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Distribution of rotifers in North Island, New Zealand, and their potential use as bioindicators of lake trophic state

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Key words: rotifers, trophic state, bioindicators

Abstract

The distribution and ecology of planktonic rotifers was investigated in 33 lakes in the North Island, New Zealand, between 1997 and 1999. A total of 79 species of monogonont rotifer were identified, with an average of 21 species per lake, a diversity which is high in comparison with many previous New Zealand studies. Most species recorded were cosmopolitan taxa, and were widespread in their distribution over the North Island. Multivariate analyses (Multi-Dimensional Scaling and Canonical Correspondence Analysis) did not distinguish distinct lake groupings based on rotifer communities, but rather gradients in assemblages, which were most highly associated with lake trophic state. Based on these responses, the development of potential rotifer bioindicator schemes for lake trophic state is described and discussed.

Introduction

Diverse rotifer assemblages are known to exist in New Zealand, with approximately 400 species recorded to date (Shiel & Green, 1996). Many earlier studies focused on documenting new records of species from the country, rather than recording and exploring the distribution of species within and between individual lakes (see Shiel & Green, 1996, and references therein). Sanoamuang & Stout (1993) surveyed the distribution of species from 35 lakes in the South Island of New Zealand, the most widespread survey to date, although no attempt was made to infer the factors involved in determining the distribution of species between lake habitats. In the only study of factors affecting New Zealand rotifer community composition, Duggan et al. (in press) found the distribution of rotifers in 10 Rotorua lakes to be associated with lake trophic state. Based on this finding, Duggan et al. (in press) suggested rotifers may provide useful bioindicators of lake trophic state. This study was, however, based on single samples from each lake, and it is, therefore, not known if trophic state determines distribution when a wider range of seasonal variability, or a wider geographical area, is considered.

Trophic state has commonly been found to be important in determining distribution of rotifer communities elsewhere (e.g. Siegfried et al., 1989; Kaushik & Saksena, 1995; Ejsmont-Karabin, 1995). Several studies have provided lists of rotifer species indicative of different trophic states (e.g. Gannon & Stemberger, 1978; Mäemets, 1983; Berzins & Pejler, 1989a; Matveeva, 1991), although no quantitative community index has yet been developed based on these responses (however see Sládecek, 1983). This paper will assess the potential of rotifer communities as bioindicators of lake trophic status using a set of lakes spanning a wider geographical and temporal range than that used by Duggan et al. (in press), and develop a preliminary index that may potentially be utilised in the assessment of lake trophic state.

Methods

Sampling localities are shown in Figure 1. Rotifer samples were collected by vertical hauls using a standardised 40 μm mesh net with a reducing cone. Sampling was carried out between 1997 and 1999 either by the author or by Regional Councils and

