NIWA
Taihoro Nukurangi

The ecological condition of the Rotorua Lakes using LakeSPI

NIWA Client Report: HAM2008-149
September 2008

NIWA Project: BOP07208

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Prepared for

Environment Bay of Plenty

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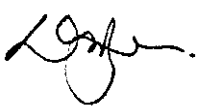

Dave Roper

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Executive Summary

NIWA was contracted by Environment Bay of Plenty to assess the condition of 12 lakes within the Rotorua Region using LakeSPI; a method that uses Submerged Plant Indicators (SPI) to assess, monitor and report on lake condition. LakeSPI results are presented as a percentage of each lakes maximum scoring potential and results used to describe three different conditions: Pristine, Historical and Present day.

LakeSPI results show many of the Rotorua lakes have undergone significant change over the last two decades and continue to be vulnerable to further changes from invasive plants and water quality deterioration. Lakes Tikitapu and Rotokakahi show the biggest change in lake condition over the last 20 years on account of deteriorating water quality and clarity; while the second biggest change to affect the Rotorua lakes has been from the introduction of invasive plant species.

The four best lakes ranked as 'good', and in descending order of condition, are Rotomahana, Rotoma, Okataina, and Rerewhakaaitu. Lake Rotomahana still maintains its high overall status but due to the recent introduction of invasive species this is not expected to last. Lakes Rotoma and Okataina appear to maintain high water quality however both lakes are under serious threat from potential hornwort invasion, which would have a major impact on their biodiversity and native character. Lake Rerewhakaaitu underwent an improvement in water clarity since the 1970's, which led to an extension in the depth range of native vegetation. This lake has remained in a stable state over the last 20 years, although the invasive impacts from *Egeria* are likely to cause a reduction in LakeSPI scores over the next few years.

The next group of lakes that are ranked 'average' condition are Okareka, Tikitapu and Rotokakahi. The overall condition of Lake Okareka has remained relatively stable over the last 3 years although it is expected that this won't continue as the full impact from *Egeria* invasion is expressed. This lake is also under serious threat from hornwort invasion, where the expected outcome would be displacement of all native charophyte meadows. Lake Tikitapu continues in a state of notable decline and on account of deteriorating water quality and clarity given there have been no new invasive species since the first full lake survey in 1988. Lake Rotokakahi also continues to appear in a state of decline due to water quality issues. Over the last 20 years both lakes have seen a reduction in the quality and extent of native plant communities present, without any direct change in invasive species presence or performance.

The remaining lakes: Tarawera, Rotorua, Okaro, Rotoiti and Rotoehu, are ranked as being in 'poor' condition. Lake Tarawera now remains in a stable state and it is not expected to change in the near future since the full impact of hornwort has now taken place. Lake Rotoehu joins this bottom group of lakes after undergoing a significant decline in lake condition on account of the recent invasion by hornwort. Lakes Rotorua, Okaro and Rotoiti all remain in a 'poor' condition.

Evaluation has begun in lakes Rotoma and Rotokakahi of two new potential indicators of future changes in lake condition. Koura (freshwater crayfish) and Kakahi (freshwater mussels) could complement submerged plant information by providing further evidence for any change in ecological condition, while also providing a direct measure of change in mahinga kai important to local Maori.

Recommendations made in this report are as follows:

- Lakes Tikitapu and Rotokakahi should be reassessed annually for further decline in LakeSPI scores since both lakes appear to be degrading faster than any of the remaining Rotorua lakes.

- Investigations should be carried out as soon as possible into the causes of water quality and clarity degradation in Lake Tikitapu and Rotokakahi.

- All possible measures should be explored for preventing the transfer (e.g., public education) and establishment (e.g., containment nets) of hornwort into vulnerable high condition lakes, such as Lakes Rotoma, Okataina and Okareka. Effective surveillance procedures will be also needed for early detection and emergency response procedures should be reviewed.

- Lake Okaro and Okareka should be reassessed annually to record any improvement in LakeSPI condition attributable to restoration works associated with these lakes such as phosphorus capping.

- Work should continue into the monitoring and evaluation of two additional indicators, koura (crayfish) and kakahi (mussels) and if successful, extended into other in lakes known to support populations.

1. Introduction

1.1 Study brief

NIWA was contracted by Environment Bay of Plenty to assess the condition of lakes within the Rotorua Region using LakeSPI (Submerged Plant Indicators); a method that focuses on submerged aquatic plants as indicators of lake condition.

The contract specified an assessment of 12 lakes being, Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotoma, Rotomahana, Rotorua, Tarawera and Tikitapu, between 2006 and 2008. LakeSPI data was used to estimate the following three conditions for each lake:

1. Pristine condition (lake plant communities in pre-impacted times).

2. Historical condition (described by historical data).

3. Present day condition (using most recent data).

LakeSPI monitoring of the Rotorua lakes using established baseline sites was first completed between September 2003 (Edwards & Clayton, 2003) and March 2005 (Clayton et al. 2005). In the future, it is intended that at least six lakes will be monitored each year ensuring that any given lake is assessed every two years. This report presents the results of LakeSPI assessments completed on 12 Rotorua lakes, with Okaro, Okareka, Rotoiti and Rotorua assessed in October 2006 and the remaining lakes during March/April 2008.

Testing of two additional indicators, Kakahi (freshwater mussels) and Koura (freshwater crayfish), also began during the 2008 surveys.

1.2 Study lakes

The lakes assessed in this report are collectively termed the 'Rotorua lakes'. This term refers to the 12 largest lakes in the Rotorua region managed through the Rotorua Lakes Protection and Restoration Action Programme being lakes: Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotoma, Rotomahana, Rotorua, Tarawera, and Tikitapu. The location of these lakes is indicated in Figure 1.

