Environment Waikato Technical Report 2008/18

Assessment of Biological Indicators of Lake Health in Waikato Shallow Lakes - a Pilot Study 2006/07

www.ew.govt.nz
ISSN 1172-4005 (Print)
ISSN 1177-9284 (Online)

Environment Waikato
REGIONAL COUNCIL

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26 September 2007

Document #: 1228520

Peer reviewed by:
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Acknowledgement

We acknowledge the field and technical assistance of Johlene Kelly and Richard Hemming. Ian Duggan (University of Waikato) carried out analyses of zooplankton communities. Cawthron Institute carried out identification of macroinvertebrate samples. NIWA carried out LakeSPI assessments. Bill Vant provided technical advice and peer review. Thank you to the landowners and land managers who approved access to lakes for sampling.

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Abstract

The development of monitoring methods and indicators of lake ecosystem health is essential in providing cost-effective methods to assess changes within and around the lakes of the Waikato region. The aim of the current project is to assess a number of biotic and functional variables as potential indicators of lake health. We evaluated the use of LakeSPI, zooplankton and invertebrate community analyses, and decomposition rates in ten shallow lakes of varying type (peat, riverine and dune) within the Waikato region. Sampling was carried out in December 2006, January 2007 and March 2007. Results obtained were compared to the results of water quality sampling and to a predetermined relative condition based on existing knowledge of each lake. Zooplankton communities were analysed to produce a rotifer inferred Trophic Level Index (TLI) for each lake. These values were similar to the TLI values calculated from the water quality results. The relative condition of lakes based on the rotifer inferred TLI values was similar to that expected for peat and riverine lakes, but not for dune lakes. The LakeSPI technique can only be used to produce an index in lakes that are vegetated, and therefore can not be used to detect small changes in shallow devegetated lakes. However the technique detected an apparent deterioration in one of the dune lakes in the current study. Three sampling techniques were used for collecting lake macroinvertebrate samples – net sweeps, artificial substrates and ponar grabs. Results of cluster analyses suggest that samples collected with the ponar grab may be the most meaningful for assessing lake health. Analysis of decomposition rates of birchwood sticks provided encouraging results and further testing of this technique is suggested. Recommendations are made for a second year of sampling to further assess indicators and sampling techniques in a greater number of lakes.

1 Introduction

The development of monitoring methods and indicators of lake ecosystem health is essential in providing cost-effective methods to assess changes within and around the lakes of the Waikato region. These tools will enable Environment Waikato to acquire a more complete knowledge of the status of our lakes. They will also provide a means with which to measure the effectiveness of our policies and the management actions of ourselves and other stakeholders.

Currently Environment Waikato carries out water quality monitoring on a selection of Waikato lakes (e.g. Barnes 2002). However this is not a feasible or cost-effective way of monitoring the health of all lakes across the region over the long term. Water chemistry can change significantly over short periods of time and requires regular and ongoing sampling to assess status and trends. A one-off water quality sample is unlikely to provide a good measure of lake condition. Furthermore, it is not feasible for Environment Waikato to sample water quality of all our lakes at a frequency required to reliably establish trends.

The aim of the current project is to assess a number of biotic and functional variables as potential indicators of lake health. We aim to find one or more techniques that can be measured across a variety of lake types. Selected indicators need to be sensitive to changes in physical, chemical and/or biological factors within a lake and provide a good "snap-shot" of lake status. Ideally indicators would be monitored frequently (up to 4 times per year) in high priority or actively managed lakes, but less frequently (3-5 yearly) in lower priority or stable lakes.

NIWA have developed LakeSPI as a means of detecting changes in lake condition by assessing the health, extent and composition of submerged plant communities. Advantages of this method are that sampling is carried out in the ecologically important littoral zone, and that aquatic plant condition reflects impacts of exotic species invasion. In addition, biota such as plants, zooplankton and invertebrates have populations that reflect environmental conditions over a long period of time prior to survey (Duggan and Barnes 2005, Edwards et al. 2007). The main disadvantages of LakeSPI are that it requires skilled staff to carry out the assessments, and it does not report on changes in lakes that are devegetated or have sparse vegetation.

Duggan et al. (2001) found that trophic state was the main determinant of rotifer distribution among lakes in the North Island, and developed a bioindicator index using community composition to infer Trophic Lake Index (TLI). This technique was used successfully to track changes in water quality of Auckland lakes between 2001-2004 (Duggan and Barnes 2005).

Macroinvertebrates are commonly used to indicate health in streams and rivers, and may provide a useful tool in the assessment of lake health. Invertebrate communities are often favoured for monitoring because they are relatively easy to collect and identify, most are sessile with short life-histories and can respond rapidly to change, and they have a diversity of functional and effects traits that provide a variety of responses to changing environmental conditions (Hellawell, 1978; Rosenberg & Resh, 1993; Boothroyd & Stark, 2000). Some studies have shown associations between lake level variability and macroinvertebrate communities (Stark 1993; Furey et al. 2006), and invertebrates have been integrated into USEPA lakes monitoring protocols (US Environmental Protection Agency, 2006).

Recently the value of incorporating measurements of ecosystem function into river monitoring programmes has increasingly been recognised (Bunn & Davies 2000; Gessner and Chauvet 2002; Carlisle and Clements 2005; Paul et al. 2006; Uehlinger 2006). In particular, functional indicators may be useful for discriminating low levels of impairment which is often problematic using conventional structural indicators. They

may also be able to detect initial moves away from degraded states that demonstrate tangible improvements in ecosystem health during the early stages following restoration (Palmer et al. 2005). Although production and respiration have been measured in lakes over many decades, other functional measures such as decomposition rates of organic substrates do not appear to have been widely used to monitor lake condition.

The aim of this pilot study is to evaluate the use of LakeSPI, zooplankton and invertebrate community analyses, and decomposition rates as indicators of lake health in shallow lakes of the Waikato region. We also assess the ease and cost of sampling techniques, and make recommendations on variables and techniques for further examination over 2007/08.

2 Methods

2.1 Study sites

Ten lakes from three lake types were selected to assess the chosen range of variables (Table 1). In order to evaluate the effectiveness of each technique/variable in determining lake health and change over time, examples of different predicted condition were chosen within each lake type. Within the peat lakes we chose lake types from slightly degraded to very highly degraded, but also included a lake (Kaituna) that has been the focus of recent substantial riparian restoration work and so may be improving in health. All of the riverine lakes in the Waikato region are eutrophic and devegetated. Therefore we chose two lakes that were typical of this type (Waahi and Ohinewai), and another lake that was considered very highly degraded (Kimihia). Within the dune lakes we included Taharoa which until recently appeared to be in good condition, but according to anecdotal reports from local iwi has deteriorated markedly in the last 2-3 years; and two lakes considered to represent the best of this lake type in the Waikato.

Three visits were carried out to each lake - December 2006, late January 2007 and late March 2007.

Table 1 Waikato region lakes included in a pilot study investigating biological and functional indicators of lake health.

