The condition of twelve lakes in the Rotorua Lakes Region using LakeSPI

NIWA Client Report: HAM2005-122
October 2005

NIWA Project: BOP05232

The condition of twelve lakes in the Rotorua Lakes Region using LakeSPI

John Clayton
Tracey Edwards
Mary de Winton

Prepared for

Environment Bay of Plenty

NIWA Client Report: HAM2005-122
October 2005

NIWA Project: BOP05232

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

Contents

Reviewed by: *Approved for release by:*

Thomas Wilding Jim Cooke

Formatting checked

A. Bartley

Executive Summary

NIWA was contracted by Environment Bay of Plenty to assess the condition of Rotorua lakes using LakeSPI. The 12 lakes assessed were Rotoma, Rotomahana, Tarawera, Tikitapu, Okataina, Rerewhakaaitu, Rotokakahi, Rotorua, Rotoiti, Rotoehu, Okareka and Okaro. This method focuses on submerged aquatic plants as indicators of lake condition. LakeSPI scores were generated from historical and recent vegetation surveys and all scores are expressed as a percentage of their maximum potential score.

The four best lakes ranked as “Good”, and in descending order of condition, were Rotomahana, Rotoma, Tikitapu and Okataina. Although presently “good”, Tikitapu appears to be undergoing significant decline. Of these four lakes, Rotomahana has the best potential for long-term protection against invasive weed species, but water clarity is the lowest of these three lakes, which limits submerged vegetation and makes it vulnerable to further deterioration. Lakes Rotoma and Okataina appear to have good potential for maintaining high water quality; however both lakes are under threat from hornwort invasion, which would have a major impact on their biodiversity and native character.

The next group of lakes that ranked as “Average” condition were Rerewhakaaitu, Okareka, Rotokakahi, Rotoehu and Tarawera. Lake Rotokakahi appears to be in a state of decline presumably because of deteriorating water quality, as no new invasive species have established since the first full lake survey in 1988. Lake Okareka LakeSPI scores have also continued to decline on account of water quality, and a further decline is expected once the full impact of *Egeria* invasion occurs. LakeSPI scores for Tarawera are not expected to change in the near future because the full impact of hornwort has now taken place. Lake Rerewhakaaitu has shown a significant improvement in LakeSPI scores since the 1970s when water quality was poor, although the recent *Egeria* invasion is likely to result in a reduction in LakeSPI over the next few years.

The lakes that ranked in “Poor” condition were Rotorua, Rotoiti and Okaro; however Lake Rotoehu is expected to be added to this group because of the recent hornwort invasion.

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 other Rotorua lakes. It is recommended that Lake Rotoehu LakeSPI scores are updated to asses the effect of hornwort since the previous 2003 survey. Lake Okaro should be reassessed annually to monitor any improvement in LakeSPI condition attributable to the restoration works. Koura (crayfish) and kakahi (mussels) should be evaluated as additional indicators at each LakeSPI baseline site to provide further evidence for any change in ecological condition, while also providing a direct measure of change in organisms important to local Maori. Finally, all possible options should be explored to prevent the transfer of hornwort to vulnerable good condition lakes, such as Lakes Rotoma and Okataina. Effective surveillance procedures are needed for early detection and emergency response procedures should be reviewed.

1. Introduction

1.1 Study brief

NIWA was contracted by Environment Bay of Plenty to assess the condition of several lakes using LakeSPI (Submerged Plant Indicators); a method that focuses on submerged aquatic plants as indicators of lake condition. The contract specified an assessment of seven lakes, being Rotoma, Rotomahana, Tarawera, Tikitapu, Okataina, Rerewhakaaitu and Rotokakahi. These were evaluated in March 2005. A further five lakes were evaluated earlier in September 2003 using the same method. Although not part of this study brief, it was decided that these lakes (Rotorua, Rotoiti, Rotoehu, Okareka and Okaro) should be included in this report, since this information was previously only available as a poster paper presented at the Rotorua Lakes Symposium (Edwards & Clayton, 2003).

1.2 History of the Rotorua Lakes

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 Lake Vegetation changes

The Rotorua lakes have been significantly affected by changes both in water quality and 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, especially 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 invasion occurred later, with Lake Rerewhakaaitu estimated to have been invaded in the mid 1980s.

The spread of these two 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, mainly of boat ramps (Johnstone et al. 1985). Lake Rotomahana is the only large lake that remains free of significant invasive weed species, which is primarily attributable to its remote location and difficult public access through private forestry land. Lake Rotokakahi is the only other lake not to have been invaded by *Lagarosiphon*, which is also attributable to restricted public access, in this case due to its sacred status to Te Arawa.

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 first report of *Egeria* and hornwort in Lake Tarawera in July 1988 (Wells & Clayton 1991) and more recent reports of *Egeria* in Lake Rerewhakaaitu and Lake Okareka (1st sighting c. 2000, pers. obs.) and hornwort in Lake Rotoehu (1st sighting 6.12.2004, Richard Mallenson, EBOP, pers. com.). The impact of *Egeria* 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 submerged aquatic plant pest.

1.4 Plants as indicators of lakes condition

Aquatic plants can be used to indicate lake ecological condition because the plants are perennial and integrate periodic changes in water clarity and nutrient status. For example, the depth that plants grow down to reflects water clarity integrated over a period of one or more years. Plant species can be used to directly assess biodiversity values and the degree of impact from invasive plant species. The spread of invasive weed species is a growing concern in this country, with recognised impacts on the utility and biodiversity of a waterbody. Finally, plants also provide a focus on lake margins and littoral zones around a lake where there is greatest public interaction and interest, while water sampled from the middle of a lake for water quality assessment can indicate different conditions.

