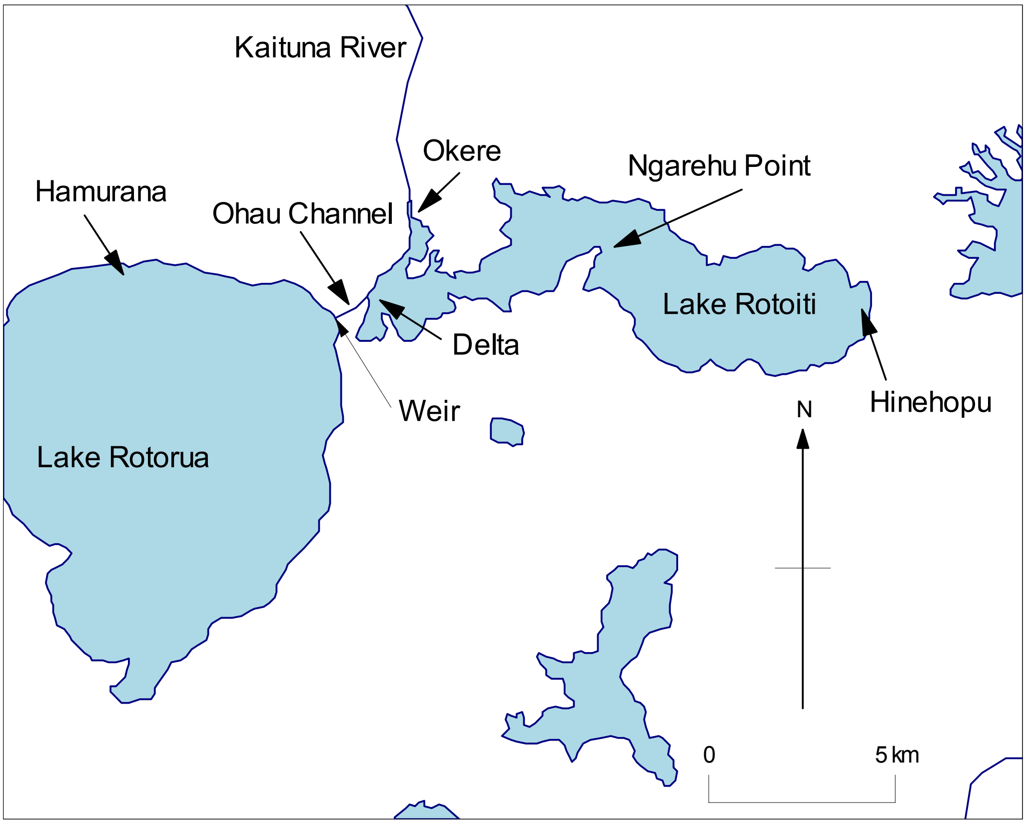

Figure 1: Location of the Ohau Channel. Water from Lake Rotorua flows down the Ohau Channel into Lake Rotoiti. The Kaituna River, which drains Lake Rotoiti, flows to the sea near Te Puke. The proposed wall is to be built where the channel enters Lake Rotoiti at the delta and will divert Lake Rotorua water towards Okere and down the Kaituna River.

Several fish species are found in lakes Rotorua and Rotoiti (Table 1) and some use the Ohau Channel as a migration corridor, whereas others use it for spawning. The proposed wall is likely to restrict the ability of these fish to access the Ohau Channel and Eastern Fish and Game is concerned that the wall may affect the trout fishery in Lake Rotoiti.

Table 1: Fish species found in lakes Rotorua and Rotoiti. Data were extracted from the New Zealand freshwater fish database (N = native, E = exotic).

Scientific name	Common name	Native/Exotic
Oncorhynchus mykiss	Rainbow trout	E
Salmo trutta	Brown trout	E
Galaxias brevipinnis	Koaro	N
Retropinna retropinna	Common smelt	N
Gobiomorphus cotidianus	Common bully	N
Gambusia affinis	Gambusia	E

One concern is that the wall may block the spawning migration of some adult rainbow trout from Lake Rotoiti into the Ohau Channel to spawn and the movement of others into Lake Rotorua to spawn in tributaries such as the Ngongotaha Stream (Rowe 2005). This would be a concern if the progeny of these fish migrated back into Lake Rotoiti as part of their life history and are a major source of trout recruitment to Rotoiti. This is unknown at present, and Eastern Fish and Game plan to monitor angler numbers and catch rates to detect any significant change in trout abundance in Lake Rotoiti that may be caused by the diversion wall. Stocking with hatchery trout could be used to mitigate any reduction in trout numbers. It is recognised that further deterioration in the water quality of Lake Rotoiti will eventually impact on the trout fishery and that nutrient diversion out of the lake is required to prevent this long-term decline. The potential effects of the diversion wall on trout abundance in Lake Rotoiti are therefore being dealt with by Eastern Fish and Game and are not addressed in this report.

Another concern is that smelt migrations into the Ohau Channel and Lake Rotorua will be prevented and that larvae produced from smelt spawning in the channel or in Lake Rotorua would be diverted out of Lake Rotoiti by the wall (Rowe 2005). As smelt are a major prey species for rainbow trout in Lake Rotoiti, this could potentially reduce the growth and production of trout in this lake. Mitigation would then be needed through the creation of a fish pass for smelt and/or by enhancing spawning habitat for smelt within Lake Rotoiti. Conditions in the resource consents provide for both options should a reduction in Lake Rotoiti smelt occur as a consequence of the construction of the wall.

In order to determine whether the wall will affect smelt (and hence trout) in Lake Rotoiti, a number of studies were proposed to establish baselines (pre-wall) for future monitoring. In particular, baseline information was required on smelt use of the Ohau Channel and on smelt abundance in Lake Rotoiti. This study reports the results of studies undertaken to determine the timing and extent of migrations by all life stages of smelt in the Ohau Channel. It also reports the results of studies made to establish baseline data and to determine the best method for long-term monitoring of smelt abundance in Lake Rotoiti.

Historic data on smelt abundance in Lake Rotoiti are scarce, although Rowe & Taumoepeau (2004) measured the density of larval smelt in this lake in December 1994 and April 1995. As the diversion wall may reduce larval smelt densities in Lake Rotoiti, the 1994/95 study was repeated in 2005/06 to provide another pre-wall data set on larval smelt densities.

A number of scientific studies have used hydro-acoustic methods to estimate the density or abundance of several smelt species (similar to the New Zealand smelt) in northern hemisphere lakes (e.g., Burczynski et al. 1987; Rudstam et al. 2003; Jurvelius et al. 2005; Malinen & Tuomaala 2005; Peltonen et al. 2006; Parker Stetter et al. 2006). Although most of these studies involved echo-counting to determine the number of smelt present, Burczynski et al. (1987) used echo-integration to determine smelt biomass. Acoustic surveys are thus an established, but still developing, method for estimating the abundance of small forage fish such as smelt in lakes.

In September 2000, an acoustic survey was carried out in Lake Rotoiti to determine the feasibility of using a high frequency, split-beam echosounder to determine the abundance of rainbow trout in this lake (Rowe et al. 2001). Although the focus of this study was trout, the data collected provide a retrospective opportunity to assess smelt abundance in Lake Rotoiti in 2000. In order to extend this baseline, further acoustic surveys were carried out in September 2005 and 2006. Echo-integration was used to estimate smelt biomass at the time of these surveys because smelt are a schooling fish and their schooling behaviour precludes identification of individual fish for echo-counting purposes.

In addition to these studies, the University of Waikato is carrying out a concurrent study to determine whether the smelt stocks in Lake Rotoiti and Rotorua can be distinguished on the basis of trace metal signatures in otoliths. If so, the proportion of smelt in Rotoiti that develop in Lake Rotorua and subsequently move into Rotoiti via the Ohau Channel might be determined. In this report, we also provide ancillary data on the meristics (gill raker and vertebrae numbers) of smelt to determine whether these differ between the two lakes and could provide another basis for stock discrimination.

The results of these pre-wall investigations will be used as a basis for determining future monitoring requirements in the Ohau Channel and Lake Rotoiti. Monitoring for at least five years after the wall is constructed has been recommended, and will need to be specified and modified as appropriate by an 'expert' advisory panel of experienced fish biologists appointed by Environment Bay of Plenty and Eastern Fish and Game (Rowe 2005).

2. Smelt use of the Ohau Channel

Three main issues were identified relating to smelt use of the Ohau Channel. Firstly, the diversion may reduce the passive transport of larval smelt from Lake Rotorua (and from smelt spawning in the Ohau Channel) into Lake Rotoiti. Larval smelt occur in the pelagic surface waters of the Rotorua lakes throughout most of the year (Rowe 1993). As they have limited swimming ability, many larvae may be passively transported out of Lake Rotorua via the Ohau Channel. However, modelling of the channel inflow indicated that there would be little entrainment of larvae from Lake Rotorua into the Ohau Channel (Rowe 2005), and studies of the channel outflow indicated that most smelt larvae present in the Ohau Channel water would be diverted down the Kaituna River in summer and only enter Lake Rotoiti in winter (Rowe 2005). To address the issue of smelt larvae in the Ohau Channel, the relative size and timing of the contribution of smelt larvae from Lake Rotorua into the Ohau Channel was determined.

Secondly, adult smelt may use the Ohau Channel for spawning and the wall may prevent this, thereby reducing recruitment of these larvae into Lake Rotoiti. To address this issue, the relative size, seasonal timing and reproductive status of adult smelt migrating into the Ohau Channel was determined and data provided on the number of smelt larvae spawned in the Ohau Channel and potentially contributing to the smelt population in Lake Rotoiti. The movement of smelt larvae out of Lake Rotoiti was also assessed to provide some indication of the relative contribution of smelt larvae entering Rotoiti via the Ohau Channel compared with those leaving the lake.

Thirdly, the diversion wall may prevent the upstream movement of juvenile smelt from Lake Rotoiti to Lake Rotorua and so affect the iwi fishery for smelt in the channel. The upstream movement of juvenile smelt has supported a small iwi fishery in the Ohau Channel in the past, but installation of the weir at the head of this channel may have affected this fishery because at high flows, the weir can create a barrier to the upstream movement of smelt (Mitchell 1989; Donald 1996). The number and size of smelt moving up or downstream in the channel were therefore measured at regular intervals throughout the year to determine when juvenile smelt migrations occurred. Information on the fishery for smelt in the Ohau Channel is being collected as part of a separate study on Maori fisheries in the lakes.

2.1 Methods

2.1.1 Smelt stock discrimination

Vertebral numbers in smelt stocks vary between 50 and 64 (Ward et al. 2005) and, along with other morphological characteristic such as gill raker counts, provide a means of separating smelt stocks.

Samples of smelt were collected from Hinehopu at the eastern end of Lake Rotoiti, the eastern side of Ngarehu Point in Lake Rotoiti, Hamurana in Lake Rotorua and from the Ohau Channel (Figure 1). The number of vertebrae and/or gill rakers was counted for a sample of 20 fish from each location. Counts were compared using two sample t tests, or one-way analysis of variance followed by a Tukey means test, to detect significant differences ($P < 0.05$) in the average number of vertebrae or gill rakers between sites.

2.1.2 Downstream drift of larvae and post larvae

The passive downstream drift of larval fish was measured regularly over a 12-month period at three sites (Figure 2). The sites were termed the Weir (where water from Lake Rotorua enters the Ohau Channel), the Delta (where water from the Ohau Channel enters Lake Rotoiti), and Okere (in the Lake Rotoiti outlet to the Kaituna River).

Plankton nets (0.56 m diameter opening, 300 μm mesh net) were set to sample downstream-drifting larvae at each site at about 15 day intervals from September to November 2005, and at monthly intervals from December 2005 to September 2006. At the beginning of the study, the nets were set at dusk as this was assumed to be the peak migration period for larval fish. This was later confirmed by setting the nets over an extended period on six occasions. From late October, regular sampling was expanded to include dawn and dusk sets at each site. Each set was 10 to 15 minutes in length (timed with a stopwatch); nets could not be set for longer periods because they became clogged with algae.

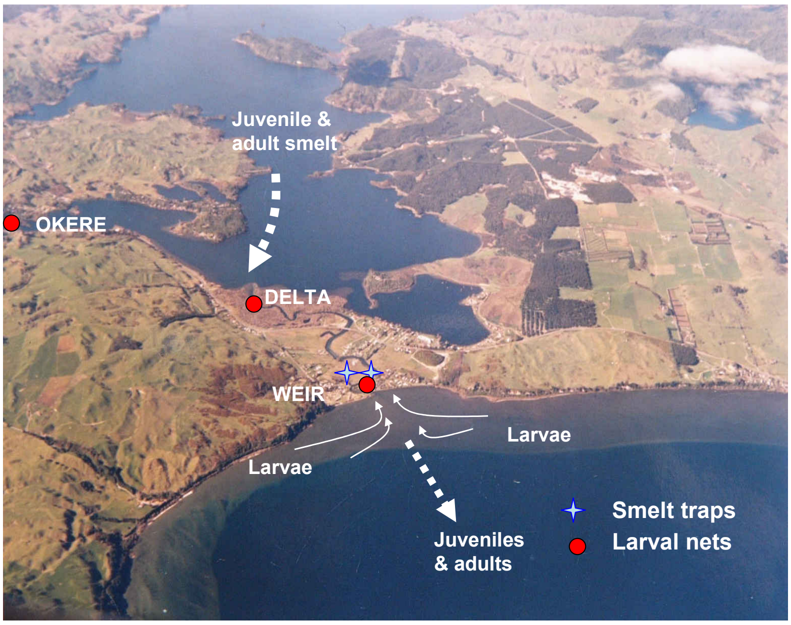

Figure 2: Location of the larval fish sampling sites (red circles) and smelt traps (blue stars) in the Ohau Channel and in the Okere arm of Lake Rotoiti, which leads to the Kaituna River. Flow direction in the channel is from Lake Rotorua at the bottom to Lake Rotoiti at the top).

The samples were preserved in alcohol or formalin with rose-bengal dye added to aid sorting. Fish were identified to species level using keys in McCarter (1994) and counted. Smelt larvae were designated as small (<15 mm) or large (15 to 30 mm). Bully larvae were also split into small (<10 mm) and large (10–20 mm) fish. Fish beyond the larval stage (i.e., above these size thresholds and showing pigmentation) were classed as juveniles.

