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An Assessment of the Water Quality of Ten Waikato Lakes Based on Zooplankton Community Composition

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by

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Contents

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Executive Summary

Zooplankton communities were documented from ten Waikato lakes from net haul samples collected in late 2006 and from species hatched from diapausing eggs in sediments collected in early 2007. Lake trophic state was inferred based on the rotifer assemblages observed, and these inferred values were compared with predetermined water quality gradients assessed based on a limited dataset by Environment Waikato.

A variety of species was observed during the study, including 43 rotifer, 6 cladoceran and 5 copepod taxa. Rotifer inferred trophic states of the lakes were ranked in an order similar to that provided by Environment Waikato. For the peat lakes, inferred Trophic Lake Index (TLI) values were highest for Lake Koromatua (7.8; hypertrophic), followed by Lake Kaituna (7.6; hypertrophic), Lake Mangahia (5.4; supertrophic) and Lake Serpentine (3.0; mesotrophic). This rank order was identical to that predetermined by Environment Waikato. The TLI inferred for dune and riverine lakes was not in the order determined by Environment Waikato. Of the dune lakes, Lake Taharoa, considered to have the poorest water quality by Environment Waikato, was assessed as having the lowest TLI using rotifer community composition (2.7; oligotrophic); this may be due to Lake Taharoa having undergone a recent and rapid decline in trophic state, with species composition not yet having adapted to recent conditions. Lakes Otamatearoa (4.6) and Harihari (4.2) were assessed as eutrophic. The riverine lakes were all inferred to be supertrophic (Lake Ohinewai; 5.2) to hypertrophic (Lakes Kimihia; 8.2 and Waahi; 6.5).

Hatching of zooplankton eggs from lake sediments assessed trophic state in the same rank order as was inferred from the plankton samples. However, higher TLI values were inferred for each lake. The rotifer inferred TLI scheme was not developed based on hatching, and species adapted to higher trophic states may be preferentially hatched. However, this method may still be useful for comparing and ranking lakes.

Introduction

In late 2006 and early 2007, Environment Waikato conducting surveys of ten lakes in the Waikato region. Most of these lakes have very limited historical water quality data, including physical, chemical and biological conditions, or have never been examined in any scientific manner. Typically, the inference of lake trophic state and other water quality characteristics relies on monthly sampling of a variety of indicators, but for lakes that are isolated or have difficult access such fine-scale monitoring is difficult or unfeasible. Bioindicator approaches, using the responses of organisms to evaluate trophic state, have often been neglected in favour of chemical and physical techniques. However, the biotic community integrates biological, physical and chemical factors over time, allowing for less fine-scale monitoring than traditional methods. Duggan et al. (2001a, b) found that trophic state was the major determinant of rotifer distribution among North Island lakes, and based on these responses developed a quantitative bioindicator index using rotifer community composition for inferring Trophic Lake Index (TLI) values (*sensu* Burns et al. 1999). Rotifers may be ideal bioindicators as they are discriminating in their responses to the environment, they are typically numerically dominant in the zooplankton, species rich, and communities likely integrate environmental conditions over time (Duggan et al. 2001).

In this report, the community composition of zooplankton was documented from single plankton samples from the ten sampled lakes. Additionally, species not found in the plankton were assessed by hatching of zooplankton eggs removed from benthic sediment samples. From the resulting species datasets, the Rotifer Community Index of Duggan et al. (2001a) was used to infer the water quality of the lakes. Finally, these inferred trophic states were compared with a rank order of water quality for the lakes as predetermined by Environment Waikato staff based on preliminary monitoring data.

Methods

Ten lakes were sampled by Environment Waikato for this study: Lakes Koromatua, Kaituna, Mangahia, Serpentine North, Kimihia, Ohinewai, Waahi, Taharoa, Otamatearoa and Harihari. Zooplankton were sampled by Environment Waikato from a central (or deep) position in each lake in late 2006, using vertical hauls through the entire water column with a plankton net (40µm mesh size; haul speed ~1 $m.s^{-1}$). Samples were immediately preserved using ethanol.