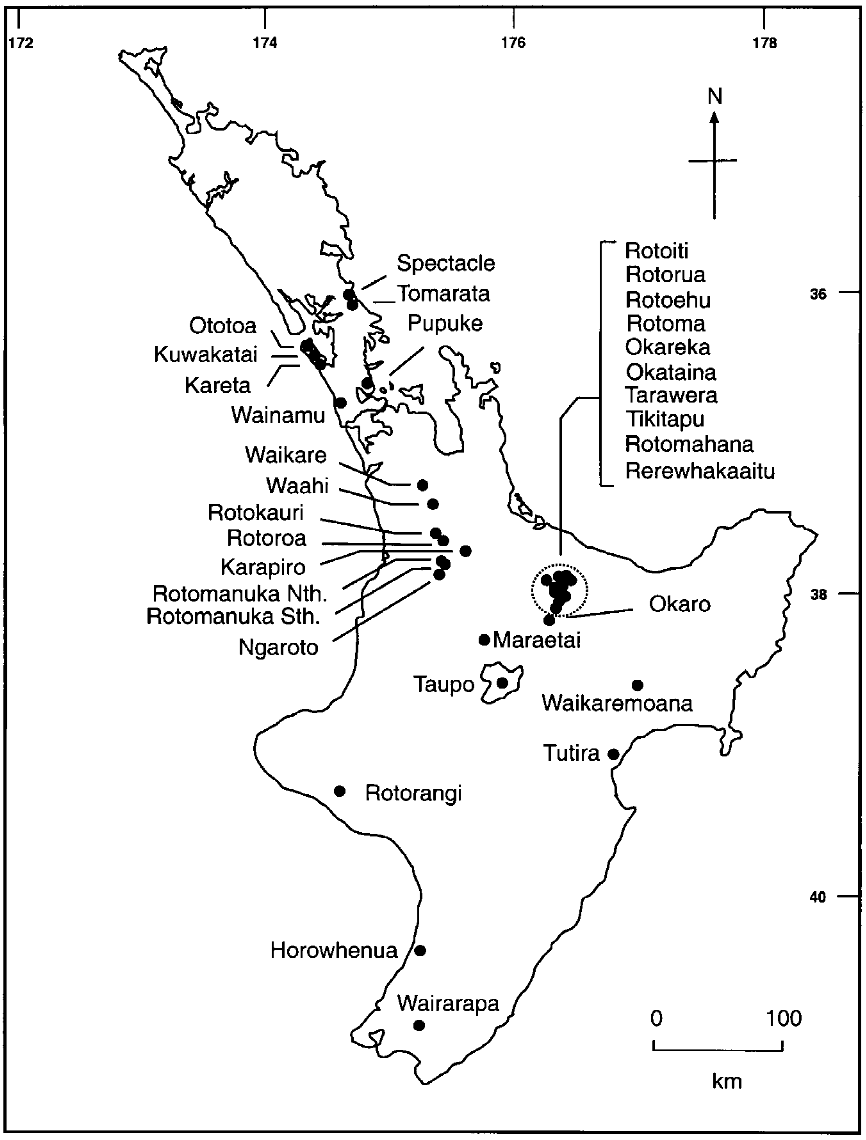

Figure 1. Sampled lakes in the North Island, New Zealand.

the National Institute of Water and Atmospheric Research (NIWA) during regular monitoring of lakes. Where possible, samples were taken once each season through the entire water column. Samples were preserved in 4% formalin. Temperature, dissolved oxygen (DO), pH, total phosphorus (TP), chlorophyll *a* and Secchi depth were determined at the time of sampling. In general, samples were taken from single central sites in each lake, except Lakes Rotorangi (2 sites) and Wairarapa (4 sites), and are initially assessed as separate entities.

For counting, samples were made up to a known volume, and enumerated until at least 1000 individuals were encountered, or until the entire sample was counted. Unknown animals were identified using Koste (1978) and Shiel (1995).

Initial analyses included only lakes for which there were more than two samples from different seasons. All data from each lake were averaged. Thirty five samples from 31 lakes were examined, with 27 species comprising greater than 4% in any sample from two lakes before averaging. As there were only single samples from Lakes Rerewhakaaitu and Rotomahana, these lakes were not included in these analyses. Cluster Analysis, Multidimensional Scaling (MDS) and Canonical Correspondence Analysis (CCA) were used to detect and classify groupings of species and to detect important physical, chemical or geographical variables associated with underlying trends. Cluster Analysis was based on the Bray-Curtis similarity coefficient calculated on the fourth root of the average relative abundances (percentages) of abundant rotifer species (comprising >4% in any two samples from different lakes). Species data were transformed to downweight dominant species. MDS was performed on the ranked Bray-Curtis similarity matrix produced by Cluster Analysis. CCA was performed using the average species relative abundance data (%), log (x+1) transformed to downweight dominant species. Environmental data was log (x+1) transformed to remove skew and subsequently standardised to zero mean and unit variance to remove the influence of differing scales of measurement. Missing temperature, DO and pH values were replaced with average values from all lakes. Standardised latitude, longitude and (log) mean lake depth data were included in the analysis, generally taken from data published by Irwin (1975), Livingston et al. (1986) and Lowe & Green (1987).

Bioindicator schemes are developed in relation to a single environmental gradient. The OECD scheme relies on separate assessments from TP, chlorophyll *a* and Secchi transparency measurements. The Trophic Lake Index (TLI) (Burns & Rutherford, 1998), developed for New Zealand conditions to enable easy comparison of trophic level of different lakes, provides an absolute indicator of lake trophic level by taking into account all of these three factors, plus total nitrogen (TN), to give a single numerical value of trophic state. On average, equivalent trophic levels are assigned using each indicator based on regression equations used in development, with the TLI value a single number that is an average of the four indicators. In the current study, TLI values were calculated only with the available data (generally four samples), without TN. The inference of lake trophic state using relative abundances of rotifer species in a sample requires a good statistical relation between the variable of interest (e.g. TP, TLI) and the rotifer taxa. In order to develop rotifer inference models for lake trophic state, the relative strengths of different trophic state indicators were estimated by running a series of Canonical Correspondence Analyses (CCA) constrained to single environmental variables (i.e. TLI, TP, chlorophyll *a* and Secchi transparency). In this type of analysis, there is one constrained axis related to each variable, and a series of unconstrained axes. The ratio of the first constrained eigenvalue (λ_1) to the second unconstrained eigenvalue (λ_2) indicates the relative importance of that environmental variable in explaining the species data (Ter Braak, 1988), and variables with high λ_1/λ_2 ratios are potential candidates for developing predictive models. Dixit et al. (1991) suggest using only those variables with λ_1/λ_2 ratios greater than 0.5 to develop inference models, with variables with lower ratios likely to be less robust. In the constrained CCAs and in the development of the bioindicator scheme, 121 samples (non-deseasonalised data) were used. In Lakes Wairarapa and Rotorangi, only samples from central sites were used so that additional samples did not to have over-representation in the construction of the bioindicator scheme. Analyses were performed using untransformed relative abundance data (%) of abundant species and raw (TLI) or log transformed (others) environmental data, averaged for each lake. Forty four species, comprising >1% of any one sample and present in five or more samples, were used to ensure a large initial species data set.