The volume of water filtered during each 10 to 15 minute set was measured with a digital flow meter set in the mouth of each net. The number of small and large larvae in each set was divided by the volume of water filtered to determine the volumetric density of fish. This was then multiplied by the mean flow on that day to estimate the total number of fish per second drifting down the channel. Flow data were obtained from two NIWA recording sites, Lake Rotorua at Mission Bay (Weir and Delta samples) and Kaituna at Taheke for samples collected at Okere. Water temperature was measured at the Delta site with a Tidbit® temperature logger.

The data from dawn and dusk sets were examined graphically to determine the extent and timing of smelt and bully downstream drift from all three sites. It was not possible to compare the data statistically over time as there was usually only one dawn or dusk set per site per sampling date.

2.1.3 Upstream/downstream migrations of smelt in the channel

A whitebait trap (0.5 m x 1 m opening, 2 mm mesh) was placed close to the bank of the Ohau Channel approximately 100 m below the weir, on each side of the channel, to capture fish moving upstream (Figures 2 & 3). Trapping was carried out from early morning until late evening on the same day that the plankton nets were set, with the traps being lifted and the catch processed at about 2 to 4 hourly intervals.

If the catch was small, the fish were identified and counted. For large catches, the catch was separated by species and weighed. A sample of fish was then retained to obtain 50 weights and lengths. The average weight of a fish in the sample and the total weight caught of that species were used to calculate the total number of that species in the catch. This process will have overestimated the actual number of fish caught because the average weight was obtained from preserved specimens and the preservative causes them to lose liquid and hence weigh less than fresh specimens. However, all the large catches were treated in the same manner and therefore relative numbers are comparable. Smelt samples were also assessed for sex (M-male, F-female, I-immature) and gonad maturity was determined using a five point scale: (1) immature, (2) developing (sex discernable), (3) maturing (gonad fills more than 1/3 of body cavity), (4) ripe (large gonad with loose eggs or running sperm), and (5) spawned/spent (contains only a few re-absorbing eggs).

Figure 3: Whitebait traps were used to sample fish moving upstream along the banks of the Ohau Channel. The traps fished from dawn to dusk on each sampling occasion and were lifted at 2 to 4 hourly intervals to process the catch.

A similar trap (0.5 m x 2 m opening, 2 mm mesh) was set in mid-channel above the weir near the mouth of the Ohau Channel. The trap faced upstream to capture any fish moving downstream from Lake Rotorua into the channel (Figure 4). It was too dangerous to set this trap when the flow in the Ohau Channel exceeded 20 $m^3 s^{-1}$, and it was only able to be used on nine occasions. Catches from this trap were processed in the same manner as the downstream facing traps.

The data from both downstream facing traps were combined. A catch per unit effort (CPUE) measure was calculated for each species on each sampling occasion by dividing the total number of fish caught by the total time the traps had been fishing that day to give the number of fish caught per minute. If trapping occurred overnight, these catches were omitted so that the comparison only included the early morning to late evening period. For smelt, the catch was divided into juvenile (< 45 mm fork length) or adult fish (≥ 45 mm fork length)[1] using the percentage of each size class present in the processed samples.

CPUE for the upstream facing trap at the weir was calculated in the same manner. Often catches in this trap were so small that a sample was not collected, and we do not report separate CPUE for juvenile and adult smelt for the upstream facing trap at the weir.

Figure 4: The upstream facing weir trap at the mouth of the Ohau Channel. This trap could only be set when flows were below 20 $m^3 s^{-1}$.

[1] This separation was based on the size at which smelt became sexually mature.

The percentage of spent females[2] (Gonad Stage 5) in the processed samples was used to ascertain when spawning took place. For this analysis, data from all the processed smelt were combined whether they were caught at the weir or in the channel.

2.2 Results

2.2.1 Smelt stock discrimination

The smelt samples collected from Ngarehu Point and the Ohau Channel in spring 2005 were preserved in alcohol prior to counting the gill rakers. This method made counting difficult, and therefore further counts were made on fresh samples collected from the two lakes in April 2006. Vertebral counts were also obtained from this latter sample of fish (Table 2).

The Ohau Channel smelt had significantly higher ($P < 0.05$) gill raker counts than Ngarehu (mid-Rotoiti) or Hamurana (Rotorua) fish, but the Ohau and Ngarehu counts should be viewed with caution because they were obtained from preserved specimens. The gill raker counts of smelt collected from the two Rotoiti sites (Hinehopu and Ngarehu) were also significantly different ($P < 0.05$), but there was no difference in the vertebral counts of smelt from Hinehopu and Hamurana ($P = 0.46$).

Table 2: Average (± SD) fish size, gill raker number and vertebral counts (n = 20) from smelt captured at four sites in lakes Rotoiti or Rotorua. Hinehopu and Ngarehu are both in the eastern basin of Lake Rotoiti, Hamurana is on the northern side of Lake Rotorua.

Site	Date collected	Length (mm)	Gill rakers (No.)	Vertebrae (No.)
Hinehopu	10/04/06	45.0 (2.8)	23.3 (1.3)	53.7 (1.0)
Ngarehu Point	18/08/05	48.6 (5.7)	22.1 (0.8)	Not counted
Ohau Channel	15/09/05	62.4 (3.2)	23.9 (0.4)	Not counted
Hamurana	10/04/06	57.8 (4.5)	22.5 (1.0)	53.9 (1.0)

We were unable to establish whether there were different smelt stocks in the lakes from this preliminary morphometric comparison. Should this line of investigation be pursued, we recommend that larger samples of similar-sized fresh fish be obtained, and that other morphometric measures useful for stock separation, such as eye diameter or head size, be included.

[2] Accurate gonad staging of preserved specimens was most reliable for female fish, and fish may remain at Stage 4 (ripe) for some time before spawning. Therefore, we used the percentage of spent females to indicate when spawning may have occurred.

2.2.2 Water temperature

Water temperature data collected from the Ohau Channel (Figure 5) showed that temperatures ranged from 8ºC in mid-winter (June/July) to 24ºC in mid-summer (February).

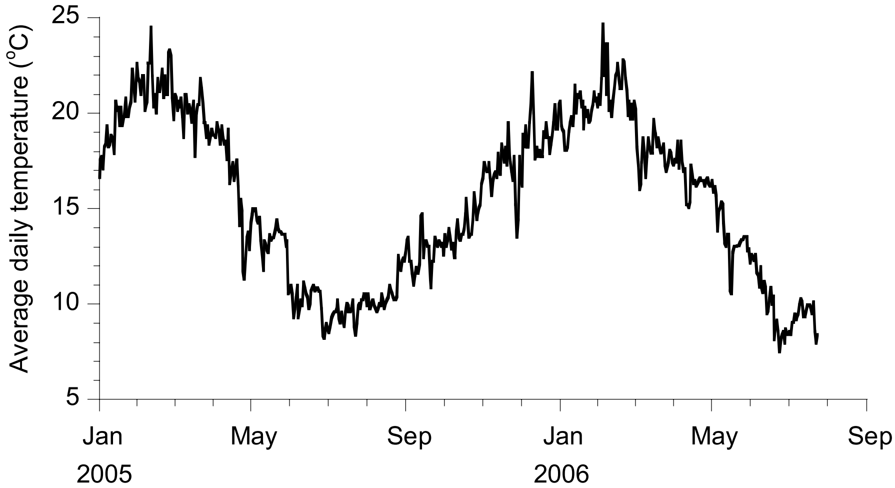

Figure 5: Average daily water temperature in the Ohau Channel between 1 January 2005 and the end of sampling in August 2006.

2.2.3 Downstream transport of fish larvae

Ichthyoplankton samples were collected from all three sites on 16 occasions during the study, and 207 samples in total were analysed (Table 3). The only fish species caught in the plankton nets were common smelt and bully and all size classes were present. Overall, larval smelt were 7 times more numerous at the Okere site than at either the Weir or Delta sites, whereas numbers of larval bullies were highest at the Weir site.

Table 3: Total numbers of smelt and bullies captured in the plankton nets from September 2005 to September 2006.

	Weir (n = 89)	Delta (n = 58)	Okere (n = 60)
Small larval smelt	634	322	5124
Large larval smelt	91	5	335
Juvenile & adult smelt	3862	84	55
Small larval bully	5359	647	1496
Large larval bully	4767	598	817
Juvenile & adult bully	200	25	35

In contrast, juvenile and adult smelt were more numerous in the trap at the Weir site, but unlike the passively drifting larvae, these fish are highly mobile and may have been upstream rather than downstream migrants.

Extra plankton samples were collected on six occasions (late October-Weir only, mid November, late November-Weir only, December, January and May) to confirm that the dawn and dusk sampling strategy was targeting the main diurnal movement periods (Figure 6). In general, there were clear peaks in larval transport around dawn and dusk even though 20–30% of the smelt larvae moving downstream on any sampling occasion could be caught during the day, particularly at Okere. Most movement occurred during dawn at Okere and dusk at the Weir

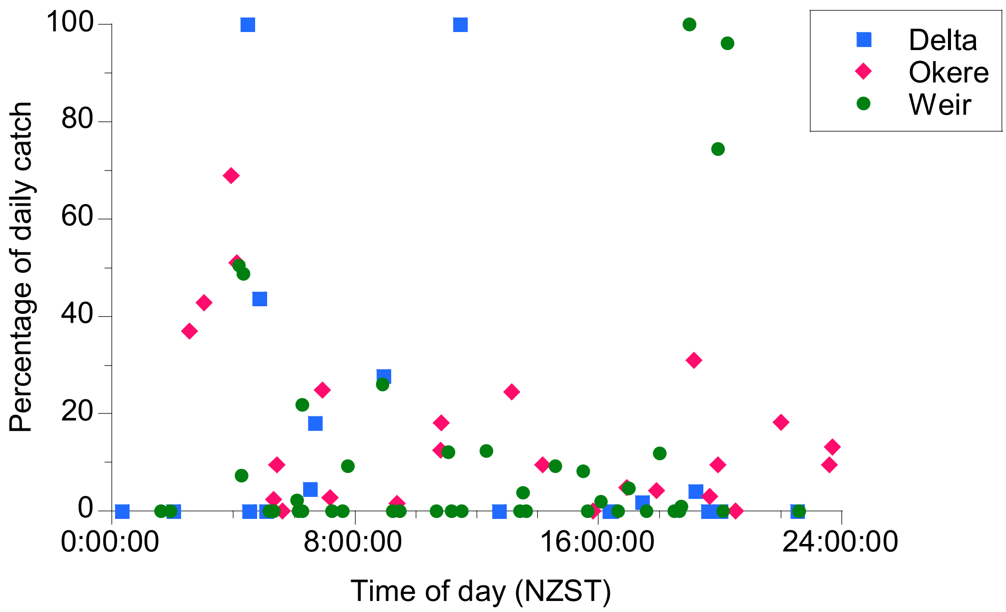

Figure 6: Percentage of the daily catch of smelt larvae at various times of day on six occasions when sampling occurred over an extended period and when at least one smelt larvae was recorded in the samples for that site.

Based on this analysis, we defined a dawn sample as any sample that occurred between 2.5 hours before and 0.5 hour after sunrise and a dusk sample as any sample between 0.5 hour before and 2.5 hours after sunset. If more than one dawn or dusk sample occurred on any sampling occasion, the catch was averaged to provide a single dawn or dusk catch for that date. This provided a total of 129 samples for analysis (Appendix I). Dawn and dusk samples were compared graphically between dates and sites to identify the timing and relative abundance of the larval movements.

The number of smelt moving downstream at each of the three sites is shown for both small and large larval smelt (Figures 7 & 8, respectively). The numbers of large larval smelt were generally minor compared with small larvae, except in April at the Okere site when a marked peak in both groups occurred. Because of the paucity of large larval smelt, the number of small larvae provide the best guide to the extent and seasonal timing of smelt larvae in the Ohau Channel (i.e., at the Weir and Delta sites).

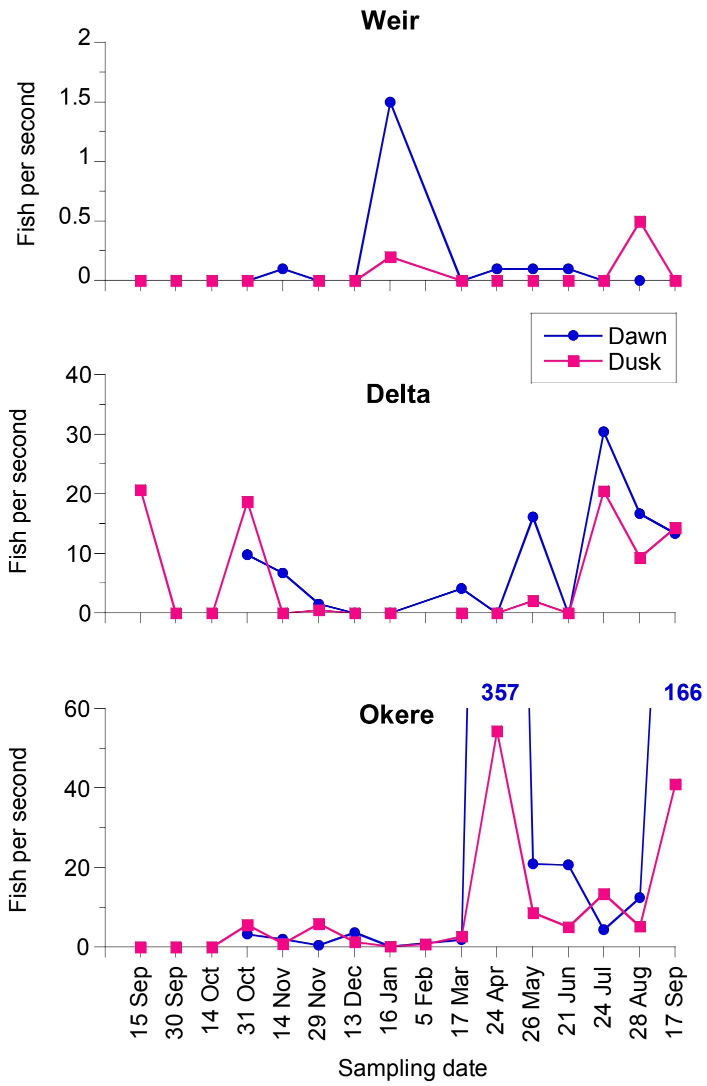

Figure 7: Estimated dawn and dusk catches of small larval smelt caught in the plankton nets at the three study sites between 15 September 2005 and 17 September 2006. Missing markers indicate that none of the sets made on that day met our criteria (see text) for occurring within the dawn or dusk period.

