Movement of rainbow trout and common smelt between lakes Rotoiti and Rotorua determined by otolith microchemistry: a summary of analyses between 1 October 2005 and 30 June 2009

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by

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Executive summary

In order to improve water quality in Lake Rotoiti, Environment Bay of Plenty (EBOP) has built the Ohau Channel Diversion Wall, which directs most of the water flowing out of Lake Rotorua directly down the Kaituna River rather than into Lake Rotoiti. Construction was completed in July 2008. Common smelt (*Retropinna retropinna*) and rainbow trout (*Oncorhynchus mykiss*) are known to move between Lake Rotorua and Lake Rotoiti, and previous work has shown that Lake Rotorua is an important spawning area for wild populations of rainbow trout that inhabit Lake Rotoiti. It is possible that the diversion wall will impede movement of these fish between the two lakes.

This study used otolith microchemistry to investigate movement of common smelt and wild adult rainbow trout between Lake Rotorua and Lake Rotoiti. Wild rainbow trout were collected from Lake Rotoiti, Lake Rotorua and the Ohau Channel, and common smelt were collected from several littoral locations in Lake Rotoiti and Lake Rotorua. The objective of the study is to examine the effects of the engineering works undertaken to protect Lake Rotoiti from the degraded water quality of Lake Rotorua. As part of efforts to improve water quality in Lake Rotoiti, Environment Bay of Plenty (EBOP) has built a wall to divert water that normally flows into Lake Rotoiti from Lake Rotorua through the Ohau Channel. The effect of this diversion wall is to direct most of the water flowing out of Lake Rotorua directly down the Kaituna River rather than into Lake Rotoiti. Construction was started in 2007 and completed in July 2008. However, Eastern Region Fish and Game has raised concerns that the diversion wall might also impede fish migrations between the lakes, and this study aims to answer those concerns.

There appears to have been a reduction in recruitment of wild rainbow trout from Lake Rotorua into Lake Rotoiti between 2005-2007, when 91% of angler-caught wild trout originated from Lake Rotorua, and 2008-30 June 2009 when only 50% recruited from Lake Rotorua. The 2005-2007 results are consistent with Riceman (2008), who found that 99% of Lake Rotorua caught trout and 86% of Lake Rotoiti caught trout originated in Lake Rotorua spawning tributaries.

For common smelt, elemental concentrations in the otolith nucleus (representing the juvenile habitat) were compared to otolith edge concentrations (representing recent habitat). In this re-analysis of 2005-2007 data, 92% of Lake Rotorua fish were shown to be residents, and but only 10% of Rotoiti fish were shown to be locally recruited from Lake Rotoiti. This indicates that Lake Rotorua is an important source of recruits for the Lake Rotoiti population. Smelt caught in Lake Rotoiti in 2008, however, showed a three-fold increase in the fish predicted to be of Lake Rotoiti origin, whereas a similar number of smelt caught in Lake Rotorua had originated there (88-92%). This suggests that the annual life cycle of the smelt showed the impact of the diversion wall during its construction in 2007 and 2008 up to the point of closure in August 2008, reducing recruitment of smelt from Lake Rotorua into Lake Rotoiti.

These results suggest that movement from Lake Rotorua into Lake Rotoiti is important for recruitment of both common smelt and rainbow trout. They also suggest that fish movement between lakes as shown by 2008-2009 samples appears to show some reduction in response to the construction of the Ohau Channel Diversion Wall. However, some fish sampled during this study, especially the longer-lived rainbow trout, may have migrated between lakes prior to the completion of the wall. Because this sample collection ended on 30 June 2009, and the sample size for trout was small, the results should be regarded as preliminary and we recommend continuing the sampling programme to 30 June 2012.

Introduction

The rainbow trout (*Oncorhynchus mykiss*) fishery in Lake Rotorua and Lake Rotoiti is internationally renowned and contributes significantly to the region's economy (Shaw, 1992). The fisheries are managed by the Eastern Region Fish and Game Council, who stock the lakes with young trout in order to improve angler catch rates. The rainbow trout's most important food source is the common smelt, *Retropinna retropinna*, a native zooplanktivorous species introduced to the lakes to provide food for trout.

The objective of the study is to examine the effects of the engineering works undertaken to protect Lake Rotoiti from the degraded water quality of Lake Rotorua. As part of efforts to improve water quality in Lake Rotoiti, Environment Bay of Plenty (EBOP) has built a wall to divert water that normally flows into Lake Rotoiti from Lake Rotorua through the Ohau Channel. The effect of this diversion wall is to direct most of the water flowing out of Lake Rotorua directly down the Kaituna River rather than into Lake Rotoiti. Construction was started in 2007 and completed in July 2008. However, Eastern Region Fish and Game has raised concerns that the diversion wall might also impede fish migrations between the lakes, and this study aims to answer those concerns.