Tolerance downweighted Weighted Averaging regression (WA-tol) was used to construct an index for assessing lake trophic state from rotifer community composition, based on the trophic indicator with the strongest relationships with rotifer communities. This method is commonly used in paleolimnological studies for inferring past environmental conditions from the responses of modern taxa (Ter Braak & Van Dam, 1989; Birks et al., 1990), and involves both regression (Ter Braak & Looman, 1987) and calibration (Ter Braak, 1987) steps. WA regression is used to estimate species indicator values, which are equivalent to the optima of a species unimodal response curve to the variable of interest. A weighted average is taken of the environmental data, in which values are weighted proportional to the species relative abundance, i.e.:

$$u^* = (y_1x_1 + y_2x_2 + \ldots + y_nx_n)/(y_1 + y_2 + \ldots y_n)$$

where u^* is the weighted average (= the species indicator value), $y_1, y_2, \ldots, y_n$ are the relative abundances of species at sites 1, 2 … n and $x_1, x_2, \ldots, x_n$ are values of environmental variables at sites 1, 2 … n.

In the calibration step, the estimates of optima of taxa are used to infer environmental conditions based on the taxonomic composition of the sample. A WA estimate for a sample is the average of the optima of taxa in that sample, weighted with respect to their

Table 1. Total cumulative α species diversity from lakes with two or more samples. The data is ordered from highest to lowest diversity

Lake	α	Lake	α	Lake	α
Maraetai	35	Okareka	22	Waikaremoana	18
Karapiro	34	Ototoa	22	Okaro	17
Rotorangi	28	Waahi	22	Rotoehu	17
Rotokauri	26	Tarawera	21	Tikitapu	17
Rotoiti	26	Rotomanuka South	21	Tomarata	17
Rotomanuka	26	Rotoroa	21	Wainamu	17
Kareta	24	Pupuke	20	Rotoma	16
Tutira	24	Waikare	20	Wairarapa	10
Kuwakatai	23	Rotorua	19	Taupo	9
Ngaroto	23	Spectacle	19		
Horowhenua	22	Okataina	18	Average	21.1

Table 2. Key to sample numbers for MDS and CCA ordinations of lake rotifer communities

n	Lake	*n*	Lake	*n*	Lake
1	Horowhenua	13	Rotoiti	25	Tikitapu
2	Karapiro	14	Rotokauri	26	Tomarata
3	Kareta	15	Rotoma	27	Tutira
4	Kuwakatai	16	Rotomanuka	28	Waahi
5	Maraetai	17	Rotomanuka South	29	Waikare
6	Ngaroto	18	Rotorangi (L2)	30	Waikaremoana
7	Okareka	19	Rotorangi (L3)	31	Wainamu
8	Okaro	20	Rotoroa	32	Wairarapa 1
9	Okataina	21	Rotorua	33	Wairarapa 2
10	Ototoa	22	Spectacle	34	Wairarapa 3
11	Pupuke	23	Tarawera	35	Wairarapa 4
12	Rotoehu	24	Taupo		

relative abundances, i.e.:

$$x_o = (y_1u_1 + y_2u_2 + ... + y_nu_n)/(y_1 + y_2 + ...y_n)$$

where x_o is the assessed environmental variable, y_1, $y_2, \ldots, y_n$ are the responses (relative abundances) of species (1, 2 … n) at the sites, $u_1, u_2, \ldots, u_n$ are the indicator values of species (1, 2 … n) (i.e., the weighted average values, u^*, determined above).

In WA-tol, each taxon is downweighted by its respective variance.

$$x_o = [(y_1u_1/t_1^2) + (y_2u_2/t_2^2) + \ldots + (y_nu_n/t_n^2)] \\ /[(y_1/t_1^2) + (y_2/t_2^2) + \ldots (y_n/t_n^2)]$$

In WA-tol reconstructions, averages are taken twice, once in the development of indicator values and again in the inference of environmental conditions. The resulting 'shrinkage' of the inferred environmental variables is corrected for using a deshrinking regression equation (Birks et al., 1990). Classical deshrinking was used as it provided more reliable estimates than inverse deshrinking. Regression analyses were performed on deseasonalised observed *versus* inferred TLI values. Deseasonalised inferred WA-tol values were obtained as an average of each lakes inferred WA-tol values from different seasons.