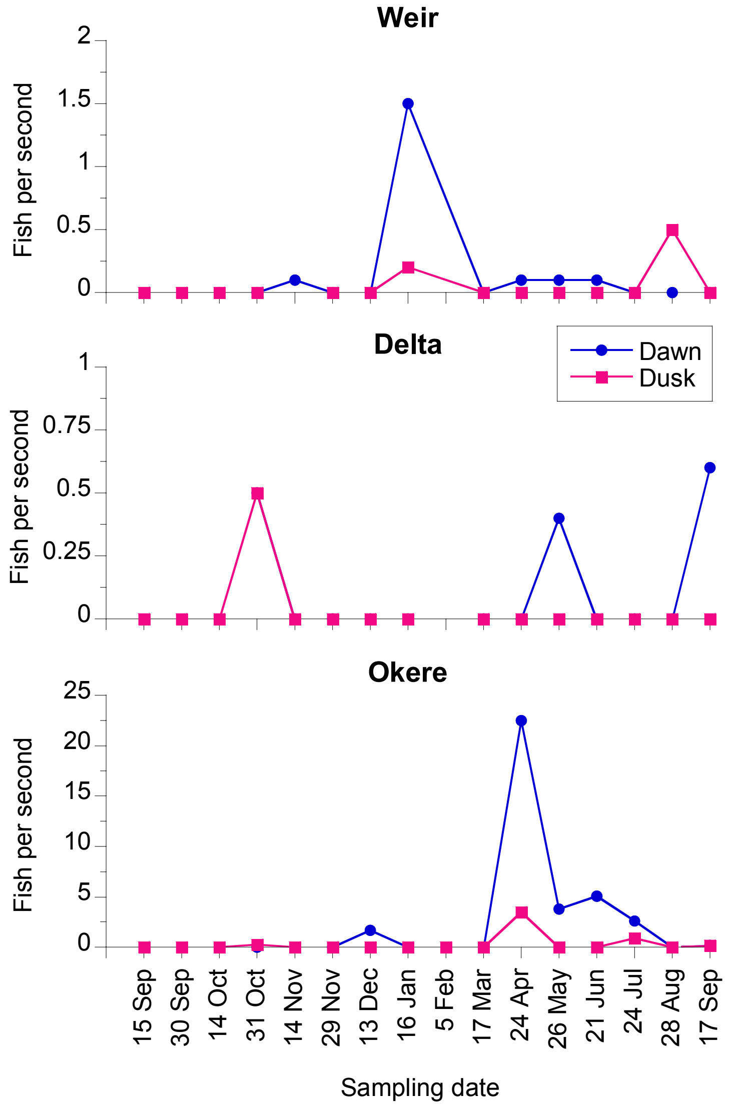

Figure 8: Estimated dawn and dusk catches of large larval smelt caught in the plankton nets at the three study sites between 15 September 2005 and 17 September 2006. Missing markers indicate that none of the sets made on that day met our criteria (see text) for occurring within the dawn or dusk period.

In general, estimated catches of larval smelt at the Weir were low, particularly in comparison with the Delta site, indicating that few smelt larvae were transported from Lake Rotorua into the channel. However, there was an increase in larval smelt numbers at both the Weir and Delta sites on 24 July 2006, indicating that some smelt larval movement was occurring from Lake Rotorua down the Ohau Channel at this time. The higher abundance of smelt larvae at the Delta site at both dawn and dusk at this time indicated that the number of larval smelt moving down the Ohau Channel was augmented by smelt larvae produced in the channel itself. The smaller peaks in larval numbers at the Delta site on 15 September, 31 October and 26 May, but not at the Weir, also indicates the likely presence of some spawning activity by smelt in the Ohau Channel over late-winter and spring. This is consistent with the movements of ripe and spent smelt in the Ohau Channel described in the next section.

There was a massive increase in the number of larval smelt moving downstream at Okere in April and again in September 2006. This was an order of magnitude greater than the catches of larval smelt at the Weir and Delta. The first peak in larval smelt numbers at Okere did not coincide with peaks at the Weir or Delta, suggesting that the larvae caught at Okere in autumn probably originated from Lake Rotoiti rather than from Lake Rotorua or the Ohau Channel. The second peak in September 2006 occurred after peaks at the Weir and Delta, and may indicate spawning in the channel, or the delta where the Ohau Channel enters Lake Rotoiti, as well as in Lake Rotoiti. Any smelt larvae caught at Okere would be carried down to the Kaituna River by the flow present in the arm and therefore lost from Lake Rotoiti.

Catches of small and large larval bullies were usually higher at dawn than at dusk, and a lack of dawn sets in September means that we can’t be sure of larval bully numbers at this time (Figure 9). Overall, there was no clear seasonal peak in small larval bully numbers originating from Lake Rotorua at the Weir, but the highest density here occurred in early October. Peak densities occurred at the Delta site in late October and at Okere in early November. Peaks in the densities of large larval bullies occurred later at each site, in December, January and April, respectively (Figure 10). Hence, for both small and large larval bullies, peak movements occurred first at the Weir, then at the Delta, and lastly at Okere, with the larger larvae being transported downstream at a different time of year compared with the smaller larvae.

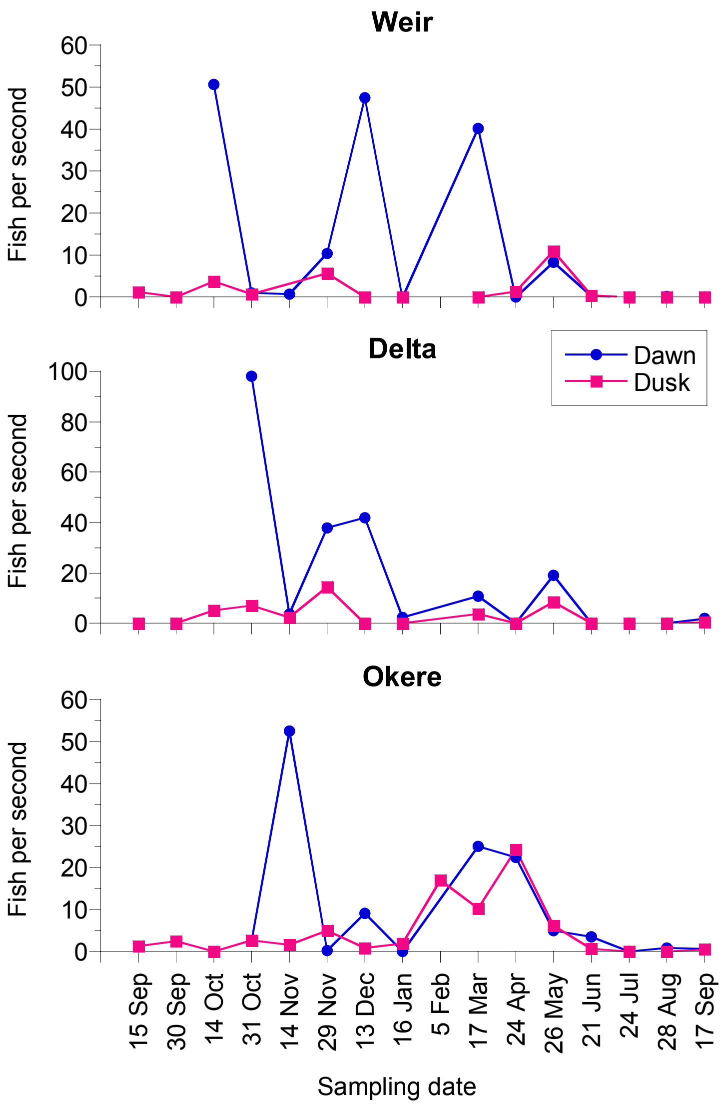

Figure 9: Estimated dawn and dusk catches of small larval bullies caught in the plankton nets at the three study sites between 15 September 2005 and 17 September 2006. Missing markers indicate that none of the sets made on that day met our criteria (see text) for occurring within the dawn or dusk period.

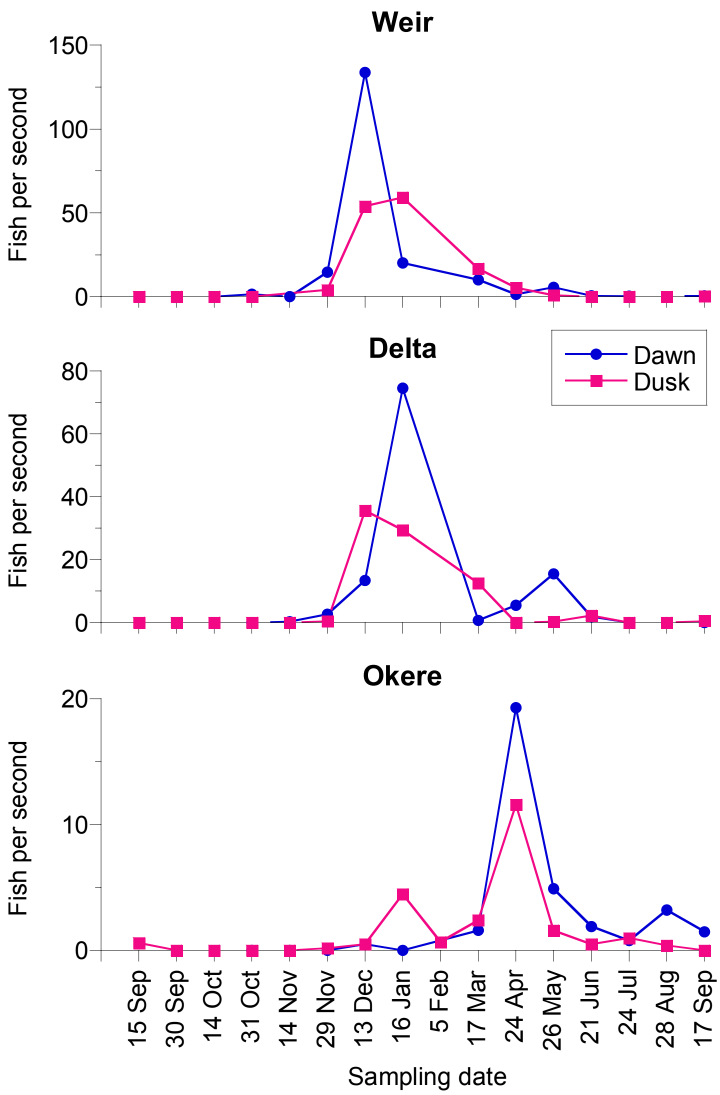

Figure 10: Estimated dawn and dusk catches of large larval bullies caught in the plankton nets at the three study sites between 15 September 2005 and 17 September 2006. Missing markers indicate that none of the sets made on that day met our criteria (see text) for occurring within the dawn or dusk period.

2.2.4 Migrations of juvenile and adult smelt through the Ohau Channel

The downstream facing traps on either side of the channel (set to catch fish moving upstream along the banks) were set on all 16 sampling occasions (Appendix II). Generally only smelt and bullies were caught in the traps, although low numbers (usually just one fish) of gambusia, trout, and koaro were recorded on one, two and three occasions, respectively.

The number of smelt moving upstream in the Ohau Channel peaked in February (mid-summer), and this coincided with a run of both juvenile and adult smelt (Figure 11). At the peak of this run, about 25 juvenile and 10 adult smelt per minute were moving along the edges of the channel. In August 2006, another, smaller run of adult smelt occurred. Relatively few smelt were caught during the rest of the year and these were almost all adult fish.

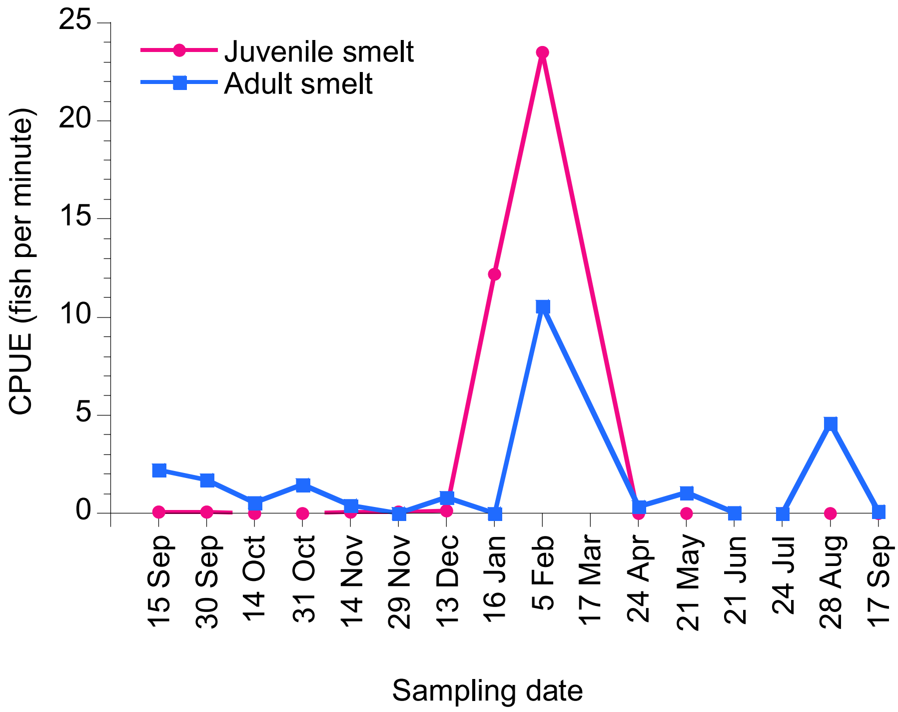

Figure 11: Catch per unit effort (CPUE) of juvenile (red line) and adult (blue line) smelt migrating upstream in the Ohau Channel on each sampling occasion between September 2005 and 2006. No smelt size data are available for March, but the total catch on that occasion was less than 1 fish per minute.

