The ecological condition of the Rotorua Lakes using LakeSPI - 2009

NIWA Client Report: HAM2009-162
September 2009

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Prepared for

Environment Bay of Plenty

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Contents

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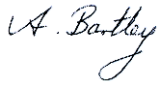


Executive Summary

NIWA was contracted by Environment Bay of Plenty to assess the ecological condition of 12 lakes within the Rotorua Region using LakeSPI (Submerged Plant Indicators). LakeSPI was developed according to Ministry for the Environment agreed criteria for freshwater indicators, for the establishment of long-term baselines for lake State of the Environment reporting and to monitor trends over time. LakeSPI results are presented as a percentage of each lakes maximum scoring potential to enable comparisons between lakes. To identify time trends, each lake has also been assessed using three baseline conditions: Pristine condition (lake plant communities in pre-impacted times), Historical condition (described by historical data) and Present day condition (using most recent data).

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.

Present day LakeSPI Indices for lakes in the Rotorua region ranged widely from 18% to 63% and using the LakeSPI lake classification system were categorised amongst five groups as Excellent (0 lakes), High (2 lakes), Moderate (7 lakes), Poor (4 lakes) and Non-vegetated (0 lakes).

In descending order of condition, the two best lakes that are classified as being in 'high' condition are Rotomahana and Rotoma. Lake Rotomahana still maintains its high overall status but due to recent invasion by *Egeria* and hornwort this is not expected to persist. Lake Rotoma is an exceptional lake and although it appears to maintain high water quality, it remains under serious threat from potential hornwort invasion. This would have a major detrimental impact on the native character and biodiversity value of this lake.

Lakes Okataina, Rerewhakaaitu, Okareka, Tikitapu, Rotokakahi, Rotorua and Tarawera are currently classified as being in 'moderate' condition. Lake Okataina appears to maintain high water quality and the recent discovery of hornwort fragments from within the lake provides an important reminder of the very real threat that this lake has from potential hornwort invasion. 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 last 6 years has seen the overall condition of Lake Okareka remain relatively stable but 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 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 Rotokakahi and Tikitapu have seen a reduction in the quality and extent of native plant communities present, without any direct change in invasive species presence or performance. Lake Rotorua is the only lake to have shown increasing lake condition scores over the last 21 years due to a recovery of native plant communities during the recent survey. This result could be temporary however due to the high variability in native plant communities growing within the large shallow littoral zone that is vulnerable to seasonal storm disturbance. 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.

Lakes Rotoiti, Okaro and Rotoehu are classified as being in a 'poor' condition and are not expected to move from this position in the near future. A slight improvement was noted in scores for Lake Okaro during the 2009 survey reflecting an increase in both native and invasive plant covers. 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 in the future.

Compared nationally, the Rotorua Region have no lakes classified as being in 'excellent' condition (representing those close to their maximum potential ecological condition) and only two lakes classified as being in 'high' condition. The largest proportion of lakes nationally, including those in the Rotorua Region, fell into the group of lakes classified as being in 'moderate' condition which tended to represent those that are impacted in varying degrees by invasive weeds. A smaller proportion of the Rotorua lakes classified as in 'poor' condition were consistent with others in this group around the country that tended to represent those with extensive invasion and dominance by one of the country's worst weeds, hornwort, or compromised water quality (Lake Okaro).

Evaluation continued during the 2009 surveys into the use of two new potential indicators for measuring change in lake condition. In the future 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 iwi. Evaluation of these additional indicators will continue during 2010.

Recommendations made in this report are as follows:

All possible measures should be explored for preventing the transfer (e.g., public education) and establishment (e.g., containment nets) of hornwort into vulnerable lakes, such as Lakes Rotoma and Okareka. Lake specific surveillance procedures should be established and reviewed to ensure early detection and emergency response procedures are optimal.

Hornwort has been introduced into Lake Okataina and the source of infestation has yet to be determined. Surveillance measures to date should be reviewed and an Action Plan agreed and implemented during early 2010.

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.

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

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 of these fauna.

1. Introduction

1.1 Study brief

NIWA was contracted by Environment Bay of Plenty (EBoP) 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 ecological condition. The LakeSPI method (Clayton and Edwards 2006) was developed according to Ministry for the Environment (MFE) agreed criteria for freshwater indicators, for the establishment of long-term baselines for lake SOE reporting, and to monitor trends over time. LakeSPI has been favourably reviewed in a recent report by MFE describing it as a 'tool offering considerable value to monitor and report on ecological condition' that is 'gaining wide acceptance in New Zealand' (MFE 2006), and this method has now been applied by agencies in eight regions of New Zealand. LakeSPI compliments traditional water quality monitoring, such as the Trophic Level Index method (Burns et al. 1999), by providing ecological information.