LakeSPI is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring trends. It provides an insight into the native and invasive character of a lake, and presents a component index for each; a Native Condition Index and an Invasive Condition Index. These indices are integrated into an overall lake index (LakeSPI index) that allows for changes in overall lake condition to be monitored over time.

LakeSPI can be used in many ways depending on what the management needs are for individual lakes or for a selection of lakes. Indices generated by LakeSPI will allow lake managers to:

- Assess and compare the ecological condition of different lakes within or between regions.
- Monitor trends occurring within selected lakes over time.
- Compare current lake condition with indices generated from historical vegetation records.
- Make comparisons between dissimilar lakes through use of baselines to provide a benchmark against which LakeSPI indices can be interpreted.
- Provide relevant information for regional and national reporting requirements.

- Help assess the effectiveness of catchment and lake management initiatives.

Apart from describing lake ecological condition, LakeSPI also establishes long-term baselines for SOE (state of environment) reporting. A LakeSPI webpage reporting system is now available online (www.lakespi.niwa.co.nz) and this enables ready access to LakeSPI results in a user friendly form suitable for lake condition monitoring purposes and SOE reporting.

2. Methods

Potential baseline sites for each lake were selected after evaluating historic submerged vegetation surveys for all twelve lakes. Additional sites were also nominated beforehand in case any were not found to be representative or suitable as long-term baseline vegetation records when assessed in the field. The selection of sites in this way combined with on-site inspection meant that five sites were chosen for each lake that was considered representative both now and in future. Five of the lakes were surveyed and baselines established in September 2003, and the remaining lakes in March 2005. Survey procedures followed Clayton & Edwards (2002). Further details and the LakeSPI manual are available online (www.lakespi.niwa.co.nz).

LakeSPI indices were calculated for each lake using both the recent survey data and the historic vegetation data. LakeSPI indices have been expressed as a percentage of their maximum potential score, which is determined by the maximum depth of each lake and assumes native vegetation without invasive species or anthropogenic disturbance. LakeSPI indices integrate both Native Condition Index and Invasive Condition Index scores and provide an overall indication of lake ecological condition. A high Native Condition Index means a diverse and healthy native plant community, while high Invasive Condition Index means lake vegetation is dominated by invasive species. Further explanation of this process can be found in the LakeSPI Technical Report (Clayton et al. 2002). For the purpose of categorising the lakes into “Good”, “Average” and “Poor”, the following scale was used for the LakeSPI Index: <25 = Poor; 25-40 = Average; 40+ = Good.

3. Results

The lakes are discussed in order of their LakeSPI scores, beginning with the highest ranked lake. The most recent LakeSPI scores reported for each lake were based either on 2003 or 2005 field data. It should be noted that it is already likely that at least one of these lakes (Rotoehu) will have changed its ranking compared to other lakes because of recent vegetation changes. Each lake has one or more historic scores, along with the most recent LakeSPI survey results presented in a table. Following each table is a bar graph of only the most recent LakeSPI scores using the mean of five representative baseline sites to depict the overall condition of each lake. Indices are 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.

3.1 Lake Rotomahana

Table 1: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	70	66	19
2002	73	61	7
1988	68	64	21

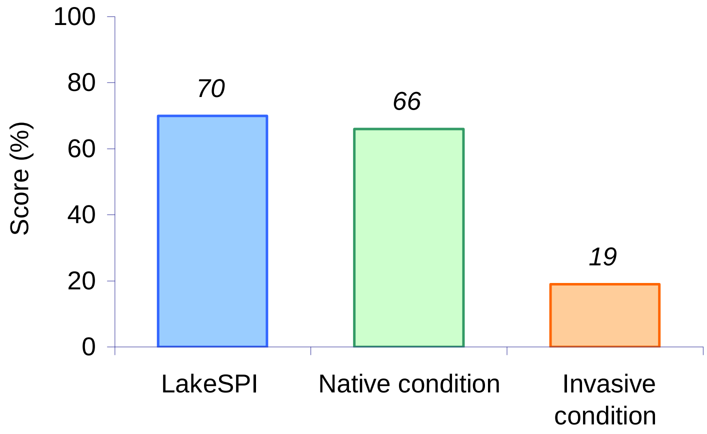

Figure 1: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Lake Rotomahana is the highest ranked lake and there has been no significant change in this status or in the LakeSPI scores over the last 17 years. The lake is dominated by native vegetation and is presently free of any of the problematic vegetatively reproducing invasive plants such as hornwort or "oxygen weed" species. Only one invasive aquatic plant, *Potamogeton crispus*, was recorded, however this species is widespread throughout New Zealand and is spread primarily by seed and wildlife rather than humans. *P. crispus* is a relatively benign invasive plant and tends to have a limited impact in most water bodies, as reflected in Lake Rotomahana recording the lowest Invasive Condition Index for any of the Rotorua lakes. *P. crispus* tends to be quite seasonal and can also vary in abundance from year to year. This is reflected in the low 2002 score for Invasive Condition Index, while the Native Condition Index and LakeSPI scores have remained very similar over the last 17 years.

3.2 Lake Rotoma

Table 2: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	52	58	51
2001	52	54	44
1988 *	54	57	41
1973	69	63	19

* The 1988 survey score is based on only 4 sites.