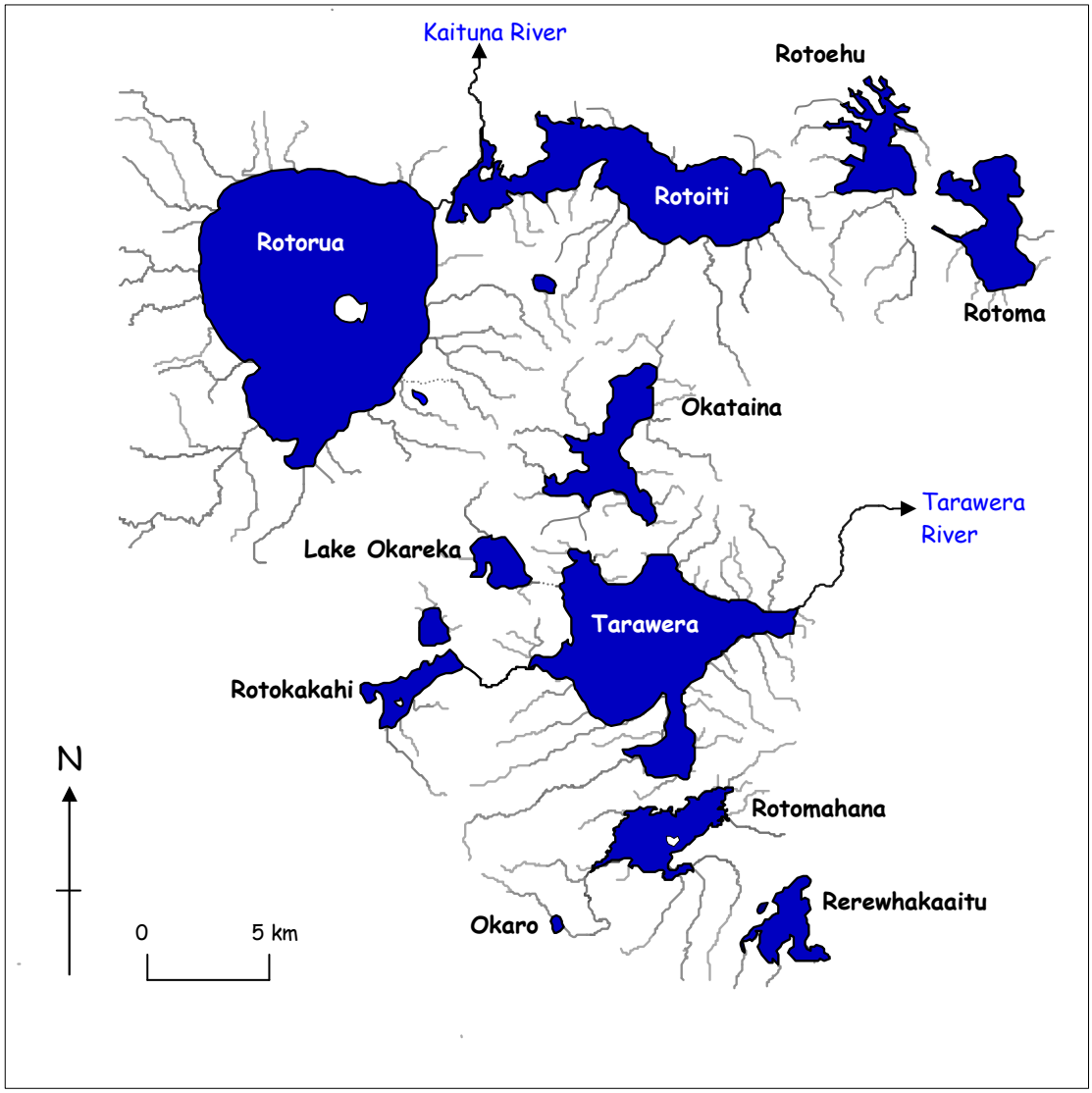

Figure 1: Map showing location of the 12 Rotorua lakes.

Table 1: Summary of lake characteristics.

Lake	Maximum Depth (m)	Mean Depth (m)	Size (km^2)	Catchment Area (km^2)
Okareka	33.5	20	3.33	19.6
Okaro	18	12.5	0.33	3.9
Okataina	78.5	39.4	10.8	59.8
Rerewhakaaitu	15.8	7	5.8	37.0
Rotoehu	13.5	8.2	8.1	49.2
Rotoiti	125	31.5	34.6	123.7
Rotokakahi	32	17.5	4.5	19.7
Rotoma	83	36.9	11.2	27.8
Rotomahana	125	60	9.0	83.3
Rotorua	44.8	11	80.8	508.0
Tarawera	87.5	50	41.7	143.1
Tikitapu	27.5	18	1.5	6.2

1.3 History of the Rotorua Lakes

1.3.1 Geophysical changes

The Rotorua Lakes District contains a diverse range of geologically young waterbodies formed from volcanic activity, with the youngest, Lake Rotomahana having been substantially modified and enlarged by the 1886 Tarawera eruption.

Chapman (1970) noted that until the 1900s most of the catchments were densely forested with native trees or covered in manuka scrub. Clearing and planting of *Pinus radiata* forests began in the early 1900s with sawmilling starting around 1940. Farming was slower to prosper on account of "bush sickness" but once the problem of cobalt deficiency was identified and resolved in the mid 1930s, large-scale sheep and dairy farming conversion took place in the late 1940s and 1950s.

Urban development combined with sewage waste disposal, intensification of land uses and tourism have all contributed to nutrient enrichment problems and associated eutrophication of the Rotorua lakes.

1.3.2 Lake vegetation changes

The Rotorua lakes have been significantly affected by changes both in water quality and through the introduction of invasive aquatic plants. Deterioration in the condition of the Rotorua Lakes has been occurring for many years (White 1977, Rutherford 1984, Vincent et al. 1984). Parallel deterioration in the amount of aquatic vegetation and key submerged species have also been recorded from the 1960s to the 1980s (Coffey & Clayton 1988). Land use practices have led to a progressive deterioration in water clarity, reducing the depth to which vegetation can grow. There are some exceptions to this general trend of deteriorating water quality and clarity as evidenced by Lake Rotoma, which appears to have retained a constant maximum vegetated depth limit since the early 1970s. Lake Rerewhakaaitu has seen an improvement in water clarity and a corresponding increase in the depth of submerged vegetation since the early 1970s.

The second important factor affecting the aquatic vegetation in the Rotorua Lakes is the introduction of a range of invasive plant species. The first 'oxygen weed' species (family Hydrocharitaceae) to establish in the Rotorua lakes was *Elodea canadensis*, followed by *Lagarosiphon major*. *Elodea* is likely to have established in Lake Rotorua during the 1930s, given that the Ngongotaha trout hatchery had 'oxygen weed' in their hatchery around that time and ponds were flushed annually into the Ngongotaha Stream, which flows into the lake (Chapman 1970). By the mid 1950s *Lagarosiphon* had appeared in Lake Rotorua and by 1957 it was recorded in Lake Rotoiti. By the late 1950s major weed problems were apparent in these two lakes, particularly from *Lagarosiphon*. From 1958, large onshore accumulations of weed drift occurred after storms, resulting in an aquatic weed nuisance unprecedented in New Zealand. *Lagarosiphon* appears to have spread rapidly through many of the Rotorua Lakes, with Lakes Rotoma, Okataina and Tarawera likely to have been colonised in the mid to late 1960s (Coffey 1970, Brown & Dromgoole 1977, Clayton 1982). Invasion of lakes further away from the epicentre of introduction occurred later, with Lake Rerewhakaaitu estimated to have been invaded in the mid 1980s.