Lake	Type	Size (ha)	Predicted condition
Serpentine North	Peat	5.3	Slightly degraded
Mangahia	Peat	8.4	Highly degraded
Kaituna	Peat	15	Very highly degraded/recovering
Koromatua	Peat	6.8	Very highly degraded
Waahi	Riverine	537	Highly degraded
Ohinewai	Riverine	16	Highly degraded
Kimihia	Riverine	55	Very highly degraded
Harihari	Dune	18	Natural
Otamatearoa	Dune	5	Slightly degraded
Taharoa	Dune	205	Moderately degraded/deteriorating

2.2 Water quality

2.2.1 Water sampling

Water quality sampling followed the protocols used by the Environment Waikato Environmental Monitoring team (Appendix 1). A depth sounder and, where available, a bathymetric map were used to locate the deepest part of each lake. The dissolved oxygen/temperature profile within the lake was measured using a WTW Oxi 197-S DO meter, and a set of water samples were collected at this point (surface and bottom waters). Samples were taken during all three visits to each lake. Samples were processed by Hills Laboratory and the results entered into the Environment Waikato database.

Calculations of Trophic Level Index (TLI) followed Burns et al. (1999). Some caution does need to be applied to these values; for our study values were averaged for results obtained in December, January and March and therefore did not include a winter value. Burns et al. (1999) developed the TLI using the annual average values for each lake.

2.3 Zooplankton

Zooplankton samples were collected in December 2006 by carrying out three hauls of a 40 µm plankton net over the deepest part of a lake. Material from each haul was pooled into a single sample per lake. Samples were stored in 70% ethanol and delivered to Dr Ian Duggan, University of Waikato for analysis.

In January 2007 a sediment sample was collected from the deepest part of the lake using a petite ponar grab. At least 250 g of sediment was collected from each lake, with the exception of Lake Otomatearoa from which we were unable to sample through the dense beds of hornwort (*Ceratophyllum demersum*). Samples were stored (without preservative) in a 10 L bucket and delivered to Ian Duggan for zooplankton hatching trials.

For details on methodology for analysis and calculations of rotifer inferred trophic states see Duggan (2007).

2.4 Submerged macrophytes

LakeSPI assessments were carried out under contract by NIWA. Briefly, LakeSPI involves the use of a SCUBA diver to survey five representative transects within a lake, recording information on native and exotic vegetation. This data is then used to generate scores for native condition, invasive condition and an overall LakeSPI index. For full details on methodology see Edwards *et al.* (2007).

2.5 Decomposition rates

To quantify decomposition rates, white birchwood (*Betula platyphylla*) coffee stirrer sticks (114 x 10 x 2 mm) were deployed midway in the water column at the central point in each lake. They were attached to a taut weighted rope tied to a buoy. Each stick was labelled with a permanent marker pen and a hole was drilled at one end of the stick. The air-dried mass of each stick was measured (to the nearest 0.1 mg) and then 5 sticks were tied together, along with a plastic label, using nylon string. Short lengths (10 mm) of plastic drinking straws were used to keep the individual sticks separated in the groups of five sticks. These were left in place for a period of six weeks before being removed. Following retrieval, the sticks were kept on ice during transport to the laboratory and then frozen until analysis. After thawing the sticks were gently washed and then dried to constant weight in a 60°C oven and re-weighed. A set of control sticks was oven dried to determine the difference between fresh weight and dry weight, which averaged 90% (range 89-90%). This correction factor was used to estimate initial dry weights for the sticks that were deployed. For calculation of

decomposition rates, mean temperature-unadjusted exponential decay rates (*k*) were used (see Young *et al*. 2004).

2.6 Invertebrates

2.6.1 Sample collection and processing

Invertebrates were sampled using three different techniques at each of three sites per lake. In lakes where a LakeSPI assessment had been carried out, the three sampling sites were chosen from the 5 LakeSPI transects. In devegetated lakes the sites were placed within representative littoral vegetation at points spaced approximately evenly around the perimeter. Sampling techniques were as follows:

- Artificial substrates: In January 2007 one Hester-Dendy sampler made up of 15 perspex plates (75 x 75 mm; artificial substrate) was placed at each of the three sites. Substrates were set attached to a secured bamboo pole amongst littoral vegetation and suspended from a rope to a depth approximately 50-100 mm from the lake bottom. Substrates were left in place for a period of six to seven weeks. They were removed by gently lifting the substrates until a 0.5 mm mesh hand net could be placed underneath them. Substrates were then placed in a container along with contents of the net, and transported on ice back to the laboratory where the sampler was disassembled and individual plates were cleaned under running water over a sieve. Invertebrates were transferred into a 100 mL plastic pottle.

- Littoral netting: During March 2007 invertebrates were collected using a 0.5 mm mesh sweep net to sample available habitat in an approximately 5-m x 2-m area over a 2-minute period. The net was skimmed over the surface of the substrate and through emergent and submerged littoral vegetation (if present) during this time. Net contents from each individual site were placed in a 20-L bucket containing about 5 litres of water. Invertebrates were washed from any macrophytes that had been gathered, and the bucket contents strained through a 0.5 mm net. Invertebrates and detritus were transferred into a 1-L plastic pottle.

- Benthic sampling: This was carried out in March 2007. One or two ponar samples were taken approximately 10 metres from the lake edge using a petite ponar grab. Total sediment from each site was combined in a 20-L bucket with water. Invertebrates were washed from any macrophytes in the sample and bucket contents were strained through a 0.5 mm net and the remaining invertebrates and detritus were transferred into a 1-L plastic pottle.

- All invertebrate samples were preserved in c.70% isopropynol/1-2% glyoxal and sent to the Cawthron Institute for processing and identification to the lowest practical taxonomic level (generic as a minimum). Samples were analysed using the 200 fixed count method (Protocol P2 in Stark *et al*., 2001), followed by a search of the whole sample for other (rare) taxa.

2.6.2 Data analysis

For the purpose of initial data analysis, invertebrate counts from all replicates were combined for each sample type (ponar, sweep, artificial substrates) in any lake. Any taxa recorded as “rare” were given a nominal value of 0.5; final total numbers ranged from 23 in ponar samples from Lake Kimihia to 781 in sweep samples from Lake Harihari. Ten of the 30 pooled samples had counts of over 500 individuals, and 23 had counts exceeding 100. Data were converted to percent abundances for all pooled samples (i) for each sampling method, (ii) for ponar and sweep samples combined as these methods require only one site visit, and (iii) for all sampling methods combined.

Cluster analyses were conducted using percent abundance and presence-absence data for various combinations of sampling methods (ponar, sweep, artificial substrate, ponar + sweep, and all methods combined) to investigate which method(s) grouped

sites in a similar way to the pre-determined expected relative conditions. The group-average linkage method and Bray-Curtis distance were used in the cluster analyses. Based on the results of the cluster analyses, data from ponar sampling were analysed using non-metric multidimensional scaling (NMDS) on a Bray-Curtis similarity matrix to explore associations between species relative abundance and sample distribution in multi-dimensional space. Biplots with a cut-off of P = 0.2 were used to define associations between sample and species distributions, and between macroinvertebrate communities and other potential indicators of ecosystem health. The directions of the biplot arrows indicate their association with samples in ordination space, and the length of the arrows indicates the strength of any association.