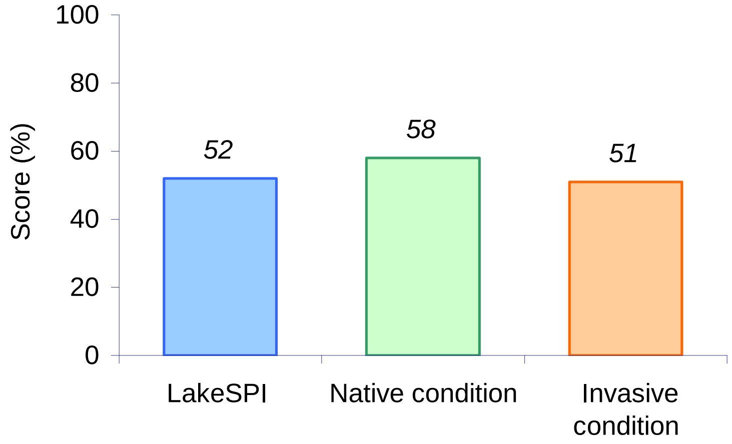

Figure 2: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

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 17 years from 1988 to 2005 have shown a more gradual increase in the Invasive Condition Index, but with minimal change to the Native Condition Index or LakeSPI score. After Lake Rotomahana, this lake presently has the second highest Native Condition Index and one of the lowest Invasive Condition Index scores.

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 30 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 Tikitapu

Table 3: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	46	45	50
1988	63	75	47
1970	70	77	33

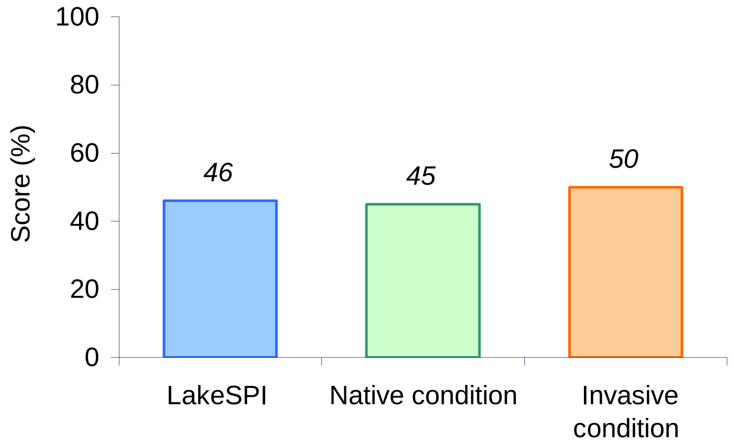

Figure 3: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Lake Tikitapu LakeSPI and Native Condition Index scores have significantly declined between 1970 and 2005. Since 1988 this is the greatest change for any of the 12 Rotorua lakes. This decline was not due to the impact from invasive species as the Invasive Condition Index has changed little since 1988. The significant decline in Native Condition Index and its effects on the LakeSPI score is presumably related to water physicochemical properties, and 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.com.). Lake Tikitapu is presently ranked as one of the top four of these 12 Rotorua lakes, placing it in the "Good" category; however all of the other three lakes in this top group have shown a LakeSPI score reduction of between 2 – 3 % over the last 17 years, while Lake Tikitapu has shown a 17% decline.

Coffey (1979) and 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. 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 2005 survey in both charophyte cover and depth range, with a maximum depth of 17.8 metres recorded for only one of five sites. This trend indicates on-going deterioration in the water quality and clarity of this lake and if charophyte vegetation cover declines any further the LakeSPI score will place this lake below Okataina with an overall category of "Average".

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 has 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.

3.4 Lake Okataina

Table 4: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	44	51	65
1988	47	53	57
1981 *	51	57	53

* The 1981 survey used different sites to those in 1988 and 2005.

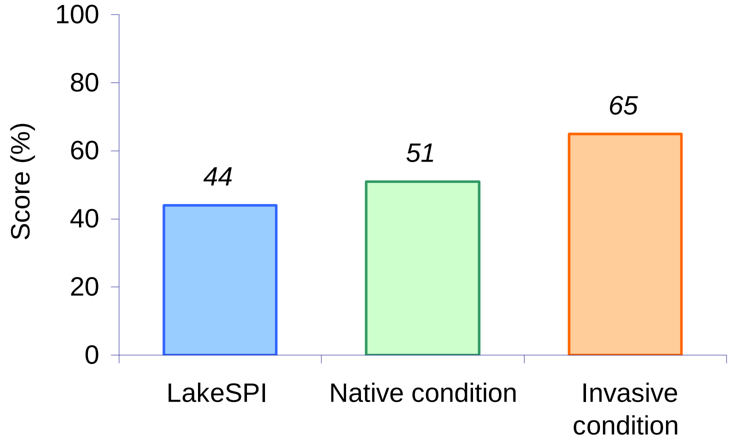

Figure 4: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

LakeSPI scores for Lake Okataina have been reasonably stable with only a gradual decline of 7% in LakeSPI condition over the last 24 years from 1981 to 2005 (and 3% from 1988 to 2005), which appears to be largely attributable to an increase in the Invasive Condition Index. Although there is some evidence of a decline in lake condition based on the LakeSPI results, care must be taken in interpreting these results. Lake level changes can affect the available habitat for submerged vegetation in shallow water and also the depth of charophyte colonisation. Okataina has no outlet, so levels can very by several metres.