Hornwort (*Ceratophyllum demersum*) was first recorded in Lake Rotorua in 1975 and *Egeria densa* in 1983 (Wells & Clayton 1991). Both of these species have continued to spread to other lakes with the most recent invasion by *Egeria* and hornwort found in Lake Rotomahana in April & May 2007 (Clayton & de Winton 2007). The impact of Egeria on the Rotorua lakes has been less than expected; however in contrast, the impact from hornwort has exceeded all expectations with this species now ranked as New Zealand's worst widespread submerged aquatic plant pest.

The spread of significant invasive weed species into the remaining Rotorua Lakes is a gradual and on-going process, and there is a strong correlation with boat traffic and lake accessibility, with weed introduction mainly at boat ramps (Johnstone et al. 1985). Lake Rotomahana was the last of the large lakes to remain relatively weed free which had been attributed to its remote location and difficult public access, but the discovery of Egeria and Hornwort around boat launching areas in 2007 highlights the ease and speed that invasive weeds can establish. Although Lake Rotokakahi is widely impacted by elodea it is now the only well vegetated Rotorua lake to remain free of the worst invasive weed species (lagarosiphon, egeria and hornwort), primarily attributable to its restricted public access due to its sacred status to Te Arawa.

2. Study methods

2.1 Plants as indicators of lake condition

Submerged plants have a number of advantages that favour their use as indicators of lake condition. For example, they are predominantly rooted or anchored to the bed of lakes. They are also macroscopic and perennial in nature, and together these features make them easy to observe, sample and identify. This contrasts with many other biota that can be highly mobile (e.g., fish) or difficult to sample, measure or identify (e.g., plankton).

Submerged plants also effectively integrate the range of environmental conditions supporting plant growth over an extended period of time prior to survey. This contrasts with other physio-chemical methods (e.g., water chemistry and Secchi disc), which may change markedly over short time periods and require frequent measurements throughout the year.

In lakes where the littoral zone (lake margin to maximum plant depth) represents a large proportion of the lake area (e.g., small shallow dune or peat lakes), the open water (or centre lake) condition can have quite different water quality and ecological condition compared to the littoral zone. Given the importance of the littoral zone to the overall ecological state and recreational value of many lakes it is important to monitor the ecological well-being and biological functioning of the littoral zone where submerged plants tend to dominate.

Increased sediment and nutrient loading from catchment activities, and displacement of native vegetation by invasive alien plant species are major influences on lake ecology and condition. The submerged plant indicators used in LakeSPI provide an effective means of assessing these impacts.

2.2 LakeSPI

LakeSPI is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring trends in lake ecological condition. Key features of aquatic vegetation structure and composition are used to generate three LakeSPI indices:

- 'Native Condition Index' – This captures the native character of vegetation in a lake based on diversity and quality of indigenous plant communities. A higher score means healthier, deeper, diverse beds.

- 'Invasive Condition Index' – This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A higher score means more impact from exotic species, which is often undesirable.

- 'LakeSPI Index' – This is a synthesis of components from both the native condition and invasive condition of a lake and provides an overall indication of lake condition. The higher the score the better the condition.

Key assumptions of the LakeSPI method are that native plant species and high plant diversity are taken to represent healthier lakes or better lake condition, while invasive plants are ranked for undesirability based on their displacement potential and degree of measured ecological impact (Clayton & Edwards 2006).

Because lakes have differing physical characteristics that can influence the extent and type of submerged vegetation, each of the LakeSPI indices are expressed in this report as a percentage of a lake's maximum scoring potential. Scoring potential reflects the maximum depth of the lake to normalise the results from very different types of lakes. A lake scoring full points for all LakeSPI indicator criteria would result in a LakeSPI Index of 100%, a Native Condition Index of 100% and an Invasive Condition Index of 0%.

For full LakeSPI method details, the LakeSPI Technical Report and User Manual can be viewed at http://www.niwascience.co.nz/ncwr/tools/lakespi. An online LakeSPI web reporting system (www.lakespi.niwa.co.nz) enables ready access to results in a form suitable for lake monitoring purposes and trend reporting.

2.3 Baselines

To help put the LakeSPI indices into context, each lake has been assessed using three different conditions: Pristine, Historical and Present day.

1. Pristine condition

This baseline describes the best possible condition for a lake, which in most New Zealand lakes would indicate lake condition as it theoretically would have been in pre-

impacted times. However, because of the volcanically young history of the Rotorua lakes and impacts from geological events including earthquakes and eruptions along with fluctuating water levels in the last 150 years, the baseline used in this capacity would not be so relevant. Instead for the purpose of establishing a pristine baseline for the Rotorua lakes we have adopted the limitation posed by lake depth as the maximum scoring potential for all lakes. This condition assumes that any lake in a pristine, undisturbed state would have supported a diverse range of submerged plant communities and have had no invasive plant species. A 'pristine condition' baseline allows lake managers to better compare present day lake condition with what the lake once would (or could) have been.

2. Historical condition

The LakeSPI method can be applied to available historic vegetation survey data using key vegetation information from macrophyte data in FBIS (Freshwater Biodata Information System - fbis.niwa.co.nz). Additional information on the nature of vegetation cover, proportion of native to invasive vegetation and the depth boundary for 10% cover was estimated from examination of the original survey sheets. Reference to historical LakeSPI scores allows changes over the last few decades to be followed.

3. Present day condition

Present day condition was calculated for each lake based on the most recent survey data. These assessments provide managers with information on present condition, a benchmark for monitoring future changes and can help to assess the effectiveness of catchment and lake management initiatives.

3. Results

LakeSPI results for each lake have been presented in the form of a table identifying the LakeSPI Index, Native Condition Index, and Invasive Condition Index. Indices are presented as a percentage of each lakes maximum scoring potential and can be interpreted as follows:

HIGHER LakeSPI Index = Better lake condition.
HIGHER Native Condition Index = Better lake condition.
LOWER Invasive Condition Index = Better lake condition.

The lakes are discussed in order of their LakeSPI scores, beginning with the highest ranked lake.

For the purpose of categorising the lakes condition into "Good", "Average" and "Poor", the following scale was used for the LakeSPI Index: <25 = Poor; 25-40 = Average; >40 = Good.

Table 1: Summary of current LakeSPI indices for 12 Rotorua lakes in order of their overall lake condition (2006 or 2008).

Lake	Most Recent LakeSPI Survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)	Overall Condition
Rotomahana	28/04/2008	66	63	24	Good >40
Rotoma	01/04/2008	48	53	54	
Okataina	01/04/2008	48	54	63	
Rerewhakaaitu	31/03/2008	41	52	64	
Okareka	31/10/2006	34	39	76	Average (25 – 40)
Tikitapu	31/03/2008	32	28	63	
Rotokakahi	29/04/2008	31	32	71	
Tarawera	31/03/2008	22	27	92	Poor (<25)
Rotorua	31/10/2006	22	21	78	
Okaro	30/10/2006	19	6	54	
Rotoehu	31/03/2008	18	26	85	
Rotoiti	30/10/2006	18	18	90	

3.1 Lake Rotomahana

Lake condition: Good

Stability: Stable with signs of decline.