The contract specifies an assessment of 12 lakes being, Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotoma, Rotomahana, Rotorua, Tarawera and Tikitapu; with LakeSPI data 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). It is intended that this monitoring will continue with at least six lakes being 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, Okataina, Rotoiti, Rotoma, Rotomahana and Rotorua assessed in March 2008 (Edwards & Clayton, 2008) and May 2009.

Testing of two additional indicators, Kakahi (freshwater mussels) and Koura (freshwater crayfish), has also continued during the 2009 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.

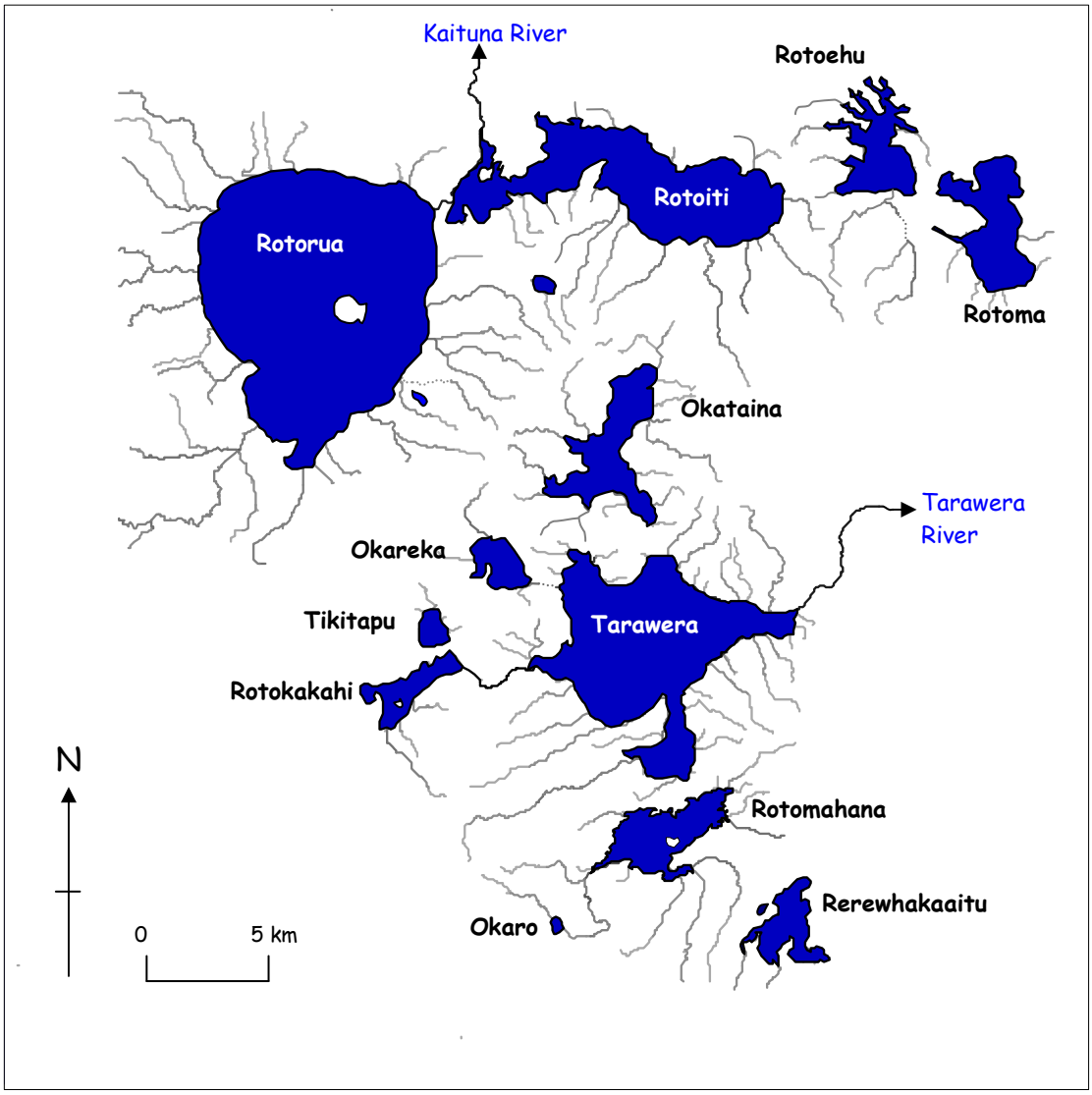


Figure 1: Map showing location of the 12 Rotorua lakes.