In the laboratory, preserved samples were examined for zooplankton community composition. Larger micro-crustaceans and rotifers were enumerated and identified until a total of at least 300 individuals were counted. As rotifers are the zooplankton group most useful for water quality monitoring, counting continued on this group until a total of at least 300 individuals of "indicator species" were recorded; i.e., species that have an assigned TLI optima and tolerance score given by Duggan et al. (2001a). Alternatively, the sample was counted until complete if fewer than 300 indicator taxa were found (Lake Otamatearoa only). Based on the resulting lists, the bioindicator scheme of Duggan et al. (2001a) was used to infer trophic state.

For analysis, lakes were divided into three groups chosen by Environment Waikato based on lake formation:

1) Peat Lakes: Koromatua, Kaituna, Mangahia, Serpentine North

2) Riverine Lakes: Kimihia, Ohinewai, Waahi

3) Dune Lakes: Taharoa, Otamatearoa, Harihari

Within each group lakes were subjectively ordered from "worst" to "best", as listed above, based on preliminary monitoring data obtained by Environment Waikato. Results from the rotifer interred TLI were compared with this ordering.

The University of Waikato received nine unpreserved bottom sediment samples, collected by Environment Waikato in early 2007 using an Eckman Grab from a central (or deep) position in each lake. Lake Otamatearoa could not be sampled at this time, and results for this lake using this method are therefore not included in this report. Sediments were stored in a cool room (<4°C) for greater than one month. After this time, eggs were removed from sediments using a sugar flotation method. To do so, two 40g subsamples of sediment from each lake were washed through a 40μm sieve to remove fine particles, before being washed into centrifuge tubes using a 1:1 (weight:volume) mixture of sugar and water. After centrifugation for 5 minutes at 27 x gravity, the supernatant was rinsed through a 40μm sieve to remove the sugar. Diapausing stages and other collected organic matter were transferred to Petri-dishes filled with synthetic pond water (48mg $NaHCO_3$, 38mg $CaSO_4 \cdot 2H_2O$, 30mg $MgSO_4$, and 0.5mg KCl in 1L distilled water; Hebert & Crease 1980). Eggs in Petri-dishes were incubated at either 10 or 20°C and monitored for zooplankton hatching over 21 days (daily for the first 11 days, every two days until the completion of the experiment). This method was intended to provide a more complete list of zooplankton than might be expected from a single visit (i.e., including species not present in the summer plankton collections; e.g., Duggan *et al.* 2002a, Bailey *et al.* 2005). Results of counts of individuals hatched at the completion of the experiment were treated identically as for the net sample results. Due to low overall hatch rates, results from the 10 and 20°C experiments were combined for each lake in analyses. Identifications of species from net samples and hatched from sediments were made to species level wherever possible.

Results and Discussion

Community composition

A large variety of zooplankton taxa were recorded during the study. Forty three rotifer, six cladoceran and five copepod taxa were recorded, as well as planktonic mites (Table 1). One benthic Bryozoan species was hatched from Lake Taharoa. Most taxa were fairly typical for North Island lakes. For example, all of the rotifers recorded in this survey were also found in the North Island survey of Duggan et al. (2002b), except for *Brachionus lyratus* (Lake Otamatearoa) and *Polyarthra vulgaris* (Lake Kimihia). Although *Brachionus lyratus* is apparently rare in North Island lake habitats, it is seemingly common in shallow Waikato ponds (author's unpublished data). *Polyarthra vulgaris*, on the other hand, is a common species globally, but is seemingly rare in New Zealand lakes. Why *P. vulgaris* is present in this lake, but seemingly so rare elsewhere in the North Island, is unclear. Rotifer species recorded ranged from those typically found in oligotrophic to those found in highly eutrophic sytems. Species recorded that are typical of oligotrophic to mesotrophic lakes included *Conochilus dossuarius* from Lake Taharoa (known elsewhere from, for example, Lakes Ototoa, Tarawera, Taupo and Waikaremoana) and *Synchaeta longipes* in Lakes Serpentine North and Harihari (known elsewhere from Lakes Rotoiti, Rotoma and Okareka). Species recorded that are more typical of highly eutrophic systems included *Brachionus budapestinensis* in Lake Kaituna (known previously in New Zealand only from Lakes Waahi, Rotokauri, Ngaroto and Horowhenua) and *Filinia longiseta* (e.g., Lakes Waikare, Ngaroto, Okaro, Horowhenua). Many species were recorded in the Lake Otamatearoa plankton samples that are more typically found associated with bottom sediments or macrophytes (e.g., *Lecane bulla*, *L. closterocerca*, *L. flexilis*, *L. lunaris*, *Lepadella acuminata*, *Mytilina mucronata* and *Trichocerca tenuior*; e.g., Duggan et al. 1998).