Lake ranking: 1st

Table 3: LakeSPI results for Lake Rotomahana. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
	1988	72	64	13
Historical data	2002	73	61	7
	2005	70	66	19
Present day	2008	66	63	24

Lake Rotomahana, while still the highest ranked lake in the Rotorua region, is showing signs of declining condition as indicated by the most recent LakeSPI assessment. This is due to the recent invasion of the lake by two of New Zealand's worst aquatic plant species, *Egeria densa* and *Ceratophyllum demersum* (hornwort). Discovered for the first time in April 2007, Egeria was found to be established in two areas of the lake, at the north-eastern end and in the southern embayment, while Ceratophyllum fragments were found growing amongst native plants in the southern embayment (Clayton & de Winton, 2007; Scholes and Bloxham, 2008). Since then both species have continued to spread with Egeria now present at 2 of the 5 LakeSPI baseline sites forming bands of weed growth down to a depth of 9m. The maximum depth of aquatic plant growth at these 2 sites is 12m. As both Egeria and hornwort increasingly continue to impact negatively on the diversity and quality of indigenous plant communities we can expect to see the Native Condition Index for this lake decline while the 'Invasive Condition Index' continues to increase.

3.2 Lake Rotoma

Lake condition: Good

Stability: Stable

Lake ranking: 2nd

Table 4: LakeSPI results for Lake Rotoma. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
	1973	69	63	19
	1988	54	57	41
Historical data	2001	52	54	44
	2005	52	58	51
Present day	2008	48	53	54

In 1973 Lake Rotoma had a high LakeSPI score, which reflected the early stage of *Lagarosiphon* invasion and the extensive high cover charophyte meadows in this lake. By 1988 the Invasive Condition Index had more than doubled, which in turn reduced both the Native Condition Index and LakeSPI score for this lake. The following 20 years from 1988 to 2008 have shown a more gradual increase in the Invasive Condition Index, but with minimal change to the Native Condition Index or LakeSPI score. This lake presently has the second highest Native Condition Index after Lake Rotomahana and one of the lowest Invasive Condition Index scores for any of the lakes, which contributes to its high LakeSPI ranking.

In 1972 an underwater marker buoy was placed at the bottom boundary of submerged plant growth at one of the five LakeSPI baseline sites. Despite some water level fluctuations since that time this buoy still accurately marks the deepest plant boundary after more than 35 years, which provides good evidence for the stability in water

clarity during this period. This information confirms that the impact of invasive species on submerged vegetation has been the key driver of change in LakeSPI scores since that time.

3.3 Lake Okataina

Lake condition: Good

Stability: Stable

Lake ranking 3rd

Table 5: LakeSPI results for Lake Okataina. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
	1981	51	57	53
Historical data	1988	47	53	57
	2005	44	51	65
Present day	2008	48	54	58

LakeSPI scores for Lake Okataina have been reasonably stable with only minor fluctuations in LakeSPI condition over the last 27 years from 1981 to 2008. Care must be taken in interpreting these results since Lake Okataina has no outlet, and water levels can vary by several metres. Although lake level changes tend to be quite slow, they can still affect the available habitat for submerged vegetation in shallow water and the corresponding adjustments in the maximum depth of charophyte colonisation may respond more slowly.

In April 2007 a single *Ceratophyllum demersum* plant was found growing adjacent to a dilapidated wharf at the northern end of the lake (Scholes and Bloxham, 2008). An overturned steel drum with fitted lid was effectively used to enclose and destroy this plant and an extensive search failed to locate any further plants. *Ceratophyllum* still remains a major threat to Lake Okataina.

3.4 Lake Rerewhakaaitu

Lake condition: Good

Stability: Stable

Lake ranking 4th

Table 6: LakeSPI results for Lake Rerewhakaaitu. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	92	0
	1973	55	58	37
Historical data	1988	41	48	57
	2005	38	47	65
Present day	2008	41	52	64

Lake Rerewhakaaitu submerged vegetation was first surveyed in 1973 (Chapman and Clayton 1975) at a time when there was government concern over the degree of eutrophication occurring within several of the Rotorua Lakes. This lake was selected as a candidate for catchment restoration. As a base-line to which future changes could be related, a survey was carried out of the marginal and submerged vegetation using scuba and a submarine. A benthic blue-green algal bloom (*Tolypothrix*, *Lyngbya* & *Oscillatoria*) was prevalent around the lake margin and on plants in shallow water. The submerged vegetation was dominated by native species, with the benign weed *Potamogeton crispus* the only exotic species recorded. None of the problematic 'oxygen weed' species (*Elodea*, *Lagarosiphon* & *Egeria*) or hornwort (*Ceratophyllum*) were present at that time. In 1973 water clarity was low (in water visibility c.1.3m) and charophytes only grew to a maximum depth of 4.5 - 5m, with occasional specimens to 5.5 metres.

The 1988 & 2008 surveys show two significant changes since the 1973 survey. Firstly, water clarity improved, enabling charophyte meadows to extend approximately twice as deep (c. 8-9 m); secondly, *Lagarosiphon* invaded and has had a major impact on the vegetation with a substantial increase in the Invasive Condition Index (27% over 35 years). The invasive impact has primarily influenced the LakeSPI score, while the improved water clarity has allowed an extension in charophyte depth limits that has helped negate the impact on the Native Condition Index. Over the last 20 years the LakeSPI and Native Condition Index scores have remained very stable with only minimal change, although the Invasive Condition Index has continued to increase.

3.5 Lake Okareka

Lake condition: Average

Stability: Declining

Lake ranking 5th

Table 7: LakeSPI results for Lake Okareka. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
Historical data	1980	40	49	67
	1988	44	53	66
	2001	41	50	70
	2003	34	42	77
Present day	2006	34	39	76

Lake Okareka has recorded a 10% decrease in the LakeSPI Index over the last 18 years, from 1988 to 2006, resulting from a decline in the quality of native plant communities present, indicated by the Native Condition Index, and an increase in the Invasive Condition Index over the same time frame.

Egeria densa was first reported in Lake Okareka in 2000 (Clayton et al. 2005). While not located at any of the 5 LakeSPI baseline sites during the 2001 survey, by 2003 it had spread to 3 of the 5 sites. As Egeria continues to spread around the lake, displacing *Lagarosiphon* with taller and denser weed growth and occupying a wider depth range, we can expect to see the LakeSPI Index for this lake continue to decline. Despite the predicted spread of egeria around the lake, hornwort (*Ceratophyllum*) still poses a major threat to Lake Okareka with the potential to reduce the LakeSPI even further, by occupying deeper water than egeria and by displacing all remaining deep water charophyte meadows.