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 water bodies 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 presence of key submerged species has 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 2007 & May 2007 respectively (Clayton & de Winton 2007). The impact of Egeria on the Rotorua lakes has been less than expected; in contrast to the impact from hornwort, which 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 Impact 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 impact 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 Impact 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

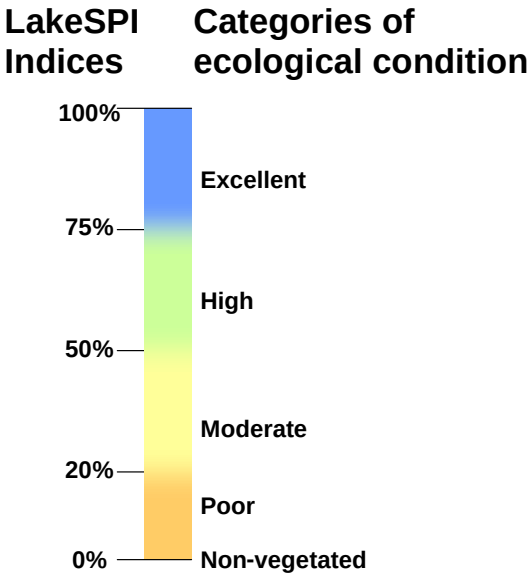
The LakeSPI method can be applied to available historic vegetation survey data using key vegetation information from macrophyte data in FBIS (Freshwater Biodata Information System - fbis.niwa.co.nz). Additional information on the nature of vegetation cover, proportion of native to invasive vegetation 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.

2.4 Lake classification

For the purposes of ranking and discussing LakeSPI results, lakes have been categorised into five main groups indicating overall lake condition based on the LakeSPI Index. Lakes are grouped as being in an 'excellent', 'high', 'moderate', 'poor', or 'non-vegetated' condition (Figure 2).



Note: These categories are imposed on a continuum scale of scores; therefore we recognise some flexibility in the placement of lakes with scores close to the transition between categories. Lake placement in these cases will be made using expert opinion based on the current status of the lake and the pressures exerted on it.

Figure 2: LakeSPI indices categorise lakes into five lake condition groups.

Lake categories differ to those in previous Rotorua LakeSPI reports after a need was recognised to standardise the lake classification system nationally. These new lake groupings support an MfE initiative to ensure national consistency in terminology and reporting and will allow for better comparisons of lakes nationally and regionally.

2.5 Lake stability

Changes in LakeSPI indices over the last five years (or survey next closest to the five year timeframe) have been used to provide an indication of current stability in lake condition and direction of any change. The stability of lakes over this five year time frame, is indicated either as being stable (±3%), declining (>-3%) or improving (>+3%).

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 Impact 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 Impact Index = Better lake condition.

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

Table 2: Summary of current LakeSPI indices for 12 Rotorua lakes in order of their overall lake condition (2008 or 2009).

Lake	Most Recent LakeSPI Survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Rotomahana	05/05/2009	63	61	30	High
Rotoma	04/05/2009	47	53	56	
Okataina	05/05/2009	45	47	60	Moderate
Rerewhakaaitu	31/03/2008	41	52	64	
Okareka	05/05/2009	34	39	76	
Tikitapu	31/03/2008	32	28	63	
Rotokakahi	29/04/2008	31	32	71	
Rotorua	04/05/2009	27	31	78	
Tarawera	31/03/2008	22	27	92	
Rotoiti	06/05/2009	21	29	89	Poor
Okaro	05/05/2009	21	13	77	
Rotoehu	31/03/2008	18	26	85	

3.1 Lake Rotomahana

Lake condition: High

Stability: Declining

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 Impact Index (%)
Pristine		94	90	0
Historical data	1988	72	64	13
	2002	73	61	7
	2005	70	66	19
	2008	66	63	24
Present day	2009	63	61	30

Lake Rotomahana, whilst 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 hornwort 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 3 of the 5 LakeSPI baseline sites (1 site more than 2008) forming bands of weed growth down to a depth of 9.7 m. The maximum depth of aquatic plant growth at these 3 sites is around 11 m. As both Egeria and hornwort continue to have an impact on the diversity and quality of indigenous plant communities in Lake Rotomahana we can expect to see the Native Condition Index decline while the 'Invasive Impact Index' continues to increase.