3.5 Lake Rerewhakaaitu

Table 5: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	36	41	65
1988	38	42	57
1973	52	50	37

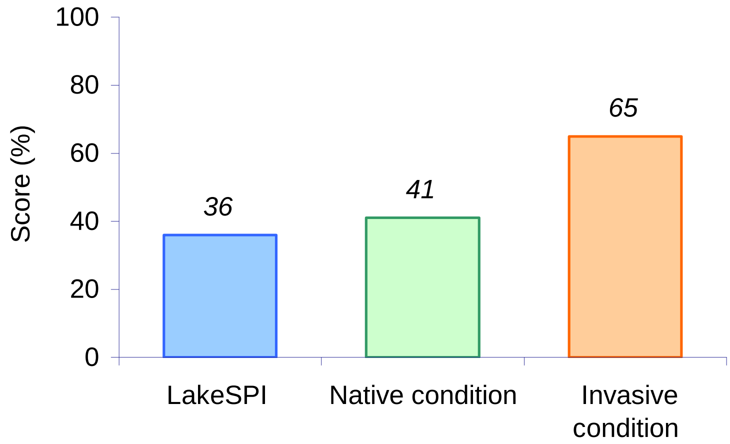

Figure 5: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

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 rather benign *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 & 2005 surveys show two significant changes since the 1973 survey. Firstly, water clarity significantly improved, enabling charophyte meadows to extend approximately twice as deep (c. 8-9 m); secondly, *Lagarosiphon* invaded and have had a major impact on the vegetation with a substantial increase in the Invasive Condition Index (57% over 32 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 17 years the LakeSPI and Native Condition Index scores have been very stable with a maximum 2% change, although the Invasive Condition Index has continued to get worse.

3.6 Lake Rotokakahi

Table 6: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	35	36	71
1988	52	61	53

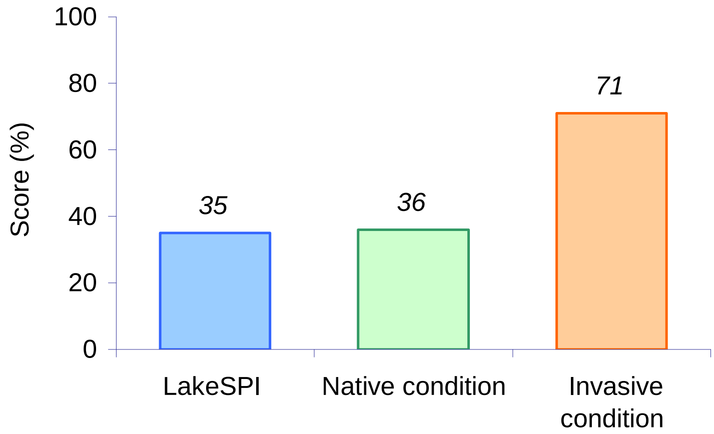

Figure 6: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Lakes Rotokakahi and Tikitapu have both undergone a 17% decline in LakeSPI scores over the last 17 years, which is the largest decline shown for all 12 lakes over this period. The Native Condition Index has almost halved with a 25% reduction largely because of the decline in charophyte meadows. Even though there has been no change in *Elodea* the dominant invasive species in this lake, it has still meant that the relative impact of invasive presence on overall submerged vegetation has increased. However, in this case the decline in lake condition is not due to invasive weeds, but due to the decline in native condition. The primary reason for this decline appears to be a reduction in water quality. Additional observations support this, 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 plant 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. 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.

3.7 Lake Okareka

Table 7: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2003	34	42	77
2001	41	50	70
1988	44	53	66
1980	40	49	67

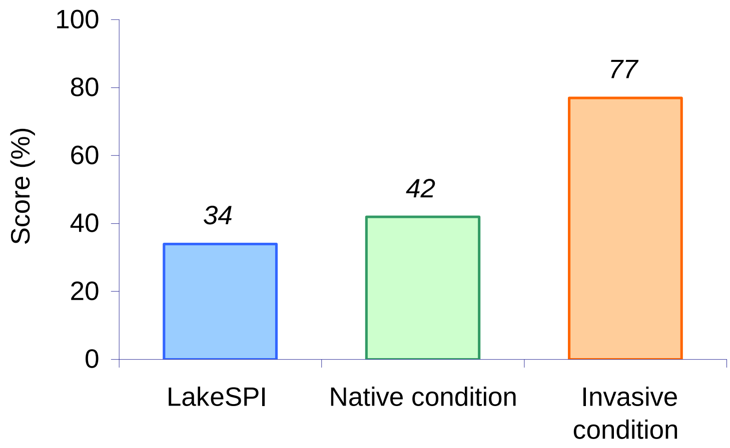

Figure 7: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Lake Okareka has recorded a 10% decline in LakeSPI score over the last 15 years from 1988 to 2003. This matches the decline in Native Condition Index and increase in Invasive Condition Index over the same time frame.

The recent *Egeria* invasion into this lake (first reported in 2000) is expected to soon have a measurable impact on the LakeSPI results for this lake. The 2001 and 2003 survey sites did not include *Egeria*, but from additional observations in the main area of infestation near the old ski lanes it was apparent that *Egeria* was effectively displacing *Lagarosiphon* with taller and denser growth and occupying a wider depth range.