Flows in the Ohau Channel only permitted the upstream facing trap at the weir to be set on 9 of the 16 sampling dates. On most occasions, no fish were caught in this trap, and the catch comprised only smelt and/or bullies apart from one juvenile trout. The maximum rate of downstream movement of smelt was recorded in January 2006 at just 1.4 fish per minute. This is minor compared with the peaks of nearly 35 fish per minute moving upstream in February 2006 and nearly five smelt per minute later in August 2006 (Figure 11).

The number of adult bullies caught in upstream traps in the Ohau Channel peaked between December and February (Figure 12). During summer, huge numbers of bullies were caught in the traps (over 90,000 on January 16 2006), indicating a substantial movement of bullies through the Ohau Channel at this time. The average size of bullies caught in the traps changed over the year, with fish caught in late spring and summer being, on average, smaller than those caught in late autumn/winter. The smallest bullies were present in January, although there were several occasions when no samples were kept for analysis.

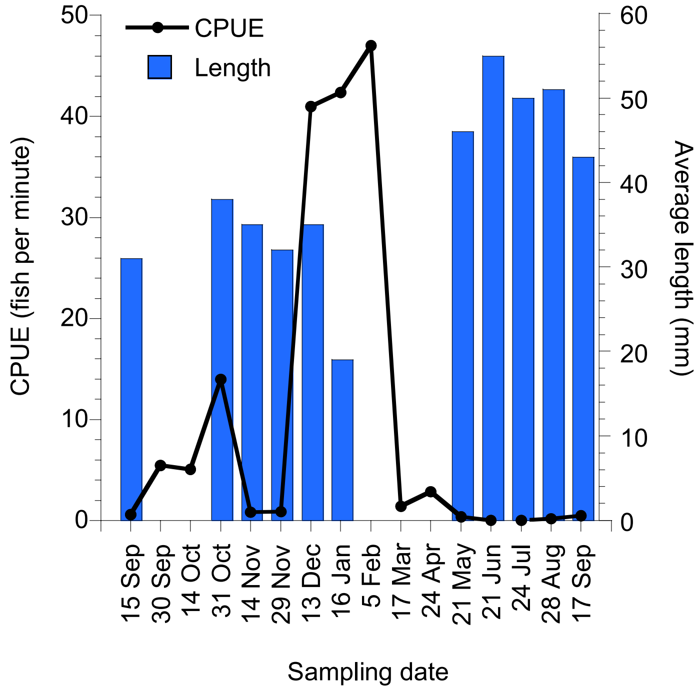

Figure 12: Catch per unit effort (CPUE) of bullies (black line) in the Ohau Channel downstream facing traps from sampling occasions between September 2005 and September 2006. Coloured bars indicate the average length of bullies when samples of at least 50 fish were measured.

2.2.5 Smelt gonad analysis

The percentage of spent (Gonad Stage 5) female smelt in the Ohau Channel varied over the 12-month sampling period (Figure 13), and it appeared that spawning occurred over the whole year as spent fish occurred in spring, summer and winter months. The catch of larval smelt in the Ohau Channel (both the Weir & Delta sites) increased in July 2006 and the larvae caught in July–September 2006 were mostly newly hatched, with many still having their yolk sacs attached. These observations indicate that some spawning was occurring in the Ohau Channel during winter months, especially late-winter when a run of sexually mature and spent fish entered the channel.

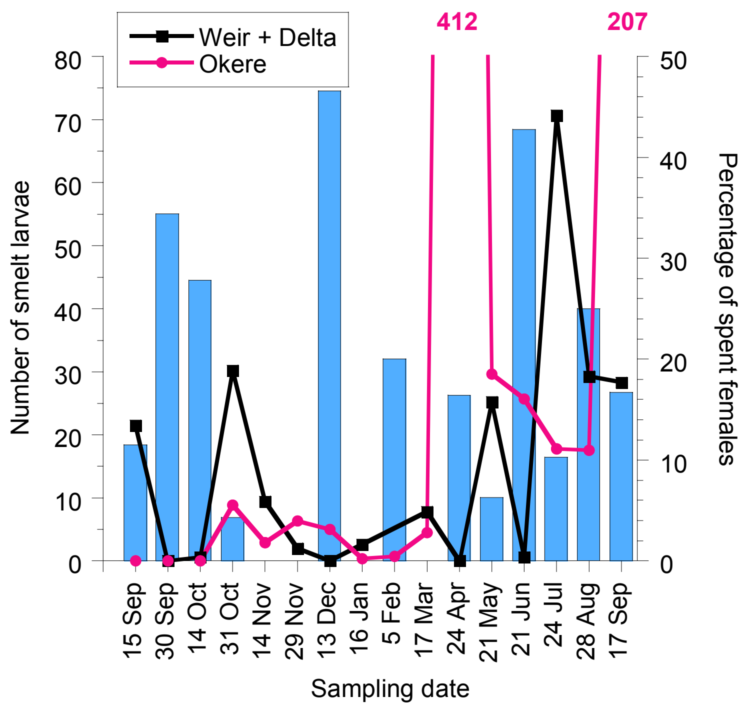

Figure 13: Percentage of spent females (Gonad Stage 5) in the processed samples of smelt caught in the Ohau Channel between September 2005 and September 2006 (blue bars) compared to smelt larvae catches in the Ohau Channel (black line) and at Okere (red line). The number of smelt larvae is the sum of the averaged dawn and dusk samples shown in Figure 5. No sample of smelt was collected in March whereas there were no spent females in November or January.

2.3 Discussion

We could not differentiate between smelt stocks in lakes Rotorua and Rotoiti based on gill raker or vertebral counts. It appears that there is considerable overlap in such morphometric variables for the smelt in these lakes, and this may be because the environmental factors that affect these variables are similar in both lakes. Our results also show that some smelt larvae from Rotorua can be expected to enter Lake Rotoiti, whereas some Rotoiti smelt migrate up the Ohau Channel and may spawn in Rotorua. Hence, there is likely to be a large amount of interchange between the smelt in these two lakes, and this interchange could be sufficient to prevent the separation of the stocks.

In general, lower catches of larval smelt occurred at the Weir site near the entrance of the Ohau Channel than at the Delta near its outlet to Lake Rotoiti. This indicates that larval smelt from Lake Rotorua make a relatively small contribution to the population in the channel and hence to Lake Rotoiti. Nevertheless, it is apparent that some smelt larvae originate from spawning in the Ohau Channel during winter/spring months. The high percentage of spent smelt present in the channel in June plus the presence of large numbers of newly hatched larvae in July confirms such winter spawning. The large run of sexually mature fish in August, including a large number of spent smelt, indicates that spawning may have increased in the channel in late-winter. However, larval smelt numbers in the channel in September were not as high as in July. This indicates that either many of the sexually mature smelt in the channel during August did not spawn or, that they did but egg survival was reduced.

Overall, the much larger number of larval smelt caught at Okere than in the Ohau Channel, and the difference in the timing of peak catches, suggests that there is substantial transport of smelt larvae from Lake Rotoiti down the Okere Arm and into the Kaituna River. The number of larval smelt transported out of Rotoiti via Okere dwarfs the input of smelt larvae from the Ohau Channel.

Because it was not possible to place plankton nets immediately below the outflow of the Ohau Channel into Rotoiti, and because some smelt can be expected to spawn on the sandy delta at the mouth of the Ohau Channel, it was not possible to estimate larval smelt production from here. However, the total area of smelt spawning substrate at the delta will be relatively small compared with that in the Ohau Channel or in Lake Rotoiti, so smelt recruitment from the delta region of the Ohau Channel is unlikely to be a major factor affecting smelt recruitment to Rotoiti.

Juvenile smelt appeared in trap catches in the Ohau Channel as early as November 2005, and a major run occurred during January and February 2006. This run peaked in February when large numbers of juvenile fish (almost 25 per minute) were recorded moving upstream. Mitchell (1989) and Donald (1996) have also reported migrations of juvenile smelt (whitebait) into the Ohau Channel in summer months. Mitchell (1989) indicated that runs occurred mainly in March and April, whereas Donald (1996) recorded juveniles in January and February. There is reasonable agreement between these studies over the seasonal timing of juvenile smelt migrations, with mid-summer (February) being the peak time. However, it appears likely that in some years migrations may occur earlier or later, or may occur during all these months. These migrations are akin to the late-spring/early-summer migrations of anadromous juvenile smelt into rivers to seek adult feeding habitats (McDowall 1990). The somewhat later migration time for juvenile lacustrine smelt is likely to be related to the differences in the time of spawning between anadromous and lacustrine adult smelt identified in Ward et al. (2005). It is not known what determines the specific timing of these runs, however long-term observations by local iwi indicate that wind and temperature are important factors.

Two main migrations of adult smelt into the Ohau Channel occurred; one in February along with the run of juvenile fish and the other in August/September 2006. On both occasions, about 20–25% of the fish were spent females. However, in the August/September samples, most of the remaining fish were ripe, whereas none of those caught in February were. Our results indicate that the seasonal timing of smelt spawning runs in the Ohau Channel appears to occur primarily in late-winter through to spring. As the summer (February 2006) run of adult smelt into the Ohau Channel included some spent smelt, but no ripe ones, it was not a spawning migration. Mitchell (1989) noted that runs of adult spawners occurred from late-September to early October and Donald (1996) found mature adult smelt in the channel in November. Both indicated that sexually mature fish occurred in the channel until January. It should be noted that these studies did not systematically trap smelt throughout the year and the suggestion that smelt spawning runs, which start in spring, continue through summer months until January, were not borne out by the 2006 data. The run in February 2006 was clearly not a spawning migration.

The winter/spring timing of smelt spawning in the Ohau Channel is at odds with the reported spring/summer spawning reported for smelt in lakes Rotorua and Taupo (Jolly 1967; Stephens 1984). Ward et al. (2005) reviewed the literature on common smelt and found that anadromous smelt spawn in autumn/winter whereas lacustrine smelt spawn in spring/summer. The smelt spawning migration into the Ohau Channel lies between these times and it is feasible that a separate spawning stock occurs in Lake Rotoiti, with these fish migrating through the Ohau Channel to spawn in Lake Rotorua in late-winter/spring while other smelt spawn along the beaches of Rotoiti during spring, summer and autumn. Alternatively, smelt spawning occurs over a much wider period (e.g., late winter to summer) in Lake Rotoiti than would be expected from studies in other lakes.

Historically, seasonal runs of both adult and juvenile smelt are thought to have occurred from Lake Rotoiti into Lake Rotorua via the Ohau Channel (Jolly 1967). However, these runs are now thought to be affected by the installation of a weir at the head of the Ohau Channel (Mitchell 1989; Donald 1996). This weir is used to maintain water levels in Lake Rotorua, and the weir structure creates zones of high water velocity that could restrict smelt migrations into Lake Rotorua. Our observations and data support this view, as large numbers of adult smelt were often caught in the Weir plankton net, whereas few large adults were caught at the other two sites. This suggests that smelt concentrate below the weir when conditions prevent passage into Lake Rotorua. As a consequence, very high concentrations of smelt can occur in the channel when runs occur and when water velocities across the weir are high. At such times, smelt can be expected to concentrate in the channel below the weir. This effect has been noted by both Mitchell (1989) and Donald (1996) and was observed from 16

August-mid-September 2006, when large concentrations of adult smelt occurred below the weir and attracted large numbers of avian predators (primarily shags and gulls). Reports from anglers indicated that trout fishing at the mouth of the Ohau Channel was excellent at this time, and it is likely that the trout were attracted by the high concentrations of smelt in the channel as well as the few that managed to pass the weir and enter Lake Rotorua.

It is possible that the diversion wall will prevent runs of smelt into the Ohau Channel, particularly if their attraction to the channel is based on a positive response to water currents and/or olfactory cues. If so, this may benefit Lake Rotoiti in the sense that the adult smelt may be forced to remain in this lake. Sandy banks in shallow waters to the south east of Okawa Bay provide large areas of potential spawning habitat, but it is not known whether smelt would use this habitat or not. Conversely, preventing smelt access to spawning grounds in the Ohau Channel may prevent some larval recruitment into Rotoiti in winter after the autumnal loss of larvae from lake spawning smelt. Unfortunately, too little is known about the spawning behaviour of smelt in Lake Rotoiti to predict which of these options is more likely.

3. Smelt abundance in Lake Rotoiti

Monitoring of smelt abundance in Lake Rotoiti is required both before and after the diversion wall is constructed to detect any impact of the diversion on the smelt population in Lake Rotoiti. Smelt are a major prey item for trout in this lake and a significant reduction in smelt abundance could be expected to reduce the growth and production of trout.

Rowe (1993) found that schools of adult smelt could be readily detected in Lake Rotoiti using high frequency (200kHz) echosounding. However, larval smelt could not be detected acoustically, even with a high frequency echosounder, because unlike larval bullies, they lack an air-bladder. This organ is responsible for reflecting much of the sound from fish. Thus, while echosounding can be used to determine changes in the abundance of adult smelt, other methods are needed to determine changes in larval abundance and to determine whether changes in adult smelt abundance in this lake are related to a decline in recruitment.

Historic data on the density of larval smelt in Lake Rotoiti (Peterson 1982; Rowe & Taumoepeau 2004) provide an initial baseline for detecting major changes in larval smelt density and hence recruitment. Repeat surveys of larval smelt density were therefore carried out in 2005/2006 to augment these historic data and to determine whether it will be feasible to monitor changes in smelt recruitment in Rotoiti. The main concern was that inter-annual variation in smelt recruitment may be too large and the pre-wall database too small to detect even a large (e.g., 50%) decline in smelt recruitment.

Monitoring of adult smelt abundance in Lake Rotoiti will be possible if reliable estimates of smelt abundance can be produced from the acoustic surveys carried out in September 2000, 2005 and 2006. One limitation with this method is that transducers are normally towed in a paravane behind boats to provide a stable platform for the transducer with respect to depth, and to avoid the rocking motion of boats caused by wave action. The paravane is normally towed at a depth of 3–4 m to avoid propeller wash. As transducers do not detect fish within the first metre or so below their face, no fish echoes are detected in the top 4–5 m of the water column. Schools of juvenile smelt (30–40 mm long) are often present within such shallow waters, so acoustic methods are limited in their ability to determine the abundance of juvenile smelt. However, most adult smelt (40–80 mm long) are present in deeper water (Rowe 1993) and so are readily detected by echosounding.