3.2 Lake Rotoma

Lake condition: High

Stability: Declining

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 Impact Index (%)
Pristine		94	90	0
Historical data	1973	69	63	19
	1988	54	57	41
	2001	52	54	44
	2005	52	58	51
	2008	48	53	54
Present day	2009	47	53	56

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 Impact Index had more than doubled, which in turn reduced both the Native Condition Index and LakeSPI score for this lake. The following 21 years from 1988 to 2009 have shown a more gradual increase in the Invasive Impact 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 Impact 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: Moderate

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 Impact Index (%)
Pristine		94	90	0
	1981	51	57	53
Historical data	1988	47	53	57
	2005	44	51	65
	2008	48	54	58
Present day	2009	45	47	60

LakeSPI scores for Lake Okataina have been reasonably stable with only minor fluctuations in LakeSPI condition over the last 28 years from 1981 to 2009. 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 hornwort (*Ceratophyllum demersum*) plant was found growing adjacent to a 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. However, in March 2009 five fragments of hornwort were found floating in Tahunapo (Log Pool) Bay on

the Western side of the lake (authors pers obs.) and two further fragment was found by EBoP surveyors near Kaiwaka Bay on the Eastern side of Okataina (Matthew Bloxham, EBoP, pers comm.). An extensive search of the lake by EBoP following this development failed to locate any further hornwort fragments or a parent colony. It is difficult to determine at this stage if the fragments found were escapees originating from recent boating activity (e.g., contaminated anchor) or if an undetected but established parent colony is currently growing in the lake. Hornwort still remains a major threat to Lake Okataina.

3.4 Lake Rerewhakaaitu

Lake condition: Moderate

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 Impact 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.1.3 m) and charophytes only grew to a maximum depth of 4.5 – 5 m, 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 Impact 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 Indices have remained very stable with only minimal change, while the Invasive Impact Index has continued to increase. The introduction of *Egeria* to Rerewhakaaitu was first recorded in the lake in 2000 (Champion et al. 2006) and is now present at 2 of the 5 LakeSPI baseline sites. *Egeria* is expected to have a significant impact on overall LakeSPI condition in years to come.

3.5 Lake Okareka

Lake condition: Moderate

Stability: Stable

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 Impact Index (%)
Pristine		94	90	0
Historical data	1980	40	49	67
	1988	44	53	66
	2001	41	50	70
	2003	34	42	77
	2006	34	39	76
Present day	2009	33	39	78

Lake Okareka currently appears to be in a stable condition indicated by the recent LakeSPI indices showing little change over the last six years, from 2003 to 2009. Prior to this however, Lake Okareka recorded a 10% decrease in the LakeSPI Index between 1988 an 2003, resulting from a decline in the quality of native plant communities present, indicated by the Native Condition Index, and an increase in the Invasive Impact 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 sites and during the most recent survey it was well established at 4 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 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: Moderate

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 Impact Index (%)
Pristine		94	90	0
Historical data	1970	70	77	33
	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 other 11 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 decreased from 12.4 m in 2005 to only 8.8 m in 2008 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 Impact scores over this same time frame has occurred not on account of any new invasive plant introductions or spread of existing invasive plants but rather 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 m (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 11-16 m 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 20.5 m. Further deterioration was clearly evident by the 2008 survey in both charophyte cover and depth range, with a maximum depth of 19 m recorded at only two of five sites and at one of these sites cover at this depth was less than 5%. This trend indicates on-going deterioration in the water quality and clarity of this lake at an alarming rate. The widespread decline in native charophyte meadows in Lake Tikitapu may be contributing to decline in water quality due to the loss of their beneficial sediment and water stabilisation influences (Donk & van de Bund 2002, Blindow et al. 2002). The presence of remnant, limited deep water charophyte meadows over several years suggests factors additional to water quality and clarity may be involved in charophyte decline. An assessment of likely contributing drivers of change should be explored.

