

The ecological condition of the Rotorua Te Arawa Lakes using LakeSPI - 2013

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Contents

- Executive summary7**

- 1 Introduction9**
 - 1.1 Study brief9
 - 1.2 Study lakes9
 - 1.3 History of the Rotorua Lakes 11

- 2 Study methods 14**
 - 2.1 LakeSPI 14
 - 2.2 Field surveys 14
 - 2.3 LakeSPI stability..... 15
 - 2.4 LakeSPI Status 15

- 3 Results 16**
 - 3.1 Lake Rotoma..... 17
 - 3.2 Lake Okataina 19
 - 3.3 Lake Rotomahana 21
 - 3.4 Lake Tikitapu..... 23
 - 3.5 Lake Rerewhakaaitu 25
 - 3.6 Lake Okareka..... 27
 - 3.7 Lake Okaro 29
 - 3.8 Lake Rotokakahi 31
 - 3.9 Lake Tarawera 33
 - 3.10 Lake Rotorua 35
 - 3.11 Lake Rotoiti 37
 - 3.12 Lake Rotoehu..... 39

- 4 Discussion 41**
 - 4.1 Current lake stability..... 41
 - 4.2 Long term changes 42
 - 4.3 National comparison 43

- 5 Conclusions..... 46**

- 6 Recommendations 49**

- 7 Acknowledgments..... 49**

8 References.....50

Tables

Table 1:	Summary of lake characteristics.	11
Table 2:	Summary of current LakeSPI indices for 12 Rotorua Te Arawa lakes in order of their overall lake condition (2012 or 2013).	16
Table 3:	Summary of current LakeSPI results	41

Figures

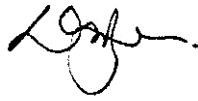
Figure 1:	Map showing location of the 12 Rotorua lakes.	10
Figure 2:	Depth profiles within a lake	13
Figure 3:	Guidelines for assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.	15
Figure 4:	LakeSPI results for Lake Rotoma. LakeSPI Indices expressed as a percentage of lake maximum potential.	17
Figure 5:	LakeSPI results for Lake Okataina. LakeSPI Indices expressed as a percentage of lake maximum potential.	19
Figure 6:	Invasive weed bed of hornwort (<i>Ceratophyllum demersum</i>)	20
Figure 7:	LakeSPI results for Lake Rotomahana. LakeSPI Indices expressed as a percentage of lake maximum potential.	21
Figure 8:	LakeSPI results for Lake Tikitapu. LakeSPI Indices expressed as a percentage of lake maximum potential.	23
Figure 9:	LakeSPI results for Lake Rerewhakaaitu. LakeSPI Indices expressed as a percentage of lake maximum potential.	25
Figure 10:	LakeSPI results for Lake Okareka. LakeSPI Indices expressed as a percentage of lake maximum potential.	27
Figure 11:	LakeSPI results for Lake Okaro. LakeSPI Indices expressed as a percentage of lake maximum potential.	29
Figure 12:	LakeSPI results for Lake Rotokakahi. LakeSPI Indices expressed as a percentage of lake maximum potential.	31
Figure 13:	LakeSPI results for Lake Tarawera. LakeSPI Indices expressed as a percentage of lake maximum potential.	33
Figure 14:	LakeSPI results for Lake Rotorua. LakeSPI Indices expressed as a percentage of lake maximum potential.	35
Figure 15:	LakeSPI results for Lake Rotoiti. LakeSPI Indices expressed as a percentage of lake maximum potential.	37
Figure 16:	LakeSPI results for Lake Rotoehu. LakeSPI Indices expressed as a percentage of lake maximum potential.	39
Figure 17:	Percentage of change as indicated by the LakeSPI Index over the last 25 years, 1988/1989 to 2012/13.	42
Figure 18:	The most recent LakeSPI scores for the Rotorua Te Arawa Lakes (red lines) are plotted with scores for a total of 242 New Zealand lakes.	44
Figure 19:	Proportion of lakes that fall into each of five categories of LakeSPI Index for the region (12) and nationally (242), with number of lakes assessed shown in parenthesis.	45

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Executive summary

NIWA has been contracted by Bay of Plenty Regional Council (BOPRC) to assess the ecological condition of 12 Rotorua Te Arawa lakes using LakeSPI (Submerged Plant Indicators). The LakeSPI method provides a quick and cost-effective bio-assessment tool for monitoring and reporting on the ecological condition of lakes. It allows lake managers to assess and report on the status of lakes at an individual, regional or national level; monitor change in a lake or group of lakes over time and prioritise lake management initiatives accordingly (e.g., protection, monitoring, weed surveillance). LakeSPI is recommended by the Ministry for the Environment as one indicator for State of the Environment (SOE) reporting.

Six lakes (Rotoma, Rotomahana, Okareka, Okaro, Rotorua and Rotoiti) were surveyed in 2013, and the remainder (Okataina, Rerewhakaaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu) were previously surveyed in 2012. This report provides an update on lake ecological condition and considers the changes evident in LakeSPI Indices over a recent time-frame since 2008 (4 to 5 years) and also the long-term (24-32 years).

LakeSPI results show many of the Rotorua Te Arawa Lakes have undergone significant change over the long-term and continue to be vulnerable to further changes from invasive plants and water quality deterioration. Lakes Rotomahana and Tarawera show the biggest change in lake condition over the long-term on account of impacts from invasive plant species; while the second biggest change to affect the Rotorua Lakes has been from changing water quality in Tikitapu and Rotokakahi.

Present day LakeSPI Condition Indices for lakes in the Rotorua region ranged widely from 18% to 55% with one Rotorua Te Arawa lake assessed as being in 'high' condition, ten lakes as 'moderate' and one lake categorised as in 'poor' condition. None of the 12 Rotorua Te Arawa lakes were recorded in the 'excellent' or 'non-vegetated' categories.

Lake Rotoma is classified as being in 'high' condition and has been stable. This 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, Rotomahana, Tikitapu, Rerewhakaaitu, Okareka, Okaro, Rotokakahi, Tarawera, Rotorua and Rotoiti are currently ranked as being in 'moderate' condition. Lake Okataina appears to maintain high water quality and has been stable, but the presence of hornwort now in the lake poses a serious threat to future lake condition. Lake Rotomahana has undergone significant change due to the more recent invasion by egeria and hornwort and is expected to decrease in ranking over time. LakeSPI results for Lake Rotomahana show the largest decline recorded in any of the Rotorua lakes since 2008. Lakes Tikitapu and Rotokakahi have shown substantial deterioration over the long-term, but have been more stable recently. Both lakes have seen a reduction in the diversity and extent of native plant communities present, without any direct change in invasive weed presence or increased performance. A small recent improvement in Lake Okaro and Lake Rotoiti may reflect recent management efforts by BOPRC, which may have improved water clarity, resulting in a

positive vegetation response. Lake Rerewhakaaitu has deteriorated over the long-term and since 2008 due to the increasing invasive impacts from egeria, while water quality impacting on charophyte depth limits are of concern for the future state of this lake. Although the overall condition of Lake Okareka has remained stable over the long-term, the recent discovery of hornwort in the lake in March 2012 raises concern for future condition. As hornwort becomes established in Lake Okareka we can expect it to displace all native charophyte meadows in this lake. Lake Tarawera has remained in a stable state since 2008, following the complete invasion of this lake by hornwort that caused reductions in lake condition over the longer-term. Lakes Rotorua has remained stable, in a moderate condition.

Lake Rotoehu is classified as being in a 'poor' condition. This lake has the lowest LakeSPI Index and one of the highest Invasive Impact scores recorded for any of the 12 Rotorua Te Arawa lakes. Invasion by hornwort has seen the lake condition decline in the long-term and some small recent changes in invasive status are evident.

Compared to the lakes that have been assessed nationally, the Rotorua region is under-represented in the high (1 lake) to excellent categories. As is the case nationally, most Rotorua Te Arawa Lakes (10 lakes) fell into the group of lakes classified as being in 'moderate' condition. However, the Rotorua Te Arawa Lakes were also under represented in the poor (1 lake) and non-vegetated (no lakes) categories, that tend to represent those with extensive invasion and dominance by one of the country's worst weeds, hornwort, and/or compromised water quality.

Recommendations made in this report are as follows:

All possible measures should be explored for preventing further hornwort transfer (e.g., public education) and establishment into vulnerable lakes. Of particular concern is Lake Rotoma which remains at high risk of invasion by hornwort due to its proximity to other hornwort infested lakes (e.g., Lake Rotoehu).

There may be merit in assessing some lakes annually. In particular those lakes where significant changes are taking place either by deterioration (e.g., Tikitapu, Rotokakahi, Rerewhakaaitu) or from improvements (e.g., Okaro and Rotoiti) attributable to restoration works such as phosphorus capping and nutrient diversion.

To gain a further understanding of the overall state of the lakes in this region it is suggested that one-off surveys be completed for lakes not yet surveyed: Rotokawau, Te Hapua, Rotokawa, Rotongata (Mirror Lake), Rotoatua and the Rerewhakaaitu crater lake. Limited historic information is known about these lakes which may or may not be vegetated, but knowing their current condition will provide a better understanding of the regions diversity of lakes and factors that influence macrophyte presence. Lake Pupuwharu was last surveyed in 2006 and is recommended for re-survey.

1 Introduction

1.1 Study brief

Since 2005, NIWA has been contracted by Bay of Plenty Regional Council (BOPRC) to assess the ecological condition of 12 Rotorua Te Arawa lakes using LakeSPI (Submerged Plant Indicators). The LakeSPI method provides a quick and cost-effective bio-assessment tool for monitoring and reporting on the ecological condition of lakes. It allows lake managers to assess and report on the status of lakes at an individual, regional or national level; monitor changes in a lake or group of lakes over time and prioritise lake management initiatives accordingly (e.g., protection, monitoring, weed surveillance). LakeSPI is recommended by the Ministry for the Environment as one indicator for State of the Environment (SOE) reporting.

LakeSPI monitoring of the Rotorua Te Arawa lakes using established baseline sites was first completed between September 2003 and March 2005 (Clayton et al. 2005). Since this time the lakes have been surveyed approximately biennially, ensuring each lake is re-assessed every two years.

This report presents updated LakeSPI results for lakes Okaro, Okareka, Rotoiti, Rotoma, Rotomahana and Rotorua assessed in April and June 2013, and lakes Okataina, Rerewhakaaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu last assessed in 2012 (Edwards and Clayton, 2012).

1.2 Study lakes

The lakes assessed in this report are collectively termed the 'Rotorua Te Arawa lakes'. This term refers to the 12 largest lakes in the Rotorua region managed through the Rotorua Te Arawa Lakes Programme, a partnership created by the Bay of Plenty Regional Council, Rotorua District Council and Te Arawa Lakes Trust (www.rotorualakes.co.nz). The 12 Rotorua Te Arawa lakes include: Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotoma, Rotomahana, Rotorua, Tarawera, and Tikitapu. The location of these lakes is indicated in Figure 1.