Table 1. Zooplankton species present in the net hauls and hatched from eggs removed from sediment of ten Waikato lakes.

	Koromatua (plankton)	Koromatua (hatching)	Kaituna (plankton)	Kaituna (hatching)	Mangahia (plankton)	Mangahia (hatching)	Serpentine North (plankton)	Serpentine North (hatching)	Taharoa (plankton)	Taharoa (hatching)	Otamatearoa (plankton)	Harihari (plankton)	Harihari (hatching)	Kimihia (plankton)	Kimihia (hatching)	Ohinewai (plankton)	Ohinewai (hatching)	Waahi (plankton)	Waahi (hatching)
ROTIFERA																			
Anuraeopsis fissa												x							
Ascomorpha ovalis											x	x	x						
Asplanchna brightwelli		x	x		x	x								x					x
Asplanchna priodonta							x	x	x	x						x			
Brachionus angularis	x	x	x	x	x	x	x	x		x			x	x	x		x	x	x
Brachionus budapestinensis			x																
Brachionus caliciflorus		x	x	x		x		x					x	x	x		x		x
Brachionus lyratus											x								
Brachionus quadridentatus				x		x													
Brachionus urceolaris																			x
Collotheca sp.			x						x	x	x			x	x			x	
Colurella uncinata			x																
Conochilus dossuarius									x	x									
Conochilus unicornis							x		x										
Filinia novaezealandiae			x			x	x							x	x	x		x	x
Filinia pejleri					x														
Flinia longiseta		x		x		x								x	x	x		x	x
Hexarthra intermedia						x								x		x			
Hexarthra mira							x	x											
Keratella cochlearis					x		x		x		x	x				x		x	
Keratella slacki	x				x														
Keratella tecta			x				x		x			x		x		x		x	x
Keratella tropica	x	x	x		x		x	x			x			x		x			
Lecane bulla											x								
Lecane closterocerca											x								
Lecane flexilis											x								
Lecane lunaris											x								
Lepadella acuminata											x								
Monommata sp.									x										
Mytilina mucronata											x								
Pleurotrocha petromyzon			x																
Polyarthra dolichoptera	x	x		x		x	x		x	x	x	x			x				
Polyarthra vulgaris														x					
Pompholyx sp.	x		x	x	x	x	x									x			x
Synchaeta grandis												x							
Synchaeta longipes								x				x							
Synchaeta oblonga			x						x	x	x				x	x	x		x
Synchaeta pectinata					x				x	x						x		x	
Testudinella patina											x								
Trichocerca pusilla			x					x	x	x				x		x			x
Trichocerca similis									x		x	x				x			
Trichocerca tenuior											x								
Bdelloids			x	x						x	x								
ARTHROPODA																			
Cladoceans																			
Alona sp.				x															
Bosmina meridionalis	x		x	x	x		x	x	x	x	x	x		x		x	x		x
Ceriodaphnia dubia				x															
Chydorus sp.											x					x			
Daphnia dentifera	x		x	x	x			x			x			x		x		x	
Simocephalus vetulus											x								
Copepods																			
Boeckella delicata					x		x												
Calamoecia lucasi							x		x		x	x		x		x		x	
Diacyclops bicuspidatus											x								
Macrocyclops albidus											x								
Mesocyclops leuckarti	x		x				x		x			x				x			
nauplii	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
Mites									x	x									
BRYOZOA																			
Plumatella sp.										x									