Smelt and trout are known to move between Lake Rotorua and Lake Rotoiti. Major upstream migrations of juvenile smelt have been observed between January and March, and upstream migrations of adults have been observed between October and January, though migration also occurs outside these times (Donald, 1996). Donald (1996) speculated that fish were spawned in Lake Rotorua and washed down the Ohau Channel into Lake Rotoiti, then later returned to Lake Rotorua to spawn.

An otolith microchemistry study was carried out prior to the completion of the diversion wall in order to assess movement of smelt (*Retropinna retropinna*) and rainbow trout (*Oncorhynchus mykiss*) between Lake Rotorua and Lake Rotoiti (Riceman and Hicks, 2007; Riceman, 2008). Over 86% of trout caught in Lake Rotorua, 88% of trout caught in Lake Rotoiti, and all trout caught in the Ohau Channel had originated in the spawning tributaries of Lake Rotorua, indicating that movement between the two lakes is very important for sustaining Lake Rotoiti populations (Riceman, 2008). This study also concluded that around 70% of smelt had not moved from their lake of origin, and around 30% had moved between the lakes.

Otoliths are paired structures found in the inner ear of teleost fishes. They are made up almost entirely of $CaCO_3$ with other elements present in small amounts (Campana, 1999). Elements from the surrounding water are taken up via the gills or intestine, then transported in the blood to the endolymph, where they are deposited on the otolith surface (Campana, 1999). Otoliths are metabolically inert, and therefore not reabsorbed during periods of stress (Campana, 1999). New material is deposited continuously on the otolith surface even if somatic growth stops (Maillet and Checkley, 1990). These characteristics allow otoliths to be used as a chronological record of the environment experienced by a fish during its life (Campana, 1999).

Otolith chemical signatures are increasingly being used to identify movement patterns in fish (Elsdon et al., 2008). The natal origins, and consequently, the importance of different recruitment sources to a population, may be assessed using otolith microchemistry. This technique has been used to identify natal areas of marine (Thorrold et al. 2001), estuarine (Miller, 2007) and freshwater fish (Wells et al., 2003; Brazner et al., 2004; Clarke et al., 2007). In this study, otolith chemical signatures were used to assess movement between Lake Rotorua and Lake Rotoiti.

It is possible that the Ohau Channel Diversion Wall may impede movement of smelt and trout between Lake Rotorua and Lake Rotoiti. Ongoing monitoring of trout and smelt movements is necessary to assess the effects of the wall. The objective of this report is to assess movement of trout and smelt between lakes between October 2007 and June 2009, during and immediately after completion of the wall, and compare these results with analyses from October 2005-June 2007. This report also compares recent otolith chemistry results to the results found in a previous study of trout and smelt movement (Riceman and Hicks,2007; Riceman, 2008).

Methods

Study area

Rainbow trout were collected from anglers fishing at Lake Rotorua, Lake Rotoiti and the Ohau Channel (Figure 1). Ohau Channel trout were collected between October 2007 and June 2008, Lake Rotorua trout were collected in January and February 2009, and Lake Rotoiti trout were collected between October 2008 and June 2009. Smelt were caught from littoral areas of Lake Rotorua and Lake Rotoiti between February and October 2008 using a seine net. Smelt were sampled at Ngongotaha, Mission Bay, Te Pohue Bay, Hamurana, and Hannah's Bay in Lake Rotorua, and Pikiao, Hot Pools, Cherry Bay, Hinehopu, and Ruato Bay in Lake Rotoiti (Figure 2). All fish were frozen after collection, then defrosted before otolith dissection.

Figure 1. Map of sample area showing Lake Rotorua, Lake Rotoiti, trout spawning tributaries (black circles) and other important features (black squares).