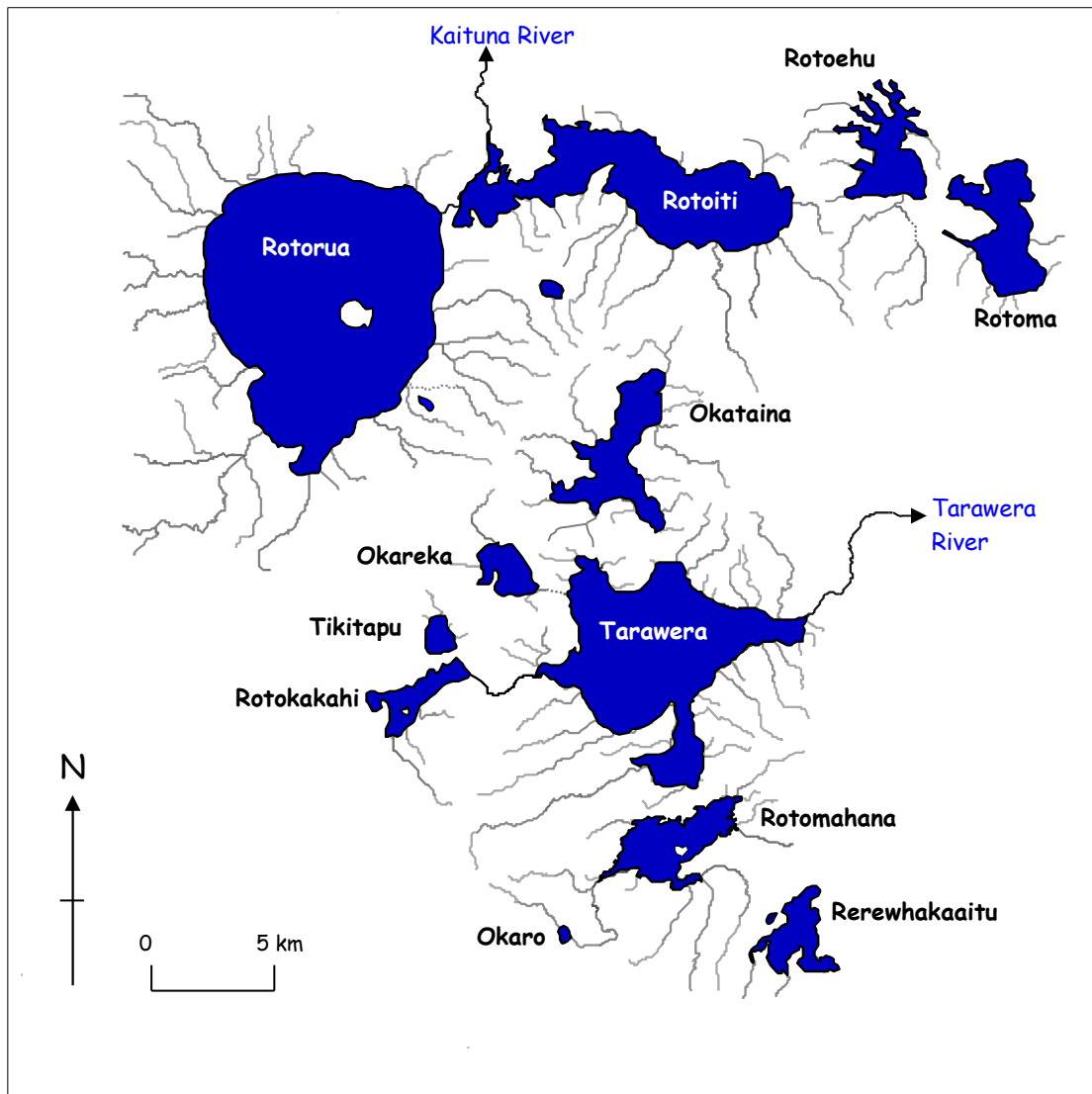


Figure 1: Map showing location of the 12 Rotorua lakes.

Table 1: Summary of lake characteristics.

Lake	Maximum Depth (m)	Mean Depth (m)	Size (km ²)	Catchment Area (km ²)
Ōkāreka	33.5	20	3.33	19.6
Ōkaro	18	12.5	0.33	3.9
Ōkātina	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
Rotomā	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, beef 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 Te Arawa lakes.

1.3.2 Lake vegetation changes

The Rotorua Te Arawa 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 Te Arawa Lakes has been occurring for many years (White 1977, Rutherford 1984, Vincent et al. 1984). Parallel deterioration in the extent of aquatic vegetation and presence of key native 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 saw a period of improved water clarity and a corresponding increase in the depth of submerged vegetation over earlier investigations.

The second important factor affecting the aquatic vegetation in the Rotorua Te Arawa Lakes is the introduction of a range of invasive plant species (Figure 2). The first 'oxygen weed' species (family Hydrocharitaceae) to establish in the Rotorua Te Arawa 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 Te Arawa 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), and both of these species have continued to spread to other lakes. 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 Te Arawa Lakes is a gradual and on-going process, and there is a strong correlation with boat traffic and lake accessibility, with early 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.

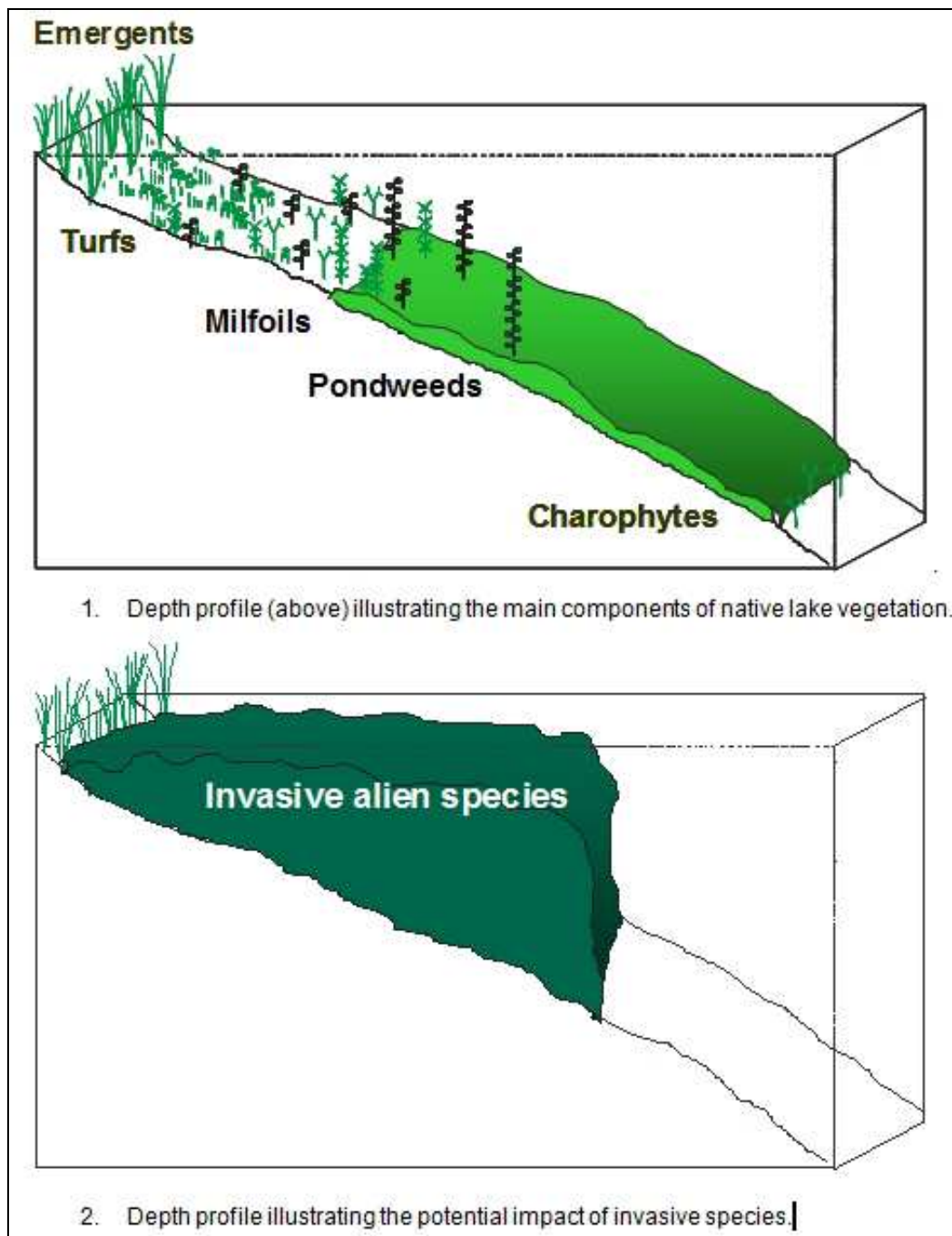


Figure 2: Depth profiles within a lake illustrating the difference between a lake maintaining native plant communities and that which is invaded with invasive weed species.

2 Study methods

2.1 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. 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 extent 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 represents 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 2006b).

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%.

A complete description of measured characteristics is given in the technical report and user manual at www.lakespi.niwa.co.nz/about. The LakeSPI method is supported by a web-reporting service found at www.lakespi.niwa.co.nz, where scores for lakes assessed to date can be searched and displayed. This secure and freely-accessible data repository allows agencies to compare lake scores with other lakes regionally and nationally as required.

2.2 Field surveys

The LakeSPI method was reapplied at five established baseline sites within each of the six lakes re-assessed for this year: Okareka, Rotoiti, Rotoma and Rotomahana assessed in April, and Lake Rotorua assessed in June 2013.

Baseline sites were re-located with reference to site maps, GPS references and shoreline photos. At each site, divers recorded relevant vegetation characteristics on data sheets. A full description of the vegetation features that are assessed for the LakeSPI method can be found in the technical report and user manual on the web-reporting pages (www.lakespi.niwa.co.nz), but includes measures of diversity from the presence of key plant communities, the depth extent of vegetation and the extent that invasive weeds are represented.

Observations were then entered into the NIWA LakeSPI database and used to calculate LakeSPI indices for each lake.

2.3 LakeSPI stability

Changes in LakeSPI indices over a recent time-frame, taken as since 2008 (i.e., the last four to five years or three to four surveys), provide an indication of current stability in lake condition and the direction of any change. Guidelines (Figure 3) give a scale of probabilities for ecologically significant change in lake condition over longer periods and multiple surveys, using averaged LakeSPI indices over repeated surveys. These guidelines, based on expert judgement, have considered variation by different observers and the response of LakeSPI scores to major ecological events in lakes.

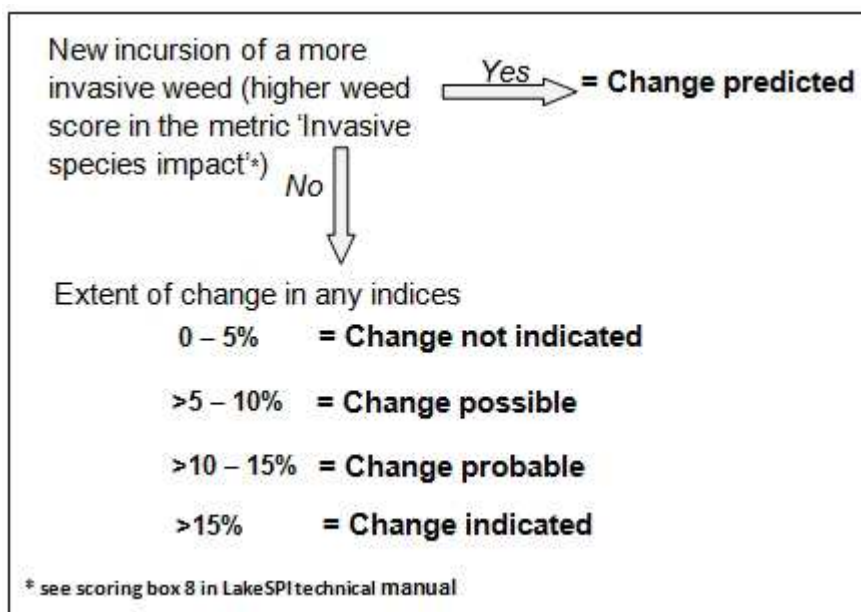


Figure 3: Guidelines for assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.

2.4 LakeSPI Status

For ease of reporting results, five lake condition categories are used to provide a description of a lakes status at the time of a survey. These categories are allocated according to the LakeSPI Index score:

Score	= LakeSPI Category
>75%	= Excellent
>50-75%	= High
>20-50%	= Moderate
>0-20%	= Poor
0%	= Non-vegetated

3 Results

Table 2 presents LakeSPI results for each lake, with the indices presented as a percentage of maximum scoring potential. In the following section 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 Te Arawa lakes in order of their overall lake condition (2012 or 2013).

Lake	Most Recent LakeSPI Survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Rotoma	16/04/2013	55	57	42	High
Okataina	29/03/2012	44	47	63	
Rotomahana	15/04/2013	42	48	59	
Tikitapu	08/02/2012	41	33	48	
Rerewhakaaitu	28/03/2012	36	52	78	
Okareka	15/04/2013	36	41	70	Moderate
Okaro	15/04/2013	35	25	49	
Rotokakahi	29/03/2012	31	26	75	
Tarawera	28/03/2012	24	26	88	
Rotorua	12/06/2013	23	25	82	
Rotoiti	15/04/2013	21	31	91	
Rotoehu	29/03/2012	18	24	90	Poor

3.1 Lake Rotoma



Lake condition: High
 Stability: Stable
 Lake ranking: 1st

Lake Rotoma is the highest ranked lake in the Rotorua region and is categorised as being in high ecological condition with a LakeSPI Index of 55% (Figure 4).