Cluster analysis and MDS were performed using the Plymouth Routines in Multivariate Research statistical package (PRIMER, 1994; Clarke & Warwick, 1994), and CCA using CANOCO 4.0 (Ter Braak & Smilauer, 1998). WA-tol regression and calibration and calculation of deshrinking equations were performed using CALIBRATE v. 0.8.2 (Juggins & Ter Braak, 1998).

Results

Seventy nine species of monogonont rotifer were found during this study. Mean lake species diversity, estimated from lakes with two or more samples, was 21.1 species per lake (Table 1). Lakes Taupo and Wairarapa contained the lowest diversities with nine and ten species, respectively, and Lakes Karapiro and Maraetai the greatest with 34 and 35 species.

Cluster analysis (Fig. 2) of the rotifer communities averaged seasonally for each lake revealed eight groupings of lakes at a 58% similarity level. The majority of samples were found in two clusters only (Clusters B and C). The remaining samples generally did not form distinct cluster groupings, indicating a gradation in community structure. Rotifer distribution appears to broadly relate to lake trophic state. Clusters A and B comprised mainly oligotrophic to mesotrophic lakes, Cluster C mesotrophic to eutrophic lakes, and Clusters D, E, F and G eutrophic to hypereutrophic lakes. Samples taken from different positions of the same water body were generally closely related to one another, e.g. the samples from the two sites in Lake Rotorangi, the four sites in Lake Wairarapa and the connected hydroelectric reservoirs, Lakes Karapiro and Maraetai. There appeared to be some geographical basis to the distribution of communities, with many of the Waikato riverine lakes (e.g. Lakes Ngaroto, Rotokauri and Rotomanuka South) or Rotorua volcanic lakes (e.g. Lakes Rotoma, Okataina and Okareka) being closely related to one another, although these lakes generally had similar trophic states.

The MDS of these lakes shows a general gradation in species composition based on trophic state (Fig. 3,

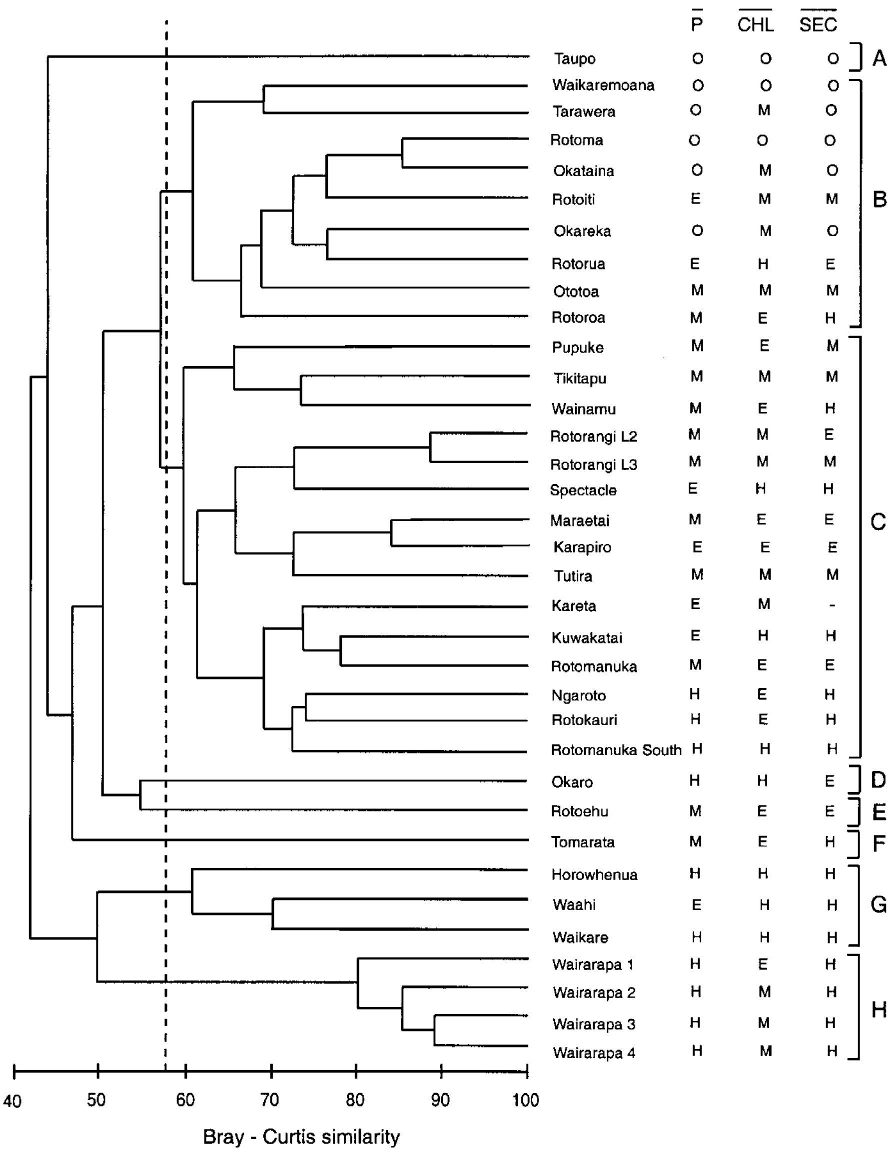

Figure 2. Cluster analysis of lakes based on mean percentage rotifer species composition, and inferred trophic states, using mean total phosphorus, mean chlorophyll *a* concentration, and mean Secchi transparency, based on the OECD (1982) fixed boundary system. Dashed line indicates 58% level of similarity.