Larval bullies (5–18 mm long) and trout (100–600 mm long) also occur in deeper water and are detected by echosounding. Inclusion of their echoes with those of adult smelt would bias results for smelt, so their echoes need to be excluded. There are two ways that are generally used to exclude echoes from non-target fish species. Where the depth distributions of species overlap, the proportion of each species within a depth zone is determined (e.g., by trawling) and the results from acoustic surveys are partitioned according to this ratio. Clearly, this process can create uncertainties because of selective bias in sampling methods, even trawling, and this necessarily places a limitation on interpretation of results. The other method is used when fish distributions do not overlap, and it relies on identification of the discrete depth zone occupied by the target fish species, in this case adult smelt. As the majority of adult smelt in Lake Rotoiti are present in a depth zone below the larval bullies (Rowe 1993, 1994), we used this approach. It also has limitations in that it may exclude some adult smelt present in shallower waters and it may include some larval bullies and trout present in deeper waters. In practice, fish depth distributions in lakes (and marine environments) are never perfectly discrete, and individual fish may occur over a much wider depth range than the bulk of the population. Results therefore always need to be interpreted with this limitation in mind.

3.1 Methods

3.1.1 Larval smelt

Rowe & Taumoepeau (2004) reported larval smelt densities in Lake Rotoiti for December 1994 and April 1995. Their estimates were obtained by Wisconsin drop-netting (mesh size 250 µm, mouth area 0.25 m^2) through the water column to a depth of 40–50 m or to just above the lake bed in shallower waters. Their sampling was carried out at 15 semi-random sites spread throughout the lake. Counts per haul were converted to areal densities, with the mean of these was calculated to provide a lake-wide estimate of larval smelt density. Sampling was carried out in December and April to cover the main spring/summer/autumn spawning season reported for smelt in central North Island lakes (Jolly 1967; Stephens 1984), as well as to account for the time lag between spawning and hatching as well as for larval development.

Incubation of anadromous smelt eggs takes 10–30 days depending on water temperatures (Mora & Boubée 1993), but incubation times for lacustrine smelt may be shorter because their eggs are much smaller. For example, Jolly (1967) indicated that eggs for lacustrine smelt hatched in 10–15 days depending on temperature. The largest larvae in lakes are around 25 mm long and according to growth rates for larval anadromous smelt (Ward et al. 2005), they would achieve this size after 100 days. Given these egg incubation and larval growth rates, the larvae from spring to early summer spawning smelt in Lake Rotoiti will be present in the lake (i.e., not yet schooling juveniles or whitebait) up until December, whereas larvae from mid-summer and autumn spawning will still be present in April..

To determine larval smelt densities in Lake Rotoiti in 2005 and 2006 and so provide another pre-diversion wall baseline, we followed the method used by Rowe & Taumoepeau (2004). Drop-netting was carried out at 15 semi-random sites throughout the lake in August 2005, December 2005 and April 2006. The net used was the same as that used in the 1994–1995 survey so that the results could be directly compared. In April 2006, sampling was also carried out in Lake Okataina to determine whether it could provide a useful reference site, as this may be required for longer term monitoring to distinguish any effects of the diversion wall from those related to annual changes in climate related factors affecting smelt recruitment.

3.1.2 Adult smelt

The hydro-acoustic survey of fish in Lake Rotoiti carried out in September 2000 used the NIWA 70kHz split-beam CREST acoustic detection system (Coombes 1994). The results of this survey were used to determine trout abundance in Lake Rotoiti before and after hatchery-reared trout were stocked into the lake (Rowe et al. 2000), so the data were collected for echo-counting (i.e., conversion of echoes into counts of individual fish) rather than echo-integration (conversion of all echoes into a measure of fish biomass). Nevertheless, the raw data on smelt can be re-analysed to provide an estimate of smelt biomass.

The CREST system was subsequently replaced with a 120kHz SIMRAD EK60 scientific sounder. The latter does not include as wide a scope for data analysis as the CREST system, but it provides a more compact and robust machine better suited to use in smaller vessels on lakes. The SIMRAD system would be used for any on-going monitoring in Lake Rotoiti, therefore, it was used to collect data on smelt abundance in September 2005 and September 2006.

The 2005 and 2006 surveys followed the September 2000 transects in order to cover the entire lake and to maintain methodological consistency (Figure 14). Slight changes in the location of Transects 4 and 5 were made to avoid the confounding effects of bubbles emanating from geothermal fumeroles along the southern side of the lake.

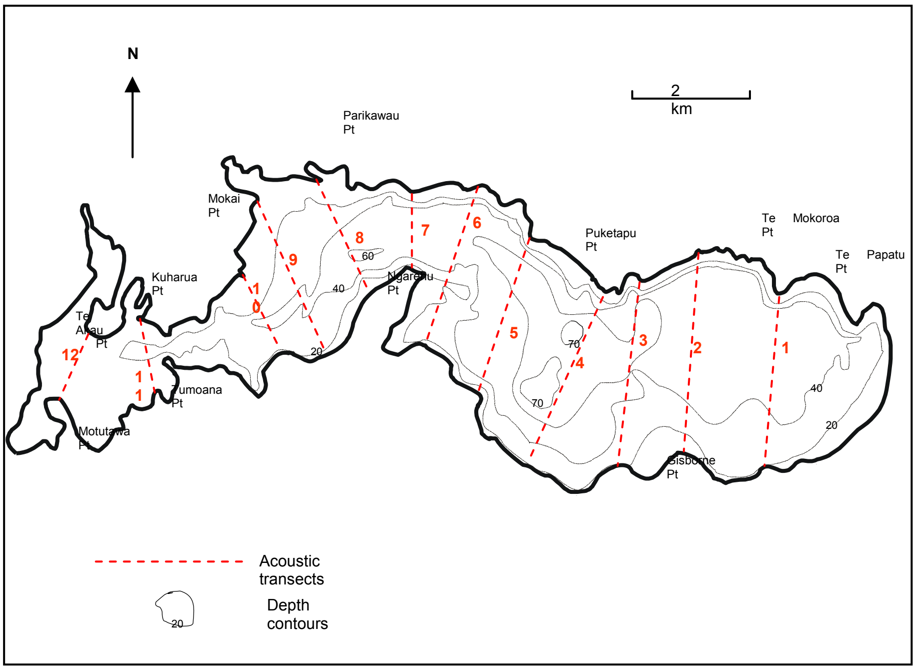

Figure 14: Transects (dashed red lines labelled 1–12) used for the acoustic surveys in Lake Rotoiti in 2005 and 2006.

The difference in sound frequency between the transducers of these machines (70kHz versus 120kHz), plus the lack of precise information on the target strength of smelt detected by the transducers, means that the results from the two machines will differ slightly. However, such differences will not prevent the results from being used to establish a baseline level of abundance for smelt. Data from the 2000 survey were therefore analysed to produce a comparable result to that obtained using the SIMRAD machine.

In the 'single-target' analysis of the 2000 survey data, three filters were used to exclude echoes that were clearly not from fish-like objects in mid-water (e.g., weed beds, submerged buoys, electronic noise, etc.) as well as to reduce bias in target strength estimation (Rowe et al. 2001). Echoes whose durations were shorter than 50% or longer than 150% of the transmitted pulse length were excluded, as were echoes that arrived at an angle of more than 3.5 degrees off the transducer normal. A third filter excluded echoes from any of the four quadrants of the split-beam transducer whose width differed by more than 50% of the pulse length. The first and third filters were also applied to the 2005 and 2006 survey data collected by the SIMRAD sounder, but the second filter could not be applied because the SIMRAD machine does not record data on variations in echo strength within the individual beams of the split-beam system. Instead, we used a filter that excluded the echoes from discrete targets whose position in the beam varied significantly while the target was being detected. This means that estimates of smelt abundance for 2000 are not directly comparable with those for 2005 and 2006 and so should only be used to provide a comparable estimate of smelt biomass in 2000.

Noise was present in the 2006 survey results, probably produced by strumming of the towing cable or some other motion-related noise source. It was significantly reduced when the boat was stationary and the motor was idling. Noise inserts small random echoes into the results and so can be expected to inflate the results from echo integration, but would not significantly affect echo-counting. It can be removed in processing, but this takes large amounts of time so is therefore best removed by trial and error prior to carrying out acoustic surveys. It has not been removed from the 2006 data, so these can be expected to increase the estimates of smelt abundance for 2006 by a small but unknown amount.

In general, three main layers of ‘fish echoes’ occurred in most of the deeper areas of Lake Rotoiti, as described by Rowe (1993). The depth distribution for adult smelt was identified by firstly examining the layers of fish (Figure 15A) and then using target strength filters and knowledge of smelt target strength (see below) to identify the depth zone for the adult smelt (Figure 15B). The regions within the echogram where adult smelt occurred were then delineated for each transect (Figure 15C).

The back-scattering of sound from all fish within the delineated regions was summed (integrated) for each transect. The back-scattering coefficient is a measure of the total sound energy produced within a given region and is directly proportional to the number of acoustic scatterers and hence to the total biomass of fish detected by the echosounder throughout the transect. The back-scattering coefficient was calculated for each transect and converted to an areal basis based on the length of the transect and the shape of the acoustic beam (i.e., its cone of detection) through the water column. This process was carried out using the ESP2 suite of software (McNeill et al. 2003).

As indicated above, knowledge of the target strength of smelt and other fish is required to identify the depth zone occupied by smelt. The target strength range for echoes produced by adult trout (>30 cm long), smelt (30–80 mm long) and larval bullies (4–18 mm long) was determined empirically in Lake Rotoiti (Rowe et al. 2001), and the ranges for these fish were in good agreement with the results reported for similar-sized fish species in other lakes (e.g., Naken & Olsen 1977; Carlson 1979; Warner et al. 2002; Peltonen et al. 2006). In particular, the target strength for smelt of various sizes in Rotoiti agreed very well with the target strength for similar-sized (40–80 mm) northern hemisphere smelt (*Osmerus eperlanus)* studied by Peltonen et al. (2006). Hence, echoes with a target strength of greater than -40 decibels (db) were deemed to be from trout, echoes with a target strength of -45 to -65 db to be from smelt, and those with a target strength of -60 to -65 db to be from larval bullies.

The frequency distributions of target strengths for all echoes in Lake Rotoiti in both 2000 (70 kHz transducer) and 2005 (120 kHz transducer) are shown in Figure 16.

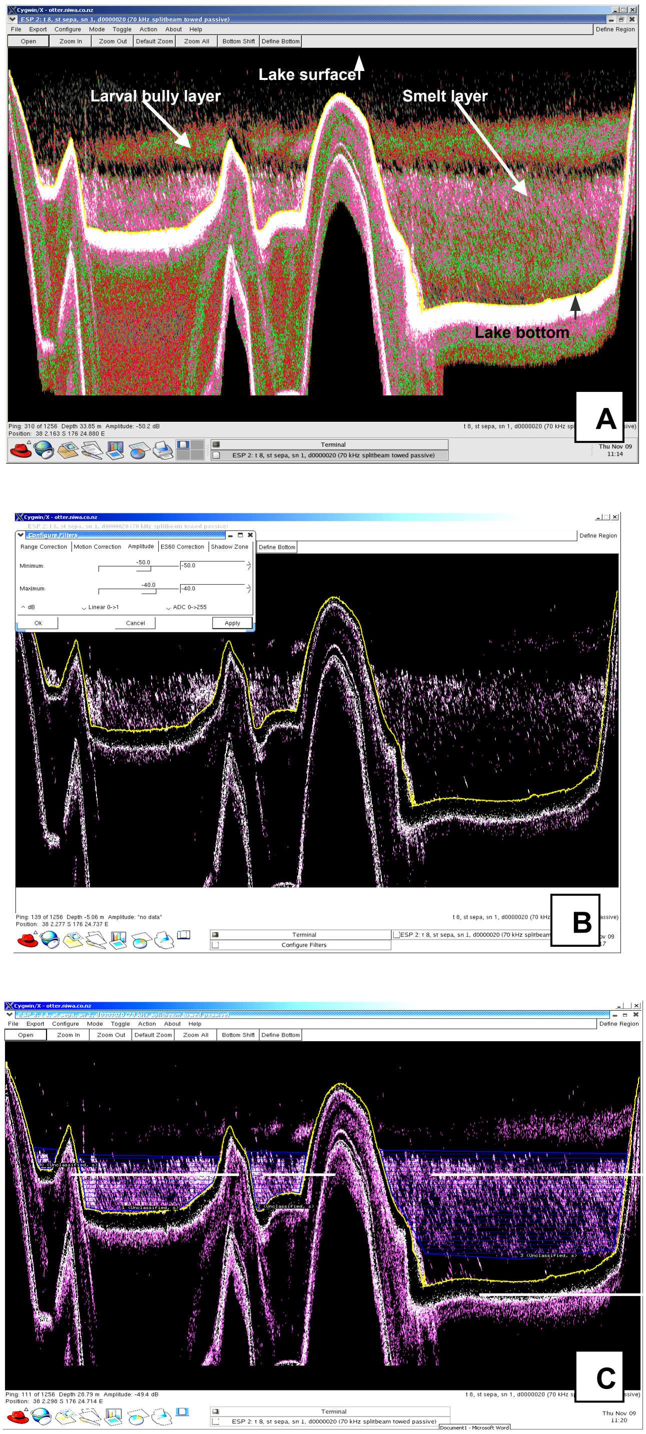

Figure 15: (A) the raw echogram (all data displayed) showing the larval bully and smelt layers in Rotoiti, (B) filtered echogram showing only echoes between -40 and -55 dB (i.e., large smelt) to identify their depth zone, (C) regions of the water column containing large and smaller adult smelt are delineated (white lines).for echo integration analysis.

The three modes correspond respectively, with echoes from zooplankton (range -80 to -70 decibels, or dB), larval bullies (-65 to -60 dB), and smelt (-65 to -45 dB). Note that as decibels are a measure of sound energy and are expressed as minus values; a larger number indicates a smaller amount of sound energy and therefore smaller echo-producers, or fish. Echoes from adult trout typically range from -40 to -25 dB (Rowe et al. 2001). The consistent offset in modes between the 2000 and 2005 data (slightly higher target strengths in 2000) reflects the difference in transducer frequency (70 versus 120 kHz). Higher frequency transducers can detect smaller echo-producers, thus, the higher proportions of smaller echoes in 2005 than in 2000 can be expected to partly reflect the higher frequency of the transducer used in 2005 (NB. the use of a different single-target filter will also have contributed to a higher number of smaller echoes in 2005).