3.8 Lake Rotoehu

Table 8: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2003	34	34	64
1988	33	33	73

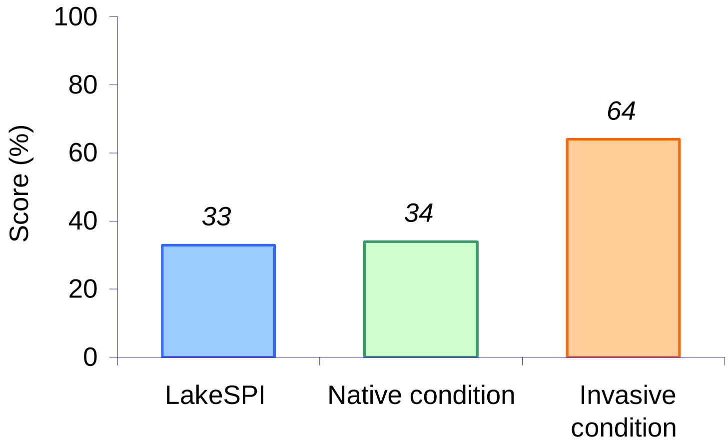

Figure 8: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Since the 4.9.03 survey on Lake Rotoehu a major infestation of hornwort has spread through this lake. Hornwort was first recorded in the lake off Otautu Bay on 6.12.04 (R. Mallinson, EBOP) and by late summer 2005 there were extensive weed beds along much of the shoreline. An updated LakeSPI assessment is predicted to drop the overall condition to “Poor” group (Table 13). 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. 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 a significant threat to Rotoma.

3.9 Lake Tarawera

Table 9: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2005	28	33	88
1994	22	30	89
1988	41	50	70

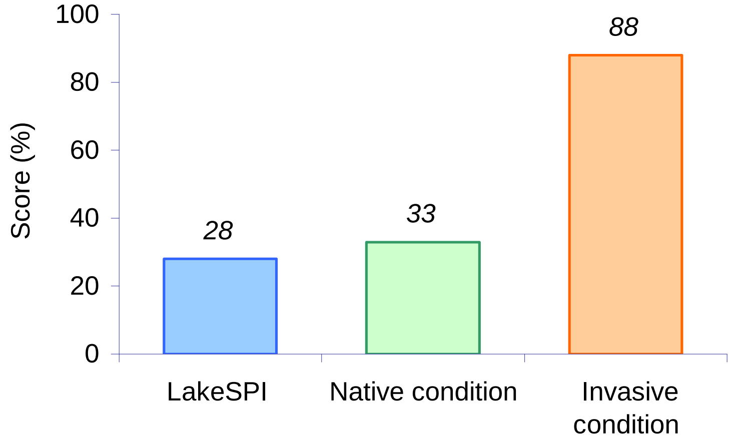

Figure 9: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

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). An almost identical Invasive Condition Index (88%) was recorded in 2005, which was the second highest Invasive Condition Index score for all 12 Rotorua lakes after Lake Rotoiti (90%). The LakeSPI score 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 significantly from 1988 to 1994 and has remained low, with *Ceratophyllum* responsible for widespread displacement of almost all the former deep water charophyte meadows.

3.10 Lake Rotorua

Table 10: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2003	22	21	77
2001	22	17	74
1988	18	21	90
1982	27	23	68

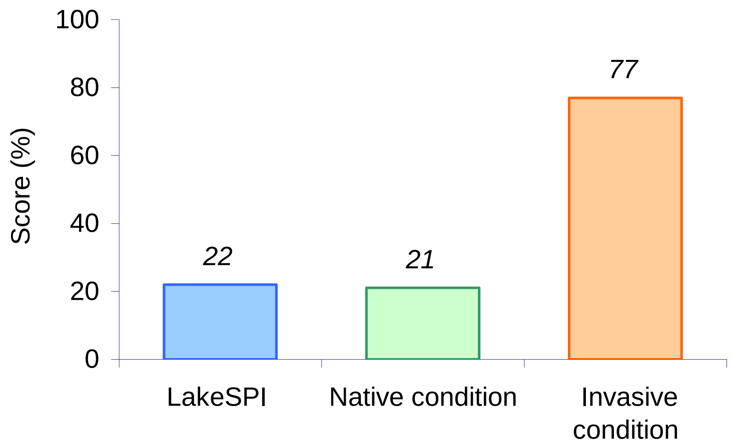

Figure 10: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Lake Rotorua has one the lowest LakeSPI scores for lakes in this region, placing this lake in the bottom three "Poor" category. The LakeSPI scores and Native Condition Index have not changed much over the 21 years from 1982 to 2003. 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 it had established significant 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 for 2001 and 2003 declining from the 1988 peak.

3.11 Lake Okaro

Table 11: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2003	19	6.4	76
1982	31	29	67

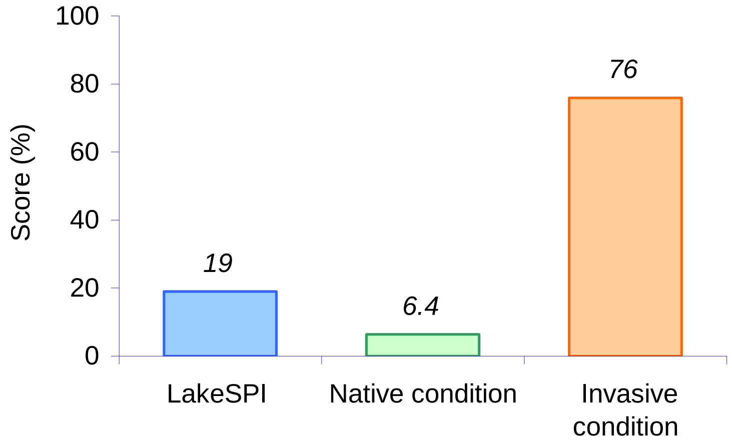

Figure 11: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Elodea is the only invasive species ever 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 during periods of oxygen stress and anoxia. On several occasions we have observed rooted shallow water *Elodea* beds, while at around 2 metres 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 2003 Native Condition Index was the lowest (6%) of the 12 lakes, while the overall LakeSPI score of 19% was one of the lowest recorded.