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: Moderate

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 Impact 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, whilst 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 (*Elodea canadensis*) in this lake; although the relative impact of invasive presence on overall submerged vegetation has increased. The declining condition of Lake Rotokakahi, like Lake 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 Lake 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 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 2008 LakeSPI 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 Rotorua

Lake condition: Moderate

Stability: Improving

Lake ranking 8th

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 Impact Index (%)
Pristine		94	90	0
Historical data	1982	27	23	68
	1988	18	21	90
	2001	22	17	74
	2003	22	21	77
	2006	22	21	78
Present day	2009	27	31	78

Lake Rotorua is the only lake to have shown improving lake condition scores over the last 21 years. This lake has a large shallow littoral zone subject to considerable wave action, which has the effect of reducing silt build up and helps prevent large surface-reaching weed beds forming around much of the lake margin. The wave washed shallow regions of this lake can support a wide range of native turf-forming species along with shallow water charophyte beds and the presence of these native plants resulted in the higher Native Condition Index generated from the most recent 2009 survey. Charophyte meadows were recorded at 4 of the 5 LakeSPI baseline sites, compared to only 1 site in 2006, and they grew down to a maximum depth of 6.5 m. This and the extended area that the native plant communities are currently occupying has seen a 10% increase in the Native Condition Index for Lake Rotorua over the last 3 years. Care must be taken when interpreting these results however as these shallow water plant communities are also subject to seasonal storms and can be temporary in nature.

Prior to the recent survey, the LakeSPI scores and Native Condition Index did not change a lot over the 24 years from 1982 to 2006. The variable Invasive Impact 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 Impact 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 (Wells & Clayton, 1991). In the early 1990s *Egeria* underwent a major decline and has never recovered, which is reflected in the Invasive Impact Index from 2001 declining from the 1988 peak.

3.9 Lake Tarawera

Lake condition: Moderate

Stability: Declining

Lake ranking 9th

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 Impact 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 hornwort (*Ceratophyllum demersum*) 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 hornwort 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 Impact Index recorded in 1994 (89%) has remained almost the same and now at 92% is the highest Invasive Impact Index score for the 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 hornwort responsible for widespread displacement of almost all the former deep-water charophyte meadows.

3.10 Lake Rotoiti

Lake condition: Poor

Stability: Stable

Lake ranking 10th equal

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 Impact Index (%)
Pristine		94	90	0
Historical data	1981	26	33	82
	1988	26	33	85
	2001	20	24	90
	2003	18	22	90
	2006	18	18	90
Present day	2009	21	29	89

Lake Rotoiti has consistently had one of the highest Invasive Impact Index scores and during the most recent 2009 survey it continued to have one of the lowest LakeSPI Indices so far recorded for any of the 12 lakes in this region. A small increase in the LakeSPI Index over the last 3 years, 2006 to 2009, is attributable to the development of native charophyte meadows at 2 of the 5 LakeSPI baseline sites, growing to a maximum depth of 7.6 m, and is reflected by an increase in Native Condition scores.

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 in the past been predominantly influenced from Lake Rotorua inflows and there had been a progressive decline in submerged vegetation in several arms of Lake Rotoiti such as Okawa Bay, Wairau Bay and Te Weta Bay. Construction of the diversion wall to entrain Lake Rotorua inflows down the Kaituna River may see reduced water quality impacts, especially in this area. However flow-on

effects on submerged vegetation is not yet clear. Sheltered areas with low water quality are presently 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.

3.11 Lake Okaro

Lake condition: Poor

Stability: Stable

Lake ranking 10th equal

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 Impact Index (%)
Pristine		94	89	0
Historical data	1982	31	29	67
	2003	19	6	76
	2006	19	6	53
Present day	2009	21	13	77

Elodea is the only invasive species currently reported in this lake. 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 2 m 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 Impact Index, while the Native Condition Index and LakeSPI scores have remained low. Despite Native Condition scores showing an improvement since the 2006 survey, the 2009 Native Condition

Index was still the lowest (13%) of the 12 lakes, while the overall LakeSPI score of 21% 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, consistent with the increase in Native Condition and Invasive Impact Indices generated from the most recent survey.

3.12 Lake Rotoehu

Lake condition: Poor

Stability: Declining

Lake ranking 12th

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 Impact 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 hornwort (*Ceratophyllum demersum*) 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 3 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 may 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 phosphorous (R. Mallinson EBoP, pers comm.).

The proximity of hornwort to Lake Rotoma now raises particular concerns over the risk of spread to this lake with boat traffic representing the greatest threat to Lake Rotoma.

4. Discussion

Many of the Rotorua Lakes have undergone significant change over the last two decades (Figure 3) 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.