Crustacean species recorded were generally also typical inhabitants of North Island lakes. *Boeckella delicata*, found in this study from Lakes Mangahia and Serpentine North, is a calanoid copepod seemingly confined to the Waipapa technostratigraphic basement terrane (i.e., micro-plate) of New Zealand, and is therefore found naturally in many Waikato lakes (Banks 2007). *Calamoecia lucasi* was found in six lakes, and is a common inhabitant of North Island lakes (irrespective of basement terrane). Coexistence of calanoid copepod species in New Zealand lakes is apparently rare, but *B. delicata* and *C. lucasi* were both found in Lake Serpentine North; this has been noted in the same locality by Chapman & Green (1987). Of the cyclopoid copepod species, *Macrocyclops albidus* (Lake Otamatearoa) and *Mesocyclops leuckarti* (six lakes) are common components of the plankton in New Zealand (Chapman & Lewis 1976). However, *Diacyclops bicuspidatus* was recorded from Lake Otamatearoa, and is not typically found in the plankton except in ponds, being more commonly found associated with macrophytes in lakes (Chapman & Lewis 1976). The finding of such a benthic species in the plankton of this lake corresponds with the littoral rotifer assemblage also recorded from this lake. The cladoceran species recorded were also typical New Zealand inhabitants. Lake Otamatearoa was notable again with the presence of *Simocephalus vetulus*, a weedbed associated species now seemingly rare in the Waikato. Worryingly, *Daphnia dentifera*, a recently discovered non-indigenous species (Duggan et al. 2006), was recorded from all of the lakes except Lake Harihari and Lake Taharoa.

A greater number of species was found for many lakes in the single summer plankton samples than was recorded from hatching of eggs removed from sediments. Only Lakes Waahi, Mangahia and Koromatua hatched more rotifer species than were caught in the single summer plankton sample. Additionally, for all of these lakes species were present in the plankton samples that were not hatched from sediment. These results were largely unexpected, as it was hoped hatching would result in a more complete rotifer species list than the single lake samples; 20-40 species were thus expected from each lake (e.g., Duggan et al. 2002b). For some lakes the low richness hatched may be due to unforeseen circumstances, such as difficulty collecting adequate bottom sediment due to macrophtyes on the lake bed (e.g., Lake Otamatearoa), or organic matter removed with eggs from the sugar flotation containing high concentrations of oil globules - seemingly derived from cyanobacteria - that may have inhibited hatching (Lake Ohinewai). Such factors cannot apply to all lakes, however. A greater number of replicates may have gone some way to remedying this problem. For example, Bailey et al. (2005) conducted similar unreplicated experiments on ballast sediments, and noted these enabled accurate determination of the dominant species from each ship; however, a greater numbers of replicates allowed for a greater probability of rare species emerging and hence larger species lists. Additional replicates, although adding value with respect to species richness, would greatly add to the time and expense of the method. However, the unreplicated hatching method was valuable in that it did reveal a number of additional species from the lakes that were not present in plankton samples.

Trophic state assessment

Trophic state of the lakes inferred by rotifer species composition was compared with the subjectively chosen gradients of water quality provided by Environment Waikato. For the peat lakes, the rotifer inferred TLI values assessed all four lakes in a corresponding order: Lake Serpentine North had the best water quality, followed by Lakes Mangahia, Kaituna and Koromatua with the poorest water quality (Figure 1). Lake Serpentine North was assessed as being mesotrophic, but bordering on oligotrophic, Lake Mangahia as supertrophic, while the remaining lakes were assessed as hypertrophic. Although I do not have access to monitored data to compare these results with, the resulting values do not seem unreasonable. The dune and riverine lakes were not assessed in the order predetermined by Environment Waikato. Lake Taharoa, considered to have the poorest water quality of the dune lakes by Environment Waikato, contained high proportions of *Conochilus dossuarius* and *Polyarthra dolichoptera* in the community, both indicative of good water quality (Appendix 1). Both are feeders on small algal particles, whereas lakes with high nutrient loadings are typically dominated by bacterial feeders (Duggan et al. 2002b). *Conochilus dossuarius*, in particular, was the species calculated by Duggan et al. (2001a) to have the lowest TLI optima, with peak abundances at a TLI value of 3.1, and is found in high relative abundances in lakes such as Lake Ototoa, Lake Waikaremoana and Lake Taupo. Lake Taharoa has apparently undergone a marked decrease in water quality over the last two years (pers. comm., Keri Neilson,