All analyses were done using PC-Ord v.5 (McCune & Mefford 1999).

3 Results

3.1 Water quality

Mean values over the three sampling periods for the variables used to calculate TLI are listed in Table 2. Values for each parameter varied considerably within lakes over the three sampling periods, and there was no apparent consistent pattern between lakes.

Table 2 Mean water quality measurements and Trophic Level Index (TLI) values for ten Waikato lakes. Results are averaged from samples collected in December 2006, January 2007 and March 2007. TLI calculations follow Burns et al. (1999).

Lake	Type	Secchi (m)	Chla (mg m^{-3})	TN (mg N m^{-3})	TP (mg P m^{-3})	TLI	Trophic status
Serpentine North	Peat	2.12	11	1120	23	4.7	Eutrophic
Mangahia	Peat	0.46	41	2919	673	6.9	Hypertrophic
Kaituna	Peat	0.14	95	3952	400	7.3	Hypertrophic[+]
Koromatua	Peat	0.25	359	4672	734	7.8	Hypertrophic [+]
Waahi	Riverine	0.33	97	1575	69	6.3	Hypertrophic
Ohinewai	Riverine	0.44	44	1785	126	6.2	Hypertrophic
Kimihia	Riverine	0.13	198	3320	329	7.4	Hypertrophic [+]
Harihari	Dune	4.71	2	285	15	3.5	Mesotrophic
Otamatearoa	Dune	2.97	1.5	325	10	3.4	Mesotrophic
Taharoa	Dune	1.26	25	637	42	5.1	Supertrophic

[+] TLI in range 7.0-8.0 not defined by Burns et al. (1999) but is a level above hypertrophic

Although the TLI values are likely to be on the high side due to our sampling being carried out only from December - March, the relative position of the lakes is similar to that predicted (based on existing knowledge) prior to the work beginning (Figure 1). For the peat lakes, TLI scores increased from Serpentine North to Koromatua. Kaituna and Koromatua in particular had very high TLI values. Values for the riverine lakes indicate that they are all hypertrophic, but as predicted Kimihia was in particularly poor condition. Harihari and Otamatearoa had the lowest TLI values of all lakes and had chlorophyll *a* concentrations within the range expected for oligotrophic lakes (Table 2). As predicted, Lake Taharoa had the worst water quality of the dune lakes.

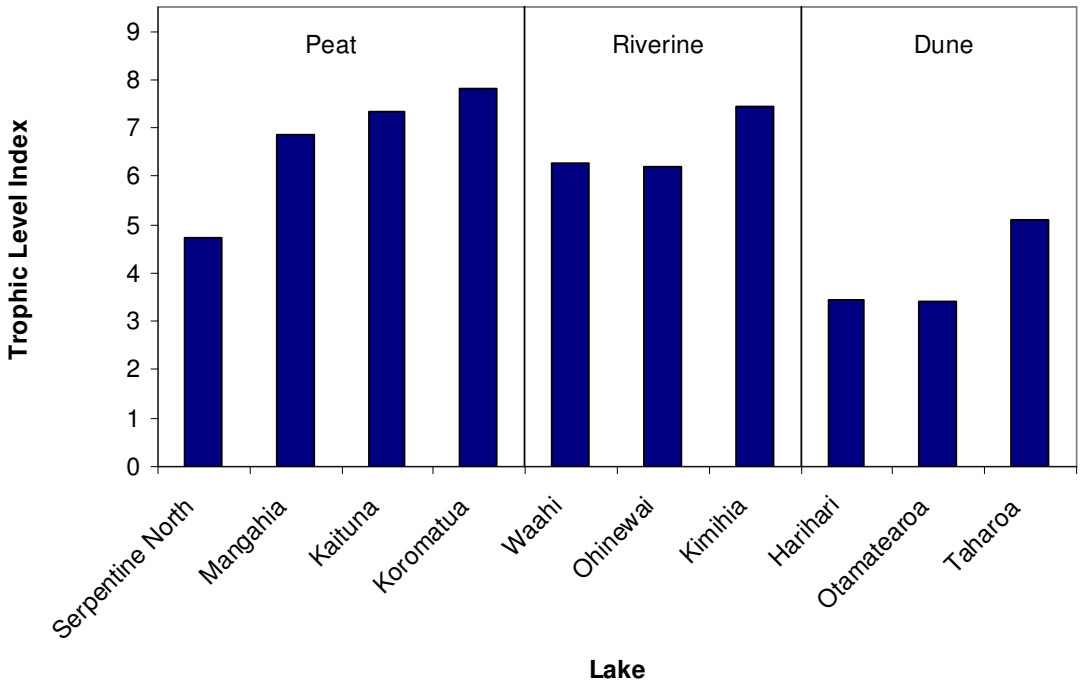


Figure 1 Trophic Level Index (TLI) values for 10 Waikato lakes. Lakes are grouped according to type, and ordered within groups from predicted best to worst condition.

3.2 Zooplankton

Rotifer inferred TLI values based on net haul samples for the peat lakes were similar to the TLI values obtained in 3.1 above, although predicted condition for Serpentine and Mangahia was better with the rotifer inferred TLI. Relative condition of the peat lakes was as predicted (Figure 2).

For the riverine lakes, Kimihia was found to have the worst condition based on rotifer inferred TLI (8.2), however unlike the TLI values from water quality; Ohinewai (5.2) had a lower score than Waahi (6.5).

Lake Taharoa had the lowest rotifer inferred TLI of any of the lakes (2.7) with Harihari (4.2) and Otamatearoa (4.6) having values closer to that of Ohinewai.

Hatching of zooplankton eggs from sediment samples resulted in lakes being assessed by rotifer inferred TLI in the same order as from the net haul samples. However the TLI values were consistently higher (by approximately 1 unit) for each lake using this method.

A full report on the results of the zooplankton sampling can be found in Duggan (2007).