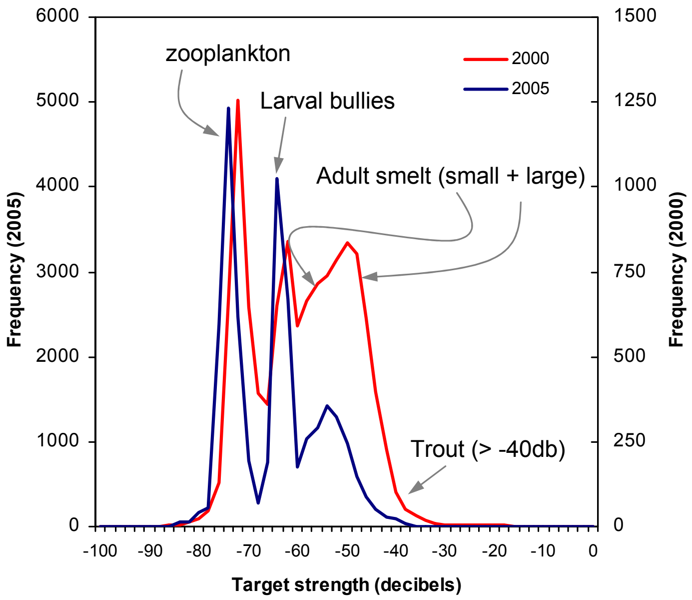

Figure 16: Frequency distributions for target strengths of all echoes in the September 2000 and September 2005 surveys in Lake Rotoiti (NB. The 2000 data are plotted against the Y2 axis).

The frequency distributions for all target strengths (Figure 16) show that there is an inflection point in the distribution for smelt echoes (range -60dB to -40dB) and that this occurs at about -55dB. This inflection point indicates that that two size classes of smelt are present in the deeper waters of Lake Rotoiti. Rowe (1993) also found two size classes of adult smelt in the deeper waters of Lake Rotoiti, with smaller adult smelt in deeper water. Thus, smelt with slightly higher target strengths (e.g., range -40 to -55 dB in Figure 16) can be expected to be shallower than those with the lower target strength (range -55 to -65 dB). For the purposes of monitoring smelt abundance in Rotoiti, we have focussed on the larger smelt, but our estimates of smelt abundance can also be expected to contain a large proportion of the smaller smelt as they are also present in deeper waters where the larger smelt occur and the distribution of both size classes frequently overlapped.

The mean back-scattering coefficient for each survey provides an indirect estimate of the biomass of smelt present in the lake. To convert this figure to actual biomass requires knowledge of the mean target strength of smelt present in the lake at the time of each survey and knowledge of the relationship between target strength and smelt size. The best available estimate of the latter is provided by Peltonen et al. (2006) who determined the target strength/fish size relationship for northern hemisphere smelt (*Osmerus eperlanus* L.). This is a different species to the southern hemisphere common smelt present in Rotoiti (*Retropinna retropinna*) and the *O. eperlanus* used by Peltonen et al. (2006) were slightly longer than the smelt in Rotoiti (70–90 mm long versus 50–80 mm long, respectively). Nevertheless, the fish size-target strength relationship developed by Peltonen et al. (2006) for a 120 kHz transducer agrees almost exactly with estimates of target strength for common smelt of various sizes obtained in Rotoiti. Consequently, the Peltonen et al. (2006) relationship can be used for common smelt in Rotoiti. It currently provides the best fit, short of a specific study to determine the relationship for common smelt in Rotoiti. The relationship is:

$$\mathbf{TS} = 20\log_{10}\mathbf{L}\text{-}65.9\ (\pm 0.23)$$

- where **TS** is target strength and **L** is length in mm

The relationship between smelt length and weight also needs to be determined. Cryer (1991) provided this from data obtained by Stephens (1984) in Lake Taupo. The relationship for Lake Taupo smelt was:

$$\mathbf{W} = 1.316 \times 10^{-4}\ \mathbf{L}^{4.053}$$

- where **W** is weight in g and **L** is length in mm

Although these two relationships can be used to derive estimates of smelt biomass from the mean back-scattering coefficient, a comparison between the 2000 surveys (using the 70 kHz transducer) and the 2005 & 2006 surveys (120 kHz transducer) requires good knowledge of the mean target strength of smelt at the time of the surveys. In the absence of this, we used the modal target strength values for smelt echoes in the target strength frequency distribution for the 2000 and 2005 surveys (Figure 16). These were -50dB and -54dB respectively. These values were used to convert the mean back-scatter coefficients to fish number so that the 2000 and 2005 data could be compared. However, for the purposes of monitoring smelt biomass in Lake Rotoiti in the future, the mean back-scattering coefficient provides a more direct estimate of biomass. Better knowledge of smelt target strength values in relation to smelt size in Lake Rotoiti will allow the 2005 and 2006 back-scattering values, and any future estimates obtained by the SIMRAD machine, to be converted to actual biomass.

3.2 Results

3.2.1 Larval smelt

Drop-netting caught larval smelt, bullies and koaro in the limnetic zone, although koaro were rare, with only 2 being recorded in Lake Rotoiti (1 in August and the other in December). None were found in April in either lake. In general, larval smelt occurred throughout Lake Rotoiti. However, smelt in Okataina were more prevalent in the deeper southern end of the lake than in the shallower northern end. Larval bullies dominated the catch in all lakes in December and April (summer/autumn), but they were scarce in August.

The size of larval smelt in Lake Rotoiti in 2005/2006 ranged from 6–24 mm, and in Lake Okataina from 5–24 mm (Figure 17). Smelt present in Lake Rotoiti in August 2005 were generally larger than those present in both December 2005 and April 2006, and are likely to have resulted from a summer or autumnal spawning. The smallest smelt in Lake Rotoiti were recorded in April 2006. This is consistent with autumn spawning.

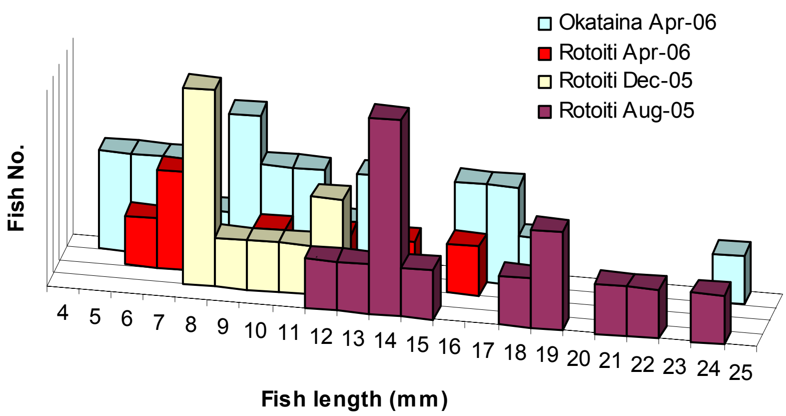

Figure 17: Size frequency distributions for smelt larvae in Lake Rotoiti at different times of the year and in Lake Okataina in April 2006.

The mean density (± standard error) of larval smelt in Lake Rotoiti in December 1994 and April 1995 was 27.6 (± 3.2) and 5.6 (± 2.0) larvae/m^2, respectively (Rowe & Taumoepeau 2004). The comparable figures for December 2005 and April 2006 were 2.4 (± 0.8) and 1.9 (± 0.5) larvae/m^2, respectively. The densities of smelt larvae in

Lake Rotoiti in both December 2005 and April 2006 were therefore much lower than those recorded in 1994/1995. The density of smelt in Lake Rotoiti in August 2005 was 3.5 (± 1.2) larvae/m^2 and therefore somewhat higher than that recorded in December and April. The density of smelt larvae in Lake Okataina in April 2006 was 6.1 (± 1.3) larvae/m^2.

3.2.2 Adult smelt

The areal back-scattering coefficient (i.e., the total acoustic energy back-scattered from the smelt per m^2), provides a measure of smelt biomass along each transect and is shown in Figure 18 for the September 2000 and September 2005 and 2006 surveys. It should be remembered that the data for the 2000 surveys were obtained using a 70 kHz transducer so are not directly comparable with the 2005 and 2006 surveys.

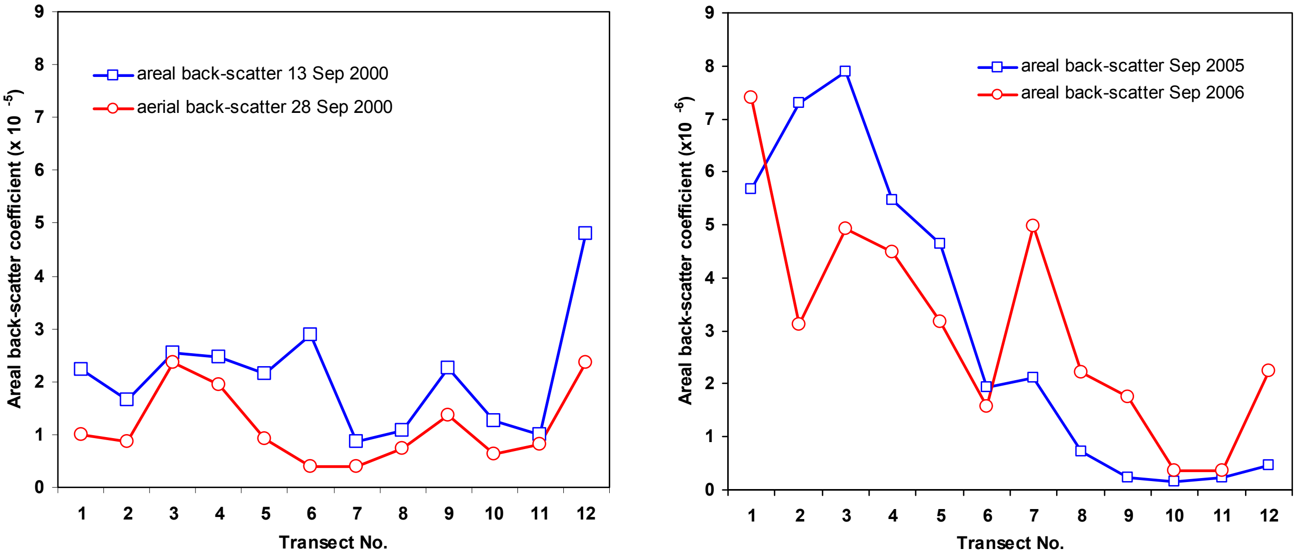

Figure 18: Back-scattering coefficients providing comparable measures of smelt biomass for each transect in Lake Rotoiti, in September 2000, 2005 and 2006.

In September 2000, smelt biomass was highest in Transect 12 on both the 13th and 28th. However, if these high values are set aside, then smelt biomass was generally higher in the deeper, eastern end of the lake (Transects 1–6) than in the shallower, western end (transect 7–11). This trend was much more marked in the September 2005 and 2006 surveys. However in these years, smelt biomass was also higher in Transect 12 than in Transects 10 or 11. Whereas smelt abundance is generally higher in the deeper eastern end of the lake, an aggregation is also apparent in Transect 12, which is adjacent to the Ohau Channel. This aggregation was especially marked in the September 2000 survey.

Smelt back-scattering (or biomass) per m^2 was lower throughout Lake Rotoiti on 28th September 2000 than on 13th September 2000. In 2006, smelt biomass was lower in the deeper, eastern end of Rotoiti (Transects 1–6) than in 2005, but was higher in the western end of the lake (Figure 18). The difference in smelt biomass between the eastern and western basins of Lake Rotoiti was less marked in 2006 than in 2005, and much less marked in 2000. These data illustrate some general trends in the areal distribution of smelt in Lake Rotoiti as well as temporal changes in this distribution over both short (weeks) and long (years) time scales.

The overall abundance of adult smelt in Lake Rotoiti in 2000 is compared with that in the 2005 and 2006 surveys in Figure 19. The two points for September 2000 are directly comparable as are the points for 2005 and 2006.

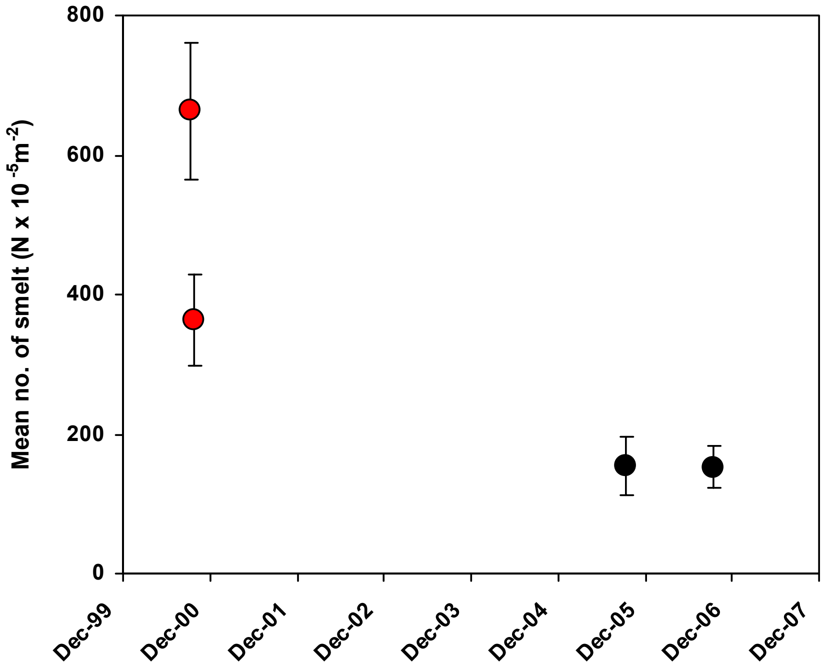

Figure 19: Relative estimates of adult smelt density (mean ± SE) in Lake Rotoiti as determined acoustically for September 2000 (two surveys 2 weeks apart) and September 2005 and 2006.

Although the data for 2000 are not directly comparable with those for 2005 and 2006 because of the different transducers used, the results for 2000 provide the best estimates of smelt density available for this period and are sufficient to determine any large scale difference with the 2005 and 2006 estimates. The data for 2005 and 2006 indicate that there has been a decline in adult smelt density in the lake between 2000 and 2006 even though the real extent of this is unknown. Although smelt density in

2006 was no different to that in 2005, the presence of extraneous noise in the data for the 2006 survey may have slightly inflated the 2006 value.