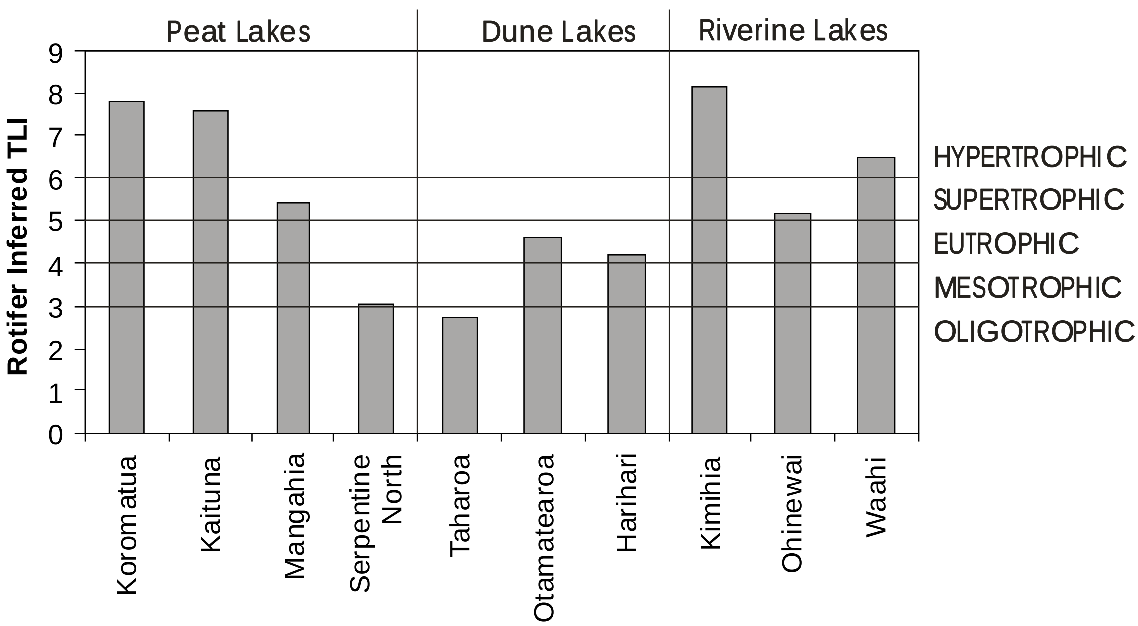

Figure 1: Rotifer inferred trophic state (TLI) from single plankton samples from ten Waikato Lakes.

Environment Waikato). It is possible therefore that the rotifer species composition has not changed in this time due to a lack of immigration of propagules more suited to higher trophic states. This may not be a result of a lack of zooplankton propagules specifically, but algal species also may not have shifted in composition to one adapted to more eutrophic conditions; algal species adapted to good water quality, and thus food for rotifers indicative of low nutrient loadings, may still dominate this lake. Inferring trophic state using rotifer communities was useful in tracking gradual improvements or declines in the water quality of Auckland lakes over several years (Duggan & Barnes 2005). However, the results from the present study raises questions over whether zooplankton communities are useful for monitoring massive trophic state changes over short time scales, where a different set of indicator species would be required to colonise, particularly in isolated locations where propagule supplies may be limited. Alternatively, it may be possible that there are unusual biological, chemical or physical conditions associated with this lake. For example, Lake Taharoa samples did contain a large predatory planktonic mite species not found in any of the other lakes sampled, and not a common component of plankton in North Island lakes, which may have affected rotifer community composition. The trophic state of the riverine lakes also was not assessed in the order expected, although Lake Kimihia was correctly assessed as having the poorest water quality. All three lakes were assessed as highly degraded, with Lakes Kimihia and Waahi both being assessed as hypertrophic, and Lake Ohinewai as supertrophic, which is likely a fair reflection of all three. It was recommended by Duggan et al. (2001a) that four quarterly plankton samples be collected over a year and averaged to obtain an accurate trophic state assessment (within 1 TLI unit), as assessments made from single samples (as used in this study) sometimes show wide variability (i.e., up to 4 TLI units for some samples; Duggan 1999). Deviation from the expected rankings for some lakes may result from the limited time frame of sampling in this study.

Trophic state assessment has not been attempted previously using the hatching of eggs from lake sediments, with the rotifer inferred TLI system developed based on plankton hauls. In all cases TLI was inferred as approximately one TLI unit greater using hatching than it was using plankton samples (Figure 2). This is seemingly because species indicative of higher trophic states are preferentially hatched, such as *Brachionus* species. This same genus was hatched almost ubiquitously from ballast sediments by Bailey et al. (2005). Interestingly, however, the lakes were assessed in the same rank order for TLI inferred from the plankton samples as it was for TLI inferred from hatching (Figure 3). Although little weight should be placed on the numerical value of the inferred TLI score from the hatched samples, hatching may be useful for ranking lakes based on water quality, and the ranking derived from hatching in this study lends some confidence to the water quality rankings provided by the single plankton samples.