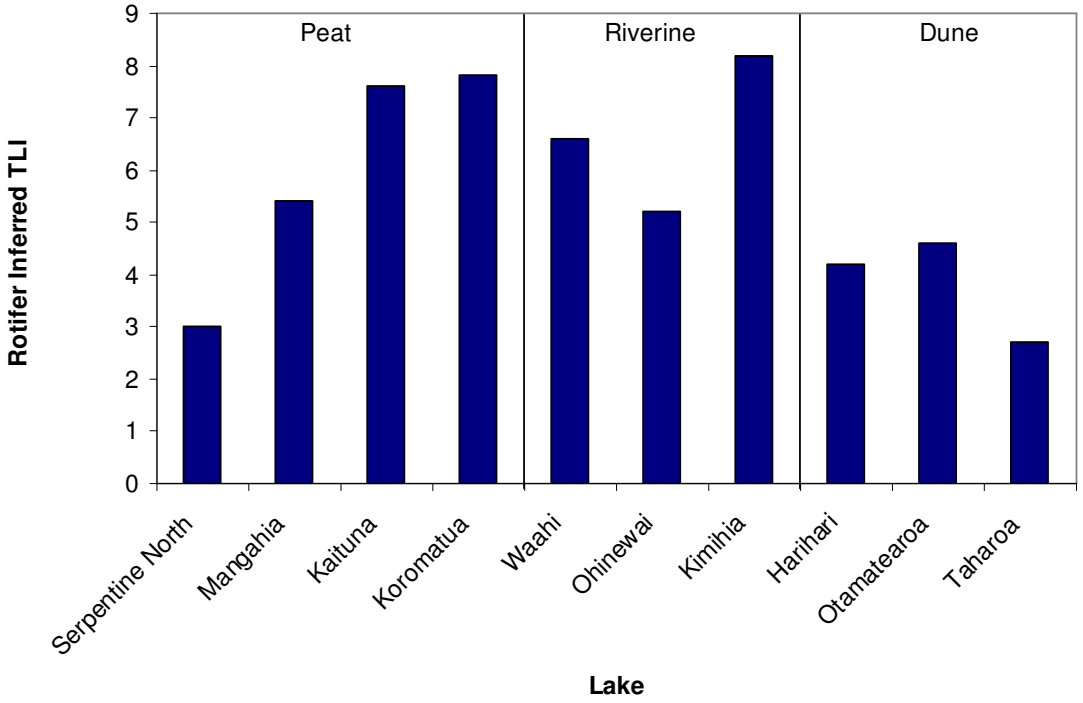


Figure 2 Rotifer inferred TLI values for 10 Waikato lakes. Lakes are grouped according to type, and ordered within groups from predicted best to worst condition.

3.3 Submerged macrophytes

NIWA did not detect any submerged vegetation in Lakes Mangahia, Kaituna or Koromatua (Table 3). This was attributed to poor water clarity in all three lakes, and in addition, strong peat staining in Lake Mangahia. Lake Serpentine North had the best LakeSPI score of any lake in the pilot study due to its extensive solely native vegetation. Assessments have been carried out biannually at this site since 2001 and results have consistently been ≥90%. It has however been noted recently that there are signs that the aquatic plants are under stress and there is a risk of a rapid decline in plant cover.

LakeSPI assessments of Lakes Ohinewai and Kimihia were completed in 2003, and Lake Waahi in 2005, and therefore surveys were not repeated for the current study. All three lakes were devegetated at the time of last assessment and have been so since the 1980s.

All three dune lakes had beds of native and exotic vegetation. Lake Harihari had not previously been assessed. It was in the best condition of the dune lakes with a rich native plant assemblage which dominated the vegetation. Lake Otamatearoa had previously been assessed in 1996, and the 2007 assessment indicated that aquatic plant assemblages had deteriorated due to an increase in invasive species. The lake still supports beds of native charophytes; however the vegetation is now dominated by hornwort (*Ceratophyllum demersum*) and *Elodea canadensis.* Lake Taharoa had last been assessed using LakeSPI in 2001. The current survey revealed that the depth extent of plants had decreased by 1.5 - 2.5 metres since 2001 indicating a reduction in lake water clarity. All three LakeSPI indices have decreased in Lake Taharoa over this time.

Table 3 Summary of LakeSPI indices for 10 Waikato lakes. Lakes are grouped according to type, and ordered within groups from predicted best to worst condition.

Lake	LakeSPI Index 9%)	Native Index (%)	Invasive Index (%)
Serpentine North	93	83	0
Mangahia	0	0	0
Kaituna	0	0	0
Koromatua	0	0	0
Waahi	0	0	0
Ohinewai	0	0	0
Kimihia	0	0	0
Harihari	50	61	58
Otamatearoa	23	43	90
Taharoa	39	46	63

3.4 Decomposition rates

Within the peat lakes, the best and worst predicted condition lakes (Serpentine and Koromatua) both had low mean daily exponential decay coefficients (k day^{-1}) (Figure 3). Lakes Mangahia (0.0037 ± 0.001 k day^{-1}) and Kaituna (0.0022 ± 0.001 k day^{-1}) had the highest mean decay rates of any of the lakes in the pilot study.

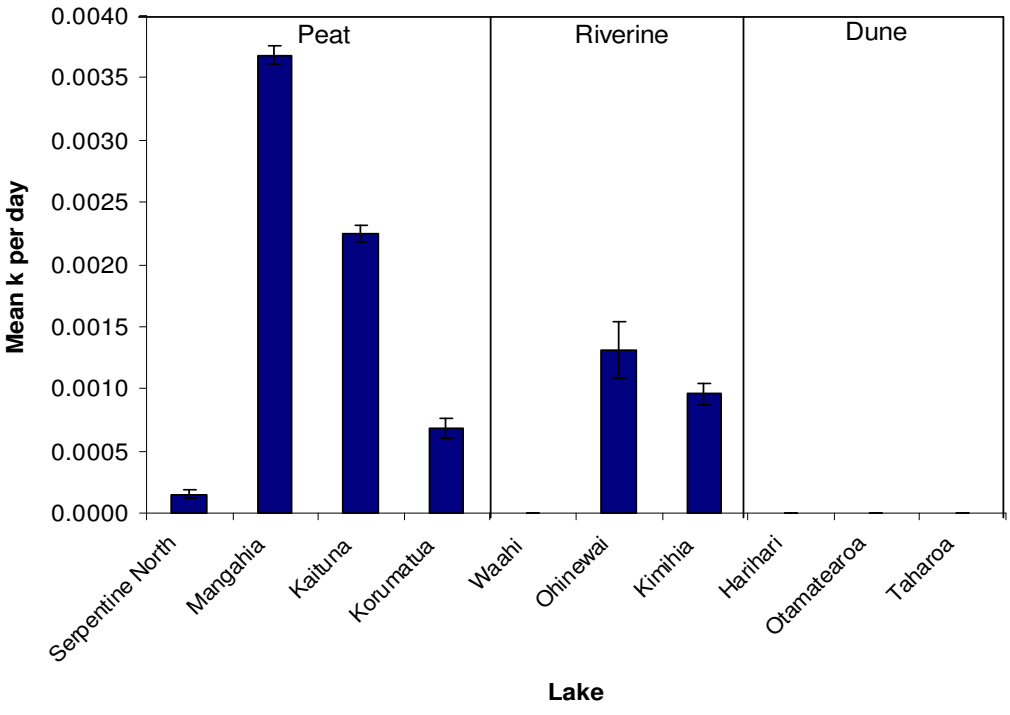


Figure 3 Mean (±1SD) daily exponential decay coefficients for 10 Waikato lakes. Lakes are grouped according to type, and ordered within groups from predicted best to worst condition.

The three dune lakes had no detectable stick decay. Lakes Ohinewai (0.0013 ± 0.002 *k* day^{-1}) and Kimihia (0.0010 ± 0.001 *k* day^{-1}) had very similar mean *k* day^{-1}, being midway between Serpentine/Waahi/dune lakes and Mangahia/Kaituna, whilst Lake Waahi had no detectable decay.

When the TLI values are regressed against the mean *k* day^{-1} there is some evidence of a curvi-linear relationship between the two variables (R^2=0.56; Figure 4). In general, the lakes with the lowest TLI values (the dune lakes and Lake Serpentine North) also had the lowest decomposition rates. Lake Waahi was the exception, with a high TLI value and low mean *k* day^{-1}. The lakes with the worst trophic state (Kimihia and Koromatua) had mid-range decomposition rates and the remaining lakes, with TLI values between 6.2 and 7.3 had the highest decomposition rates.