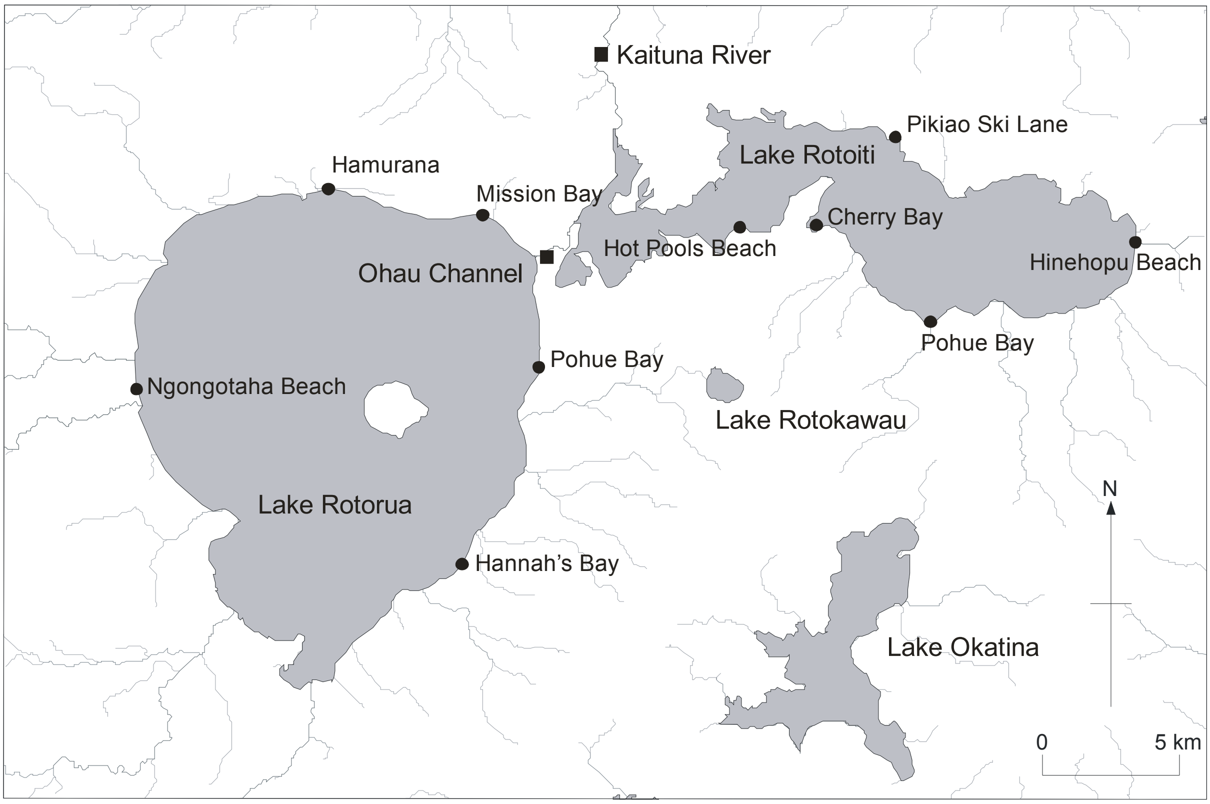

Figure 2. Map of sample area showing Lake Rotorua, Lake Rotoiti, smelt sampling beaches (black circles) and other important features (black squares).

Otolith analysis

Otolith analysis methods used in this study were identical to those used by Riceman (2008). Saggital otoliths were dissected from rainbow trout and smelt. These were washed with household bleach and Milli-Q water, and then polished using 400-2000 grit waterproof silicon carbide paper until the nucleus was clearly visible. The otoliths were mounted on microscope slides, twelve otoliths to a slide, and stored in plastic bags until ablation.

Trace elements were analysed at the University of Waikato using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). Otoliths were ablated in a sealed chamber using a New Wave Research UP-213 Laser Ablation System (Fremont, CA) with a 213 nm neodymium yttrium aluminium garnet (Nd-YAG) laser. Ablated material was carried using a mixture of helium and argon gas to a Perkin Elmer DRCII ELAN 6000 inductively coupled mass spectrometer (Waltham, MA). Isotopes analysed were magnesium (^{25}Mg), aluminium (^{27}Al), calcium (^{42}Ca and ^{43}Ca), manganese (^{55}Mn), copper (^{65}Cu), zinc (^{66}Zn), nickel (^{62}Ni), rubidium (^{85}Rb), strontium (^{88}Sr) and barium (^{137}Ba). NIST SRM 612 (National Institute of Standards and Technology Standard Reference Material 612, Gaithersburg, MD) was used as a standard for all analyses using the element concentrations reported by Pearce et al. (1997).

Background element concentrations were measured for 60 s prior to each ablation by analysing a gas blank (firing the laser with the shutter closed). One spot was ablated at the nucleus of the otolith and another at the otolith edge. Two spots on the NIST 612 reference material were ablated before otolith analysis and after every 10 to 12 otolith spots in order to account for instrument drift during the session. The sample chamber was purged with Ar and He for at least 10 minutes after each introduction of new samples. Laser settings for NIST 612 were 60% laser power, 60 µm spot size, 10 Hz repetition rate and 60 s laser dwell time, and for otoliths, 55% laser power, 50 µm spot size, 5 Hz repetition rate and 40 s laser dwell time.