3.6 Lake Tikitapu

Lake condition: Average

Stability: Declining

Lake ranking: 6th

Table 8: LakeSPI results for Lake Tikitapu. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
	1970	70	77	33
Historical data	1988	63	75	47
	2005	46	45	50
Present day	2008	32	28	63

The LakeSPI Index shows a reduction of 31% over the last 20 years indicating that the condition of Lake Tikitapu has deteriorated faster than any of the 12 Rotorua Lakes over this same period from 1988 to 2008. Unlike the other lakes this decline is not due to the impact from new invasive species but from a significant decline in the quality and extent of native plant communities present. The mean maximum depth of native plant growth at LakeSPI survey sites has declined from 12.4m in 2005 to only 8.8m resulting in a 47% decline in the 'Native Condition Index' over the last 3 years. This notable reduction in native condition is most likely related to water quality, in particular water clarity near the maximum depth limit of vegetation growth. The presence of a sustained turbid water layer with high chlorophyll *a* levels has been reported above the thermocline (David Hamilton, Waikato University, pers comm.). The increase in Invasive Condition scores over this same time frame has occurred not on account of any new invasive plant introductions but due to the existing invasive vegetation now having a greater relative impact on overall vegetation status.

Historic records for Lake Tikitapu show a lake that has been deteriorating over time. Brown (1975) stated that charophytes in Lake Tikitapu formed a dense "meadow with 100 per cent ground cover at depths from 4 to 20 metres", with a "dissected meadow" between 20-25 metres Coffey (1970). By the 1988 survey, Clayton et al. (1990) reported "charophyte vegetation was not continuous throughout its reported depth range, with typically few plants found between 11-16m water depth", even though covers of up to 100% were still recorded either side of this low cover zone down to a maximum depth of 20.5m. Further deterioration was clearly evident by the 2008 survey in both charophyte cover and depth range, with a maximum depth of 19 metres recorded at only two of five sites and at one of these sites cover was less than 5%. This trend indicates on-going deterioration in the water quality and clarity of this lake at an alarming rate.

When the water chemistry of Lake Tikitapu was assessed in the early 1970s it had the lowest alkalinity recorded for any of the Rotorua lakes and it also had low sediment and water nutrient levels (McColl 1972). The reported low alkalinity, calcium and silicon levels may explain the on-going absence of kakahi, the low abundance of snails, koura and diatoms and even the unusual low stature and lax growth habit of *Lagarosiphon* in this lake. The decline in condition of charophyte vegetation indicates that water chemistry is likely to be changing. This is supported by Burns et al. (2005) who reported that anoxia is occurring in bottom waters, possibly triggering phosphorous release in this phosphorous limited lake.

3.7 Lake Rotokakahi

Lake condition: Average

Stability: Declining

Lake ranking 7th

Table 9: LakeSPI results for Lake Rotokakahi. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
Historical data	1988	52	61	53
	2005	35	36	71
Present day	2008	31	32	71

Lake Rotokakahi has undergone the second largest decline behind Lake Tikitapu shown for any of the 12 lakes over the same 20 year time period. The LakeSPI Index has decreased by 21% from 1988 to 2008, while the Native Condition Index has almost halved with a 29% reduction largely due to a decline in charophyte meadows. This has occurred even though there has been no change in the dominant invasive species in this lake *Elodea canadensis*, although the relative impact of invasive presence on overall submerged vegetation has increased. The declining condition of Lake Rotokakahi, like Tikitapu, is not due to invasive weeds but rather a decline in native condition presumably due to a reduction in water quality. Additional observations support this in Rotokakahi, with filamentous algae prevalent on submerged vegetation and blue-green algal mats often covering sediments beyond the maximum depth of plant growth. These are good indicators of poor lake health. Nutrient inputs are likely to be entering this lake from the predominantly farmland catchment as well as from sediment nutrient release during summer stratification. Recent logging in the catchment appears to have further increased lake turbidity since the last LakeSPI 2008 survey. A decline in oxygen content in deeper water has been

noted by David Hamilton (Waikato University pers comm.), which is consistent with hypolimnetic nutrient enrichment taking place. Lake Rotokakahi is now the only Rotorua lake to remain relatively free of significant invasive weed species.

3.8 Lake Tarawera

Lake condition: Poor

Stability: Stable

Lake ranking 8th

Table 10: LakeSPI results for Lake Tarawera. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
Historical data	1988	41	50	70
	1994	22	30	89
	2005	28	33	88
Present day	2008	22	27	92

At the time of the 1988 survey, *Lagarosiphon* and *Elodea* were the two dominant invasive weed species in Lake Tarawera. Although *Ceratophyllum* was first recorded in July 1988, it was limited to Kotukutuku Bay near the boat ramp and was not present in any of the survey sites used for LakeSPI. By the time of the 1994 survey *Ceratophyllum* had spread around much of the lake and had doubled the depth range of invasive vegetation, without displacing *Lagarosiphon* significantly (Wells et al. 1997). The high Invasive Condition Index recorded in 1994 (88%) has remained almost the same and now at 92% is the highest Invasive Condition Index score for all 12 Rotorua lakes. The LakeSPI Index declined by 19% in only 6 years from 1988 to 1994 and has remained low since that time. This was the largest LakeSPI decline for any of the Rotorua lakes over such a short time frame. The Native Condition Index also declined substantially from 1988 to 1994 and has remained low, with *Ceratophyllum* responsible for widespread displacement of almost all the former deep-water charophyte meadows.

3.9 Lake Rotorua

Lake condition: Poor

Stability: Stable

Lake ranking 9th

Table 11: LakeSPI results for Lake Rotorua. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
Historical data	1982	27	23	68
	1988	18	21	90
	2001	22	17	74
	2003	22	21	77
Present day	2006	22	21	78

Lake Rotorua has a low LakeSPI Index placing it in the bottom group of 5 lakes categorised as being in 'poor' condition. The LakeSPI scores and Native Condition Index have not changed much over the 24 years from 1982 to 2006. The variable Invasive Condition Index over this same period was attributable to the 'boom & bust' of *Egeria*, which was first recorded in this lake in July 1983 and by 1988 had established weed beds around most of the lake resulting in a peak Invasive Condition Index of 90%. In 1988 it was estimated that *Egeria* comprised more than 80% of the vegetation in the lake with an area of 440 ha. In the early 1990s *Egeria* underwent a major decline and has never recovered, which is reflected in the Invasive Condition Index from 2001 declining from the 1988 peak.