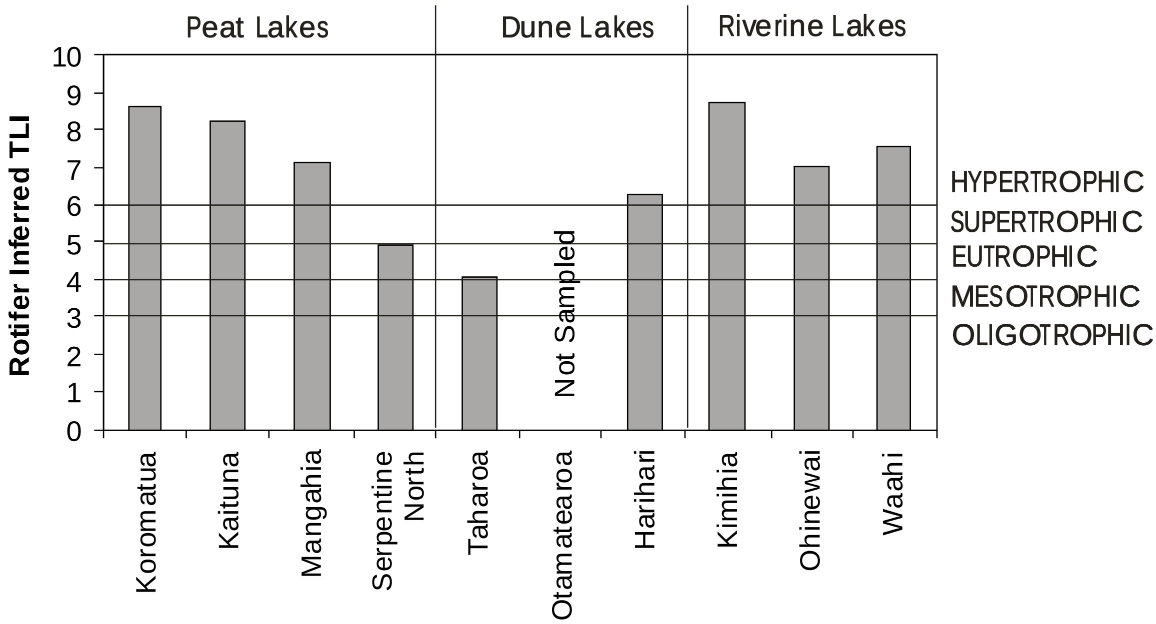

Figure 2: Rotifer inferred trophic states (TLI) from hatching of eggs removed from the bottom sediment samples of nine Waikato Lakes.