Data were selected and reduced using GLITTER (GEMOC Laser ICP-MS Total Trace Element Reduction) version 4.4.1 (Van Achterbergh et al., 2001). Element concentrations were standardised to the stoichiometric abundance of CaO in $CaCO_3$ (56.03%). Concentrations were calculated using a linear interpolation of NIST standard ablation spots in order to account for instrument drift during the session. Minimum detection limits (MDL) were calculated by GLITTER at the 99% confidence interval using background readings and Poisson counting statistics. The elements used in further analyses, Mg, Mn, Zn, Rb, Sr and Ba, were always above detection limits. The first few seconds of ablation were excluded from further analyses in order to avoid any surface contamination of the otolith.

Statistical analyses

Data were square root transformed in order to meet the assumptions of normality and homogeneity of variance for linear discriminant function analysis (DFA). Cases (otolith spots) were excluded if one or more element concentrations fell outside three standard deviations from the mean. Analysis of variance (ANOVA) and DFA were carried out using STATISTICA, version 8 (Statsoft, Inc., 2007).

Differences in the mean elemental concentrations in the otolith edges of trout caught in Lake Rotorua, Lake Rotoiti and the Ohau Channel were assessed using ANOVA. Tukey's honestly significant difference (HSD) tests were used to assess differences between locations, and sort locations into homogeneous groups for each element. Levene's tests were used to check homogeneity of variances of means between groups. The variances were all homogeneous between groups after square-root transformation.

For rainbow trout, otolith nucleus laser spot samples were assigned to spawning tributaries using the discriminant functions created by Riceman (2008, Appendix 1) in a DFA of juvenile trout otoliths.

The DFA discriminated juvenile trout otolith nuclei caught from the six spawning tributaries with an accuracy of 98% (Riceman, 2008).

For common smelt, classification functions created by Riceman's (2008) discriminant function analysis of otolith edge concentrations were applied to otolith nucleus elemental signatures from smelt collected in 2008 (Appendix 2). This is referred to as the 2005-2007 DFA, as the smelt were collected between 2005 and 2007.

To assess differences between the two sampling periods, a DFA was carried out on the otolith edge concentrations of smelt collected in 2008. Two DFAs were carried out; one discriminating the otolith signatures between capture sites, and one discriminating otolith signatures between the two lakes. The first DFA was unsuccessful and is not presented. The second DFA distinguished smelt caught in the two lakes accurately and is referred to as the 2008 DFA. The 2008 DFA was then applied to all smelt otolith nucleus signatures caught between 2005 and 2008; because the nucleus represents juvenile habitat, this allows the determination of the natal habitat of the fish. Results are presented for all smelt (2005-2008), for smelt caught 2005-2007, and for smelt caught in 2008.

Results

Summary of rainbow trout and smelt otoliths processed

To date, element concentrations in otoliths from 129 Lake Rotoiti smelt and 116 Lake Rotorua smelt have been analysed (Table 1). Otoliths from 62 Lake Rotoiti rainbow trout, 52 Lake Rotorua trout and 32 Ohau Channel trout have been analysed (Table 1).

Table 1. Summary of rainbow trout and smelt otoliths analysed in 2005-2007 and in 2008-2009. Each otolith represents an individual fish.

	Rainbow trout	Smelt
<u>Lake Rotoiti</u>		
Collected 2008-2009	20	83
Collected 2005-2007	43	58
Total Lake Rotoiti	63	141
<u>Lake Rotorua</u>		
Collected 2009	19	50
Collected 2005-2007	32	43
Total Lake Rotorua	51	93
<u>Ohau Channel</u>		
Collected 2008	7	
Collected 2005-2007	17	
Total Ohau Channel	32	

Trout otolith chemistry

Elemental concentrations in the edges of trout otoliths caught in the Ohau Channel, Lake Rotoiti and Lake Rotorua are given in Figure 3 and Table 2. Mean otolith edge Mg, Zn and Rb concentrations were significantly different between locations (Figure 3). Mean Sr concentrations in trout otolith edges were lower, and Ba concentrations were higher, than in smelt otolith edges (Tables 2 and 4).