Table 2). Lakes with relatively low trophic state appear at the bottom of the ordination, medium trophic state lakes central, and more highly trophic state lakes near the top and top left of the ordination. This distribution was reflected within clusters also, with the more oligotrophic lakes in Cluster B (e.g. Waikaremoana and Rotoma) distributed nearer to Cluster A, and more mesotrophic lakes (e.g. Rotoiti, Rotoroa and Rotorua) closer to Cluster C. The higher trophic state lakes in Cluster C (e.g. Ngaroto, Rotokauri and Rotomanuka South) distributed nearer to Clusters D, E, H and G. Lake Tomarata (Cluster F) was found to separate from the other clusters, with distribution perhaps determined by an environmental forcing factor other than trophic state.

CCA (Fig. 4, Table 2) revealed a distribution of lakes that was similar to those shown by cluster analysis and MDS. Lower trophic state lakes (Clusters A and B) were negatively associated with Axis 1, and mesotrophic to eutrophic samples (Cluster C)

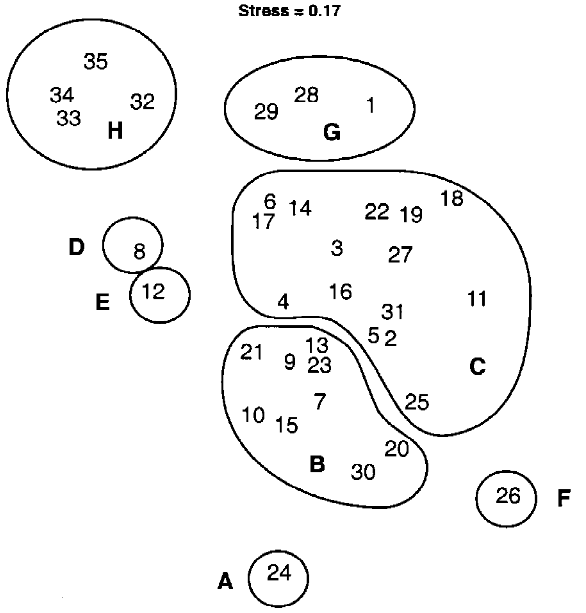

Figure 3. Non metric multi-dimensional scaling (MDS) plot of lakes based on mean% rotifer species composition (fourth root transformation). Numbers correspond to sample numbers (Table 2). The MDS is overlaid with groupings found in cluster analysis.

Table 3. Results of forward selection and Monte Carlo permutation tests from CCA of North Island rotifer species. Environmental variables are listed by the order of their inclusion in the model (lambda-A)

	Lambda-1	Lambda-A	*P*
Secchi	0.21	0.21	0.005
Temperature	0.10	0.11	0.005
Chlorophyll *a*	0.12	0.09	0.005
DO	0.09	0.06	0.080
Mean lake depth	0.16	0.04	0.200
Latitude	0.09	0.04	0.290
TP	0.20	0.04	0.420
Longitude	0.08	0.03	0.375
pH	0.05	0.05	0.215

samples were generally found central in the ordination. Clusters D, E, G and H samples were positively associated with Axis 1, with Cluster E (Lake Rotoehu) strongly positively associating with Axis 2. *Conochilus dossuarius, Conochilus unicornis, Ascomorpha ovalis* and *Conochilus coenobasis* strongly negatively associated with Axis 1, and *Keratella tropica, Keratella tecta, Brachionus budapestinensis, Synchaeta oblonga* and *Hexarthra intermedia* were strongly positively associated. *Filinia terminalis, Trichocerca pusilla*, *Trichocerca longiseta, H. intermedia* and *C. dossuarius* were strongly positively associated with Axis 2, and *Anuraeopsis fissa, Keratella slacki, B. budapestinensis* and *K. tecta* strongly negatively associated. Forward selection and associated Monte Carlo permutation tests of the significance of environmental variables (Table 3) indicate that Secchi transparency, TP, average depth and chlorophyll *a* explain most of the variation in species distribution when considered by themselves. After the addition of Secchi transparency, only temperature and chlorophyll *a* explained any significant amount of the remaining variation ($P<0.05$). TP and chlorophyll *a* were most strongly positively associated with Axis 1, and Secchi and mean lake depth most strongly negatively associated, indicating this axis was mainly related to lake trophic state and lake depth. Temperature was strongly negatively associated with Axis 2 and DO strongly positively associated. This axis is therefore likely to reflect warm and cold water assemblages caused by seasonal, latitudinal or altitude variation, e.g. *Filinia terminalis* and *Trichocerca pusilla* in colder water and *Anuraeopsis fissa* and *Keratella slacki* in warmer water. Comparing rotifer distributions with measured environmental variables, species associated with Cluster A and B samples (*Conochilus dossuarius, Conochilus unicornis, Ascomorpha ovalis* and *Conochilus coenobasis*) are associated with high Secchi transparency, and low TP and chlorophyll *a* levels. Rotifer community composition showed strong relationships with trophic state so was, therefore, investigated as a variable for constructing a bioindicator scheme.