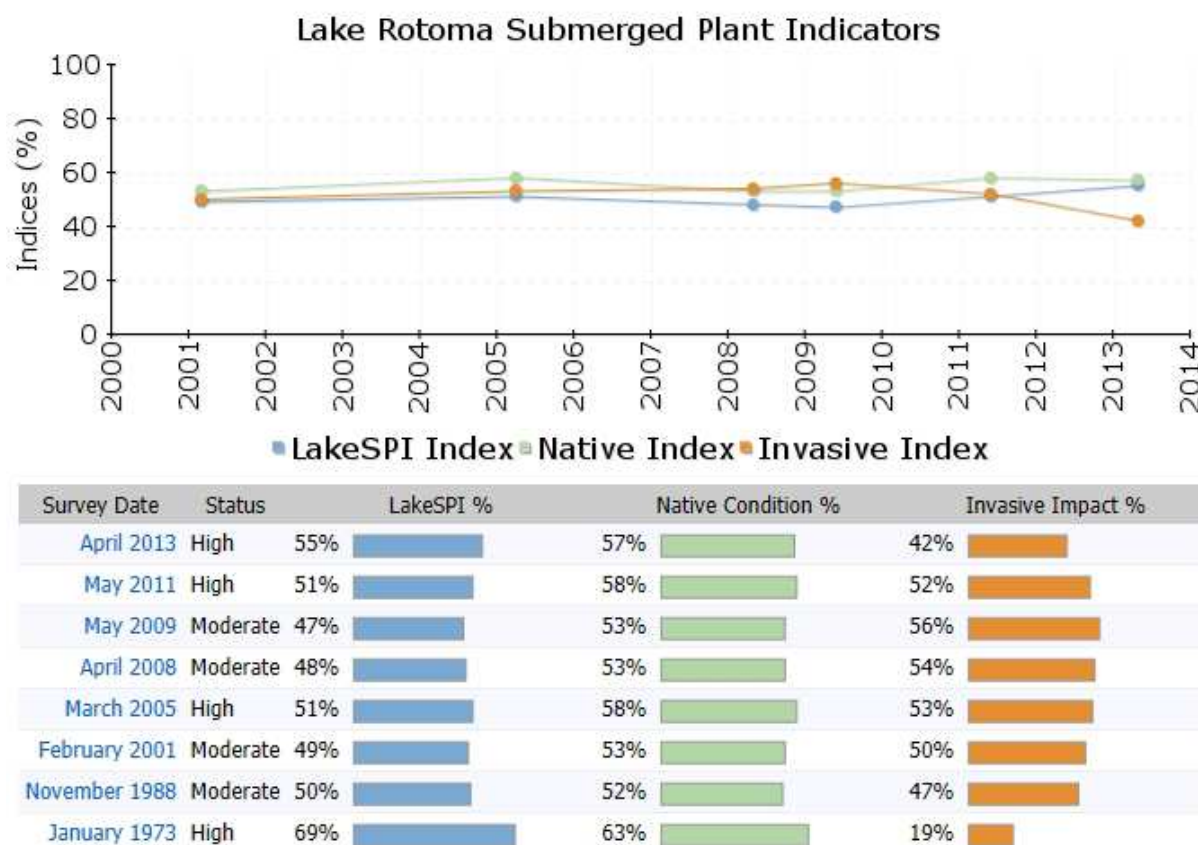


Figure 4: LakeSPI results for Lake Rotoma. LakeSPI Indices expressed as a percentage of lake maximum potential.

LakeSPI scores for lake Rotoma have remained stable over the last 25 years, from 1988 – 2013. A minor increase in the LakeSPI Index during the recent survey resulted from lower abundance of the weed lagarosiphon at some baseline sites. Lagarosiphon is still the dominant invasive plant species in Lake Rotoma, growing down to a maximum depth of 6.1

m. Lake Rotoma was retrospectively calculated to have a high LakeSPI score in 1973, which reflected the early stage of lagarosiphon invasion and the extensive high cover charophyte meadows in this lake (Clayton 1978). By 1988 the Invasive Impact Index had more than doubled, and the Native Condition Index decreased, which in turn reduced the LakeSPI score for this lake. Since then, changes have been minor. As a result this lake presently has the highest Native Condition Index for any of the lakes and the lowest Invasive Impact Index 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 in 2013 after 40 years, which provides good evidence for the stability in water clarity during this period. This confirms that the impact of invasive species on submerged vegetation was the key early driver of change in LakeSPI scores.

The proximity of hornwort in Lake Rotoehu continues to raise particular concern over the risk of spread to Lake Rotoma, with contaminated boat traffic representing the greatest threat.

3.2 Lake Okataina



Lake condition: Moderate

Stability: Stable

Lake ranking: 2nd

Lake Okataina is categorised as being in moderate ecological condition with a LakeSPI Index of 44% (Figure 5).

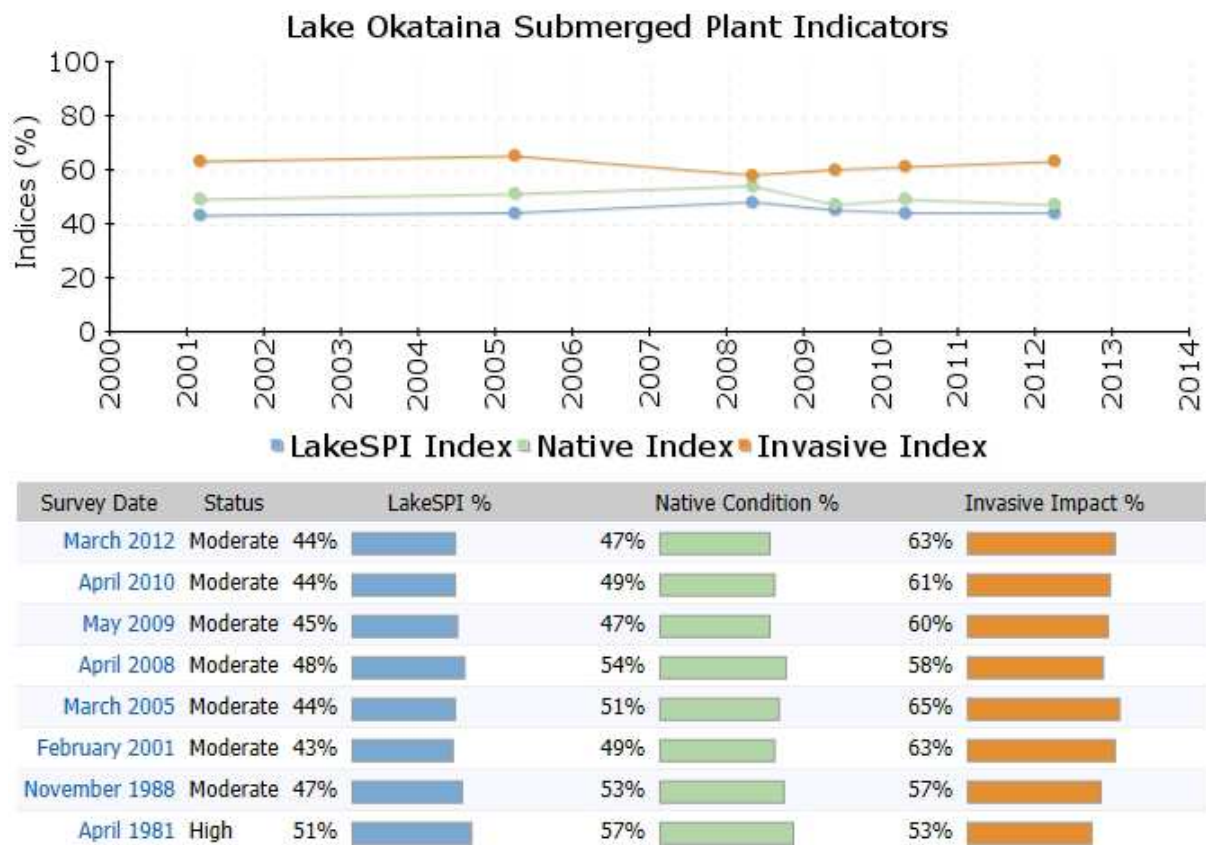


Figure 5: LakeSPI results for Lake Okataina. LakeSPI Indices expressed as a percentage of lake maximum potential.

A moderate LakeSPI index results from the maintenance of native plant communities that are impacted to a degree by the invasive weed lagarosiphon. Native charophyte species formed meadows at most baseline sites in Okataina in 2012, growing down to a maximum depth of 15.6 m. Lagarosiphon remained the dominant invasive species present, forming high cover weed beds at most sites and generating an Invasive Impact Index of 63%.

Hornwort is in the early stages of invasion and is not yet recorded at any LakeSPI sites, but continues to pose the most serious threat to the future condition of Lake Okataina. Hornwort was first detected in Lake Okataina in 2007, but this colony was successfully eradicated. It was not until 2009 that the detection of additional drift fragments led to the discovery of a major hornwort incursion in 2010. Incursion management to date, using a weed cordon and diquat herbicide, has likely reduced the spread and impact of hornwort. Therefore, reductions in LakeSPI scores may not be so rapid or substantial in this lake as in the other waterbodies that have recently been invaded by hornwort.

Over the long-term, LakeSPI scores for Lake Okataina have also been stable, with only minor fluctuations. Care must be taken however in interpreting small scoring variations. Lake Okataina has no outlet and water levels can vary by several metres, so there is potential for water levels to affect the available habitat for submerged vegetation in shallow water, and the maximum depth of charophyte colonisation. Nevertheless, these water level changes tend to be slow, so vegetation can usually compensate by migrating up- and down-slope.



Figure 6: Invasive weed bed of hornwort (*Ceratophyllum demersum*) forming a wall of growth 8 m high and growing down to 12 m depth at the south-western end of Lake Okataina in 2010.

3.3 Lake Rotomahana



Lake condition: Moderate

Stability: Declining

Lake ranking: 3rd

Lake Rotomahana is categorised as being in moderate ecological condition with a LakeSPI Index of 42% (Figure 7).

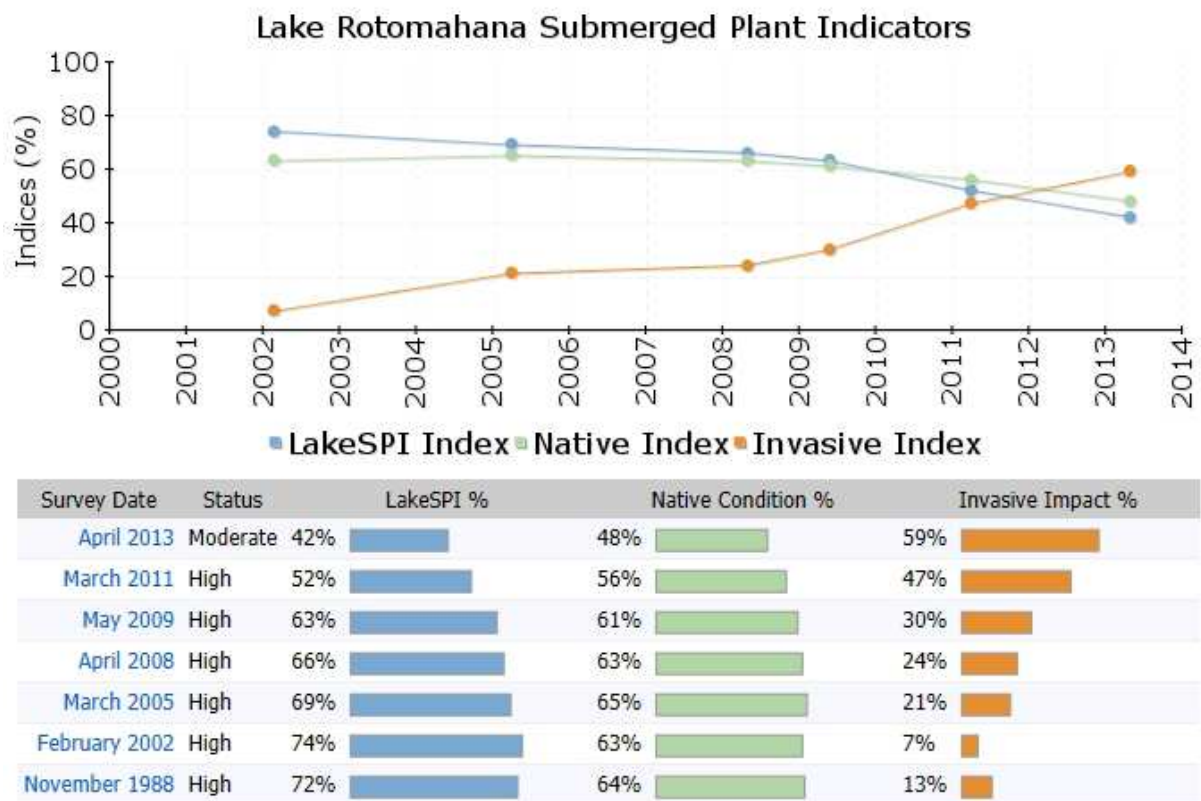



Figure 7: LakeSPI results for Lake Rotomahana. LakeSPI Indices expressed as a percentage of lake maximum potential.