3.12 Lake Rotoiti

Table 12: Historic and current LakeSPI, Native and Invasive Indices expressed as a percentage of their maximum potential.

	LakeSPI Index	Native Index	Invasive Index
2003	18	22	90
2001	20	24	90
1988	26	33	85
1981	26	33	82

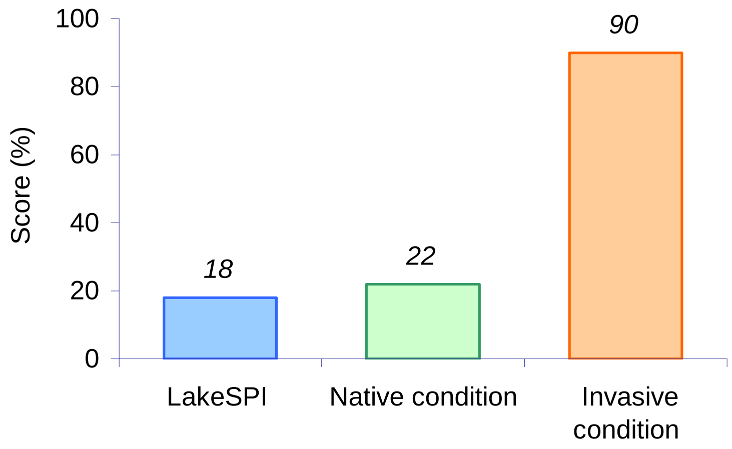

Figure 12: LakeSPI Indices expressed as % of lake potential. Overall LakeSPI index, Native Condition Index, and Invasive Condition Index (from left to right).

Lake Rotoiti has consistently had one of the highest Invasive Condition Index scores and during the most recent 2003 survey it had the lowest LakeSPI so far recorded for 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, 22, 90) and Rotorua (22, 21, 77). The only substantial difference is in the Invasive Condition Index, which can be quite variable for Lake Rotoiti. 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 is 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

Comparing LakeSPI scores between 12 lakes is made easier by incorporating them into one table (Table 13). This has the advantage that they can be also ranked in order of overall condition.

Table 13: Summary of current LakeSPI indices for 12 Rotorua lakes in order of their overall lake condition using the most recent data collected (2003 or 2005). Scores are the average of five baseline sites.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Condition Index (%)	Overall Condition
Rotomahana	70	66	19	Good
Rotoma	52	58	51	
Tikitapu	46	45	50	
Okataina	44	51	65	
Rerewhakaaitu	36	41	65	Average
Rotokakahi	35	36	71	
Okareka	34	42	77	
Rotoehu	34	34	64	
Tarawera	28	33	88	
Rotorua	22	21	77	Poor
Okaro	19	6.4	76	
Rotoiti	18	22	90	

It is interesting to compare the overall condition of these lakes (Table 13) 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 2003 & 2005 LakeSPI surveys.

An alternative and more recent approach that specifically focuses on the water quality condition of lakes is the Trophic Level Index (TLI). For this method five physicochemical measurements are recorded from the central lake basin, including chlorophyll a, total phosphorus and nitrogen, secchi depth and dissolved oxygen depletion rate (Burns et al. 1999 & 2005). Overall there is a good correlation between LakeSPI (Table 13) and TLI rankings (Table 14). Lakes Rotoma and Okataina are classed as “Good” lakes (LakeSPI) and are oligotrophic (TLI). Lakes Okareka, Rotokakahi and Rerewhakaaitu group closely together and rank as “average” and are mesotrophic. Similarly, lakes Rotoiti, Rotorua and Okaro group together and have the lowest ranking under both classification systems.

The 2003 LakeSPI scores for Lake Rotoehu will have changed following the recent hornwort invasion, and reassessment is now expected to place this lake into the lowest LakeSPI category. Likewise, the declining cover and depth of charophyte beds in Lake Tikitapu is expected to place this lake below Okataina in the near future. If these LakeSPI scores change as predicted, then both lakes would have a similar ranking to the TLI.

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 had the highest LakeSPI score. These two lakes highlight the differences in the information used to rank lakes. Lake Rotomahana has the highest LakeSPI scores because of its predominantly native vegetated condition and the absence of more problematic invasive plants. The benefit of comparing TLI and LakeSPI results is that LakeSPI emphasises the importance of protecting Rotomahana from invasive plants; while TLI draws attention to the somewhat degraded water quality, which has the potential to compromise biodiversity management objectives. 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.

Table 14: Summary of Trophic Level Index (TLI) for 12 Rotorua lakes in ascending order from Burns et al. 2005.