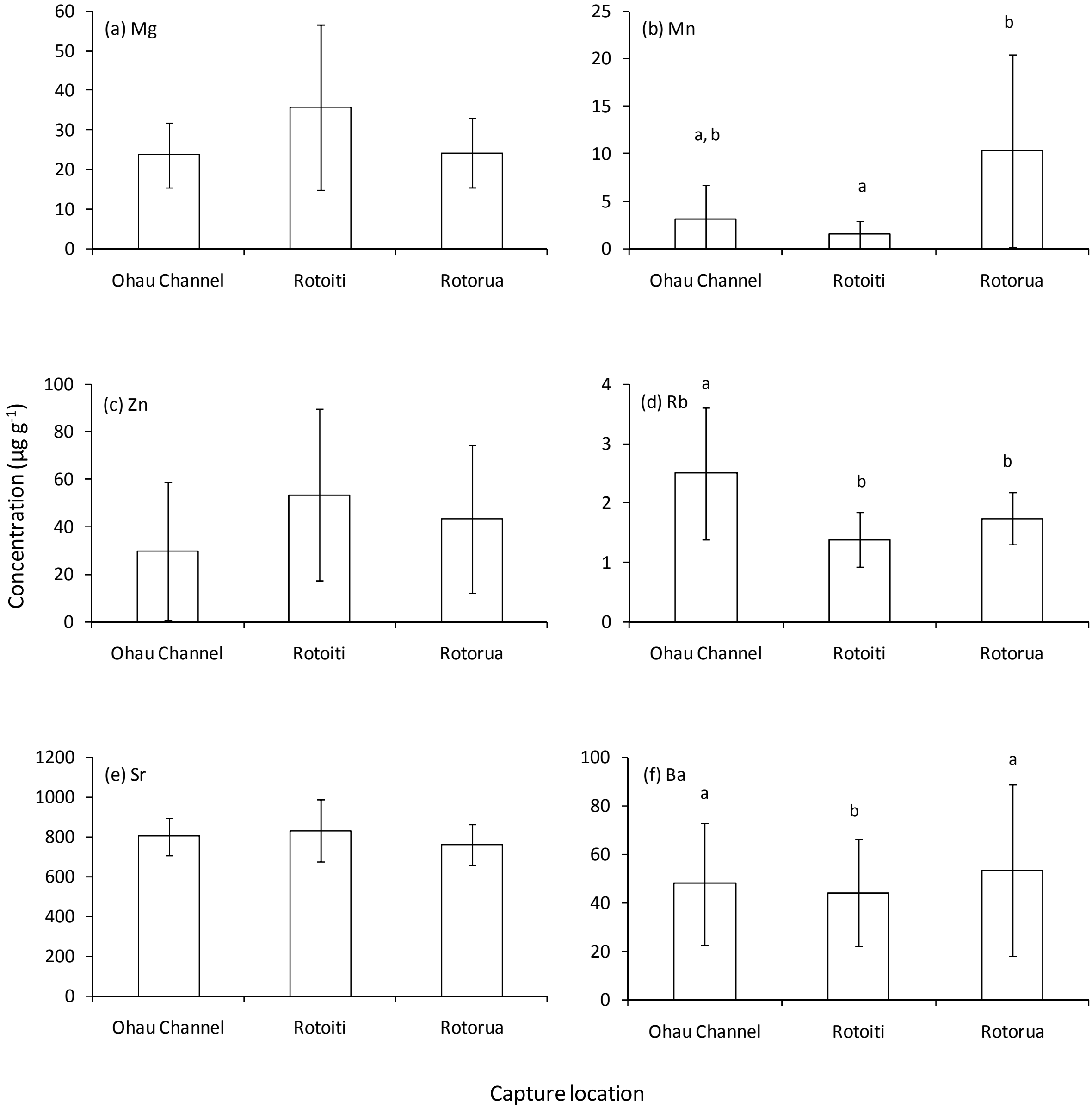

Figure 3. Mean concentrations of (a) Mg, (b) Mn, (c) Zn, (d) Rb, (e) Sr, (f) Ba in edges of trout otoliths caught in the Ohau Channel, Lake Rotoiti and Lake Rotorua. Error bars show ± 1 SD. Letters above bars show homogeneous groups (Tukey's HSD, $p<0.05$).

Table 2. Mean and standard deviation (SD) of Mg, Mn, Zn, Rb, Sr and Ba concentrations (ppm) in the otolith edges of trout caught from the Ohau Channel, Lake Rotoiti and Lake Rotorua.