3.10 Lake Okaro

Lake condition: Poor

Stability: Stable

Lake ranking 10th

Table 12: LakeSPI results for Lake Okaro. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	89	0
Historical data	1982	31	29	67
	2003	19	6	76
Present day	2006	19	6	52

Elodea is the only invasive species reported in this lake. It is possible other invasive species have been introduced but were not able to establish or thrive. The hypereutrophic nature of this lake presents an unfavourable habitat for submerged vegetation. This is reflected in the highly variable cover and depth range of *Elodea*, both seasonally and annually. It is also likely to explain root lyses (root death and detachment) in *Elodea* beds from periods of oxygen stress and anoxia. On several occasions we have observed rooted shallow water *Elodea* beds, while at around 2m depth and deeper all of the *Elodea* appears as non-rooted 'drift'. This may well coincide with periods of shallow stratification with severe anoxia below the thermocline resulting in root death and shoot detachment.

The degraded nature of Lake Okaro and the wide fluctuations in water quality and clarity also account for variation in the Invasive Condition Index, while the Native Condition Index and LakeSPI scores are likely to remain low. The 2006 Native Condition Index was the lowest (6%) of the 12 lakes, while the overall LakeSPI score of 19% was one of the lowest recorded.

Recent efforts by Environment Bay of Plenty to reduce nutrient influx to the lake and nutrient release from hypolimnetic sediment may well improve water clarity and result in a positive vegetation response.

3.11 Lake Rotoehu

Lake condition: Poor

Stability: Declining

Lake ranking 11th

Table 13: LakeSPI results for Lake Rotoehu. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		89	88	0
Historical data	1988	33	33	73
	2003	34	34	64
	2006	22	32	82
Present day	2008	18	26	85

Since the 2003 survey of Lake Rotoehu a major infestation of *Ceratophyllum demersum* (hornwort) has spread through this lake resulting in a 16% decline in the LakeSPI Index over the last 5 years. Hornwort was first recorded in the lake off Otautu Bay in December 2004 (R. Mallinson, EBOP, pers comm.) and by late summer 2005 there were extensive weed beds along much of the shoreline. The recent LakeSPI results show the negative impact hornwort is having on native submerged vegetation within the lake and Lake Rotoehu is now sitting in the bottom group of lakes categorised as being in 'poor' condition. On a positive note, given the recent history of poor water quality and frequent blue-green blooms, it is quite possible the development of extensive hornwort beds around the margins of this shallow lake may reduce algal blooms by storing nutrients, despite the detrimental impact hornwort will have on littoral condition. Nutrient removal by means of weed harvesting could not only reduce weed impact but also help remove stored nutrients. Out of all the Rotorua lakes, Lake Rotoehu was the only one estimated to have sufficient harvestable weed biomass to potentially reduce the lake nutrient budget by a beneficial amount

(Matheson & Clayton 2002). A total of 600 tonnes of hornwort was harvested and removed from Lake Rotoehu over a 4 week period from April to May 2008, which equated to removal of 720 Kg of nitrogen and 96 Kg of phosphorus (R. Mallinson EBOP, pers comm.).

The proximity of hornwort to Lake Rotoma now raises particular concerns over the risk of spread to this lake. Rotoma overflows to Rotoehu occasionally, however boat traffic represents the greatest threat to Lake Rotoma.

3.12 Lake Rotoiti

Lake condition: Poor

Stability: Stable

Lake ranking 12th

Table 14: LakeSPI results for Lake Rotoiti. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)
Pristine		94	90	0
Historical data	1981	26	33	82
	1988	26	33	85
	2001	20	24	90
	2003	18	22	90
Present day	2006	18	18	90

Lake Rotoiti has consistently had one of the highest Invasive Condition Index scores and during the most recent 2006 survey it continued to have the lowest LakeSPI Index so far recorded for any of the 12 lakes in this region. It is interesting to note the similarity of LakeSPI scores, Native Condition Index and Invasive Condition Index between Lakes Rotoiti (18, 18, 90) and Rotorua (22, 21, 78), 2006 surveys. Lake Rotoiti has a complex morphometry with areas along the northern shoreline that are too steep to support submerged vegetation making them unsuitable for LakeSPI. The western end of Rotoiti has been predominantly influenced from Lake Rotorua inflows and there has been a progressive decline in submerged vegetation in several arms of Lake Rotoiti such as Okawa Bay, Wairau Bay and Te Weta Bay. Sheltered areas with low water quality are now often dominated by loose filamentous algae, attached benthic blue-green algal mats and planktonic blue-green algal blooms. The LakeSPI scores indicate poor water quality in this lake.

4. Discussion

Many of the Rotorua lakes have undergone significant change over the last two decades (Figure 2) and continue to be vulnerable to further changes from invasive plants and water quality deterioration. The submerged plant indicators used in LakeSPI provide an effective and alternative means to being able to assess these changes and monitor trends over time.

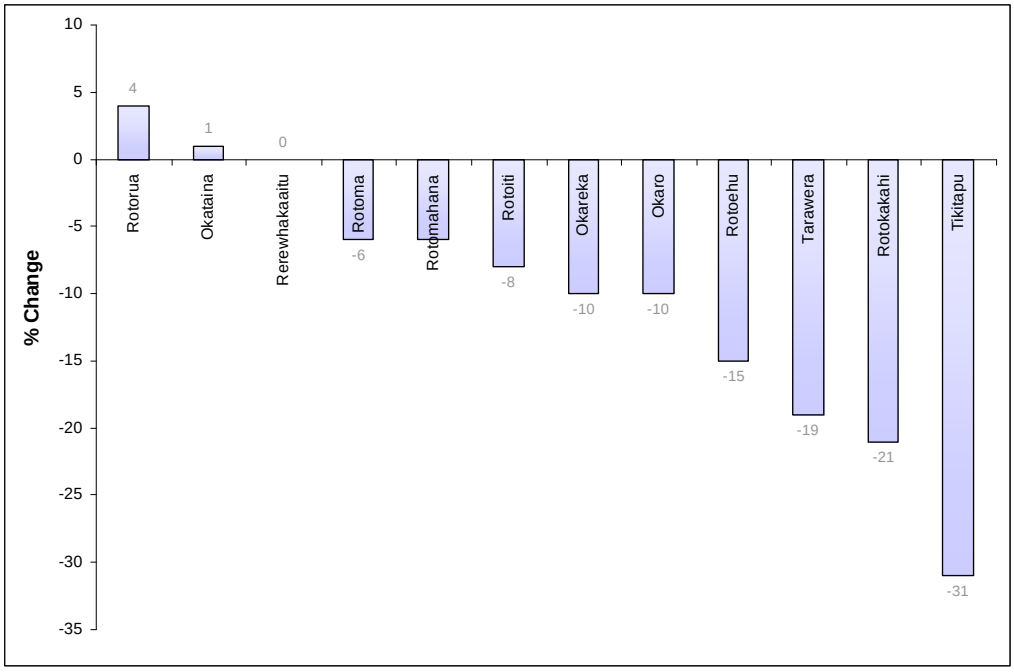

Figure 2: Percentage of change as indicated by the LakeSPI Index over the last 20 years, 1988 to 2006/08.