In constrained CCAs, TLI was identified as the measure of lake trophic state most highly associated with rotifer distribution (λ_1/λ_2 ratio = 0.505), followed by TP (0.490), Secchi transparency (0.465) and chlorophyll *a* (0.427). TLI is the only variable whose first constrained eigenvalue can be considered large (>0.5) compared to the other unconstrained eigenvalues (cf. Dixit et al., 1991). The predictive ability of the inference model was assessed from the coefficient of determination (R^2) between the observed and the rotifer inferred TLI or RCI values, and the deviation between observed and inferred values of samples (Fig. 5, Table 4). Only Lake Waahi was assessed as having TLI levels greater than 2 TLI units different from the observed. The WA optima and tolerance of species is given in Table 5. The WA-tol classical deshrinking

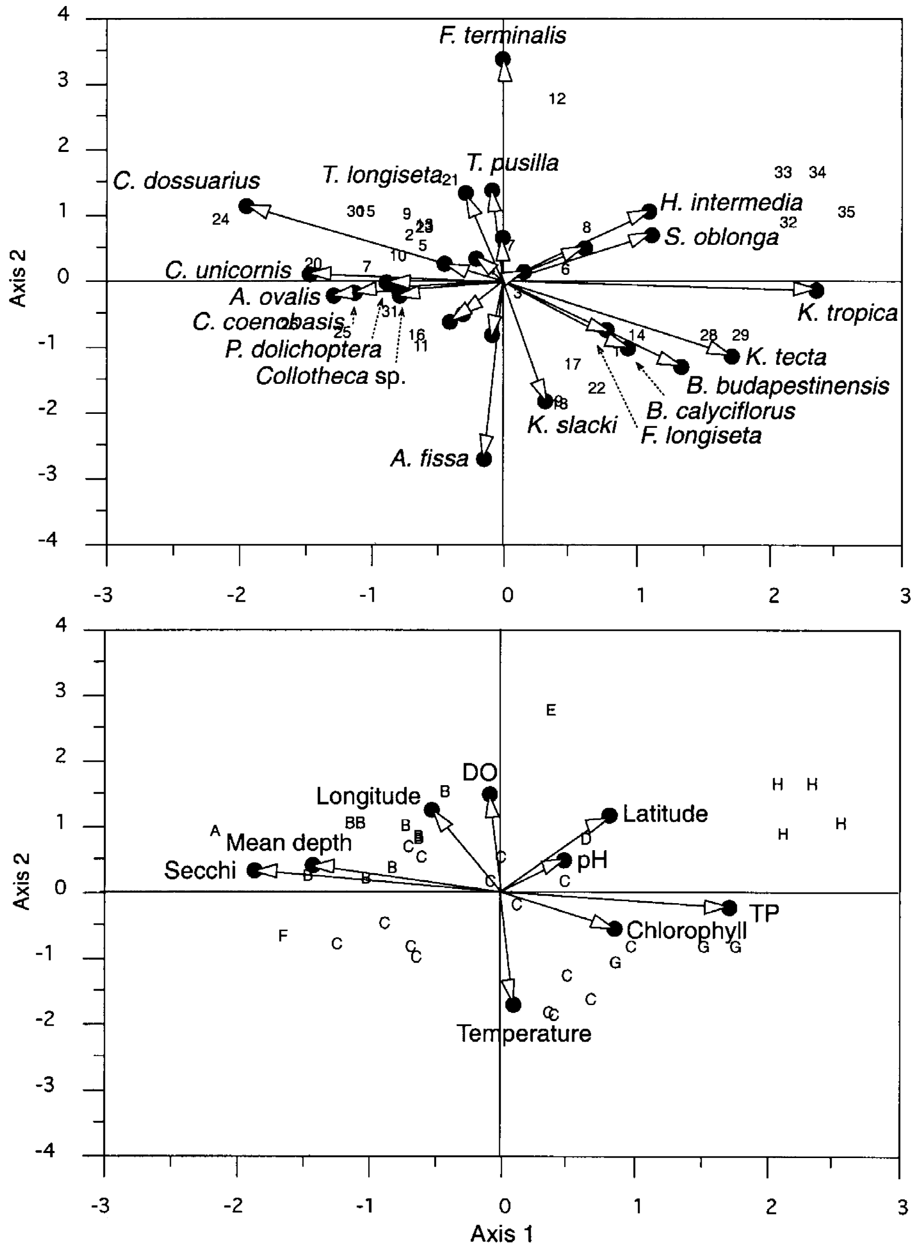

Figure 4. Ordination diagram based on canonical correspondence analysis (CCA) of North Island rotifer species with respect to environmental variables. Eigenvalues for the first two axes = 0.243 and 0.125. Scores of rotifer species and environmental variables were scaled to fit the sample ordination. Numbers correspond to sample numbers (Table 2). Species weakly associating with both Axes 1 and 2 have been omitted from the ordination for clarity.

equation is:

$$TLI_{final} = (TLI_{initial} - 2.932)/0.371.$$

Estimates of the average yearly TP and chlorophyll *a* can be calculated from the TLI value using the following equations derived from Burns & Rutherford (1998):

$$\log(TP) = (TLI - 0.218)/2.92$$
$$\log(chlorophyll\,a) = (TLI - 2.22)/2.54$$

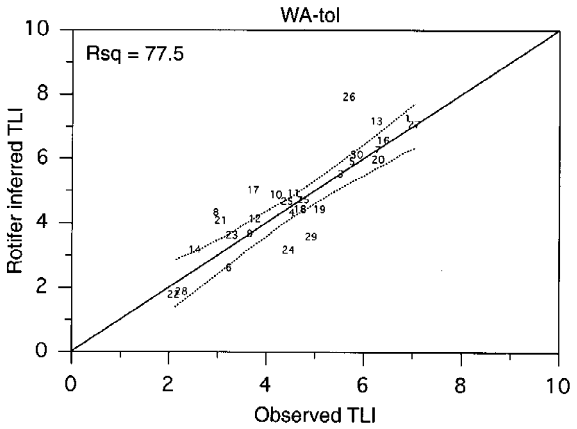