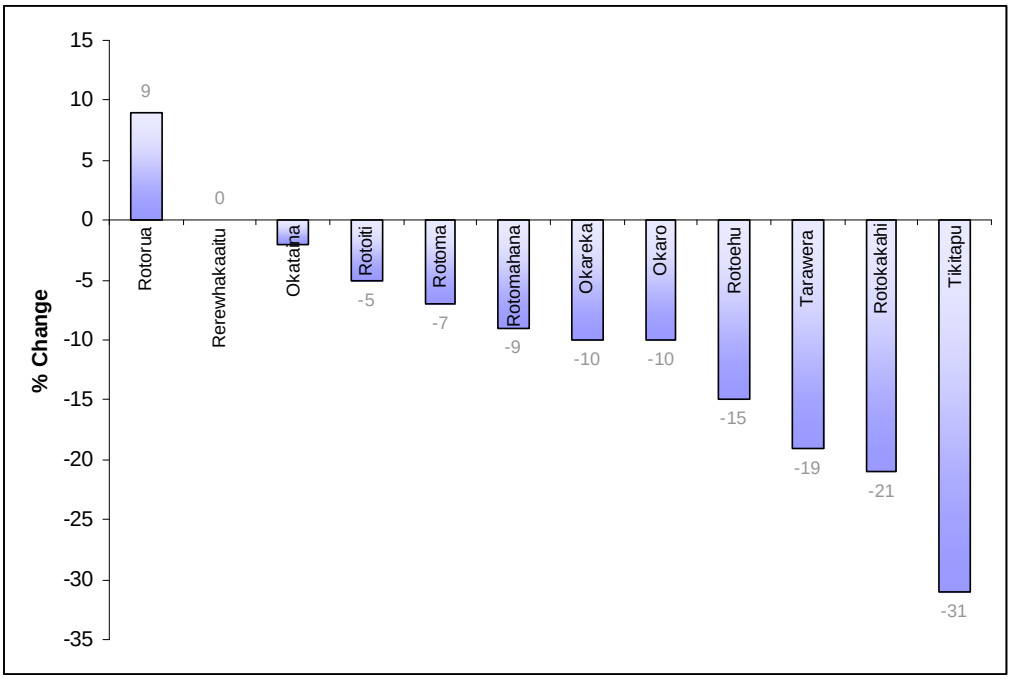


Figure 3: Percentage of change as indicated by the LakeSPI Index over the last 21 years, 1988 to 2008/09.

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 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 19.5 m. By 2008, the mean maximum depth of

plant growth had declined to only 8.8 m 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 3). 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.

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. In 2008 EBoP established a containment net out from the boat ramp at the western end of Lake Rotoma. This net will act to contain any hornwort fragments liberated at this launch site by boats or trailers coming from any nearby hornwort infested waterbodies, such as Lakes Rotoehu or Rotoiti. A similar containment net should be considered a priority for the eastern end of Lake Rotoma and at the boat ramps at Lakes Okareka and Okataina.

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 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. The ranked order of these lakes is in good agreement with the 1988 LakeSPI results and with the exception of Tikitapu, which has undergone some significant changes, is also supported by the most recent LakeSPI surveys, 2008 and 2009.

The Trophic Level Index (TLI) is currently being used by EBoP 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 water quality indicators (Burns et al. 1999). For this method five water quality measurements are recorded from the central lake basin of each lake, including chlorophyll a, total phosphorous 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 14). Lakes Rotoma and Okataina are ranked highly (2nd and 3rd highest) by LakeSPI and are oligotrophic (TLI). Lakes Rerewhakaaitu, Okareka and Rotokakahi group closely together in 'moderate' condition and are mesotrophic. Similarly, lakes Okaro, Rotoehu and Rotoiti group together in 'poor' condition (bottom three in LakeSPI) and have the lowest ranking under both classification systems.

Table 14: Summary of most recent LakeSPI and Trophic Level Index (TLI) results for 12 Rotorua lakes.

Lake	LakeSPI Index (%) 2008-09	Overall Condition	3 yearly average TLI to 2008	Classification
Rotomahana	63	High	3.9	Mesotrophic
Rotoma	47	High	2.6	Oligotrophic
Okataina	45	Moderate	2.8	Oligotrophic
Rerewhakaaitu	41	Moderate	3.6	Mesotrophic
Okareka	34	Moderate	3.3	Mesotrophic
Tikitapu	32	Moderate	3.0	Oligotrophic
Rotokakahi	31	Moderate	3.8	Mesotrophic
Rotorua	27	Moderate	4.8	Eutrophic
Tarawera	22	Moderate	2.9	Oligotrophic
Rotoiti	21	Poor	4.0	Eutrophic
Okaro	21	Poor	5.3	Supertrophic
Rotoehu	18	Poor	4.5	Eutrophic

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 limited impact from invasive plants. Although this situation is rapidly

changing, 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 inevitable that LakeSPI will decline rapidly during future assessments and this lake will 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.