3.3 Discussion

3.3.1 Larval smelt

The mean density of larval smelt in Lake Rotoiti was reduced by 66% between December 1994 and December 2005 and by 91% between April 1994 and April 1995. Over the two summer periods the mean decline was 78%. Data presented in Peterson (1982) for the 1980s do not allow direct comparison with these data as the method was not described in sufficient detail. However, they do indicate that smelt density in Lake Rotoiti was relatively high in the 1980s and comparable with the 1994/95 levels.

The 1980 data indicated that larval smelt abundance was greatest in summer (February), had fallen by autumn (May), and was lowest in late winter (August). The data for 1994/95 and 2005/06 show a similar trend, with the highest abundance in summer (December) and a reduction by autumn (April). However, smelt density in Lake Rotoiti in late winter (August) 2005 was higher than the density in the summer/autumn months. This suggests that recruitment from spring and summer spawning smelt has been reduced, but not that from autumn spawners. Such seasonal variations in smelt recruitment can be expected to occur naturally depending on annual variations in climatic factors influencing egg and larval mortality rates. At present, our knowledge of such processes is too limited to determine the implications of such variation in larval smelt numbers for adult abundance in this lake.

Because climatic factors may result in a large decline in smelt larval numbers in any one year, mean smelt densities also need to be determined in a control lake. Lake Okataina was selected as a control lake and the mean density of larval smelt (±SE) for April 2006 (6.1 ± 3.6) was 78% lower than the April 1995 density. Thus, smelt densities in the Rotorua lakes in autumn 2006 may have been lower than normal because of climatic factors affecting larval smelt recruitment.

This aside, the historic data indicate that there has been some reduction in the density of larval smelt in Lake Rotoiti since the mid 1990s. This may be a consequence of a further deterioration of the lake's water quality since 1994/1995. Rowe & Taumoepeau (2004) found that mean smelt densities in the Rotorua lakes declined as the trophic status of the lake increased. The recent closures of Lake Rotoiti during summer and autumn months of 2001 to 2004 because of blue-green algal blooms indicate that the water quality in this lake has deteriorated since 1994. Hence, the reduction in larval smelt density between 1994 and 2006 may reflect this deterioration.

This possibility can be examined by using the relationship between mean larval smelt density and secchi disc depth (reflecting lake trophic status) developed for the Rotorua lakes by Rowe & Taumoepeau (2004) (Figure 20). The mean density of larval smelt in Rotoiti in 2006 was consistent with the decline in secchi disc depth in this lake between 1995 and 2006 and within the expected range of variation for the Rotorua lakes.

The mean density of larval smelt in 2005/2006 provides a benchmark against which any future changes in smelt density can be assessed after the diversion wall is constructed. A further and sustained reduction in larval smelt density over the next five years (i.e., post-wall construction) to less than 1 larvae/net with no corresponding decline in water transparency would indicate that a decline in larval smelt had occurred as a consequence of factors other than a decline in lake tropic status. It would more than likely indicate an effect of the diversion wall on smelt recruitment. This would be especially so if acoustic monitoring also revealed a decline in adult smelt abundance. In contrast, and assuming the low density of larval smelt in 2005/06 is a consequence of climatic factors rather than trophic deterioration in the lake, an increase in larval smelt density in the future can be expected to indicate that any effects of the diversion wall on recruitment are minor in relation to factors affecting inter-annual variation.

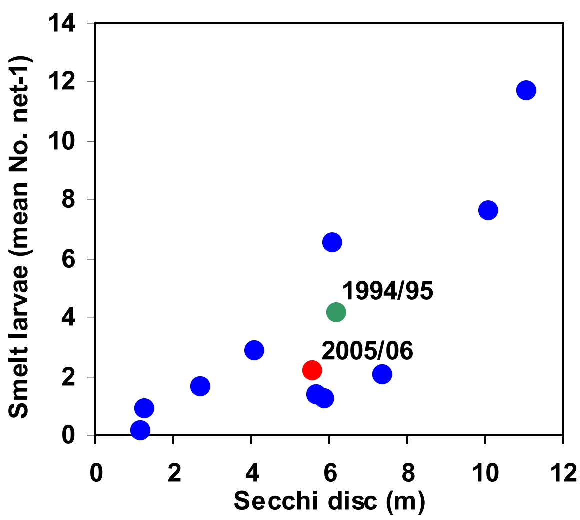

Figure 20: Relationship between larval smelt density averaged over summer and autumn months and secchi disc depth in the Rotorua lakes (values for Lake Rotoiti are shown in green for 1994/95 and red for 2005/06).

3.3.2 Adult smelt

The biomass of adult smelt in Lake Rotoiti also declined over time (2000–2006) and reflected the decline in larval recruitment between 1995 and 2006. This concurrence between methods provides reassurance that together they are capable of detecting long-term changes in smelt abundance in this lake.

The lake-wide hydro-acoustic estimates of smelt abundance (mean back-scatter/m^2 ± SE) provide a baseline for assessing any significant decline in smelt abundance in Lake Rotoiti. However, smelt abundance in this lake can be expected to vary naturally between years because of inter-annual variations in recruitment success and juvenile mortality rates. For example, Burczynski et al. (1987) found that smelt biomass in Lake Oahe varied by a factor of 3 over three years. However, these data are for *O. eperlanus*, which is a different species to the southern hemisphere species. Comparatively primitive measures of biomass were obtained for New Zealand common smelt (*R. retropinna*) using acoustic data for Lake Taupo collected over a longer time frame (10 years). The abundance of smelt was assessed visually in each of 42 echograms recorded from throughout the lake in March and was scored against an 8 point abundance scale (Dedual & MacLean 1997). The mean score was determined for each of the 4 years for which data were available between 1988 and 1997, and revealed that smelt biomass in this lake could vary naturally between years by a factor of up to 4. Hence, smelt abundance in Lake Rotoiti can also be expected to vary naturally between years by a factor of up to 4. Any decline in the abundance of smelt in Lake Rotoiti related to the presence of the diversion wall would therefore require a drop from current mean back-scattering levels of $3 \times 10^{-6}/m^2$ (equivalent to an overall mean density of 150 fish/m^2) to values of less than $0.8 \times 10^{-6}/m^2$ (or 40 fish/m^2) for at least three years in a row.

4. Options for remediation

4.1 Trout abundance

Should fishery monitoring and creel census data reveal a sudden and sustained decline in trout catch rates in Lake Rotoiti after the Ohau Diversion wall is constructed, this may indicate a decline in the recruitment of trout from Lake Rotorua to Rotoiti related to the wall. However, a dramatic increase in harvest by anglers or a natural decline in trout recruitment related to climatic factors, especially spring/summer floods, could also account for such a decline in the catch rates of adult trout in Lake Rotoiti. Floods are unlikely to occur each year over a period of more than 3 years. Hence, a sustained decline in catch rates over a prolonged period (e.g., 3–5 years) would be symptomatic of reduced trout recruitment from Lake Rotorua. This could also be caused by a dramatic increase in harvest by anglers over the 5 year period after installation of the diversion wall but fishery monitoring can be expected to reveal this.

Eastern Fish and Game have carried out monitoring of trout catch rates in Lake Rotoiti over an extended period, and whereas more data is always desirable, the existing information will form a good database for assessing any large decline in catch rates related to trout density.

Eastern Fish & Game propose to mitigate any sustained decline in trout recruitment to Rotoiti by increasing stocking rates of hatchery-reared fish, although it will be difficult to determine the appropriate increase in stocking rate except through trial and error. As a consequence, any significant decline in the natural recruitment of trout from Lake Rotorua into Lake Rotoiti can be expected to de-stabilise the fishery for some time and result in complaints from anglers until a new stocking regime is established.

Mitigation of the effects of the diversion wall on the trout fishery, apart from increased stocking of hatchery fish, may also involve the enhancement of natural recruitment in one or more of the few spawning streams in Lake Rotoiti. Te Toroa Stream (Figure 21) is the main ‘natural’ spawning tributary for rainbow trout in Lake Rotoiti. Some spawning also occurs in the Hauparu and Ruato streams in adjacent bays to the east of this. Other inlet streams are generally smaller or contain barriers to the upstream migration of trout (e.g., Waiiti Stream). Natural recruitment from the streams where trout spawn, especially the Te Toroa Stream, could be enhanced through provision and improvement of fry rearing habitat. The riparian planting along the edges of Te Toroa Stream in the vicinity of the Moose Lodge golf course has had an observable effect on the number of trout fry and fingerlings in the lower reaches of this stream. Its capacity to provide nursery habitat for trout has also been increased by widening (as a consequence of floods in May 2001). The tree planting and withdrawal of cattle on this stream above SH30 has probably also improved spawning habitat for trout in the northern branch of this stream where it runs alongside SH30. Opportunities for the creation of more spawning and nursery habitat no doubt exist within this stream, especially its main branch. In particular, retirement of certain sections of the stream bank above SH30 through fencing and riparian planting can be expected to increase spawning and rearing habitat for trout.

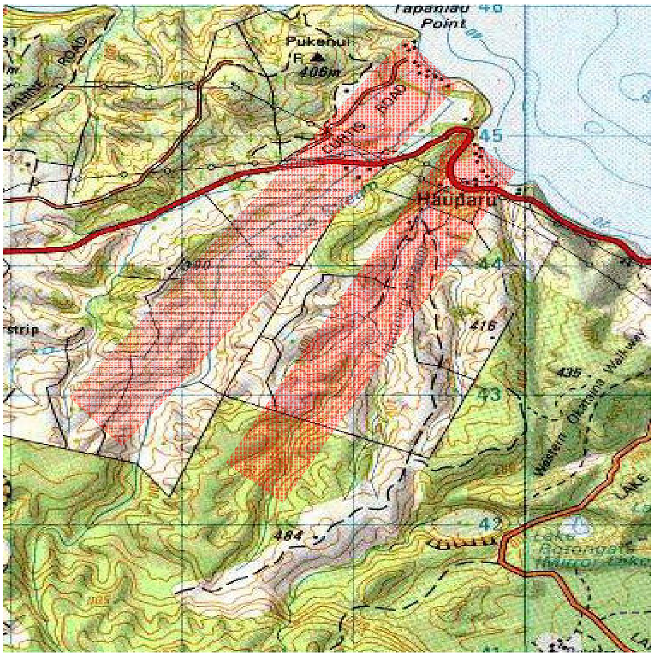

Figure 21: The two main spawning tributaries for rainbow trout in Lake Rotoiti, Te Toroa Stream and Hauparu Stream (shaded red). Potential area for juvenile trout habitat improvement in the Te Toroa Stream by riparian planting is hatched.

4.2 Smelt

Remediation of any decline in smelt recruitment in Lake Rotoiti is more problematic than for trout because less is known about the habitat requirements for smelt spawning in lakes and stocking may not be economically feasible. To address this knowledge gap, Environment Bay of Plenty has agreed to fund a PhD study that will focus on the dynamics of smelt reproduction and recruitment in the lake.

In general, lacustrine smelt are known to spawn on the shallow (0.5–2.5 m deep) sandy shorelines of lakes and in the lower reaches of streams where there is an adequate water depth (> 0.5 m) and where water velocities are relatively low (Jolly 1967; Stephens 1984; Rowe et al. 2002; Ward et al. 2005). However, smelt do not spawn in all habitats conforming to this description, and reasons for this are unknown.

In Lake Rotoiti, the area of potential smelt spawning habitat is much more limited than in Lake Rotorua because of the fewer (and smaller) inlet streams and the smaller area of shallow sandy beach habitat not affected by weed growth. Relatively small and narrow pockets of potential spawning habitat occur around most of the lake, but the main 'potential' spawning grounds are shown in Figure 22. Some of these coincide with ski-lanes, which may pose a conflict of interest in mid-summer when both activities coincide. Apart from the Ohau Channel, smelt spawning in streams entering Lake Rotoiti can be expected to be minimal because of the small size of these streams and the paucity of smelt spawning habitat within them.

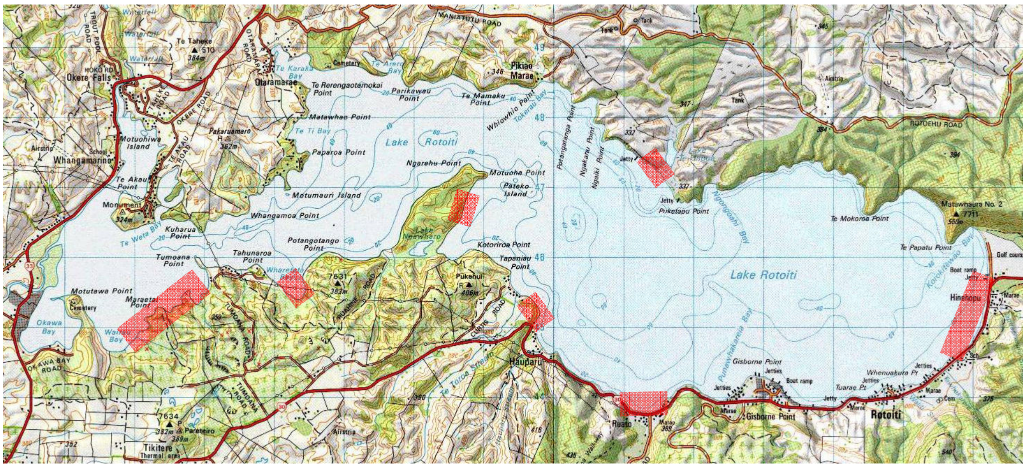

Figure 22: The main potential locations for smelt spawning in Lake Rotoiti (red shaded areas) provided by large shallow, sandy beaches or by large shallow sand banks.

Improvement of smelt spawning habitat and/or a reduction in factors currently limiting smelt recruitment would require further study to identify the main physical variables that can be controlled and that will affect these processes. It should be noted that restoration of lake water quality in Lake Rotoiti can be expected to achieve this in the very long term (Rowe & Taumoepeau 2004). In the short term, better knowledge of smelt spawning habitats and what controls them is required. Rowe et al. (2002) noted the importance of natural variations in lake level for the amount of smelt spawning habitat in Lake Taupo. The effect of the controlled and therefore very limited lake level variation in Lake Rotoiti may affect smelt spawning habitat in this lake and so also requires investigation.