Lakes Tikitapu and Rotokakahi show the biggest change in lake condition over the last 20 years resulting from a notable reduction in the quality and extent of native submerged vegetation present in the lakes. There has been no new invasive species in either lake since full lake surveys were first completed in 1988, so these changes are likely the result of deteriorating water quality and clarity. Submerged plants are able to integrate long term changes in water clarity and nutrient status over time and often one of the first signs of deterioration is a retraction of the lower depth limit of plant growth (Schwarz et al. 1999). In many lakes the first valuable plant community to disappear is the charophyte meadow that grows into deeper water and this has been the case in Lake Tikitapu. In 1988 Lake Tikitapu supported extensive charophyte meadows at all 5 LakeSPI sites down to a mean depth of 19.5m. By 2008, the mean maximum depth of plant growth had declined to only 8.8m with Charophyte meadows

(>75% cover) found at only one LakeSPI site with remnants (<5% cover) found at one other.

Next to water quality, the second biggest change affecting the condition of the Rotorua Lakes is the introduction of invasive plant species. Invasive species tend to impact negatively on lake condition by displacing native plant communities to around a depth of 6-10 metres with the worst of these invasive species, hornwort, able to out-grow and smother native vegetation to around 15 metres. Hornwort is now present in 5 of the 12 Rotorua lakes and is the dominant invasive species in 2 of these lakes. Interestingly these 2 lakes, Tarawera and Rotoehu, show the next biggest change in lake condition over the last 20 years (Figure 2). Lake Tarawera now remains in a stable state and it is not expected to change much in the near future since the full impact of hornwort has now taken place. Hornwort is nearing full impact status in Lake Rotoehu also, although we can expect to see some further decline in LakeSPI scores as hornwort continues to impact negatively on the native vegetation still present. The recent invasion in Lake Rotomahana by hornwort and *Egeria* is expected to have a detrimental effect on lake condition. This lake was already vulnerable to change on account of low water clarity and the limits this posed on the extent of native submerged vegetation. As *Egeria* and hornwort continue to spread and displace native vegetation we can expect to see a notable decline in the status of this lake. As the water quality for Lakes Rotoehu and Rotomahana were much lower to begin with than for a large lake like Tarawera, we might expect to see a much larger impact more quickly than we did for Tarawera.

Three lakes (Rotoma, Okataina and Okareka) are considered to be under particular threat of a major decline in LakeSPI scores based on their potential for invasion by hornwort and the impact that this species would have on their present vegetation status. Lake Rerewhakaaitu could also be severely impacted, but the risk is less imminent on account of its greater distance from nearby hornwort infestations and much lower boat traffic. Lake Rotoma has recently had a containment net established by Environment Bay of Plenty out from the boat ramp at the western end of the lake. This net should effectively contain any hornwort fragments that might be transferred by boat or trailer from any nearby hornwort infested waterbodies, such as Lakes Rotoehu or Rotoiti. A similar containment net should be considered for the eastern end of Lake Rotoma and at the boat ramp at Lake Okataina and Okareka.

It is interesting to compare the overall condition of these lakes with the trophic classification given to six of these same lakes approximately 30 years ago by McColl (1972). Based on a wide range of trophic indicator parameters (e.g., chlorophyll *a*, N, P, secchi), Lakes Rotoma, Tikitapu and Okataina were classed as oligotrophic; Okareka and Rotokakahi were classed as mesotrophic, and Okaro was classed as

eutrophic. These same groupings are supported by the 1988 LakeSPI results and with the exception of Tikitapu which has undergone some significant changes, are also supported by the most recent LakeSPI surveys, 2006 and 2008.

The Trophic Level Index (TLI) is currently being used by Environment Bay of Plenty as one of the main methods to assess and monitor water quality in the Rotorua lakes. It is an alternative method to that of using submerged plants as indicators and instead focuses on physiochemical indicators. For this method five physicochemical measurements are recorded from the central lake basin of each lake, including chlorophyll a, total phosphorus and nitrogen, secchi depth and dissolved oxygen depletion rate (Burns et al. 1999 & 2005). Overall there is good agreement between LakeSPI and TLI rankings (Table 15). Lakes Rotoma and Okataina are classed as 'good' lakes (LakeSPI) and are oligotrophic (TLI). Lakes Okareka, Tikitapu and Rotokakahi group closely together and rank as 'average' and are mesotrophic. Similarly, lakes Rotorua, Okaro, Rotoehu and Rotoiti group together and have the lowest ranking under both classification systems.

Table 15: Summary of most recent LakeSPI and Trophic Level Index (TLI) results for 12 Rotorua lakes.

Lake	LakeSPI Index (%) 2006-08	Overall Condition	3 yearly average TLI to 2007	Classification
Rotomahana	66	Good	3.9	Mesotrophic
Rotoma	48	Good	2.5	Oligotrophic
Okataina	48	Good	2.8	Oligotrophic
Rerewhakaaitu	41	Good	3.5	Mesotrophic
Okareka	34	Average	3.3	Mesotrophic
Tikitapu	32	Average	3.0	Mesotrophic
Rotokakahi*	31	Average	3.2	Mesotrophic
Tarawera	22	Poor	2.8	Oligotrophic
Rotorua	22	Poor	4.9	Eutrophic
Okaro	19	Poor	5.5	Supertrophic
Rotoehu	18	Poor	4.6	Eutrophic
Rotoiti	18	Poor	4.1	Eutrophic

* Rotokakahi has not been monitored in the last 3 years - TLI unit shown is 3 yearly average TLI to 2000.

There were two notable exceptions to the similarity of results between LakeSPI and TLI. Firstly, Lake Tarawera had a high TLI (oligotrophic) but it had a low ranking using LakeSPI. Secondly, Lake Rotomahana was ranked quite low using TLI whereas it has the highest LakeSPI Index. These two lakes highlight the differences in the

information used to rank lakes. Lake Rotomahana previously had the highest LakeSPI Index for the Rotorua lakes because of its predominantly native vegetated condition and the absence of more problematic invasive plants. The LakeSPI method emphasised the importance of protecting Rotomahana from invasive plants; while the TLI draws attention to the somewhat degraded water quality, which may have had the potential to compromise biodiversity management objectives. Unfortunately due to the recent weed invasion in Lake Rotomahana it is likely that we will see this lake have a similar ranking to the TLI in the near future. Lake Tarawera has a relatively low ranking using the LakeSPI method because of the major impact that hornwort has had on the submerged vegetation in this lake, which in this case is not reflected in the TLI ranking.