After being the highest ranked lake in the Rotorua region for more than 20 years, declining lake condition has resulted in Lake Rotomahana moving into third rank order. The LakeSPI Index has dropped 24% since 2008 which is the largest change recorded for any of the 12 Rotorua Te Arawa lakes over this recent time frame and Invasive Impact scores have more

than doubled. This is largely due to the invasion and continued spread by two of New Zealand's worst aquatic plant species, egeria and hornwort. Discovered for the first time in April 2007, egeria was found to be established in only 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 hornwort now present at 2 of the 5 LakeSPI baseline sites and egeria at all 5 LakeSPI baseline sites. Egeria is now forming intermittent bands of weed growth in shallow waters down to a maximum depth of 6.9 m. The most recently recorded average maximum depth of vegetation (9.3 m) had reduced by more than 2 m since the 2009 survey when aquatic vegetation was recorded down to an average maximum depth of 11.4 m. This reduction in the depth and extent of vegetation is concerning and as both egeria and hornwort continue to further impact on the diversity and quality of indigenous plant communities in Lake Rotomahana, we can expect to see the Native Condition Index decline further while the Invasive Impact Index will continue to increase. 

The presence of *Lymnaea auricularia* (ear pond snail), discovered and already widespread during the 2011 survey, suggests an aquarium or ornamental pond source for egeria, hornwort and the ear pond snail, or possibly a deliberate release.

3.4 Lake Tikitapu



Lake condition: Moderate
 Stability: Improving?
 Lake ranking: 4th

Lake Tikitapu is categorised as being in moderate ecological condition with a LakeSPI Index of 41% (Figure 8).

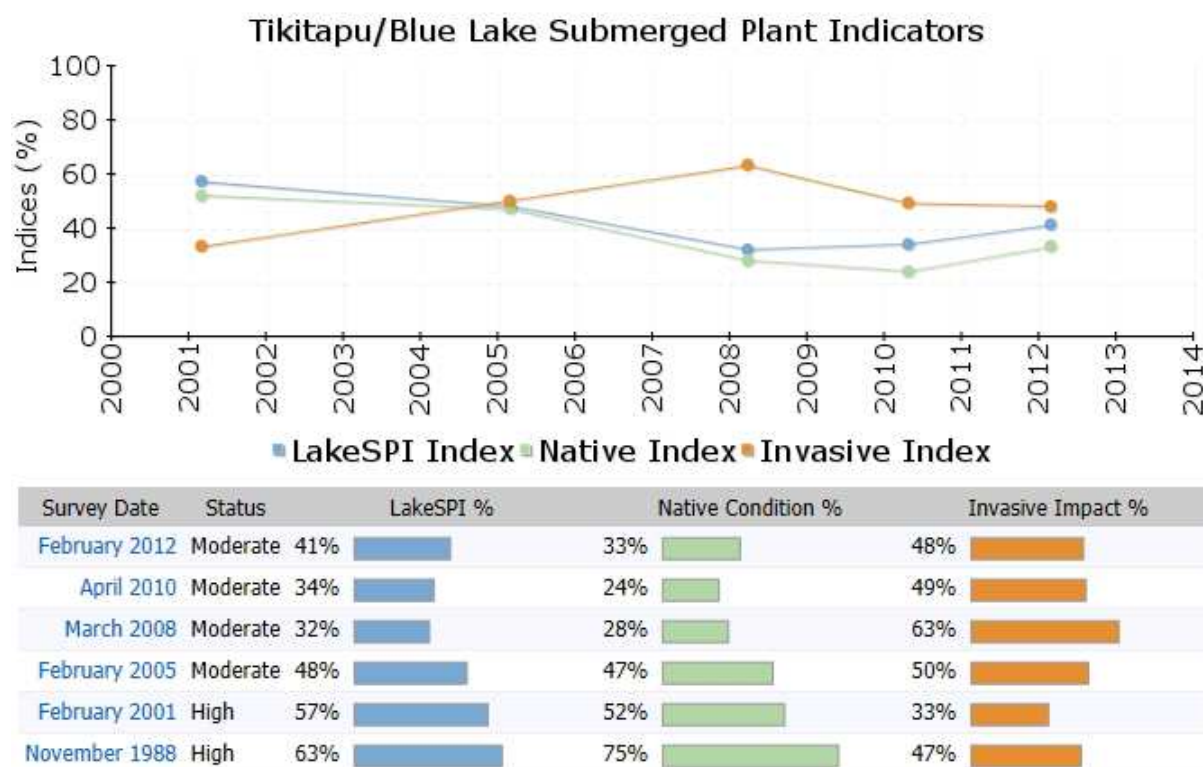



Figure 8: LakeSPI results for Lake Tikitapu. LakeSPI Indices expressed as a percentage of lake maximum potential.

This result indicates that there could be a minor recent improvement in the condition of Lake Tikitapu since the last survey, reflected by an increase in Native Condition scores from 24% in 2010 to 33% in 2012. However, changes over the recent time-frame are obscured by the intermittent development of deep water charophytes at depths of between 16 and 18 m, which greatly extend the otherwise shallow depth limit (5-6 m) for vegetation.

Caution must be used with interpreting the recent LakeSPI results for Lake Tikitapu. While some level of recent recovery in lake condition may be encouraging, the longer term trend has been one of a substantial reduction in Native Condition Index (Figure 17) reflecting a **loss in the diversity and extent of the native plant communities present**. Unlike most other lakes, decline has not been due to the **impact from new invasive species**. 

Historic records for **Lake Tikitapu also confirm the lake has been deteriorating over time**. Brown (1975) stated that charophytes in Lake Tikitapu formed a dense “meadow with 100% ground cover at depths from 4 to 20 m”, 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. Since 2008 maximum plant depths across survey sites have been variable, with **large un-vegetated areas occurring upslope of any deeper charophyte development**.

Although the aquatic weed lagarosiphon currently has a similar Invasive Impact Index to what was recorded in 1988 (Figure 8), this plant has also decreased in abundance. However, its relative influence on the submerged vegetation as a whole has remained the same or increased slightly over the recent time-frame.

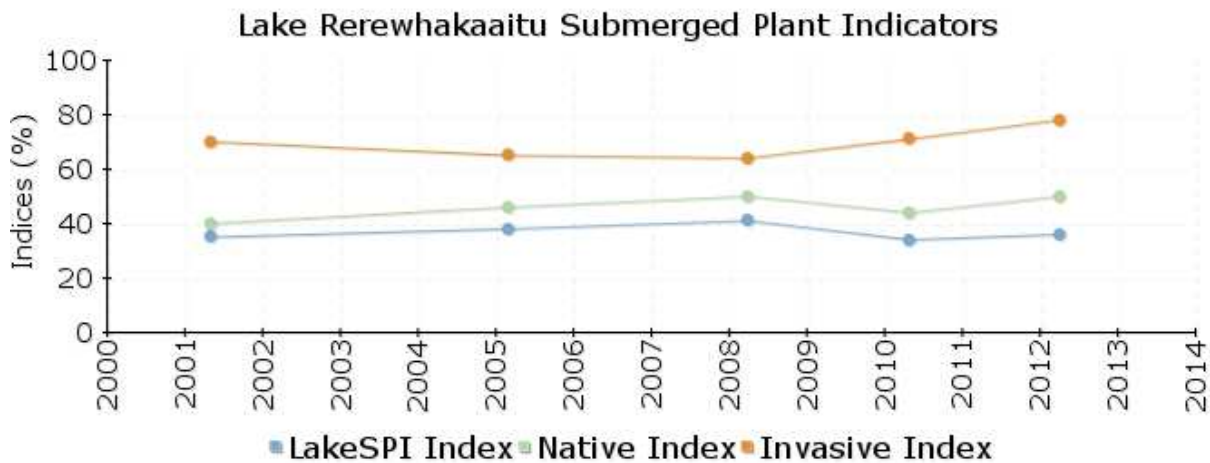
When the water chemistry of Lake Tikitapu was assessed in the early 1970s it had the lowest alkalinity recorded for any of the Rotorua Te Arawa lakes and it also had low sediment and water nutrient levels (McColl 1972). The reported low alkalinity, calcium and silicon levels may explain the on-going absence of kakahi, the low abundance of snails, koura and planktonic diatoms and even the unusual low stature and lax growth habit of lagarosiphon in this lake.

3.5 Lake Rerewhakaaitu



Lake condition: Moderate
 Stability: Declining?
 Lake ranking 5th equal

Lake Rerewhakaaitu is categorised as being in moderate ecological condition with a LakeSPI Index of 36% (Figure 9).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2012	Moderate	36%	50%	78%
April 2010	Moderate	34%	44%	71%
March 2008	Moderate	41%	50%	64%
February 2005	Moderate	38%	46%	65%
April 2001	Moderate	35%	40%	70%
November 1988	Moderate	41%	47%	57%
February 1973	High	55%	56%	37%

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

Increasing Invasive Impact scores over the long-term reflect the impacts that invasion by lagarosiphon, and more recently egeria, have had upon the lake. Egeria was introduced in 2000 (Champion et al. 2006) and by 2008 egeria was present at 2 of the 5 LakeSPI baseline sites. **By the 2010 survey, egeria had spread to all 5 sites,** causing an incremental rise in the

Invasive Impact score and during the 2012 survey, egeria was present at all 5 baseline sites growing to a maximum depth of 7 m. This development is reflected in the **increased Invasive Impact score and reduced LakeSPI Index since 2008**. Nevertheless, an increase in the depth extent of native plants, likely due to improved water clarity since the last survey, had compensated to some degree for the impact that egeria was having on the overall LakeSPI Index. Egeria is expected to have an increased negative impact on overall LakeSPI condition in years to come.

The submerged vegetation of Lake Rerewhakaaitu 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 Te Arawa 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 and egeria) or hornwort 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 plants to 5.5 metres.

By 1988, Lake Rerewhakaaitu showed two significant changes in the submerged vegetation. Firstly, water clarity improved, enabling charophyte meadows to extend approximately twice as deep (c. 8-9 m). Secondly, lagarosiphon invaded and caused a substantial increase in the Invasive Impact Index, which then increased slightly over the ensuing 20 years to 2008. LakeSPI scores decreased in response to lagarosiphon invasion, while impacts on the Native Condition Index were partly negated by the improved water clarity and extension in charophyte depth limits.



3.6 Lake Okareka



Lake condition: Moderate
 Stability: Stable
 Lake ranking: 5th equal

Lake Okareka is categorised as being in moderate ecological condition with a LakeSPI Index of 36% (Figure 10).

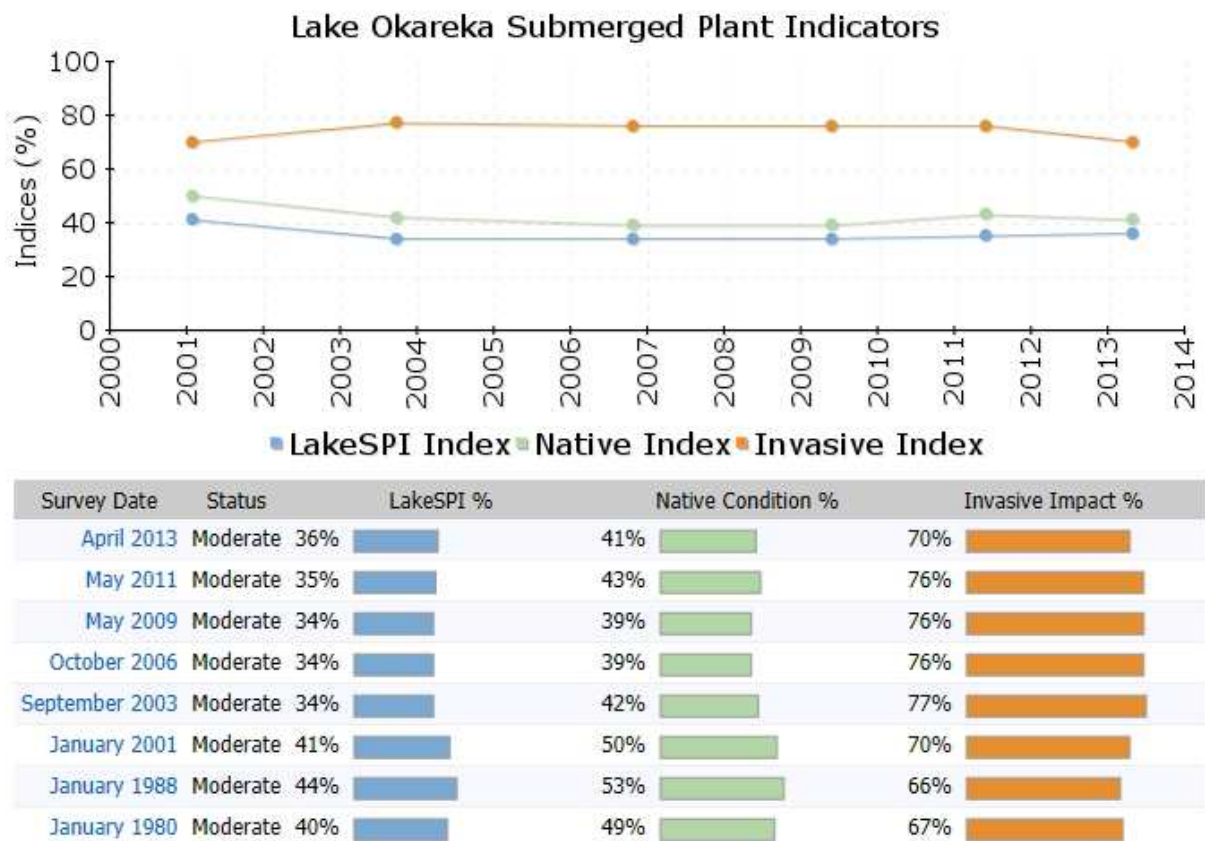


Figure 10: LakeSPI results for Lake Okareka. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Okareka is **currently in a stable condition** indicated by the recent LakeSPI indices showing little change since 2008 (Figure 10). Prior to this however, a small increase in the Invasive Impact Index in 2003 due to the establishment of egeria, led to a 10% decrease in the LakeSPI Index.