Capture location		Mean fork length	Elemental concentration in otolith edge (ppm)											
			Mg		Mn		Zn		Rb		Sr		Ba	
	N	(mm)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ohau Channel	15	559	24	8	3.2	3.5	30	29	2.5	1.1	802	93	48	25
Rotoiti	19	484	36	21	1.5	1.4	54	36	1.4	0.5	832	157	44	22
Rotorua	20	428	24	9	10.3	10	43	31	1.7	0.4	762	104	53	35

Trout movement

Concentrations of elements in the nucleus of otoliths of angler-caught adult wild rainbow trout from Lake Rotoiti, Lake Rotorua and the Ohau Channel were classified to lake of origin using the classification functions created from juvenile trout otoliths from spawning tributaries (Riceman 2008).

$$\text{Rotoiti score} = -201.399 + 5.376*\text{sqrt Zn} + 16.417*\text{sqrt Sr} + 18.867*\text{sqrt Rb} + 8.338*\text{sqrt Mn} - 15.523*\text{sqrt Ba} \quad (1)$$

$$\text{Rotorua score} = -233.286 + 4.650*\text{sqrt Zn} + 17.363*\text{sqrt Sr} + 23.309*\text{sqrt Rb} + 10.723*\text{sqrt Mn} - 15.015*\text{sqrt Ba} \quad (2)$$

Of 43 adult trout caught in Lake Rotoiti in 2005-2007, 9% of were classified to spawning tributaries of Lake Rotorua (Table 3a) with equations 1 and 2, whereas in 2008-30 Jun 2009 only 50% of 20 trout had their natal origin in Lake Rotoiti (Table 3b).

Table 3. Spawning locations of adult wild rainbow trout caught at Lake Rotorua, the Ohau Channel and Lake Rotoiti predicted from the lake discriminant functions based on elemental concentrations of Mn, Zn, Rb, Sr and Ba in juvenile trout (Riceman 2008).

a. 2005-2007.

Place of capture	Predicted lake of origin (number)			Predicted lake of origin (%)	
	Rotoiti	Rotorua	Total	Rotoiti	Rotorua
Ohau Channel	1	24	25	4	96
Rotoiti	4	39	43	9	91
Rotorua	4	28	32	13	88
Total	9	91	100	9	91

b. 2008-30 June 2009.

Place of capture	Predicted lake of origin (number)			Predicted lake of origin (%)	
	Rotoiti	Rotorua	Total	Rotoiti	Rotorua
Ohau Channel	1	6	7	14	86
Rotoiti	10	10	20	50	50
Rotorua	3	16	19	16	84
Total	14	32	46	30	70

Smelt otolith chemistry

Concentrations of Mg, Zn and Rb in the otolith edges of smelt caught in Lake Rotorua and Lake Rotoiti were similar (Table 4). Ba and Sr concentrations were higher in otoliths of Rotorua smelt than in Rotoiti smelt (Table 4).

Smelt movement

A discriminant function analysis was carried out using elemental concentrations in otolith edges from all smelt collected between 2005 and 2008. Our assumption is that otolith edges reflect the chemical conditions of capture environment. A forward stepwise DFA was used to distinguish smelt from Lake Rotorua and Lake Rotoiti. The DFA incorporated the elements (in order of inclusion) Sr, Ba, Mn and Zn, and had high discriminatory power (Wilks' Lambda=0.786; $F_{4,235}$=16.0; p<0.001). Otolith edge elemental concentrations predicted capture locations with an accuracy of 70-71% (Table 5). Otoliths were classified to locations using the standardised canonical root functions (Equations 3 and 4). A DFA of smelt caught from different beaches within the lakes was attempted, but the elemental signatures of smelt caught at different beaches were indistinguishable (data not shown).

$$\text{Rotoiti score} = -215.212 + 2.455*\text{sqrt Zn} + 15.417*\text{sqrt Sr} - 7.241*\text{sqrt Mn} - 12.814*\text{sqrt Ba} \quad (3)$$

$$\text{Rotorua score} = -231.567 + 2.053*\text{sqrt Zn} + 16.070*\text{sqrt Sr} - 5.411*\text{sqrt Mn} - 13.862*\text{sqrt Ba} \quad (4)$$

These classification functions were about 70% correct (Table 5), which may reflect a partial failure of the model or recent immigration of the smelt from the adjacent lake.

Table 4. Number of smelt sampled, mean fork length (FL), mean and standard deviation (SD) of Mg, Mn, Zn, Rb, Sr and Ba concentrations (ppm) in the otolith edges of smelt caught in Lake Rotorua and Lake Rotoiti.