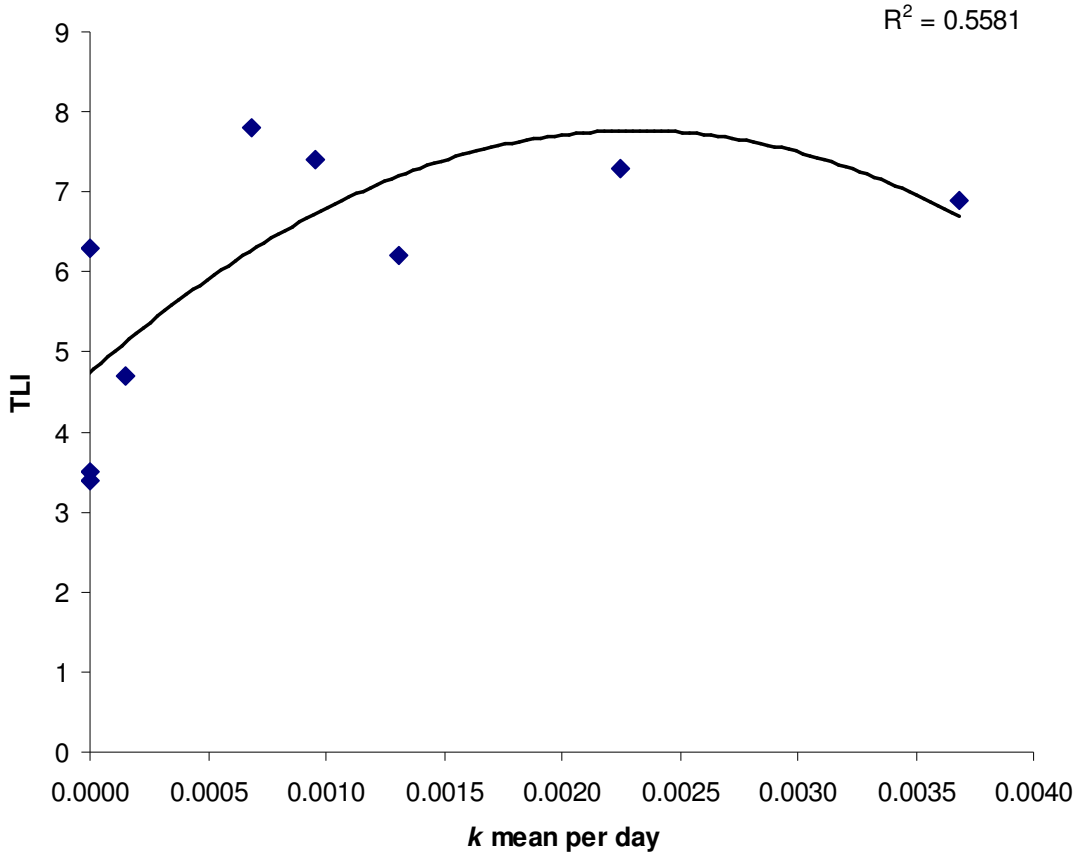


Figure 4 Regression plot showing the relationship between Trophic Level Index (TLI) values and mean decomposition rates (k mean per day) for 10 Waikato lakes.

3.5 Invertebrates

Cluster analyses using percent abundance of macroinvertebrates are displayed in Figures 5a-c. The dendrograms use the objective function which is a measure of information loss as agglomeration proceeds and provides a compromise between minimising the number of groups and maximizing the information retained.

There were similarities in the resultant groupings from each sampling method. Results from all three sampling techniques grouped the dune lakes closest to each other, although the relative distances varied. None of the techniques grouped Harihari and Otamatearoa as closest to each other even though they were the most similar in all other measured variables except for LakeSPI. Samples obtained solely from artificial substrates (Figure 5a) did not group entirely as expected based on predetermined lake health or based on the results from other variables. Lake Serpentine was grouped with

Lake Waahi - which was not very similar across other variables, different in type and not geographically close. This analysis also grouped Kimihia, Koromatua and Mangahia together. Other variables did not indicate that these three lakes were particularly similar. Mangahia was assessed as being in better condition than the other two lakes based on all other variables except LakeSPI (all are devegetated), and had dissimilar decomposition rates from Kimihia and Koromatua.

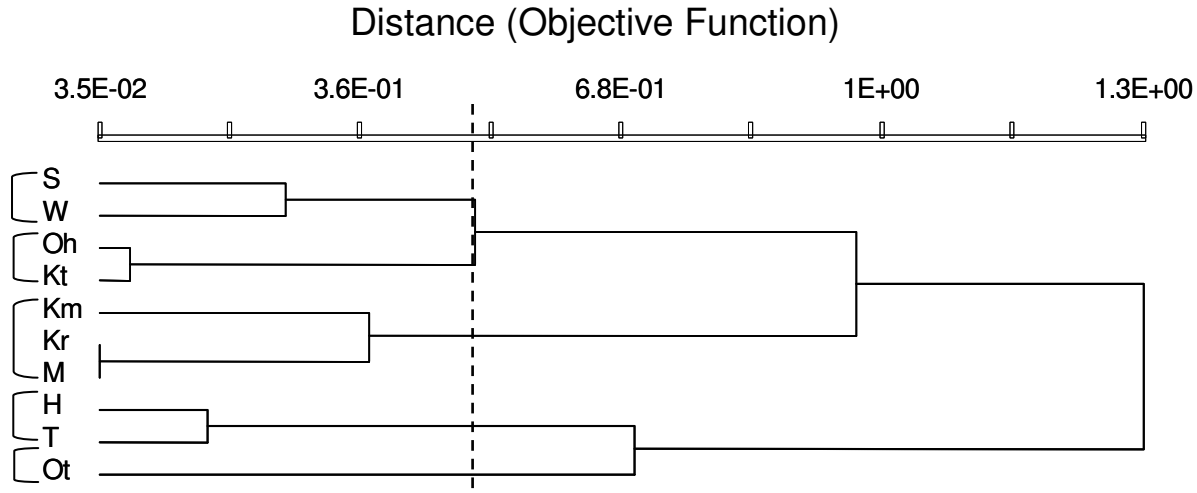
Cluster analysis using ponar samples (Figure 5b) provided groupings that were similar to that expected based on existing lake knowledge. Lake Serpentine did not group with any of the other lakes. The six lakes predicted to be highly - very highly degraded all grouped together. Harihari did not group with the other two dune lakes at the distance we used (0.5) but it was very close. This lake has the best total and native LakeSPI scores of the three dune lakes.

The results of cluster analysis based on macroinvertebrates in samples obtained from littoral net sweeps appeared to be the least meaningful in terms of perceived lake condition (Figure 5c). Lake Serpentine was grouped with Lake Kaituna and close to Waahi, both of which are in substantially poorer condition and are devegetated. Lake Koromatua was separated from all other lakes despite being similar to lakes such as Kaituna and Kimihia across most other variables.