Egeria 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. Egeria is expected to continue spreading around the lake, displacing lagarosiphon with taller and denser weed growth and occupying a wider depth range. A hornwort incursion in the lake in March 2012 is of concern for the future ecological condition of Lake Okareka, although it has not yet been recorded at LakeSPI sites. Hornwort poses a greater threat to this lake than egeria, with the potential to reduce the LakeSPI Index further, by occupying a deeper range than egeria and by displacing all remaining deep water charophyte meadows.



3.7 Lake Okaro



Lake condition: Moderate

Stability: Improving

Lake ranking: 6th

Lake Okaro is categorised as being in moderate ecological condition with a LakeSPI Index of 35% (Figure 11).

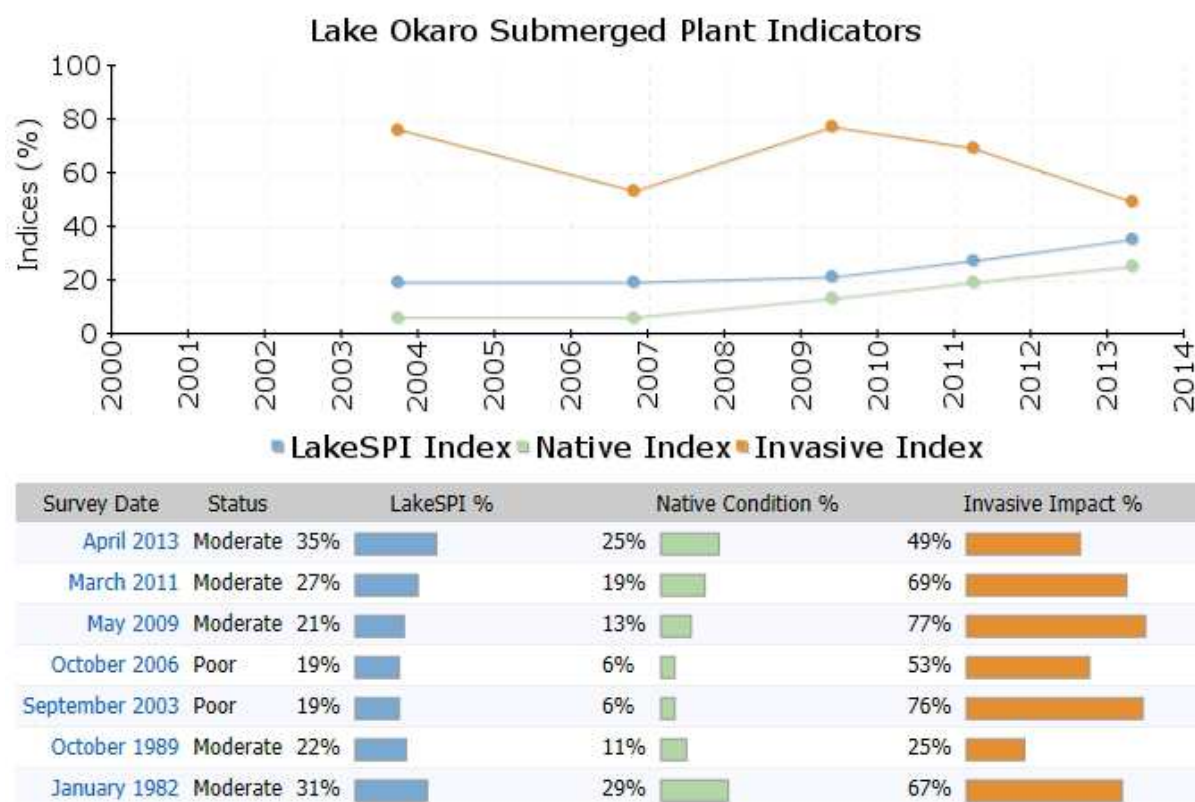


Figure 11: LakeSPI results for Lake Okaro. LakeSPI Indices expressed as a percentage of lake maximum potential.

The degraded nature of Lake Okaro and its **fluctuations in water quality and clarity** largely account for variations in LakeSPI scores generated for this lake over the long-term, and in the Invasive Impact scores in particular. LakeSPI results since 2008 however, suggest a **recent improvement in the condition** of Lake Okaro and it is now ranked in moderate condition. Over the recent time-frame, the Native Condition Index has nearly doubled to 25%

and the **LakeSPI Index has increased by 21% to 35%**. This result may reflect recent efforts by BOPRC to reduce nutrient influx into the lake and nutrient release from hypolimnetic sediments, which might have improved water clarity and resulted in a positive vegetation response. While these improvements are promising, care must be taken when interpreting any kind of recovery in the condition of Lake Okaro at this stage as it is still recognised as a highly variable and sensitive lake system.

Elodea remains the only invasive species reported in Lake Okaro. Historically the hypereutrophic nature of the lake has provided an unfavourable habitat for submerged vegetation. This is reflected in the highly variable cover and depth range of elodea. On several occasions in earlier surveys we have observed rooted elodea beds in shallow water, while from around 2 m depth and deeper all elodea was non-rooted 'drift'. This may well coincide with periods of stratification with anoxia or reduced light at or below a thermocline resulting in root death and shoot detachment.

3.8 Lake Rotokakahi



Lake condition: Moderate
 Stability: Stable
 Lake ranking 7th

Lake Rotokakahi is categorised as being in moderate ecological condition with a LakeSPI Index of 31% (Figure 12).

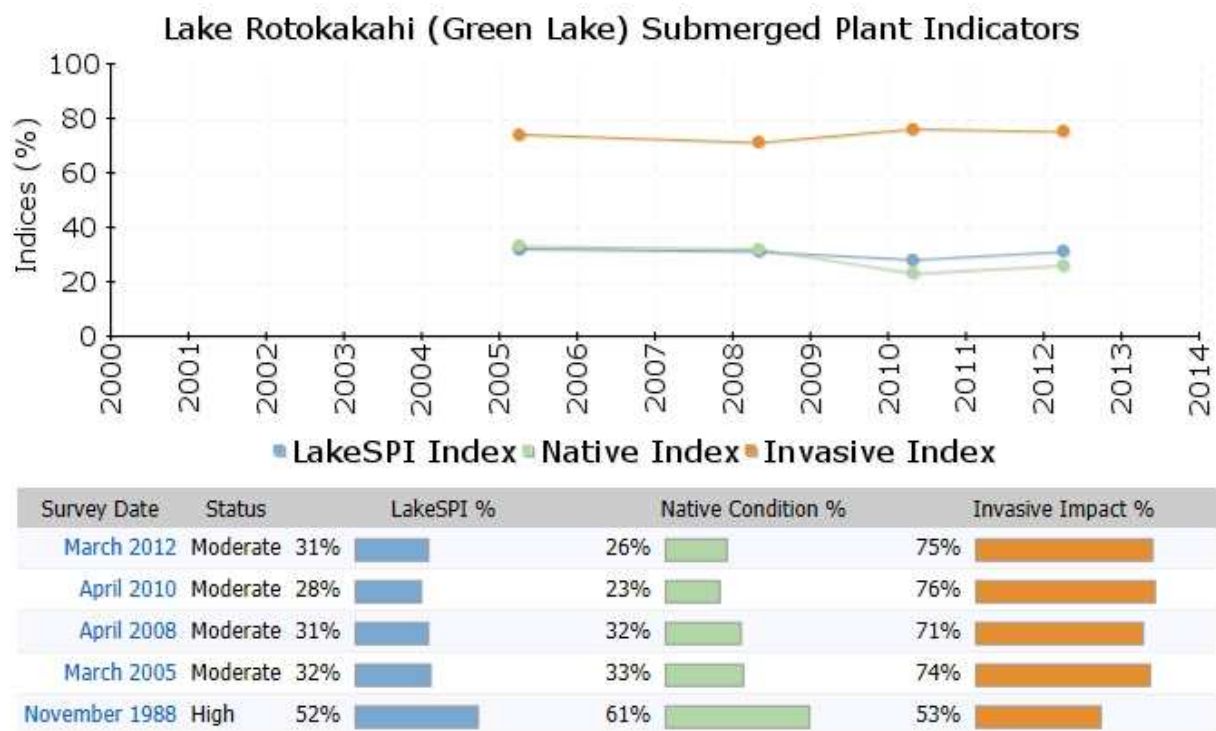


Figure 12: LakeSPI results for Lake Rotokakahi. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Rotokakahi has undergone one of the largest declines in lake condition as indicated by LakeSPI for any of the 12 lakes over the long-term (Figure 17), but most of this change took place prior to 2005. The LakeSPI Index has shown a reduction of 21% from 1988 to 2012, whilst the Native Condition Index has also declined by 35% largely due to a decline in charophyte meadows. This has occurred even though there has been no new invasive species recorded in this lake, although invasive impact of elodea slightly increased due to its greater occupancy of the vegetation with the decline of charophyte meadows.

The declining condition of Lake Rotokakahi, is not due to invasive weeds, but rather a decline in native condition presumably due to a change 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 enrichment. 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 deforestation in the catchment may also be a contributing factor. A decline in oxygen content in deeper water was noted by David Hamilton in 2010 (Waikato University pers comm.), which is consistent with hypolimnetic nutrient enrichment taking place. Lake Rotokakahi, together with Lake Okaro, are the only Rotorua Lakes to remain relatively free of the more invasive weed species.

3.9 Lake Tarawera



Lake condition: Moderate

Stability: Stable

Lake ranking 8th

Lake Tarawera is categorised as being in moderate ecological condition with a LakeSPI Index of 24% (Figure 13).

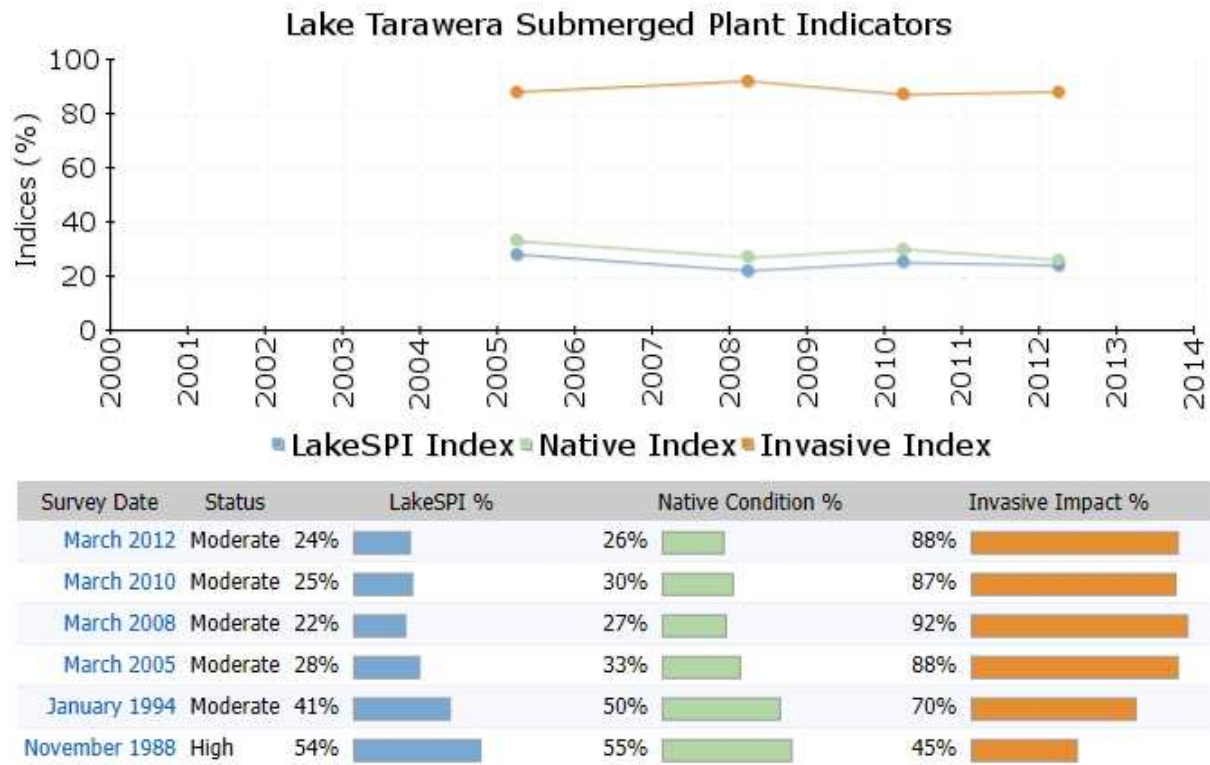


Figure 13: LakeSPI results for Lake Tarawera. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Tarawera has remained in a moderate condition over the recent time-frame. A large reduction in LakeSPI Index occurred between 1988 and 2005, driven by the invasion of hornwort, but recent change has been small since the full impact of hornwort has now taken place.