Location	N	Mean FL (mm)	Mg		Mn		Zn		Rb		Sr		Ba	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Lake Rotoiti														
Cherry Bay	15	43	17	6	0.34	0.38	4.9	2.8	2.1	0.7	1040	86	32	8
Hinehopu	5	43	20	11	0.29	0.28	3.0	2.9	3.3	0.8	1033	70	25	4
Hot Pools	16	50	15	5	0.58	0.38	5.1	4.4	2.6	1.0	1059	89	34	9
Pikiao Ski Lane	10	40	19	15	0.46	0.48	5.5	3.1	2.5	0.5	1024	122	30	10
Ruato Beach	15	54	16	9	0.31	0.18	5.3	7.8	1.7	0.6	993	86	24	7
Rotoiti summary	61	47	17	9	0.41	0.36	5.0	4.8	2.3	0.9	1030	93	30	9
Lake Rotorua														
Hamurana	15	62	13	7	0.76	0.77	3.4	3.8	1.7	0.7	1139	132	30	12
Hannah's Bay	10	42	16	7	1.54	1.01	8.4	8.3	2.8	0.5	1279	143	55	13
Mission Bay	14	62	18	17	0.71	0.47	5.1	6.4	3.0	0.7	1173	181	36	12
Ngongotaha	1	56	4	0	0.57	0.00	0.9	0.0	2.8	0.0	1208	0	29	0
Pohue Bay	10	41	20	7	1.50	0.70	12.4	16.9	2.4	0.8	1229	150	43	6
Rotorua summary	50	54	16	11	1.05	0.81	6.6	9.6	2.4	0.8	1196	156	39	14

Table 5. Classification matrix of DFA of concentrations of Mn, Zn, Sr and Ba in otolith edges for common smelt collected in lake Rotoiti and Rotorua from 2005-2008. Rows represent observed classifications (capture location) and columns represent predicted classification.

Capture location	Predicted lake (%) Rotoiti	Rotorua	Total	Percent correct
Rotoiti	90	36	126	71
Rotorua	34	80	114	70
Total	124	116		

The discriminant functions created using the otolith edge elemental signatures (Equations 1 and 2) were used to classify the otolith nuclei of these smelt to establish lake of origin (Table 6). Nearly all (92%) of the smelt caught in Lake Rotorua were classified to Lake Rotorua, indicating they had originated there (Table 6). Most (78%) of the otolith nuclei of smelt caught in Lake Rotoiti were also classified to Lake Rotorua (Table 6).

Table 6. Observed classification (capture site) compared to predicted natal area (classification of otolith nuclei) of common smelt in lakes Rotorua and Rotoiti. Classifications were predicted using Equations 1 and 2 (2008 DFA), which use Sr, Ba, Mn and Zn concentrations. Rows represent observed classifications (capture location) and columns represent predicted classifications of otolith nuclei.

a. 2005-2007.

Capture	Predicted origin (number)				Predicted origin (%)		
location	Rotoiti	Rotorua	Total		Rotoiti	Rotorua	Total
Rotoiti	6	52	58		10	90	100
Rotorua	5	59	64		8	92	100
Total	11	111	122				

b. 2008.

Capture	Predicted origin (number)				Predicted origin (%)		
location	Rotoiti	Rotorua	Total		Rotoiti	Rotorua	Total
Rotoiti	28	55	83		34	66	100
Rotorua	5	38	43		12	88	100
Total	33	93	126				

Discussion

Trout movement

There appears to have been a reduction in recruitment of wild rainbow trout from Lake Rotorua into Lake Rotoiti between 2005-2007, when 91% of angler-caught wild trout originated from Lake Rotorua, and 2008-30 June 2009 when only 50% recruited from Lake Rotorua. The 2005-2007 results are consistent with Riceman (2008), who found that 99% of Lake Rotorua caught trout and 86% of Lake Rotoiti caught trout originated in Lake Rotorua spawning tributaries. Further sampling of trout populations from Lake Rotoiti needs to be carried out in order to gain a better understanding of the effects of the diversion wall.

Smelt otolith chemistry

The otolith edge concentrations of Mn, Sr and Ba were similar between smelt caught in Lake Rotoiti in 2005-2007 and 2008 (Riceman, 2008). For smelt caught in Lake Rotorua, Mn and Zn concentrations were similar between the two sampling periods, but Rb, Sr and Ba concentrations were higher in the present study than in Riceman (2008).