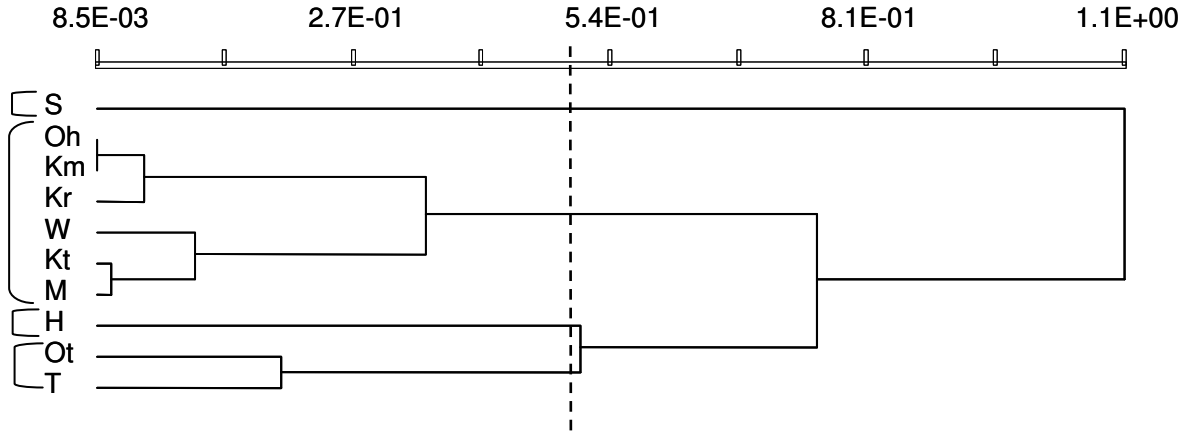
Several other analyses were run using combinations of sampling methods; however none of these produced groupings that could be interpreted to reflect lake condition better than the analyses of individual methods.

Invertebrate data from sampling by ponar grab were examined to look for associations between sample and species distributions, and between macroinvertebrates and the other potential indicators of lake health. Axes 1 and 2 of the NMDS ordination explained 80% of the variation in the dataset, and the analysis yielded a 3-dimensional stress value of 0.05. The ordination indicated that dune lake invertebrate populations were distinct from riverine or peat lake communities, and the biplots suggested that this difference was most strongly associated with Secchi depth and the total LakeSPI index (Figure 6). Lake Harihari was more distinct than the other dune lakes. With the exception of Lake Serpentine, the riverine and peat lakes occurred towards the top right and centre of the ordination and had invertebrate communities associated with total P and total N, rotifer inferred TLI, and decomposition rates. Lake Serpentine did not group with any other lakes in this plot and invertebrate communities do not appear to be associated strongly with any of the other measured variables.

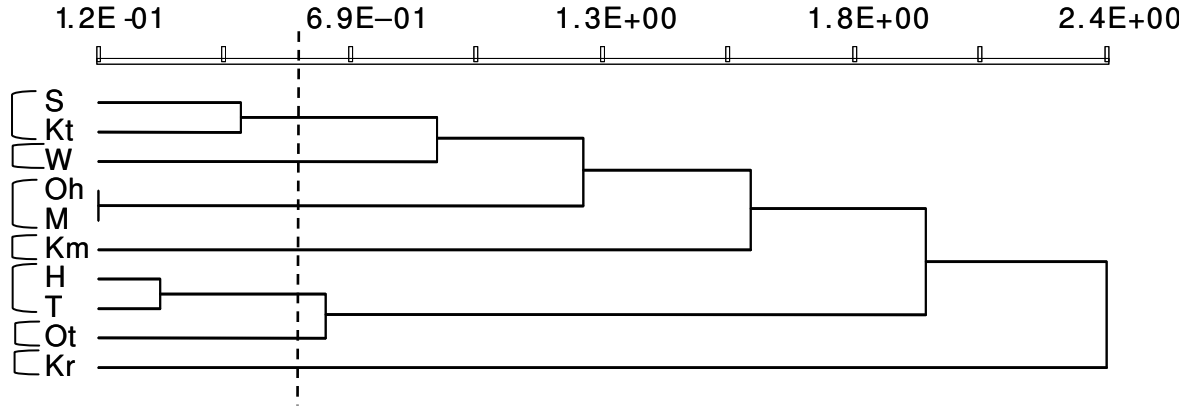
In general the lakes with the poorest trophic state were most strongly associated with macroinvertebrate populations dominated by chironomids and oligochaetes (Figure 7). The dune lake invertebrate communities were dominated by molluscs. Lake Serpentine had a diverse macroinvertebrate community with species distinguishing it from the other nine lakes.



5a. Artificial substrates



5b. Ponar samples



5c. Net sweep samples

S=Serpentine, W=Waahi, Oh=Ohinewai, Kt=Kaituna, Km=Kimihia, Kr=Koromatua, M=Mangahia, H=Harihari, T=Taharoa, Ot=Otamatearoa

Figure 5 **Cluster analyses of macroinvertebrate community composition using Bray-Curtis distance and Group-average linkage using different sampling methods in 10 study lakes.**

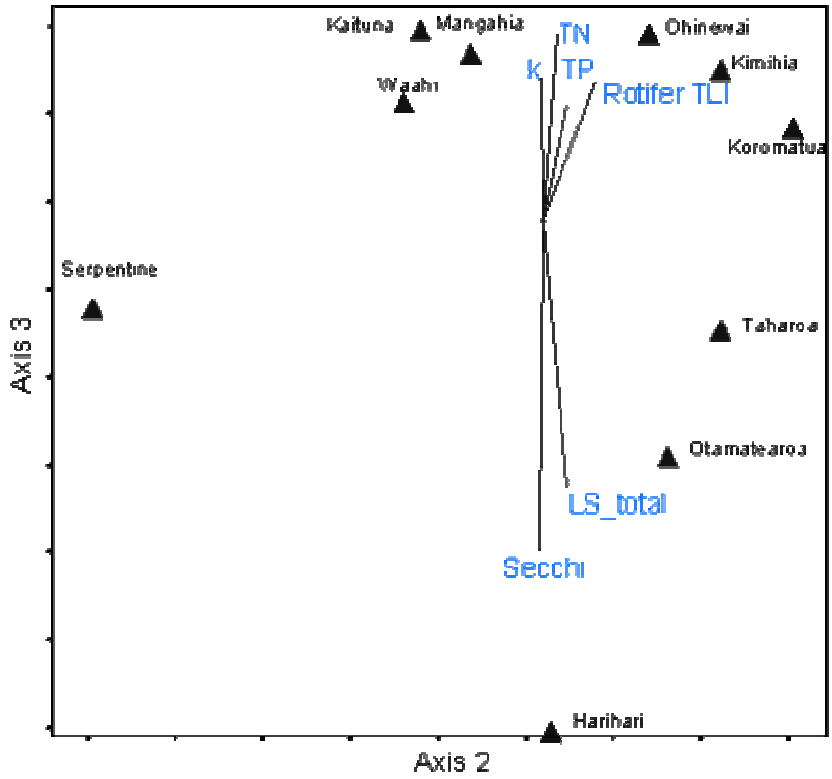


Figure 6 Non-metric multidimensional scaling plot of macroinvertebrate community composition (% abundance) from ponar grab samples in 10 study lakes with physicochemical measures shown as biplots using a r2 cut-off level of 0.3.