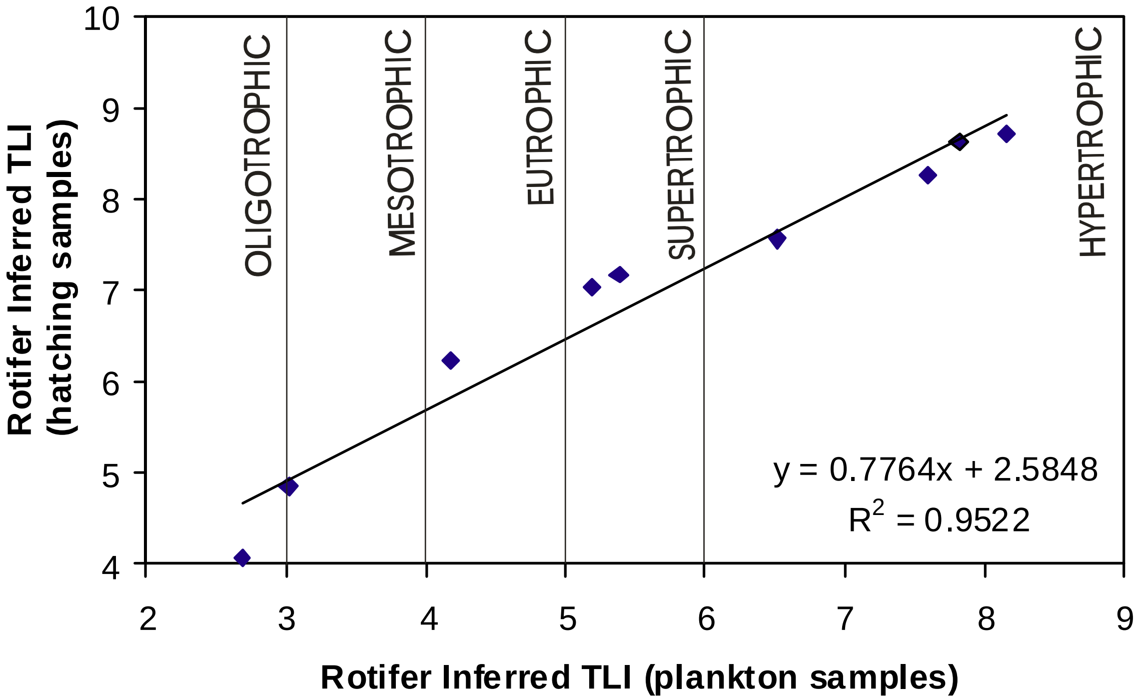

Figure 3: Regression plot showing the relationship between TLI values inferred by the counting of single summer plankton samples and from lists obtained by hatching of eggs removed from bottom sediments.

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Appendix 1

List of "indicator" rotifer species recorded during this survey as a percentage of all indicator taxa. Indicator taxa are ordered based on TLI optima from lowest to highest. Lakes are ordered from approximately lowest to highest TLI.

		Taharoa (plankton)	Taharoa (hatching)	Serpentine North (plankton)	Serpentine North (hatching)	Harihari (plankton)	Harihari (hatching)	Otamatearoa (plankton)	Ohinewai (plankton)	Ohinewai (hatching)	Mangahia (plankton)	Mangahia (hatching)	Waahi (plankton)	Waahi (hatching)	Kaituna (plankton)	Kaituna (hatching)	Koromatua (plankton)	Koromatua (hatching)	Kimihia (plankton)	Kimihia (hatching)
Conochilus dossuarius	3.0989	17.6	1.8																	
Synchaeta longipes	3.3232				6.3	1.8														
Polyarthra dolichoptera	3.4396	31.6	1.2	7.4		13.0		18.0				32.1				35.6	0.3	5.3		4.9
Conochilus unicornis	3.8036	0.8		69.3																
Ascomorpha ovalis	3.9558					0.6	75.0	3.7												
Lecane closterocerca	4.1376							1.6												
Lecane bulla	4.1650							2.1												
Testudinella patina	4.3055							0.5												
Synchaeta oblonga	4.3875	1.0	85.0					7.4	16.6	83.3				11.1	9.7					4.9
Asplanchna priodonta	4.4042	30.3	1.2	0.9	6.3				27.1											
Synchaeta pectinata	4.5011	1.0	1.2						2.2		20.6		0.3							
Collotheca sp.	4.5186	2.9	0.9					11.6					0.3		1.1				2.3	4.9
Filinia pejleri	4.5193										0.5									
Hexarthra mira	4.6060			0.4	31.3															
Asplanchna brightwelli	4.6949										7.4	5.4		5.6	20.6			5.3	1.6	
Trichocerca tenuior	4.6982					2.1														
Trichocerca similis	4.7747	1.0				0.3		48.1	28.3											
Anuraeopsis fissa	4.8205					1.5														
Keratella cochlearis	4.8324	7.5		5.0		82.2		2.1	2.2		21.1		52.2							
Filinia novaezealandiae	4.8392			7.3					4.6			35.7	9.0	22.2	10.0				16.1	4.9
Trichocerca pusilla	4.8556	2.5	8.6		43.8				3.1					11.1	0.6				0.6	
Hexarthra intermedia	5.0850								4.3			3.6							6.5	
Pompholyx sp.	5.2315			6.7					3.1		47.4	1.8		22.2	36.8	2.7	2.0			
Keratella tropica	5.8483			2.6	6.3			2.6	5.2		2.7				7.8		97.4	7.1	41.6	
Brachionus quadridentatus	5.9200											1.8				2.7				
Keratella slacki	5.9414										0.2						0.3			
Keratella tecta	6.0166	3.6		0.4		0.6			0.3				37.9	5.6	0.3				10.3	
Brachionus caliciflorus	6.1631				6.3		25.0			16.7		16.1		16.7	0.3	34.2		77.0	4.2	36.6
Flinia longiseta	6.3957								3.1			3.6	0.3	5.6		24.7		5.3	16.8	43.9
Brachionus budapestinensis	6.5324														12.8					