Smelt movement

Using discriminant function analysis, 70-71% of smelt were able to be correctly classified to their lake of capture based on the elemental signatures in their otolith edges. This analysis used all smelt otolith microchemistry data collected between 12 Dec 2005 and 23 October 2008, including the data collected by Riceman (2008). Using a larger data set did not improve accuracy of classification, as Riceman (2008) achieved a classification accuracy of 74% with a smaller data set. However, applying the new discriminant function to the 2005-2007 data set yielded considerably different results to those found by Riceman (2008). Riceman (2008) found that 59% of Lake Rotorua smelt were lake residents, and 79% of Lake Rotoiti smelt were lake residents. However, when the discriminant function analysis created using the larger data set (smelt from 2005 to 2008) was applied to the data from 2005-2007, 92% of Lake Rotorua fish were shown to be residents, and only 10% of Rotoiti fish were shown to be locally recruited from Lake Rotoiti. This discrepancy is due to methodological differences; Riceman's 2008 study compared two different discriminant function analyses, one of smelt otolith edges and one of smelt otolith nuclei. The current study carried out a DFA of smelt otolith edges, then used this as a training set to classify smelt otolith nuclei and therefore find the lake of origin. This approach is similar to the one used with rainbow trout otoliths in this study, but adult fish, not juvenile fish, are used to create discriminant functions. This method gives a better representation of the movement of individual fish between the lakes.

Smelt caught in Lake Rotoiti in 2008 showed a three-fold increase in the fish predicted to be of Lake Rotoiti origin, whereas a similar number of smelt caught in Lake Rotorua had originated there (88-92%). This suggests that the annual life cycle of the smelt showed the impact of the diversion wall during its construction in 2007 and 2008 up to the point of closure in August 2008, reducing recruitment of smelt from Lake Rotorua into Lake Rotoiti.

The results presented in this study suggest that the majority of smelt in Lake Rotoiti are recruited from Lake Rotorua. Further sampling is vital in order to assess the impact on the completed diversion wall and to assess whether smelt are still able to migrate between the lakes.

Conclusion

These results suggest that movement from Lake Rotorua into Lake Rotoiti is important for recruitment of both common smelt and rainbow trout. They also suggest that fish movement between the lakes as shown by 2008-2009 samples appears to show some reduction in response to the construction of the Ohau Channel Diversion Wall. However, some fish sampled during this study, especially the longer-lived rainbow trout, may have migrated between lakes prior to the completion of the wall. Because this sample collection ended on 30 June 2009, and the sample size for trout was small, the results should be regarded as preliminary and we recommend continuing the sampling programme to 30 June 2012.

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Appendices

Appendix 1. Trout classification functions used in classifying juvenile trout otolith nuclei to tributary stream (Riceman, 2008)

Hauparu stream classification = $-200.045 + (5.735 \times \sqrt{Mn}) + (5.481 \times \sqrt{Zn}) + (13.771 \times \sqrt{Rb}) + (15.831 \times \sqrt{Sr}) - (11.805 \times \sqrt{Ba})$

Te Toroa Stream classification = $-198.700 + (6.134 \times \sqrt{Mn}) + (5.123 \times \sqrt{Zn}) + (17.206 \times \sqrt{Rb}) + (15.799 \times \sqrt{Sr}) - (11.923 \times \sqrt{Ba})$

Ngongotaha Stream classification = $-251.177 + (9.012 \times \sqrt{Mn}) + (4.336 \times \sqrt{Zn}) + (51.231 \times \sqrt{Rb}) + (15.342 \times \sqrt{Sr}) - (9.351 \times \sqrt{Ba})$

Utuhina Stream classification = $-218.38 + (9.351 \times \sqrt{Mn}) + (4.156 \times \sqrt{Zn}) + (31.700 \times \sqrt{Rb}) + (15.792 \times \sqrt{Sr}) - (11.946 \times \sqrt{Ba})$

Waingaehe Stream classification = $-244.605 + (7.671 \times \sqrt{Mn}) + (5.229 \times \sqrt{Zn}) + (39.693 \times \sqrt{Rb}) + (15.581 \times \sqrt{Sr}) - (8.509 \times \sqrt{Ba})$

Waiteti Stream classification = $-232.122 + (8.660 \times \sqrt{Mn}) + (3.850 \times \sqrt{Zn}) + (9.154 \times \sqrt{Rb}) + (17.663 \times \sqrt{Sr}) - 13.481 \times \sqrt{Ba})$

Appendix 2. Original smelt classification functions (Riceman, 2008)

Factor 1 score (Rotoiti) = -64.526 – (1.591 x Mn) + (0.236 x Zn) + (3.947 x Rb) + (0.137 x Sr) – (0.684 x Ba)

Factor 2 score (Rotorua) = -69.964 – (1.580 x Mn) + (0.212 x Zn) + (4.876 x Rb) + 0.145 x Sr) – (0.801 x Ba)