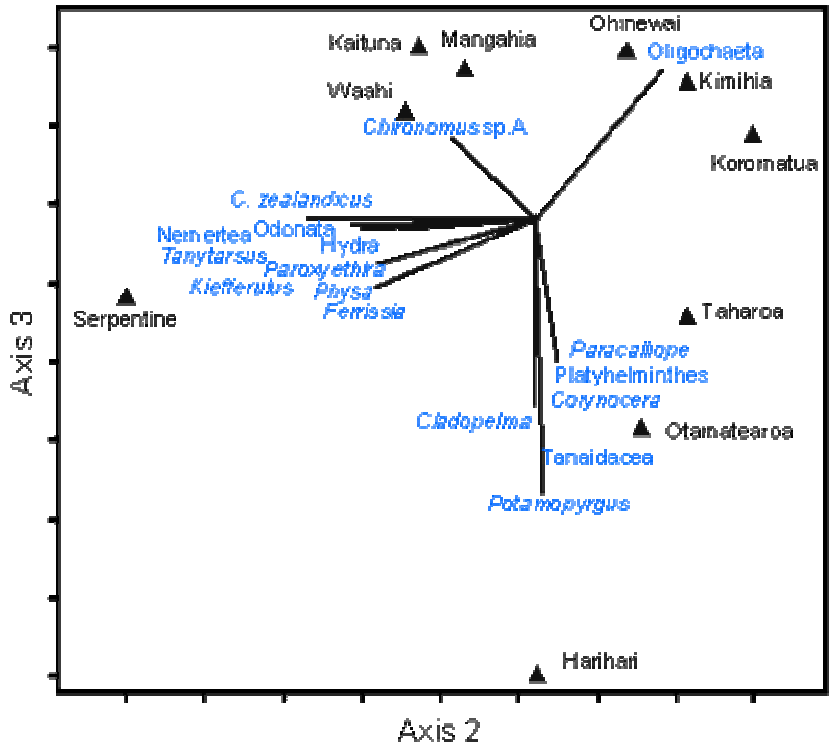


Figure 7 Non-metric multidimensional scaling plot of macroinvertebrate community composition (% abundance) from ponar grab samples combined in 10 study lakes with major macroinvertebrate groups shown as biplots using an r2 cut-off level of 0.3.

4 Conclusions and recommendations

Three potential biological indicators and one functional indicator were assessed in a pilot study using ten Waikato lakes. Results were compared against water quality samples taken during December 2006, January 2007 and March 2007 and against predicted lake condition based on previous knowledge of the chosen lakes.

The rotifer inferred TLI system for assessing lake condition was developed by Duggan *et al.* (2001). In the current study the relative values obtained for peat and riverine lakes using samples from net hauls and hatching trials matched the lake health order predicted by EW staff prior to sampling, and the TLIs calculated from water quality samples. However, rotifer community composition in the dune lakes did not match results from other sampling techniques. Lake Taharoa had the lowest rotifer inferred TLI of all lakes. Samples contained high proportions of zooplankton species that are indicative of good water quality and found in oligotrophic lakes such as Taupo and Waikaremoana (Duggan, 2007). Conversely, Harihari and Otamatearoa were predicted to be eutrophic based on the zooplankton populations, but mesotrophic based on water quality samples.

The LakeSPI assessment of Lake Taharoa did detect that there had been deterioration in water quality since the previous survey in 2001 with a decrease in the depth extent of plants and large quantities of unattached plants observed (Edwards *et al*. 2007). This finding supports the utility of this technique in indicating changes in lake health. However the LakeSPI technique had the advantage of having historical data to compare with. LakeSPI scores from 2007 alone are similar for Taharoa and Harihari and don't reflect the differences in the health of these lakes, although LakeSPI observations from Taharoa certainly indicate an unstable lake. Duggan (2007) speculated that the current state of Taharoa was not reflected in zooplankton communities due to the decline being apparently very recent, and suggested that zooplankton communities may not be sensitive to massive changes in trophic state over short time scales. It follows that, as with the LakeSPI results, recording changes in zooplankton scores over time will be more useful than one off measurements. However, the frequency of sampling may still be less than that recommended for standard water quality monitoring.

Given that rotifer inferred TLIs obtained from hatched samples matched the patterns obtained from net haul samples, future sampling should involve just one collection technique. The hatching technique for assessing lake zooplankton communities was overall more time consuming that the net haul technique (Ian Duggan, pers.comm.). As the scoring system was developed using net haul samples, and these results were closer to the TLIs obtained from water quality samples, it is recommended that collection of zooplankton samples using a net haul only continue to be assessed in the second year of the project (07/08). Duggan *et al*. (2001) used quarterly plankton samples collected over a year to develop their rotifer inferred TLI system. In the current study only one net haul sample was collected from each lake in December 2006. It is unlikely to be cost-effective to sample 4 times per year as part of an Environment Waikato lake health monitoring programme. However for sampling in 2007/2008 it is recommended that two samples are taken per lake - one in December and one in March. If this produces more accurate assessments it may justify visiting each lake twice in a year.

The use of LakeSPI in the current study provided useful information on the health of vegetated lakes. As mentioned above, it identified changes in water clarity that have affected plant growth and health in Lake Taharoa. Observations during assessments have also detected signs of stress in the submerged plants in Lake Serpentine North and identified risk of rapid plant decline (Edwards *et al*., 2007). The technique also confirmed the success of a rudd removal programme from Lake Serpentine South (Neilson *et al*., 2004; Edwards *et al*., 2007)) This information is critical to lake managers in the Waikato and justifies the ongoing use of LakeSPI as part of a wider

biological indicators project within Environment Waikato. However, the technique is only able to detect changes in lakes that are vegetated, or revegetating. Of the 40 lakes that have been assessed using LakeSPI to date, 23 lack sufficient vegetation to score. Therefore it is likely that major changes would be required in these lakes before health could be assessed using solely LakeSPI. The presence of koi carp in many of these lakes is likely to exclude plant establishment even at sites such as Lake Kaituna, where significant other restoration work is taking place (Edwards *et al*., 2007).

The use of just 10 pilot study lakes limited the extent to which we could determine the relationship between TLI and wood decomposition rates. However, the results we obtained were not entirely unexpected. In summarising leaf litter decomposition rates in rivers, Young *et al*. (2004) listed nutrient enrichment as one of the factors which increases breakdown. In our study the lakes with the best trophic state had low decomposition rates, and there was a tendency for the lakes with the poorer trophic states to have higher decomposition rates. Two anomalies were Kimihia and Koromatua which had the worst trophic state but mid-range decomposition rates. It may be that high concentrations of suspended solids (SS) in these lakes reduced the impact of high nutrient concentrations. In particular, Lake Kimihia had a mean SS concentration almost four times higher than any other lake in the study. Young *et al*. (2004) noted that in rivers where high sediment load is a problem, it may cancel out the effects of high nutrients on decomposition rates. Curvilinear responses to stress have been noted in other functional indicator studies, suggesting breakdown rates may be useful for assessing recovery from highly degraded conditions or the onset of decline in high quality systems.