Figure 5. Plot of observed TLI against inferred TLI, derived from WA-tol. Solid line indicates regression line, and dashed lines indicate 95% confidence limits.

Table 4. Key to sample numbers for inferred *versus* observed TLI

n	Lake	*n*	Lake	*n*	Lake
1	Horowhenua	11	Rotoehu	21	Tarawera
2	Karapiro	12	Rotoiti	22	Taupo
3	Kuwakatai	13	Rotokauri	23	Tikitapu
4	Maraetai	14	Rotoma	24	Tomarata
5	Ngaroto	15	Rotomanuka	25	Tutira
6	Okareka	16	Rotomanuka South	26	Waahi
7	Okaro	17	Rotorangi	27	Waikare
8	Okataina	18	Rotoroa	28	Waikaremoana
9	Ototoa	19	Rotorua	29	Wainamu
10	Pupuke	20	Spectacle	30	Wairarapa

Discussion

Trophic state was the environmental factor that was most strongly associated with the distribution of North Island rotifer species, as found on a smaller scale by Duggan et al. (in press) in lakes from the Rotorua area. Many rotifer species were found to have preferences for either particular ranges or extremes in trophic state. For example, *Ascomorpha ovalis, Conochilus coenobasis, Conochilus dossuarius, Conochilus unicornis, Polyarthra dolichoptera* and *Synchaeta longipes* were found associated with low trophic state, and *Brachionus budapestinensis, Brachionus calyciflorus, Filinia longiseta, Keratella slacki, Keratella tecta* and *Keratella tropica* with high trophic state. Species found with poor statistical associations with trophic state in the current study may, however, also have distributions more indicative of trophic state that will become apparent once a larger data set is obtained. Species

Table 5. Weighted average (WA) optima and tolerance data for TLI for abundant North Island rotifer species. Species are ordered by TLI optima