During the 2008 LakeSPI surveys we began evaluating two new potential indicators of future changes in lake condition. Koura (freshwater crayfish) and Kakahi (freshwater mussels) could complement submerged plant information by providing further evidence for any change in ecological condition, while also providing a direct measure of change in mahinga kai important to local Maori. Evaluation has begun at three LakeSPI baseline sites within both lakes Rotoma and Rotokakahi. After one year of monitoring a decision will be made whether to extend the evaluation to include additional lakes that support these biota.

5. Conclusions

Aquatic plants are valuable indicators of lake health. They are easy to measure and integrate long-term climatic and environmental influences.

The LakeSPI method is helpful for identifying the relative condition of each lake compared to other lakes in the same region. Apart from providing a cost effective monitoring tool, this information can also be used to prioritise management objectives such as surveillance strategies, appropriate protection measures for high value lakes and potential restoration objectives for degraded lakes.

The lakes ranked in 'good' condition presently are Rotomahana, Rotoma, Okataina, and Rerewhakaaitu. Lake Rotomahana still maintains its high overall status based on the 2008 survey but this is not expected to last due to the recent introduction of invasive species. Lakes Rotoma and Okataina appear to maintain good water quality however both lakes are under serious threat from potential hornwort invasion. This would have a major detrimental impact on the native character and biodiversity values of these lakes. Lake Rerewhakaaitu, following improvement in water clarity since the 1970's, has remained in a stable state and now sits on the cusp between 'good' and 'average' condition. Unfortunately invasive impacts from Egeria are likely to cause a reduction in LakeSPI scores over the next few years and will result in Lake Rerewhakaaitu sliding back to an 'average' position.

Lakes Okareka, Tikitapu and Rotokakahi are currently sitting in 'average' condition. The last 3 years has seen the overall condition of Lake Okareka remain relatively stable although it is expected that this is a short term trend and won't continue as the full impact from *Egeria* invasion is expressed. This lake is also under serious threat from hornwort invasion, with the expected loss of all charophyte meadows if this eventuates. Lake Tikitapu continues in a state of significant decline on account of deteriorating water quality and clarity given there have been no new invasive species since the first full lake survey in 1988. Lake Rotokakahi also continues to appear in a state of decline due to water quality issues. Over the last 20 years both lakes have seen a reduction in the quality and extent of native plant communities present, without any direct change in invasive species presence or performance.

The remaining lakes: Tarawera, Rotorua, Okaro, Rotoiti and Rotoehu, are categorised as being in 'poor' condition. Lake Tarawera now remains in a stable state and it is not expected to change in the near future since the full impact of hornwort has now taken place. Lake Rotoehu joins this bottom group of lakes after undergoing a significant decline in lake condition on account of the recent invasion by hornwort. Lakes

Rotorua, Okaro and Rotoiti all remain in a 'poor' condition and are not expected to move from this position in the near future. Any restoration measures on these lakes that result in a sustainable improvement in water quality and clarity would be expected to result in improved LakeSPI scores.

A summary follows of key points for each lake based on LakeSPI:

Lake Rotomahana

- Overall lake condition still good but declining.
- Recent invasion by *Egeria* and hornwort having big impact.
- Highest Native Condition Index and lowest Invasive Condition Index of any lake.

Lake Rotoma

- Overall lake condition good and appears stable.
- LakeSPI scores stable with one of the highest Native Condition Index and one of the lowest Invasive Condition Index.
- Outstanding lake with best example of extensive charophyte meadows.
- Major threat from hornwort invasion.

Lake Okataina

- Overall lake condition good and appears stable.
- High Native Condition Index exceeded only by Rotomahana.
- Major threat from hornwort invasion.

Lake Rerewhakaaitu

- Overall lake condition average and appears stable.
- Water clarity and depth of native charophyte plant growth considerably improved since 1973.
- Invasive Condition Index moderately high and will worsen as *Egeria* spreads.
- Moderate threat from hornwort invasion

Lake Okareka

- Overall lake condition average and likely to decline.
- Moderate decline in LakeSPI and Native Condition Index over last 18 years.
- Invasion by *Egeria* yet to fully influence Invasive Condition Index scores.
- Major threat from hornwort invasion.

Lake Rotokakahi

- Overall lake condition average and declining.
- Major decline in LakeSPI and Native Condition Index over last 20 years.
- No change in *Elodea* but invasive impact accentuated by decline in native plant communities.
- Now the only Rotorua lake (with the exception of Okaro) to remain relatively free of significant invasive weed species.

Lake Tikitapu

- Overall lake condition now average and declining.

- Major decline in Native Condition Index and LakeSPI scores over the last 20 years independent of any impact from new invasive species.
- Unusual water chemistry may inhibit impact from present and future invasive species.

Lake Tarawera

- Overall lake condition poor and likely to be stable in the immediate future.
- LakeSPI and Native Condition Index scores have declined significantly over the last 20 years.
- Invasion of hornwort primarily responsible for decline in LakeSPI and Native Condition Index and has the highest Invasive Condition Index of all 12 lakes.

Lake Rotorua

- Overall lake condition poor but stable.
- The LakeSPI Index and Native Condition Index have not changed much over the last 24 years.

Lake Okaro

- Overall lake condition poor and variable.
- Unstable LakeSPI scores due to variable water quality and seasonal response of *Elodea.*
- Has the lowest Native Condition Index for any of the lakes.

Lake Rotoehu

- Overall lake condition poor and declining.
- Recent invasion by hornwort is having a major impact.
- Invasive Condition Index is 3rd highest of all the lakes and expected to worsen as hornwort spreads.

Lake Rotoiti

- Overall lake condition poor.
- Has the lowest LakeSPI Index for any of the Rotorua lakes.
- Second highest Invasive Condition Index of any of the lakes.

6. Recommendations

Lakes Tikitapu and Rotokakahi should be reassessed annually for further decline in LakeSPI scores since both lakes appear to be degrading faster than any of the remaining Rotorua lakes.

Investigations should be carried out into the causes of water quality and clarity degradation in Lake Tikitapu and Rotokakahi.

All possible measures should be explored for preventing the transfer (e.g., public education) and establishment (e.g., containment nets) of hornwort into vulnerable high condition lakes, such as Lakes Rotoma, Okataina and Okareka. Effective surveillance procedures will be also needed for early detection and emergency response procedures should be reviewed.

Lake Okaro and Okareka should be reassessed annually to record any improvement in LakeSPI condition attributable to restoration works associated with these lakes such as phosphorus capping.

Work should continue into the monitoring and evaluation of two additional indicators, koura (crayfish) and kakahi (mussels) and if successful, extended into other lakes known to support populations.

7. Acknowledgments

We thank the support of Environment Bay of Plenty for funding contributions towards this study and in particular Matthew Bloxham who assisted with the diving and assessment of these lakes. On going development and refinement of the LakeSPI method is supported by funding from the Foundation for Research Science & Technology (contract C01X0510).

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