Given that measurements of decomposition rates in lakes using Birchwood sticks is very easy and inexpensive to carry out, and the encouraging results obtained in our pilot study, it is recommended that they are further tested during field visits in 2007/08.

Macroinvertebrates are increasingly being used as bioindicators of lake health outside of New Zealand (e.g. US Environmental Protection Agency, 2006; and European Water Framework Directive (cited in Raunio *et al*., 2007)). In the current study, results from the NMDS analysis indicated that macroinvertebrate community composition in our lakes was influenced by water quality factors such as Secchi depth, TP and TN; and that poor quality lakes were characterised by populations dominated by chironomids and oligochaetes, and the higher quality (dune) lakes by molluscs. There appears to be good separation between lakes of poor and good water quality. This gives us some confidence in pursuing the use of invertebrate communities in developing lake health indicators for Waikato lakes.

Other authors have previously noted that macroinvertebrate sampling variability associated with hand-net sweeps limits its use for quantitative surveying (Stark, 1981 and references therein). Field staff in the current study experienced difficulties in carrying out hand-net sweeps at some sites due to a lack of littoral vegetation. Brauns *et al*. (2007) found that eulittoral macroinvertebrate communities, although correlated with total phosphorus concentration, were not strong indicators of the trophic state of lowland lakes in Germany, but rather were more influenced by factors such as habitat and wind exposure. The USEPA recommends the use of benthic macroinvertebrates sampled in the sublittoral zone as indicators of environmental health as they incorporate factors relating to water, sediment and habitat (US Environmental Protection Agency, 2006). Our study appears to support this with the results of our cluster analyses suggesting that samples collected using a petite ponar grab 10 metres from the shore may be the most meaningful invertebrate sampling method for assessing lake health.

Costs associated with identification of macroinvertebrate samples are relatively high, particularly when more than one sampling technique is used per lake. Any long term lake health monitoring programme that is undertaken by Environment Waikato will need to be cost-effective. Therefore based on our results, and on results from the

international literature, it is recommended that macroinvertebrate sampling during 2007/08 be carried out using solely the ponar grab technique.

In summary, the second year of the Environment Waikato investigation of indicators of lake health should incorporate the following indicators and sampling techniques:

- Standard water quality monitoring
- Zooplankton communities using a net haul
- LakeSPI assessment
- Decomposition rates using Birchwood sticks
- Macroinvertebrate communities using a ponar grab in the sub-littoral zone

To test the repeatability of each technique it is recommended that 6 of the pilot study lakes be resampled (2 of each lake type). To further assess the efficacy of each technique additional lakes should be included from which there is a good existing record of water quality. Finally a sample of new lakes should be added to increase the sample size in the study and to extend the range of lake types and conditions included. Where possible the second year of the study should include as many lakes as possible that are the best representation of their lake type. This will assist in the development of a macroinvertebrate condition index. Recommended lakes are listed in Table 4.

Table 4 Waikato lakes recommended for sampling in 2007/2008 as part of a lake health indicator development programme. *=best representatives of their type

	Lake	**Type**
Repeat	Serpentine North*	Peat
	Mangahia	Peat
	Harihari*	Dune
	Taharoa	Dune
	Waahi	Riverine
	Ohinewai	Riverine
New (data present)	Serpentine East*	Peat
	Maratoto*	Peat
	Rotomanuka	Peat
	Whangape	Riverine
	Waikare	Riverine
New (data not present)	Serpentine South*	Peat
	Rotokawau	Peat
	Parangi	Dune
	Tutaeinanga*	Volcanic
	Ngahewa	Volcanic
	Okowhao*	Riverine
	Rotongaroiti	Riverine

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Appendix 1

Water quality monitoring methodology and sampling

General:

- Sampling sites should be as close to the deepest part of the lake

Secchi Disc:

- Lower disc into water on sunny side of boat
- Two measurements need to be recorded – depth at which secchi disc disappears (secchi disc A) and the depth at which secchi disc reappears (secchi disk B)
- A mean depth is calculated from the two readings
- The two observations should be within 10% of each other

Water samples:

Isothermal

A guideline for the isothermal status is: if the surface and bottom temperatures are within 3 degrees Celsius of each other

If isothermal two samples to be taken (ISO-T and either ISO-B or ISO-B/X):

ISO-T = taken at ¼ max depth of lake

- Use Van Dorne sampler – take 3 samples of water at ¼ depth and combine in a bucket. Sub-sample two x 1 litre bottles from this mix.
- Also fill 1 x TKN small sample bottle from this mix
- Rinse bucket with some of sample prior to filling

ISO-B = taken at ¾ max depth of lake

- Use Van Dorne sampler – take one sample of water at ¾ depth and use a little to rinse out sample bottle. Fill 1 x 1 litre sample bottle and 1 x small TKN bottle

ISO-B/X = taken at mid-point of <3% DO zone (anoxic). ***Only required if this zone exists***

- Use Van Dorne sampler – take one sample of water at ½ depth of this zone. Fill 1 x 1 litre sample bottle and small TKN bottle

NB: ONLY TWO SAMPLES ARE TO BE TAKEN FROM ANY ONE LAKE – ISO-B/X TAKES PREFERENCE OVER ISO-B

Stratified

Three layers exist within the stratified lake and are defined as the following:

- Epilimnion – relatively well mixed upper layer, extends to above the bottom – epi knee (change in temp)
- Thermocline – rapid change of temperature with depth
- Hypolimnion – where thermocline becomes the hypolimnion and there is a slower change of temperature with depth.

If stratified two samples to be taken (EPI and either HYP-T or HYP-B/X):

EPI = taken at 0.2, ¼, ½ and ¾ depth of epilimnion

- Use Van Dorne sampler – take 4 samples of water at 1.2, ¼, ½ and ¾ depth of epilimnion and combine in a bucket. Sub-sample two x 1 litre bottles from this mix.
- Also fill 1 x TKN small sample bottle from this mix
- Rinse bucket with some of sample prior to filling

HYP-T = taken at ½ depth of the hypolimnion if this layer contains oxygen at all depths

- Use Van Dorne sampler – take one sample of water at ½ layer depth and use a little to rinse out sample bottle. Fill 1 x 1 litre sample bottle and small TKN bottle

HYP-B/X = taken at mid-point of <3% DO zone (anoxic). ***Only required if this zone exists***

- Use Van Dorne sampler – take one sample of water at ½ depth of this zone. Fill 1 x 1 litre sample bottle and small TKN bottle

NB: ONLY TWO SAMPLES ARE TO BE TAKEN FROM ANY ONE LAKE – HYP-B/X TAKES PREFERENCE OVER HYP-T

Protocols are taken from the following guidelines

Burns, N., Bryers, G., and Bowman, E.: 2000. Protocols for monitoring trophic levels of New Zealand lakes and reservoirs. Ministry for the Environment, Wellington.