<table>
<tr><th>Lake</th><th>TLI (2000-03)</th><th>Classification</th></tr>
<tr><td>Rotoma</td><td>2.5</td><td rowspan="3">Oligotrophic
(TLI = 2-3)</td></tr>
<tr><td>Okataina</td><td>2.9</td></tr>
<tr><td>Tarawera</td><td>2.9</td></tr>
<tr><td>Tikitapu</td><td>3.1</td><td rowspan="5">Mesotrophic
(TLI = 3-4)</td></tr>
<tr><td>Okareka</td><td>3.2</td></tr>
<tr><td>Rotokakahi</td><td>3.2 *</td></tr>
<tr><td>Rerewhakaaitu</td><td>3.3</td></tr>
<tr><td>Rotomahana</td><td>3.7</td></tr>
<tr><td>Rotoiti</td><td>4.3</td><td rowspan="3">Eutrophic
(TLI = 4-5)</td></tr>
<tr><td>Rotoehu</td><td>4.7</td></tr>
<tr><td>Rotorua</td><td>4.9</td></tr>
<tr><td>Okaro</td><td>5.5</td><td>Supertrophic</td></tr>
</table>

* Three year average TLI to 2000.

The Rotorua lakes are vulnerable to further change from invasive plants and water quality deterioration. Invasive species tend to displace native vegetation to around 6-10 metres, apart from hornwort that can grow to around 15 metres. Enrichment of water bodies is associated with reduced water clarity, which has been responsible for the retraction of the lower depth limit of plant growth in most lakes. One of the first valuable communities to disappear is the charophyte meadows in deeper water. An additional negative impact from eutrophication is the proliferation of blue-green algae that is not just limited to surface blooms. As lakes deteriorate it is common to see submerged vegetation become smothered in attached filamentous blue-green algae, which can often precede the complete collapse of submerged plant communities (Clayton & Champion 2003). Once lakes become devegetated there is a loss of ecological moderating influences, which in turn leads to further decline in water quality (especially turbidity) and loss of biota. A decline in freshwater mussels and koura may often precede or accompany a decline in lake condition; therefore monitoring this biota may provide a sensitive additional indicator of future changes in lake condition.

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 in “Good” condition presently are Rotomahana, Rotoma, Okataina, and Tikitapu, however Tikitapu appears to be undergoing significant decline. Of these four lakes, Rotomahana has the best potential for long-term protection against invasive weed species, but water clarity is the lowest of these three lakes, and this limits the extent of submerged vegetation in the lake and makes the lake vulnerable to any further deterioration in water clarity. Lakes Rotoma and Okataina appear to have good potential for maintaining good water quality, however both lakes are under threat from hornwort invasion, which would have a major impact on biodiversity and native character of two lakes.

The lakes in “Poor” condition are Rotoiti, Rotorua and Okaro, however Rotoehu is expected to be added to this group on account of the recent hornwort invasion. 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.

The remaining lakes (Rerewhakaaitu, Rotokakahi, Okareka and Tarawera) are in “Average” condition. However, Lake Rotokakahi appears to be in a state of decline and presumably this is associated with deteriorating water quality, given there have been no new invasive species since the first full lake survey in 1988. Lake Okareka LakeSPI scores have also continued to decline because of reduced water quality, and a further decline is expected once the full impact of the *Egeria* invasion occurs. LakeSPI scores for Lake Tarawera are not expected to change in the near future since the full impact of hornwort has now taken place. Lake Rerewhakaaitu has shown a significant improvement in LakeSPI scores since the 1970s when water quality was poor. Unfortunately the recent *Egeria* invasion is likely to result in a reduction in LakeSPI over the next few years.

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

Lake Rotomahana

- Overall lake condition good and appears stable.
- LakeSPI scores stable with highest Native Condition Index and lowest Invasive Condition Index of any lake.
- The only lake without a serious invasive weed species.

Lake Rotoma

- Overall lake condition good and appears stable.
- LakeSPI scores stable with second 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 Tikitapu

- Overall lake condition good but indications of decline.
- Major decline in Native Condition Index and LakeSPI scores over the last 17 years independent of any impact from invasive species.
- Unusual water chemistry may inhibit impact from present and future invasive species.

Lake Okataina

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

Lake Rerewhakaaitu

- Overall condition average to good.
- Water clarity and depth of native charophyte plant growth considerably improved since 1973.
- Invasive Condition Index moderately high and will worsen as *Egeria* spreads.

Lake Okareka

- Overall condition average and still declining
- Moderate decline in LakeSPI and Native Condition Index over last 15 years
- Recent invasion by *Egeria* yet to influence Invasive Condition Index scores
- Major threat from hornwort invasion

Lake Rotokakahi

- Overall condition average and declining.
- Major decline in LakeSPI and Native Condition Index over last 17 years.
- No change in *Elodea*, the only invasive species present, but invasive impact accentuated by decline in native plant communities.

Lake Rotoehu

- Overall condition average but needs reassessment.
- Major impact from recent hornwort invasion yet to be evaluated using LakeSPI.
- Predicted that this lake will now be in the bottom group of “Poor” lakes.

Lake Tarawera

- Overall condition average and likely to be stable in the immediate future.
- LakeSPI and Native Condition Index scores have declined significantly over the last 17 years.
- Invasion of hornwort primarily responsible for decline in LakeSPI and Native Condition Index and 2nd largest increase in Invasive Condition Index.

Lake Rotorua

- Overall condition poor but stable over the last 20 years.

Lake Rotoiti

- Overall condition poor.
- Has the lowest LakeSPI and highest Invasive Condition Index score of all the Rotorua lakes.

Lake Okaro

- Overall condition poor and variable.
- Unstable LakeSPI scores due to variable water quality and seasonal response of *Elodea.*

6. Recommendations

Lake Rotoehu LakeSPI scores should be updated following the major impact from recent hornwort invasion since the previous 2003 survey.

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 flocculation.