At the time of the 1988 survey, lagarosiphon and elodea were the two dominant invasive weed species in Lake Tarawera. Although hornwort 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). By 2005, hornwort was responsible for the widespread displacement of almost all former deep water charophyte meadows in the lake resulting in a much lower LakeSPI Index of 28% (Figure 13).

3.10 Lake Rotorua



Lake condition: Moderate

Stability: Stable

Lake ranking 9th

Lake Rotorua is categorised as being in moderate ecological condition with a LakeSPI Index of 24% (Figure 14).

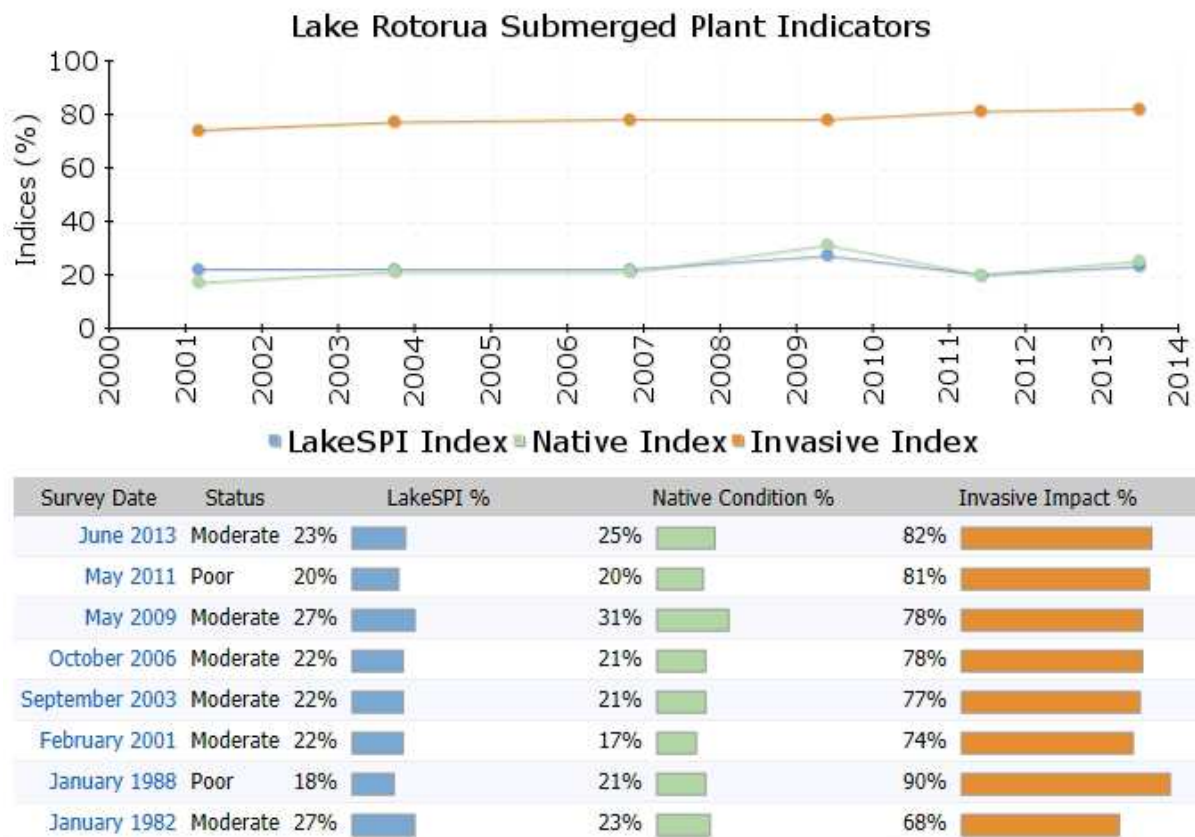


Figure 14: LakeSPI results for Lake Rotorua. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Rotorua has remained in a **stable condition long-term**, as indicated by LakeSPI. 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. Slight variations in Native Condition Index reflect some variability in the development of these communities from year to year, but these changes are small and have not been sustained.

The early variation in Invasive Impact Index over 1988 to 2001 was attributable to the 'boom and 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 and Clayton, 1991). In the early 1990s egeria underwent a major decline and has never recovered.





3.11 Lake Rotoiti



Lake condition: Moderate
 Stability: Stable
 Lake ranking: 10th

Lake Rotoiti is categorised as being in moderate ecological condition with a LakeSPI Index of 21% (Figure 15).

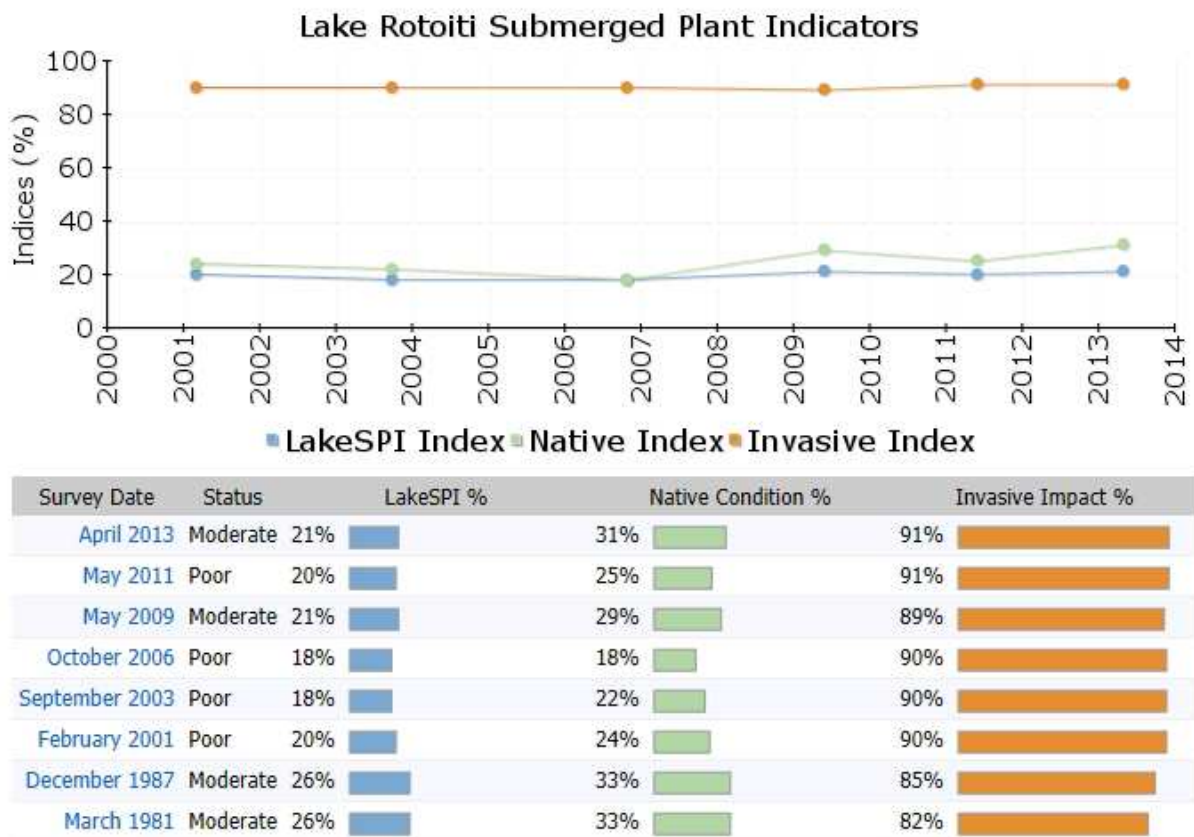


Figure 15: LakeSPI results for Lake Rotoiti. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Rotoiti has consistently had one of the highest Invasive Impact Index scores and continued to have one of the lowest LakeSPI Indices so far recorded for any of the 12 lakes in this region. Development of some deeper charophyte meadows and increases in the Native Condition Index more recently are suggestive of a slight improvement in lake condition.

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 Lake 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 in 2008 to entrain Lake Rotorua inflows down the Kaituna River may have seen a reduction in water quality impacts. However flow-on effects on submerged vegetation are not yet confirmed. 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.

3.12 Lake Rotoehu



Lake condition: Poor
 Stability: Declining?
 Lake ranking 11th

Lake Rotoehu is categorised as being in poor ecological condition with a LakeSPI Index of 18% (Figure 16).

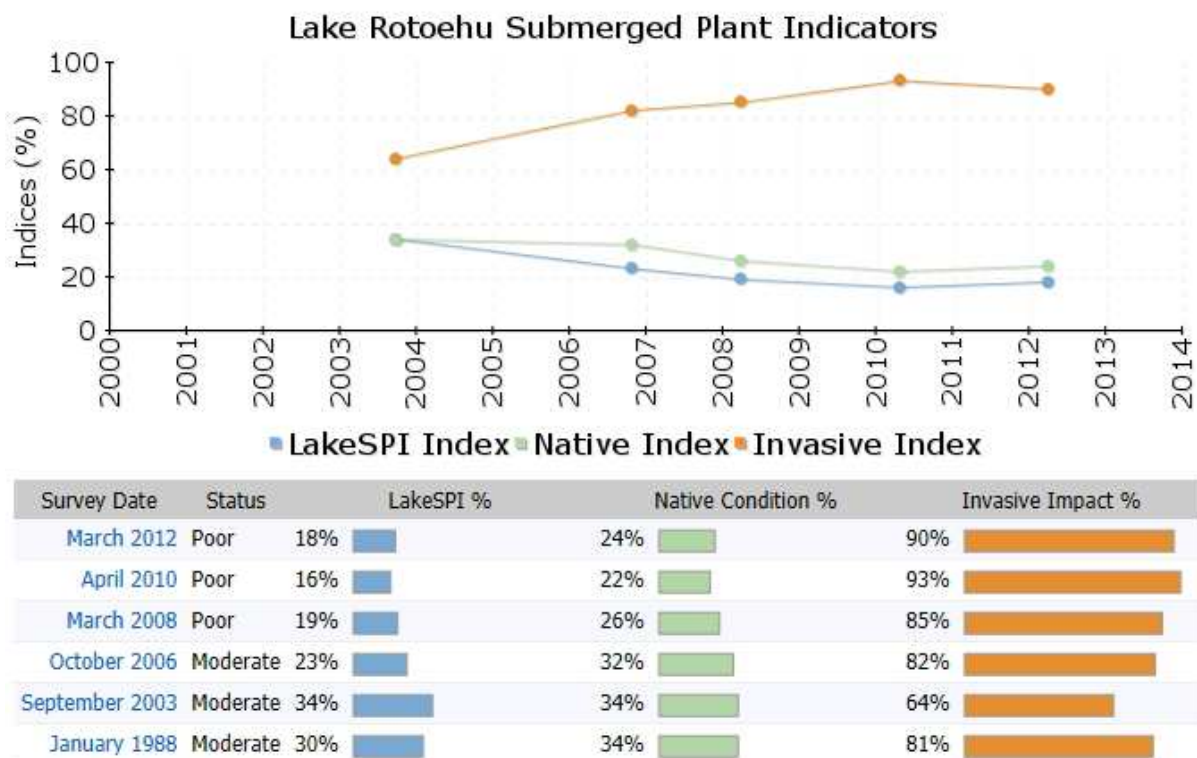


Figure 16: LakeSPI results for Lake Rotoehu. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Rotoehu now has the lowest LakeSPI Index (18%) and one of the highest Invasive Impact scores (90%) recorded for any of the 12 Rotorua Te Arawa lakes (Figure 16). This reflects a major infestation of hornwort which has spread through the lake resulting in a halving of the LakeSPI Index since the 2003 survey. Hornwort was first recorded in the lake off Otautu Bay in December 2004 (R. Mallinson, BOPRC, pers comm.) and by late summer

2005 there were extensive weed beds along much of the shoreline. Since 2008, LakeSPI results demonstrate the negative impact hornwort is having on native submerged vegetation within the lake as it approaches 'habitat saturation' in this waterbody. Lake Rotoehu remains in the bottom group of lakes, categorised as being in 'poor' condition.