Compared nationally, the Rotorua Region have no lakes classified as being in 'excellent' condition (representing those close to their maximum potential ecological condition) and only two lakes classified as being in 'high' condition (Figure 4).

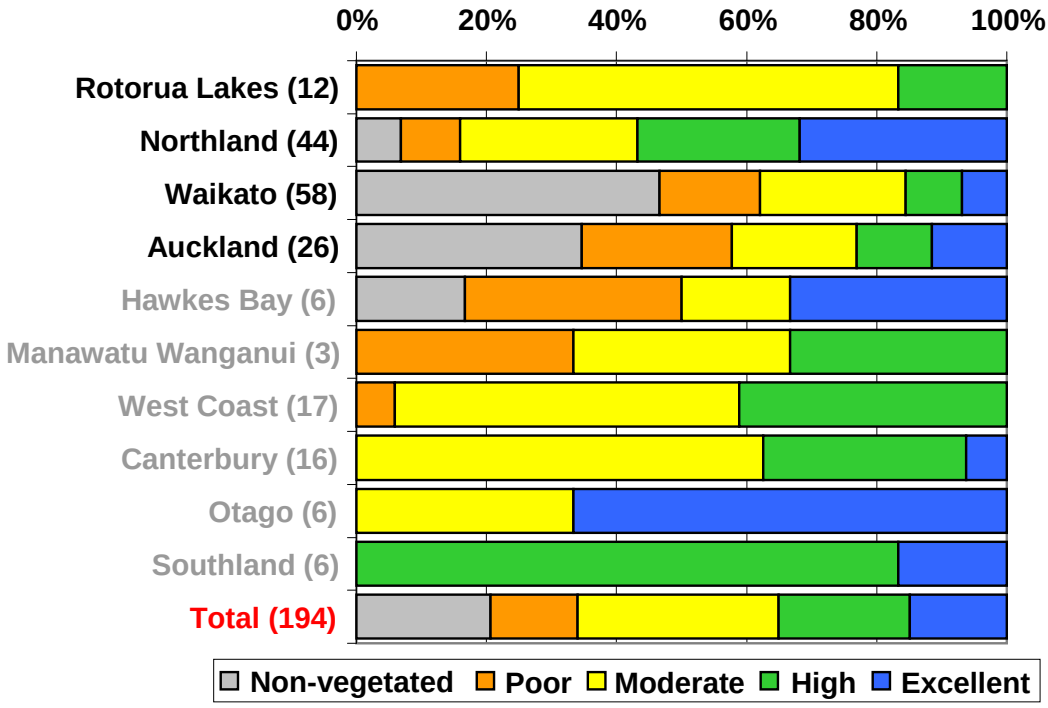


Figure 4: Proportions of lakes within a region as designated by the LakeSPI classification system, showing total and regional differences, with number of lakes shown in parenthesis. Regions labelled in grey represent those that have had only limited LakeSPI assessments carried out and are therefore under-represented in terms of lake surveys.

A ‘moderate’ condition category contains the majority of the Rotorua Lakes and contains the largest proportion of lakes nationally. This ‘moderate’ condition group of lakes are representative of those lakes that are impacted in varying degrees by invasive weeds.

A smaller proportion of the Rotorua Lakes are classified as being in a ‘poor’ condition. This group of lakes tends to represent those with extensive invasion and dominance by one of the country’s worst weeds, hornwort (*Ceratophyllum demersum*), as is the case for 2 of the 3 Rotorua Lakes ranked in this ‘poor’ category. Similar groups of substantially invaded lakes are represented in the Waikato, Auckland, and the Hawkes Bay Regions in particular. Water quality issues that have created unfavourable conditions for submerged plant growth are also often represented in this group of ‘poor’ condition lakes (e.g., Lake Okaro).

Evaluation continued during the 2009 surveys into the use of two new potential indicators of future change in lake condition. It is hoped that 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 iwi. Evaluation of these additional indicators begun in Lakes Rotoma and Rotokakahi in 2008, with experimental equipment set up at three LakeSPI baseline sites within each of the two lakes. Results at this stage look promising and evaluation of these additional indicators will continue in 2010.