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.

Two additional indicators, koura (crayfish) and kakahi (mussels) should be established for lakes known to support populations. These two indicators would complement the plant information by providing further evidence for any change in ecological condition, while also providing a direct measure of change in animals important to local Maori. It is suggested that one lake from each of the three condition categories is selected initially, such as Lakes Rotoma (Good), Okareka (Average) and Rotoiti (Poor).

All possible measures should be explored for preventing the transfer of hornwort into vulnerable high condition lakes, such as Lakes Rotoma and Okataina. Effective surveillance procedures will be also needed for early detection and emergency response procedures should be reviewed.

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 several of these lakes.

8. References

Brown, J.M.A. (1975). Ecology of macrophytes. IN: New Zealand Lakes. Editors V.H. Jolly & J.M.A. Brown. Publishers Auckland & Oxford University Press, pp 388.

Brown, J.M.A.; Dromgoole, F.I. (1977). The ecophysiology of *Lagarosiphon* in the Rotorua lakes. Proceedings of the 30th NZ Weed & Pest Control Conference, P. 130 – 140.

Burns, N.M.; Rutherford, J.C.; Clayton, J.S. (1999). A monitoring and classification system or New Zealand lakes and reservoirs. *Journal of Lake and Reservoir Management 15 (4)*: 255-271.

Burns, N.M.; McIntosh, J.; Scholes, P. (2005). Strategies for managing the lakes of the Rotorua District, New Zealand. *Lake and Reservoir Management 21 (1)*: 61-72.

Chapman, V.J. (1970). A history of the lake-weed infestation of the Rotorua Lakes and the lakes of the Waikato hydro-electric system. N.Z. DSIR Information Series 78.

Chapman, V.J.; Clayton, J. (1975). Submerged vegetation of the Rotorua Lakes, 3: Lake Rerewhakaaitu. *Hydrobiologia 47*: 399-413.

Clayton, J.S. (1982). Effects of fluctuations in water level and growth of *Lagarosiphon major* on the aquatic vascular plants in Lake Rotoma, 1973-80. *New Zealand Journal of Marine and Freshwater Research 16*: 89-94.

Clayton, J.S.; Champion, P.D. (2003). Rotorua Lakes: Plants tell the tale. Rotorua Lakes 2003: A Public Symposium on Practical Management for Good Lake Water Quality, Rotorua, October 2003.

Clayton, J.; Edwards, T. (2002). LakeSPI – A Method for Monitoring Ecological Condition in New Zealand Lakes. User Manual, Version One. August 2002. 41pp.

Clayton, J.; Edwards, T.; Froude, V. (2002). LakeSPI – A Method for Monitoring Ecological Condition in New Zealand Lakes. Technical Report, Version One. August 2002. 81pp.

Clayton, J.S.; de Winton, M.; Wells, R.D.S.; Tanner, C.C.; Miller, S.T.; Evans-McCleod, D. (1990). The aquatic vegetation of 15 Rotorua lakes. 2nd edition. Aquatic Plant Section, Ministry of Agriculture Fisheries, Hamilton.

Coffey, B.T. (1970). A contribution to the autecology and control of L*agarosiphon major*. MSc Thesis, Auckland University, 209 pp.

Coffey, B.T.; Clayton, J.S. (1988). Changes in the submerged macrophyte vegetation of Lake Rotoiti, Central North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research 22*: 215-223.

Edwards, T.; Clayton, J. (2002). Aquatic plants as environmental indicators of lake health in New Zealand. 11th International EWRS Symposium on Aquatic Weeds, Moliets et Maa, France, September 2002.

Edwards, T.; Clayton, J. (2003). Rotorua Lakes: Lake plants speak out on lake conditions. Rotorua Lakes 2003: A Public Symposium on Practical Management for Good Lake Water Quality, Rotorua, October 2003.

Howard-Williams, C.; Clayton, J.S.; Coffey, B.T.; Johnstone, I.M. (1987). Macrophyte invasions. In: Inland Waters of New Zealand (Ed. Viner A.B). *DSIR Bulletin 241*.

Johnstone, I.M.; Coffey, B.T.; Howard-Williams, C. (1985). The role of recreational boat traffic in interlake dispersal of macrophytes: *A New Zealand case study*. *Journal of Environmental Management 20*: 263-279.

McColl, R.H.S. (1972). Chemistry and trophic status of seven New Zealand lakes. *New Zealand Journal of Marine & Freshwater Research 6(4)*: 399-447.

Rutherford, J.C. (1984). Trends in Lake Rotorua water quality. *New Zealand Journal of Marine & Freshwater Research 18*: 355-365.

Vincent, W.F.; Gibbs, M.M.; Dryden, S.J. (1984). Accelerated eutrophication in a New Zealand lake: Lake Rotoiti, central North Island. *New Zealand Journal of Marine & Freshwater Research 18*: 431-440.

White, E. (1977). Eutrophication of Lake Rotorua – a review. DSIR Information Series 123.

Wells, R.D.S.; Clayton, J.S. (1991). Submerged vegetation and spread of *Egeria densa* Planchon in Lake Rotorua, central North Island, New Zealand. *New Zealand Journal of Marine & Freshwater Research 25*: 63 – 70.

Wells, R.D.S.; de Winton, M.D.; Clayton, J.S. (1997). Successive macrophyte invasions within the submerged flora of Lake Tarawera, Central North Island, New Zealand. *New Zealand Journal of Marine & Freshwater Research 31*: 449 – 459.