On a positive note, given the recent history of poor water quality and frequent blue-green blooms, it is quite possible the development of extensive hornwort beds around the margins of this shallow lake may reduce algal blooms by storing nutrients, despite the detrimental impact hornwort will have on littoral condition. Nutrient removal by means of weed harvesting may not only reduce weed impact but also help remove internal lake nutrients. Out of all the Rotorua Te Arawa 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). The fourth year of weed harvesting in Lake Rotoehu commenced in March 2013 and expectations were to remove 1,500 – 3,000 tonnes of hornwort from the lake, and thus 3.5 to 7.0 tonnes of nitrogen (Lakes Water Quality Society 2012).

4 Discussion

4.1 Current lake stability

Changes in LakeSPI indices over the recent time-frame (since 2008) have been used to provide an indication of current stability in lake condition and the direction of any change (Table 3).

Table 3: Summary of current LakeSPI results for assessed lakes showing overall condition category, current stability rating, long term changes in condition and an indication of the main impact factor affecting scores.

Lake	LakeSPI Index (%)	Overall Condition	Current Stability (~5 years)	Long term changes (>20 years)	Impact factor
Rotoma	55	High	Stable	Change not indicated	Weed
Ōkātaina	44	Moderate	Stable	Change not indicated	Weed
Rotomahana	42	Moderate	Declining	Change indicated	Weed
Tikitapu	41	Moderate	Improving?	Change indicated	Water Quality
Rerewhakaaitu	36	Moderate	Declining?	Change indicated	Weed
Ōkāreka	36	Moderate	Stable	Change possible	Weed
Okaro	35	Moderate	Improving	Change possible	Water Quality
Rotokakahi	31	Moderate	Stable	Change indicated	Water Quality
Tarawera	24	Moderate	Stable	Change indicated	Weed
Rotorua	23	Moderate	Stable	Change not indicated	Water Quality
Rotoiti	21	Moderate	Stable	Change not indicated	Water Quality
Rotoehu	18	Poor	Declining?	Change probable	Weed

Lake Okaro and Tikitapu showed some improvement in LakeSPI scores over this timeframe, however these lakes are recognised as being sensitive and variable in nature so care must be taken when interpreting any kind of improvement at this stage. Lake Rotomahana, the third highest ranked lake in the Rotorua region, has shown a marked decline in lake condition scores. The LakeSPI Index, has declined from its maximum potential by 24% since 2008 which is the largest change recorded for any of the 12 Rotorua Te Arawa lakes over this 5 year time frame largely due to the continual spread and impact by two of New Zealand's worst aquatic plant species, egeria and hornwort, in the lake. Lake Rerewhakaaitu has also deteriorated due to the expanding influence of egeria over recent years since its introduction in 2000. Recent LakeSPI scores for Lake Rotoehu have changed little as hornwort approaches complete 'habitat saturation'. All remaining Rotorua Te Arawa lakes currently appear to be in a stable condition, with little change in scores, although future change is

expected for those at risk from expanding invasive plants (Lakes Rotoma, Okataina, Okareka).

4.2 Long term changes

Longer term, many of the Rotorua Te Arawa Lakes have undergone significant change over the last two decades (Table 3, Figure 17).

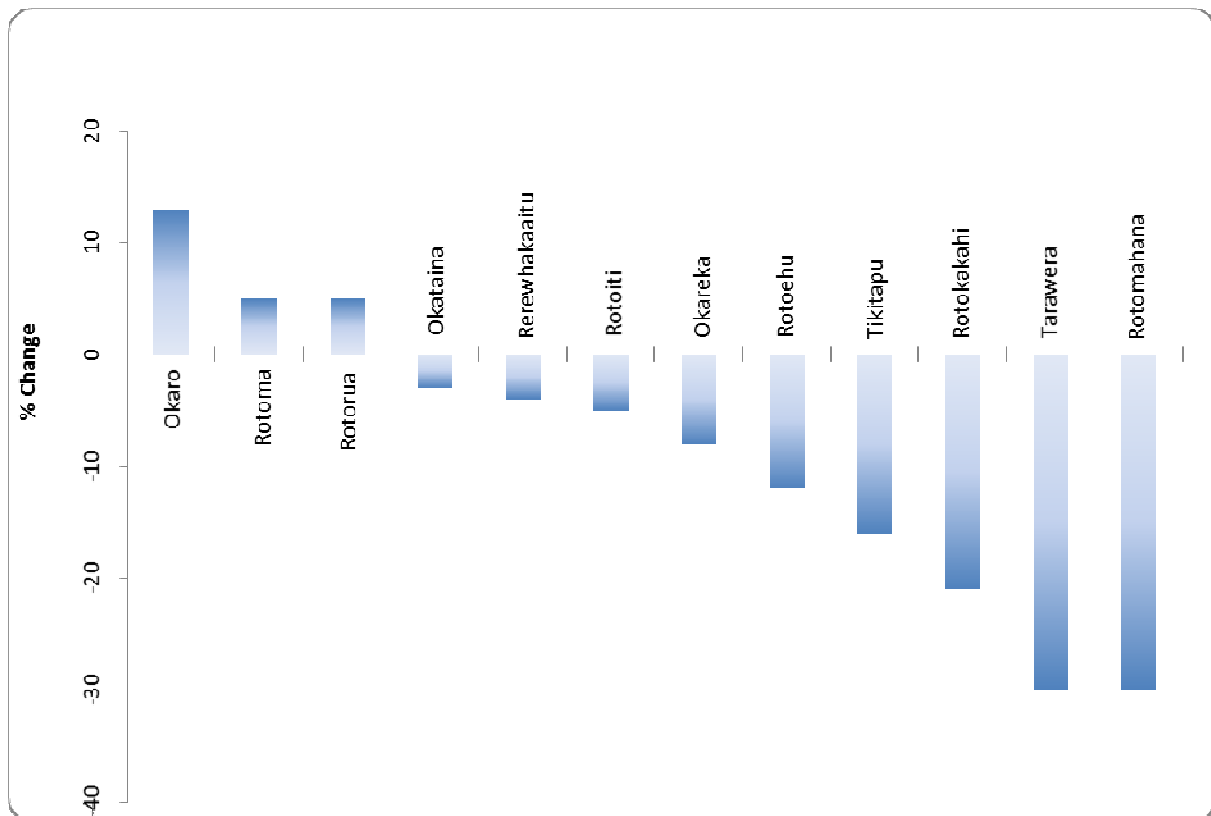


Figure 17: Percentage of change as indicated by the LakeSPI Index over the last 25 years, 1988/1989 to 2012/13.

Lakes Tarawera and Rotomahana show the biggest change in lake condition over the last 24-25 years resulting from invasion by New Zealand's worst submerged plant species. Not only do these species cause physical and biological changes in the lake littoral, they also impact on the amenity and aesthetics of lakes for the public. Invasive weeds also impact negatively on lake condition by excluding native plant communities from depths of less than 6-10 metres with the worst of these invasive species, hornwort, able to out-grow and smother native vegetation to around 15 metres depth. Hornwort is now present in 7 of the 12 Rotorua Te Arawa Lakes and is the dominant invasive weed in lakes Tarawera and Rotoehu. Lake Tarawera is now in a stable state and, since the full impact of hornwort has now taken place, it is not expected to change significantly in the near future. 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. Likewise we can expect to see a further decline in LakeSPI scores for Lake Rotomahana as hornwort continues to spread and occupy a deeper depth range than is currently occupied by egeria, However of most recent concern is the presence of hornwort in Lakes Okareka

(detected March 2012) and Okataina (detected March 2010). Based on the potential for hornwort to spread within these lakes and its likely impact, if unable to be controlled, we can expect to see a notable decline in the status of Lakes Okareka and Okataina in years to come.

Lake Rotoma remains at high risk of invasion by hornwort, which would have a major detrimental impact on the native character and biodiversity value of this lake. In 2008 BOPRC established a containment cordon out from the boat ramp at the western end of Lake Rotoma and in July 2010 established a second around the boat ramp at Matahi Spit. It is hoped these nets will act to help contain any hornwort fragments liberated at launch sites by boats or trailers coming from any nearby hornwort infested waterbodies, such as Lakes Rotoehu or Rotoiti, although they will not entirely remove the incursion risk.

Lake Rerewhakaaitu could also be severely impacted by hornwort, but the risk is less imminent on account of its greater distance from nearby infestations and much lower boat traffic.

Next to introduction of invasive plant species, the second biggest change affecting the condition of the Rotorua Te Arawa Lakes is water quality. Lakes Tikitapu and Rotokakahi show the next biggest changes in lake condition over the last 24-25 years and since there has been no new invasive species recorded since full lake surveys begun in 1988, the changes in these lakes are likely to be the result of deteriorating water quality and clarity. LakeSPI metrics (Submerged Plant Indicators) are able to integrate long term changes in water clarity 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 maximum depth of 19.5 m. By 2001 meadows had retracted to a mean maximum depth of 10.3 m and since then, charophyte meadows have only been recorded intermittently at sites.

4.3 National comparison

Compared nationally, the Rotorua Region has no lakes classified as being in 'excellent' condition (representing those close to their maximum potential ecological condition) and only one lake classified as being in 'high' condition (Figure 18 & 19).

A 'moderate' condition category contains the majority of the Rotorua Te Arawa Lakes and contains the largest proportion of lakes nationally. This 'moderate' condition group of Rotorua Te Arawa Lakes are representative of those lakes that are impacted in varying degrees by invasive weeds but still retain some native vegetation character

A smaller proportion of lakes nationally 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, as is the case in Lake Rotoehu, the only Rotorua Te Arawa Lakes ranked in this 'poor' category.

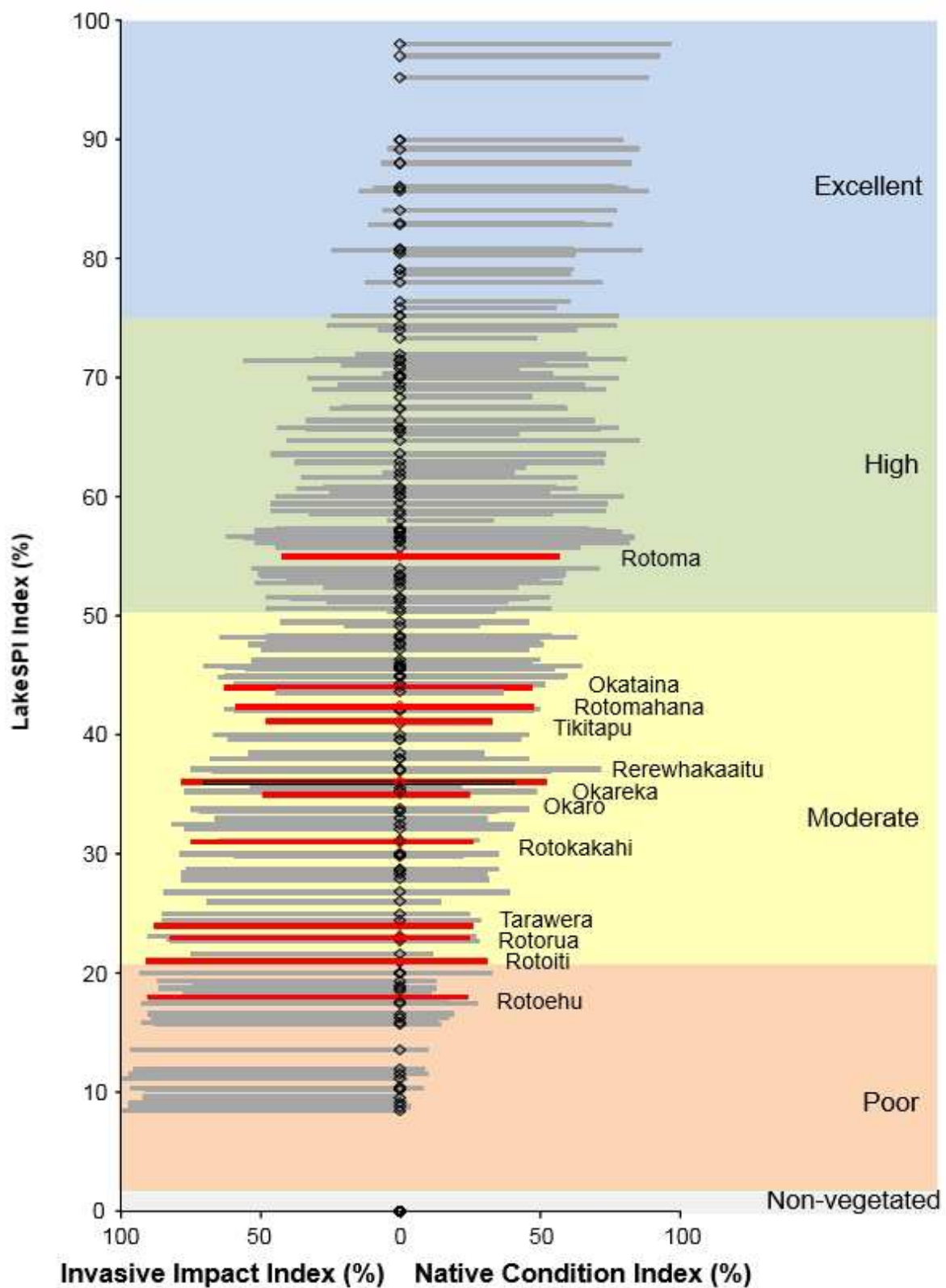


Figure 18: The most recent LakeSPI scores for the Rotorua Te Arawa Lakes (red lines) are plotted with scores for a total of 242 New Zealand lakes. The LakeSPI Index is plotted on the y-axis (points), Native Condition Index as lines to the right and Invasive Impact Index lines to the left of the x-axis. Five categories of LakeSPI condition are indicated by labelled colour bands.