Species	TLI optimum	TLI tolerance
C. dossuarius	3.0989	0.9545
S. longipes	3.3232	0.3942
P. dolichoptera	3.4396	1.3568
T. stylata	3.7553	1.2586
G. minor	3.7921	0.3662
C. unicornis	3.8036	1.1211
G. hyptopus	3.8248	1.0634
C. coenobasis	3.9056	0.6608
A. ovalis	3.9558	0.8746
L. closterocerca	4.1376	0.5969
L. bulla	4.1650	0.7413
T. patina	4.3055	1.1250
S. oblonga	4.3875	1.2897
A. priodonta	4.4042	1.3888
A. navicula	4.4189	0.5391
S. pectinata	4.5011	0.9830
Collotheca sp.	4.5186	1.6649
F. cf.*pejleri*	4.5193	0.9545
F. terminalis	4.5290	0.1414
H. mira	4.6060	0.7787
E. dilatata	4.6508	0.5745
T. tetractis	4.6885	0.1556
S. stylata	4.6926	0.5304
C. catellina	4.6947	0.4421
A. brightwelli	4.6949	0.9757
T. tenuior	4.6982	0.1236
T. porcellus	4.7448	0.3732
T. similis	4.7747	0.9012
A. fissa	4.8205	1.1542
K. cochlearis	4.8324	1.1914
F. novaezealandiae	4.8392	1.4754
T. longipes	4.8412	1.0207
T. pusilla	4.8556	0.7896
H. intermedia	5.0850	1.4825
K. procurva	5.2296	1.1108
P. complanata	5.2315	1.1958
A. sieboldi	5.6245	1.3073
K. tropica	5.8483	1.0890
B. quadridentatus	5.9200	0.9669
K. slacki	5.9414	0.9749
K. tecta	6.0166	1.1050
B. calyciflorus	6.1631	0.4242
F. longiseta	6.3957	0.7238
B. budapestinensis	6.5324	0.4540

found to be indicative of high and low trophic state in general correspond with those found in studies elsewhere, e.g. Mäemets (1983), Sládecek (1983), Pejler (1983) and Berzins & Pejler (1989a). Pejler (1983) attributed species preferences along a trophic gradient to the size and nature of the particulate food present, with ultraoligotrophic rotifer species, e.g. *Conochilus*, predominantly feeders of minute algal particles, hypereutrophic species, e.g. *Brachionus*, predominantly feeders of bacteria, and those between these ranges feeders on coarser particles. However, as with phytoplankton communities, distribution of rotifer species along the trophic gradient is likely to be caused not by competition for a single factor, e.g. food type (or nutrients in the case of phytoplankton), but by the consequential impacts of a variety of factors along the gradient (Reynolds, 1998). Examples of this are likely to include the appearance of toxic cyanobacteria (Snell, 1980; Starkweather & Kellar, 1987), the increased importance of predation on rotifers by *Asplanchna* (Ejsmont-Karabin, 1974; Pejler, 1983) and the degree of oxygen depletion (e.g. Berzins & Pejler, 1989b; Mikschi, 1989) with increasing trophic state. These factors will weigh in favour of the growth and survival of particular rotifer species, with the realised niches of species the outcome of several dimensions of variability along a common gradient.

Based on the relationships between rotifer species composition and trophic state, rotifers have previously been suggested as bioindicators. Trophic state inference in these studies has, however, generally been fairly coarse, relying on the simple comparison of rotifer composition with species lists of indicative taxa (e.g. Mäemets, 1983; Matveeva 1991). Sládecek (1983), suggested a more quantitative method that used the ratio of the number of species of *Brachionus* to *Trichocerca*, based on his findings that *Brachionus* are associated with eutrophic waters and *Trichocerca* with oligotrophic waters. However, because this relationship will generally be based on a limited number of species, it is likely to provide only a very coarse measure. Also, *Trichocerca* species were in general not found to be indicative of oligotrophic conditions in the current study, and *Brachionus* species are known to be limited in their distribution globally (e.g. Dumont, 1983), likely affecting this relationship from place to place.

Biotic score systems, based on community composition, have generally been preferred over indices based on either a single indicator taxon or diversity measures in freshwater biomonitoring (e.g. Armitage et al., 1983; De Pauw & Vanhooren, 1983; Stark, 1985). Score systems are based on the responses of a number of species, with inferred conditions based on those present in a sample, but not affected by species absence. Because of the general cosmopolitan nature of rotifer species, and the similarity between species–trophic state relations shown in this and other studies, the development of a score system for assessing lake trophic state based on North Island rotifer species may be relevant not only in New Zealand, but also possibly elsewhere with little or no modification. This provides advantages over bioindicator schemes using macroinvertebrates as these species, and therefore indices, are generally regionally specific (cf. Armitage et al., 1983; Stark, 1985).

WA-tol gave a high coefficient of correlation (77.5) and a low spread around the regression line because species with narrow tolerances are given a greater weighting than those with wider tolerances, without the removal of rare species. Ideally, indicator species need to have narrow tolerances to the variable of interest (Rosenberg & Resh, 1993), and WA-tol therefore gives preference to these species. This scheme also results in a numerical value of use to freshwater managers because it provides inferences of commonly used measures of trophic state such as TP and TLI. This, therefore, appears to be a useable method for inferring trophic state from rotifer community composition. The close relationship between this rotifer index and trophic state variables indicates that rotifers have potential as bioindicators of lake trophic state in the North Island of New Zealand. The advantage of rotifer indices over the TLI and traditional OECD assessment is that they require the measure of a single factor, so saving time and cost.

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