The rearing of large numbers of smelt larvae for re-stocking into the lake is technically feasible, but would require construction of a purpose built hatchery and the development of techniques for mass production of larvae. It should be noted that while this is technically feasible (i.e., the technology has been developed for inanga whitebait), the artificial rearing of smelt larvae and their stocking to boost natural populations has not been attempted elsewhere in the world and there is no guarantee of success.

5. Conclusions

1. There is an annual spawning migration of ripe adult smelt from Lake Rotoiti into the Ohau Channel in late-winter/spring. The specific timing of this varies from year to year. Although some spawning occurs within the Ohau Channel as evidenced by a spring increase in smelt larvae, larval production in the Ohau Channel was small (9%) relative to the loss of smelt larvae from Lake Rotoiti at this time. The adult smelt migration in summer was not a spawning migration and its purpose is unclear.

2. There is also a distinct migration of juvenile smelt into the Ohau Channel from Lake Rotoiti during summer months (particularly January-February). This is a similar migration to the entry of whitebait into river mouths in spring and early summer. As the diversion wall may disrupt the annual migrations of some smelt from Lake Rotoiti into the Ohau Channel, monitoring of smelt movements within the channel will be required post-wall construction to determine whether smelt find the new entrance.

3. Some transport of larval smelt occurred from Lake Rotorua into the Ohau Channel but this was minimal (less than 1.5 larvae per second in all months) and it was negligible compared with that from the Ohau Channel into Lake Rotoiti (10-30 larvae per second for 5 of the 13 months). Hence there is virtually no supply of smelt larvae from Lake Rotorua into Rotoiti.

4. Smelt larvae produced from smelt spawning in the Ohau Channel can be expected to enter the western end of Lake Rotoiti and contribute to the smelt population there. However, production of larval smelt in the Ohau Channel was completely dwarfed by the number recorded leaving the lake at Okere. This indicates that larval smelt production from the channel is relatively small compared with that from the lake. However, we were unable to measure larval smelt production from the delta of the Ohau Channel and, although this area of potential spawning habitat is relatively small compared with that present in either the Ohau Channel or Lake Rotoiti, it may be heavily utilised by smelt. We have no information to explain the high transport of larvae out of Lake Rotoiti in April and September 2006. It may be related to wind-induced current systems in the lake, but further information on the dynamics of larval smelt production in Lake Rotoiti will be required to determine this and the role of the lake's beaches for smelt spawning and larval recruitment in relation to that from the Ohau Channel and its delta. The proposed PhD study on smelt is expected to help provide this information.

5. The density of larval smelt in Lake Rotoiti varies seasonally and annually and has declined since the mid 1990's in line with the on-going decline in the lake's trophic status as reflected by its reduced water transparency (secchi disc depth). Monitoring can be used to detect any further large-scale decline in larval smelt densities and whether this is related to a further decline in lake trophic status or to some other extraneous factor (e.g., the diversion wall). Lower densities of larval smelt combined with the likelihood of a more patchy distribution will require a much more intensive sampling programme than that carried out in 1994/1995 and 2005/2006.

6. A hydro-acoustic method for measuring the abundance of adult smelt in Lake Rotoiti was developed and provides a means for monitoring the abundance of adult smelt throughout the lake on an annual basis. Although this method is somewhat limited by a lack of precise knowledge of the mean target strength of smelt, baseline estimates of smelt biomass (i.e., the mean back-scattering coefficient) were established for September 2005 and 2006. These data provided a threshold level for detecting any significant decline over and above the fourfold natural variation that can be expected.

7. Monitoring of smelt aggregation and movements around the vicinity of the diversion wall may be required in future to assess the need for a fish pass. The side-scanning, multiple beam swathe sounder used by NIWA to determine the presence and behaviour of schooling fish (e.g., sardines, kahawai, trevally) in shallow marine environments could prove very useful for this task.

6. Recommendations

Recommendation 1: Monthly sampling on both sides of the Ohau Channel will be required to determine whether the adult and juvenile smelt find the new entrance to the channel after the wall is constructed. This should target juvenile migrations between January and March as well as adult migrations between August and November using a two weekly sampling period.

Recommendation 2: That, in addition to a focus on smelt spawning habitats and remediation options in Lake Rotoiti, the PhD study being sponsored by Environment Bay of Plenty seek to determine the effect of larval smelt losses from the lake via the outlet at Okere on overall larval smelt density in this lake.

Recommendation 3: That larval smelt sampling be carried out annually post-wall construction in Lake Rotoiti (as per the resource consent) on a more comprehensive basis than used in 1994/1995 and 2005/2006, and that concurrent sampling be carried out in a control lake (i.e., Okataina). (NB. Some of this work may be incorporated into the PhD study).

Recommendation 4: That an acoustic survey be carried out annually (in September) post-wall construction to monitor adult smelt biomass in this lake and to detect any decline in smelt abundance related to the wall. Acoustic data collection should be expanded to obtain concurrent estimates of the mean target strength (and actual size) of adult smelt in the lake so that back-scattering coefficients can be converted into actual biomass estimates.

Recommendation 5: That the NIWA swathe sounder be tested in a freshwater lake to determine its ability to monitor smelt schools in shallow waters close to vertical structures. If suitable for this purpose, a monitoring regime then be established to detect smelt aggregations around the wall during the months when juvenile and adult migrations occur.

7. References

Burczynski, J.J.; Michaletz, P.H.; Marrone, G.M. (1987). Hydroacoustic assessment of the abundance and distribution of smelt in Lake Oahe. *North American Journal of Fisheries Management 7:* 106–116.

Coombes, R. (1994). An adaptable acoustic data acquisition system for fish stock assessment. International Conference on Underwater Acoustics, Australian Acoustical Society, December 1994. 18 pp.

Dedual, M.; Maclean, G. (1997). Chlorophyll *a* depletion in Lake Taupo- effects on smelt production. *NIWA Client Report ELE70230/2*.

Donald, R. (1996). An assessment of smelt migration over the Ohau Channel fish pass. *Environment BOP Environmental Report 96/8*. Environment Bay of Plenty, Whakatane.

Jolly, V.J. (1967). Observations on the smelt *Retropinna lacustris* Stokell. *New Zealand Journal of Science 10*: 330–355.

Jurvelius, J.; Auvinen, H.; Kolari, I.; Marjomaki, T.J. (2005). Density and biomass of smelt (*Osmerus eperlanus*) in five Finnish lakes. *Fisheries Research 73*: 353–361.

McCarter, N. (1994). A key to some larval fish from New Zealand fresh water. NIWA Ecosystems Publication No. 10.

McDowall, R.M. (1990). New Zealand Freshwater Fishes a natural history and guide. Heinemann Press, Auckland.

Malinen, J.; Tuomaala, A. (2005). Comparison of day and night surveys in hydroacoustic assessment of smelt (*Osmerus eperlanus*) in Lake Hiidenvesi. *Archives fur Hydrobiologie (Special Issue on Advances in Limnology) 59*: 161–171.

Mitchell, C.P. (1989). Environmental assessment of the Lake Rotorua control structure. *New Zealand Freshwater Fisheries Miscellaneous Report 24*. Fisheries Research Division, Ministry of Agriculture and Fisheries, Rotorua.

Mora, A.L.; Boubee, J.A.T. (1993). Effects of temperature on egg development of common smelt (*Retropinna retropinna*). NIWA Ecosystems Consultancy Report ELE074/1. 17 p.

Nakken, O.; Olsen, K. (1977). Target strength measurements of fish. *Rapports et Proces verbeaux de al Reunion du Conseil International pour l'Exploration de la Mer 170*: 52–69.

Neil, E.; Macaulay, G.; Dunford, A. (2003). ESP2 (Phase 5): User documentation. National Institute for Water and Atmosphere Research Ltd, Wellington.

Parker-Stetter, S.L.; Rudstam, L.G.; Stritzel Thomson, J.L.; Parrish, D.L. (2006). Hydroacoustic separation of rainbow smelt (*Osmerus mordax*) age groups in Lake Champlain. *Fisheries Research 82*: 176–185.

Peltonen, H.; Malinen, T.; Tuomaala, A. (2006). Hydroacoustic in situ target strength of smelt (*Osmerus eperlanus* (L.). *Fisheries Research 80*: 190–195.

Peterson, D.R. (1982). Future options for the Rotorua lakes District- Implications of alternative patterns of environmental resource use and management on the Rotorua lakes. Wildlife habitats. Progress Report No. 6. by the University of Waikato for the Rotorua District Council.

Rowe, D.K. (1993). Identification of fish responsible for five layers of echoes recorded by high frequency (200kHz) echosounding in Lake Rotoiti, North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 27*: 87–100.

Rowe, D.K. (2005). Effects on trout and smelt of diverting the flow of the Ohau Channel out of Lake Rotoiti. *NIWA Client Report HAM2005–106*.

Rowe, D.K.; Macaulay, G.; Pitkethley, R. (2001a). Acoustic estimation of trout abundance in Lake Rotoiti before and after stocking in September 2000. *NIWA Client Report NZF01504/1*.

Rowe, D.K.; Macaulay, G.; Pitkethley, R. (2001b). Acoustic estimation of trout abundance in lake Rotoiti – differences between duplicate surveys taken three days apart in June 2001. *NIWA Client Report NZF01504/2.*

Rowe, D.K.; Shankar, U.; James, M.; Waugh, B. (2002).Use of GIS to predict effects of water level on the spawning area for smelt, *Retropinna retropinna*, in Lake Taupo, New Zealand. *Fisheries Management and Ecology 9*: 205–216.

Rowe, D.K.; Taumoepeau, A. (2004). Decline of common smelt (*Retropinna retropinna*) in turbid, eutrophic lakes in the North Island of New Zealand. *Hydrobiologia 523*: 149–158.

Rudstam, L.G.; Parker, S.L.; Einhouse, D.W.; Witzel, L.D.; Warner, D.M.; Stritzel, J.L.; Parrish, D.L.; Sullivan, P.J. (2003). Application of in-situ target-strength estimations in lakes: examples from rainbow smelt surveys in Lakes Eire and Champlain. *ICES Journal of Marine Science 60*: 500–507.

Stephens, R.T.T. (1984). Smelt (*Retropinna retropinna*) population dynamics and predation by rainbow trout (*Salmo gairdneri*) in Lake Taupo. PhD Thesis, University of Waikato, Hamilton.

Warner, D.M.; Rudstam, L.G.; Klumb, R.A. (2002). In situ target strength of. alewives in freshwater. *Transactions of the American Fisheries Society 131*: 212–223.

Ward, F.J.; Northcote, T.G.; Boubee, J.A.T. (2005). The New Zealand common smelt: biology and ecology. *Journal of Fish Biology 66*: 1–32.

8. Acknowledgements

We thank Paul Dell (Environment Bay of Plenty) for his guidance and forbearance with the many changes to this project. The smelt monitoring in the Ohau Channel was done principally by Joe Tamehana and Josette Moore for Ngati Pikiao while Josh Smith and Shane Grayling assisted with larval fish monitoring and fish processing, respectively.

9. Appendix I

Diurnal migration periods (NZST) for each of the 16 plankton sampling occasions and the number of samples at each of the three sites that fell within the defined dawn or dusk period.

Date	Sunrise	Sunset	Dawn period	Dusk period	Weir		Delta		Okere	
					Dawn	Dusk	Dawn	Dusk	Dawn	Dusk
15 Sep	0616	1809	0346 to 0646	1735 to 2035	0	1	0	1	0	1
30 Sep	0554	1819	0324 to 0624	1749 to 2049	0	2	0	1	0	1
14 Oct	0531	1831	0301 to 0601	1801 to 2101	1	1	0	1	0	1
31 Oct	0512	1847	0242 to 0542	1817 to 2117	2	1	1	1	2	1
14 Nov	0457	1904	0227 to 0527	1834 to 2134	2	0	1	1	1	1
29 Nov	0448	1920	0218 to 0518	1850 to 2150	1	1	0	1	1	1
13 Dec	0448	1932	0218 to 0518	1902 to 2202	2	1	2	1	1	2
16 Jan	0512	1938	0242 to 0542	1908 to 2208	1	2	1	1	2	1
5 Feb	0631	1927	0301 to 0601	1857 to 2157	0	0	0	0	0	1
17 Mar	0615	1832	0345 to 0645	1802 to 2102	2	1	1	1	2	2
24 Apr	0650	1738	0420 to 0720	1708 to 2008	2	2	2	2	1	1
26 May	0715	1708	0445 to 0745	1638 to 1908	3	2	3	2	3	1
19 Jun	0730	1703	0500 to 0800	1633 to 1933	2	2	2	2	2	2
24 Jul	0722	1722	0452 to 0752	1652 to 1952	2	2	2	2	2	2
28 Aug	0644	1751	0444 to 0714	1721 to 1951	2	2	2	2	2	2
17 Sep	0614	1807	0414 to 0644	1737 to 2007	2	2	2	2	2	2
Total					24	22	19	21	21	22

10. Appendix II

Whitebait trap sampling data showing the date and total time in minutes the traps fished on each occasion from September 2005 to September 2006. The number of times the trap was lifted and the catch processed are shown in parentheses. The weir trap faced upstream in mid-channel while the true right and left traps faced downstream on the channel banks near the top of the channel.

Date	Weir	True right	True left
15 Sep	208 (1)	240 (1)	255 (1)
30 Sep	404 (6)	875 (7)	805 (6)
14 Oct	Not set	920 (4)	725 (4)
31 Oct	Not set	834 (5)	842 (5)
14 Nov	272 (3)	711 (4)	727 (4)
29 Nov	511 (6)	722 (5)	643 (5)
13 Dec	398 (2)	914 (5)	908 (5)
16 Jan	729 (5)	1269 (5)	1208 (5)
5 Feb	Not set	565 (3)*	570 (3)*
17 Mar	520 (3)	687 (4)	667 (4)
24 Apr	335 (2)	892 (5)	883 (5)
21 May	Not set	748 (4)	758 (4)
21 June	Not set	653 (3)	644 (3)
24 July	Not set	725 (4)	710 (4)
28 Aug	Not set	805 (4)	765 (4)
17 Sep	605 (4)	825 (4)	751 (4)

* Data missing from one lift, time reduced accordingly.