Overall, LakeSPI indices on the Rotorua Lakes have provided valuable inter-lake comparisons and information on historical changes. Continued long-term monitoring is recommended for identifying future changes in the condition of these lakes. For lake managers, LakeSPI provides relevant information for regional and national reporting requirements, including operational monitoring and state of the environment reporting. Over time the results can be used to assess the effectiveness of catchment and lake management initiatives.

5. Conclusions

Aquatic plants are valuable indicators of lake health. They are easy to measure and integrate long-term 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 as being in 'high' condition are Rotomahana and Rotoma. Lake Rotomahana still maintains its high overall status based on the 2009 survey but this is not expected to persist due to the introduction and spread of invasive species. Lake Rotoma appears to maintain good water quality but remains under serious threat from potential hornwort invasion. This would have a major detrimental impact on the native character and biodiversity value of this lake.

Lakes Okataina, Rerewhakaaitu, Okareka, Tikitapu, Rotokakahi, Rotorua and Tarawera are currently ranked as being in 'moderate' condition. Lake Okataina is the highest ranked lake classified as 'moderate' condition and appears stable. The recent finding of hornwort fragments in Lake Okataina provides an important reminder of the very real threat that this lake has from hornwort invasion. Lake Rerewhakaaitu, following an improvement in water clarity since the 1970's, also remains in a stable state. Unfortunately invasive impacts from *Egeria* are likely to cause a reduction in LakeSPI scores over the next few years. The last 6 years has seen the overall condition of Lake Okareka remain relatively stable but 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 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 Rotokakahi and Tikitapu have seen a reduction in the quality and extent of native plant communities present, without any direct change in invasive species presence or performance. Lake Rotorua is the only lake to have shown increasing lake condition scores over the last 21 years due to a recovery of native plant communities during the recent survey. Care must be taken when interpreting this result however, as because Lake Rotorua has a large shallow littoral zone the native plant communities are more subject to seasonal storms and can be temporary in nature. Lake Tarawera

also falls into this ‘moderate’ condition category and its condition is not expected to change in the near future since the full impact of hornwort has now taken place.

Lakes Rotoiti, Okaro and Rotoehu remain in a ‘poor’ condition and are not expected to move from this position in the near future. A slight improvement was noted in scores for Lake Okaro during the 2009 survey reflecting an increase in both native and invasive plant covers. 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 in the future.

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

Lake Rotomahana

- Overall lake condition still high but declining.
- Recent invasion by *Egeria* and hornwort beginning to have an impact.
- Highest Native Condition Index and lowest Invasive Impact Index of any lake.

Lake Rotoma

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

Lake Okataina

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

Lake Rerewhakaaitu

- Overall lake condition moderate and appears stable.

- Water clarity and depth of native charophyte plant growth considerably improved since 1973.

- Invasive Impact Index moderately high and will worsen as *Egeria* spreads.

- Moderate threat from hornwort invasion.

Lake Okareka

- Overall lake condition moderate and likely to decline.

- Moderate decline in LakeSPI and Native Condition Index over last 18 years.

- Invasion by *Egeria* yet to fully influence Invasive Impact Index scores.

- Major threat from hornwort invasion.

Lake Tikitapu

- Overall lake condition now moderate 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 Rotokakahi

- Overall lake condition moderate 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 the worst 'high impact' invasive weed species.

Lake Rotorua

- Overall lake condition moderate and variable.

- The 2009 survey recorded an increase in the LakeSPI and Native Condition Index with scores currently the same as they were 27 years ago.

Lake Tarawera

- Overall lake condition moderate 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 Impact Index of all 12 lakes.

Lake Rotoiti

- Overall lake condition poor.

- Has the second highest Invasive Impact Index for any of the Rotorua lakes.

- LakeSPI Index indicates poor water quality.

Lake Okaro

- Overall lake condition poor and variable.

- Unstable LakeSPI scores due to variable water quality and seasonal response of *Elodea*. Possible signs of some improvement following lake restoration measures.

- 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 Impact Index is 3rd highest of all the lakes and expected to worsen as hornwort spreads.

6. Recommendations

All possible measures should be explored for preventing the transfer (e.g., public education) and establishment (e.g., containment nets) of hornwort into vulnerable lakes, such as Lakes Rotoma and Okareka. Lake specific surveillance procedures should be established and reviewed to ensure early detection and emergency response procedures are optimal.

Hornwort has been introduced into Lake Okataina and the source of infestation has yet to be determined. Surveillance measures to date should be reviewed and an Action Plan agreed and implemented during early 2010.

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.

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

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 of these fauna.

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