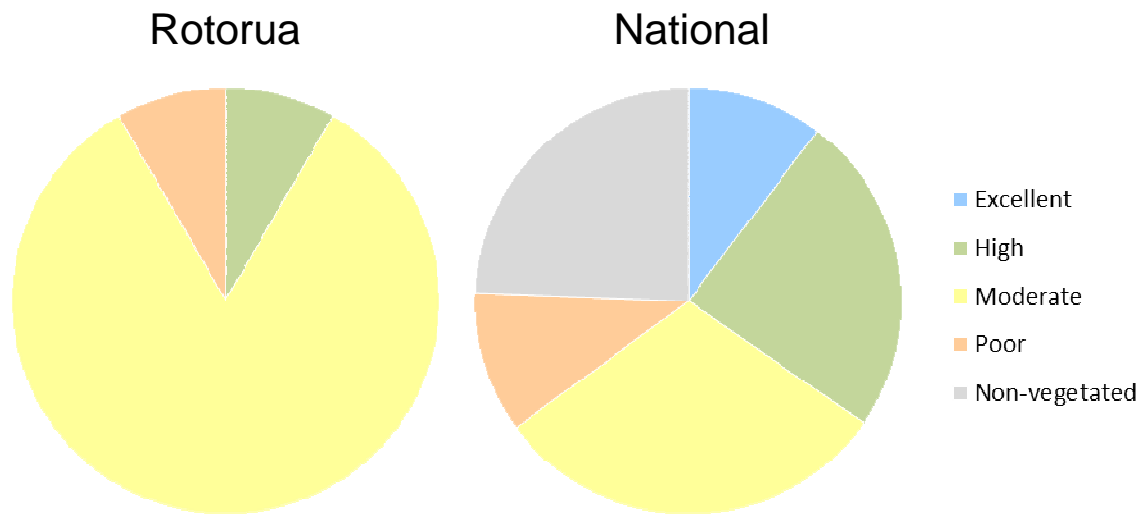


Figure 19: Proportion of lakes that fall into each of five categories of LakeSPI Index for the region (12) and nationally (242), with number of lakes assessed shown in parenthesis.

5 Conclusions

LakeSPI results show many of the Rotorua Te Arawa Lakes have undergone significant change over the last two decades while continuing to be vulnerable to further changes from invasive plants and water quality deterioration over the short term since 2008).

Present day LakeSPI Indices for lakes in the Rotorua region ranged widely from 18% to 55% with one Rotorua Te Arawa lake assessed as being in 'high' condition, ten lakes as 'moderate' and one lake categorised as in 'poor' condition. None of the 12 Rotorua Te Arawa lakes were recorded in the 'excellent' or 'non-vegetated' categories.

Lake Rotoma is categorised as being in 'high' condition and is the highest ranked lake in the Rotorua region. While it appears to maintain good water quality, it also remains under serious threat from potential hornwort invasion which would have a major detrimental impact on the native character and biodiversity value of this lake.

Lakes Okataina, Rotomahana, Tikitapu, Rerewhakaaitu, Okareka, Okaro, Rotokakahi, Tarawera, Rotorua and Rotoiti are currently ranked as being in 'moderate' condition. Lakes experiencing recent introductions of invasive weeds have either had impacts on LakeSPI scores over the last three surveys (egeria and hornwort in Lake Rotomahana and egeria in Lake Rerewhakaaitu) or are expected to be impacted in the near future (hornwort in Okataina and Okareka). A temporary reduction in charophyte depth limits for Lake Rerewhakaaitu over 2008 to 2010 also signalled some water quality concerns. Both Lakes Rotokakahi and Tikitapu have seen a reduction in the diversity and extent of native plant communities over the last 24 years without any direct change in invasive species. However, more recently these two lakes have been stable. Lakes Okaro and to a lesser extent, Rotoiti appear to be showing signs of improvement that may reflect recent management efforts by BOPRC. Lake Rotorua and Tarawera have been in a stable state according to recent LakeSPI results, following the earlier habitat saturation by hornwort in Lake Tarawera pre-2005.

Lake Rotoehu is classified as being in a 'poor' condition. This lake has the lowest LakeSPI Index and one of the highest Invasive Impact scores recorded for any of the 12 Rotorua Te Arawa lakes.

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

Lake Rotoma

- Overall lake condition high.
- Highest Native Condition Index and lowest Invasive Impact Index in the region.
- An exceptional lake and the best example of extensive charophyte meadows.
- Major threat from hornwort invasion.

Lake Okataina

- Overall lake condition moderate and appears stable.
- Recent invasion by hornwort poses a serious threat to future condition.
- High Native Condition Index.

Lake Rotomahana

- Overall lake condition moderate and declining.
- Recent invasion by egeria and hornwort having a significant impact.
- High Native Condition Index.

Lake Tikitapu

- Overall lake condition moderate and showing possible improvement.
- Major decline in Native Condition Index and LakeSPI scores over the last 22 years independent of any impact from new invasive species.
- Unusual water chemistry may inhibit impact from present and future invasive species.

Lake Rerewhakaaitu

- Overall lake condition moderate but appears to be declining.
- Invasion by egeria yet to fully influence LakeSPI Index.
- Moderate threat from hornwort invasion.

Lake Okareka

- Overall lake condition moderate, stable but likely to decline in the future.
- Invasion by egeria yet to fully influence Invasive Impact Index scores.
- Recent invasion by hornwort poses a serious threat to future condition.

Lake Okaro

- Overall lake condition moderate and showing signs of improvement following lake restoration measures.
- LakeSPI scores variable due to water quality responses by elodea.
- Has one of the lowest Native Condition Indices for any of the Rotorua Te Arawa lakes.

Lake Rotokakahi

- Overall lake condition moderate and stable.
- Major decline in LakeSPI and Native Condition Index over last 20 years.

- No change in elodea status but Invasive Impact Index reflects greater relative occupation of the remaining vegetation by elodea.
- Now the only Rotorua lake (with the exception of Okaro) to remain relatively free of the 3 worst 'high impact' invasive weed species.

Lake Tarawera

- Overall lake condition moderate and stable.
- LakeSPI and Native Condition Index scores have declined significantly over the last 25 years.
- Invasion of hornwort primarily responsible for decline in LakeSPI and Native Condition scores.

Lake Rotorua

- Overall lake condition moderate and stable.
- Slight variations in Native Condition Index reflect some variability in the development of these communities from year to year

Lake Rotoiti

- Overall lake condition is now moderate but close to the boundary with poor category.
- Has the highest Invasive Impact Index of the Rotorua Te Arawa lakes.
- LakeSPI Index indicates poor water quality.

Lake Rotoehu

- Overall lake condition poor.
- Recent invasion by hornwort has had a major impact.
- Has the lowest Native Condition Index and one of the highest Invasive Impact indices of the Rotorua Te Arawa lakes.

6 Recommendations

All possible measures should be explored for preventing further hornwort transfer (e.g., public education) and establishment into vulnerable lakes. Of particular concern is Lake Rotoma which remains at high risk of invasion by hornwort due to its proximity to other hornwort infested lakes (e.g., Lake Rotoehu).

There may be some merit in assessing some lakes annually. In particular are those lakes where significant changes are taking place either by deterioration (e.g., Rotokakahi, Rerewhakaaitu) or from improvements (e.g., Tikitapu, Okaro, and Rotoiti) which may be attributable to restoration works such as phosphorus capping and nutrient diversion.

To gain a further understanding of the overall state of the lakes in this region it is suggested that **one-off surveys be completed for lakes not yet surveyed: Rotokawau, Te Hapua, Rotokawa, Rotongata (Mirror Lake), Rotoatua and the Rerewhakaaitu crater lake.** Limited historic information is known about these lakes which may or may not be vegetated, but knowing their current condition will provide a better understanding of the regions diversity of lakes and factors that influence macrophyte presence. **Lake Pupuwharu** was last assessed in 2007 and an update of ecological status is recommended.

7 Acknowledgments

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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: 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*: 130–140.
- Burns, N.M., Bowman, E., Bryers, G. (2000) *Protocol for Monitoring the Trophic Levels of New Zealand Lakes and Reservoirs*. New Zealand Ministry for the Environment, Wellington NZ: 138.
- Champion, P., de Winton, M., Wells, R. (2006) Submerged aquatic weed surveillance for the Rotorua lakes. *NIWA Client Report HAM2006-052*: 28.
- 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., Edwards, T. (2006a) Aquatic Plants as Environmental Indicators of Ecological Condition in New Zealand Lakes. *Hydrobiologia*, 570: 147–151.
- Clayton, J., Edwards, T. (2006b) LakeSPI – A Method for Monitoring Ecological Condition in New Zealand Lakes. *Technical Report*, Version Two. June 2006: 67.
- Clayton, J., Edwards, T., de Winton, M. (2005) The condition of twelve lakes in the Rotorua lakes Region using LakeSPI. *NIWA Client Report HAM2005-122*: 48.
- Clayton, J.S. (1978) *The submerged vegetation of Lake Rotoma*. PhD Thesis, University of Auckland: 152.
- 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., 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.
- Clayton, J.S., de Winton, M.D. (2007) Lake Rotomahana: Incursion response. *NIWA Client Report HAM2007-063*: 13.
- Coffey, B.T. (1970) *A contribution to the autecology and control of Lagarosiphon major*. MSc Thesis, Auckland University: 209.
- 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.

- de Winton, M.D., Clayton, J.S., Edwards, T. (2012) Incorporating invasive weeds into a plant indicator method (LakeSPI) to assess lake ecological condition. *Hydrobiologia*, 691: 47–58.
- Edwards, T., Clayton, J. (2011) The ecological condition of the Rotorua Lakes using LakeSPI-2011. *NIWA Client Report* HAM2011-050: 46.
- Hamill & Lew (2006) *Snapshot of Lake Water Quality in New Zealand*. Ministry for the Environment, Wellington: 53.
- 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.
- Lakes Water Quality Society. (2012) Newsletter of the Lakes Water Quality Society, Issue 04, December 2012.
http://www.lakeswaterquality.co.nz/docs/LakesNews%20Dec%202012_lo%20res.pdf
(accessed 27/06/2013).
- Matheson, F., Clayton, J. (2002) Aquatic plant harvesting in lakes for nutrient renovation. *NIWA Client Report* HAM2002-010.
- McCull, 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.
- Scholes, P., Bloxham, M. (2008) Rotorua Lakes Water Quality 2007 Report. *Environmental Publication*, 2008/04: 31.
- Schwarz, A., Hawes, I., Howard-Williams, C. (1999) Mechanisms Underlying the Decline and Recovery of a Characean Community in Fluctuating Light in a Large Oligotrophic Lake. *Australian Journal of Botany*, 47: 325–336.
- 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.
- Wells, R.D.S., Clayton, J.S. (1991) Submerged vegetation and spread of *Egeria densa* Plankton 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.
- White, E. (1977) Eutrophication of Lake Rotorua – a review. *DSIR Information Series*, 123.