NIWA
Taihoro Nukurangi

Assessment of the Rotorua Te Arawa lakes using LakeSPI – 2016

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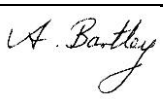	Formatting checked by:	Alison Bartley
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Executive summary

NIWA was contracted by Bay of Plenty Regional Council (BOPRC) to assess the ecological condition of 12 Rotorua Te Arawa lakes using LakeSPI (Submerged Plant Indicators). Lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu were surveyed in 2016, and Lakes Ōkāreka, Ōkaro, Rotomā, Rotomāhana, Rotoiti and Rotorua in 2015. This report provides an update of lake ecological condition and discusses the changes evident in LakeSPI indices over a recent time-frame since 2011 (4 to 5 years) and long-term (>20 years).

The 2015/16 LakeSPI indices ranged widely from 19% to 55% with three lakes assessed as being in 'high' condition, seven lakes as 'moderate' and two lakes categorised as in 'poor' condition. Compared to lakes nationally, Rotorua Te Arawa lakes are under-represented in the top two categories of 'high' to 'excellent', but also in the bottom two categories of 'poor' to 'non-vegetated', which represent those with extensive invasion and dominance by one of the country's worst weeds, hornwort, and/or compromised water quality.

Lake Ōkāreka was the top-ranked lake, categorised as in 'high' condition. This lake improved markedly from 2013 to 2015 corresponding with the BOPRC weed control programme aimed at hornwort containment. Native vegetation expanded in response to a reduction in invasive weeds, especially lagarosiphon.

Lakes Rotomā and Rotomāhana are also in 'high' condition and were ranked equally. Lake Rotomā has been stable both in recent and long-term time frames due to continued high water quality, but would be vulnerable in the event of future hornwort invasion. Lake Rotomāhana also in 'high' condition has shown past deterioration in response to weed invasion, but has stabilised recently as evident over the last two surveys.

Seven lakes were in 'moderate' condition. Lake Tikitapu is in a stable condition following some signs of recent improvement, however longer term values show a significant reduction in Native Condition values. Lake Ōkataina has remained stable over the short and long terms, however the presence of hornwort continues to pose a serious threat to future lake condition unless it continues to be actively controlled. Lake Rerewhakaaitu remained stable in the past, but a recent reduction in Native Condition values reflect increasing impacts from egeria. Lake Rotokakahi showed substantial deterioration over the long term, with no change in invasive weed presence, but more recently it has stabilised. Lake Rotorua indicates signs of improvement over the short term with an increase in the depth of native vegetation, but Native Condition values in this lake have been variable in the past. Lake Okaro also showed signs of improvement in earlier surveys and has more recently stabilised. Lake Tarawera remains in a stable state since 2008, following the complete invasion of this lake by hornwort that caused reductions in lake condition over the long term.

Lakes Rotoiti and Rotoehu are categorised in 'poor' condition. They have the highest Invasive Impact Indices for the Rotorua Te Arawa lakes on account of the pervasive dominance by weeds, especially hornwort and eutrophic water quality. While the invasion occurred historically (>20 years ago) in Lake Rotoiti, Lake Rotoehu is only just stabilising after a more recent (2003) hornwort invasion.

LakeSPI results show how the Rotorua Te Arawa Lakes have undergone significant change over the long term. Lakes Rotomāhana and Tarawera show the greatest changes in lake condition over the long term on account of impacts from invasive plant species; while the second biggest change has been from deteriorating water quality in Rotokakahi and Tikitapu. The lakes continue to be vulnerable to further changes from invasive plants and deteriorating water quality.

It is recognised by BOPRC that there may be merits in investigating other approaches for the use of LakeSPI data (E.g., limit setting) for the Rotorua Te Arawa lakes. NIWA welcomes further discussion with BOPRC to consider the possible options for extending the use of the LakeSPI data as an indicator of overall lake ecological condition.

It is also recommended that additional one-off surveys be completed for all Bay of Plenty lakes even if with no or limited vegetation. Knowledge of their current condition will provide a better understanding of the regions diversity of lakes and factors that influence macrophyte presence in the region. Benefits of further longer term monitoring should then be considered relative to assessed values and threats for each lake.

1 Introduction

1.1 Background

Bay of Plenty Regional Council (BOPRC) are responsible for implementing central government's national policy statement for freshwater management, to manage freshwaters and land around freshwater in an integrated and sustainable way (http://www.boprc.govt.nz/environment/water/managing-freshwater/). The Rotorua Te Arawa Lakes are listed as priorities in BOPRC's Ten Year Plan 2012-2022 and ongoing monitoring is identified as a key feature of the long-term implementation program.

Since 2005, NIWA has been contracted by 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 of the few indicators 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 biennially to maintain a consistent record.

This report presents updated LakeSPI results for lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu last assessed in March 2014, and also presents results for lakes Ōkaro, Ōkāreka, Rotoiti, Rotomā, Rotomāhana and Rotorua last assessed in 2015 (Burton and Clayton 2015).

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: Ōkāreka, Ōkaro, Ōkataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotomā, Rotomāhana, Rotorua, Tarawera, and Tikitapu. The location of these lakes is indicated in (Figure 1). Morphological characteristics are given in Table 1.

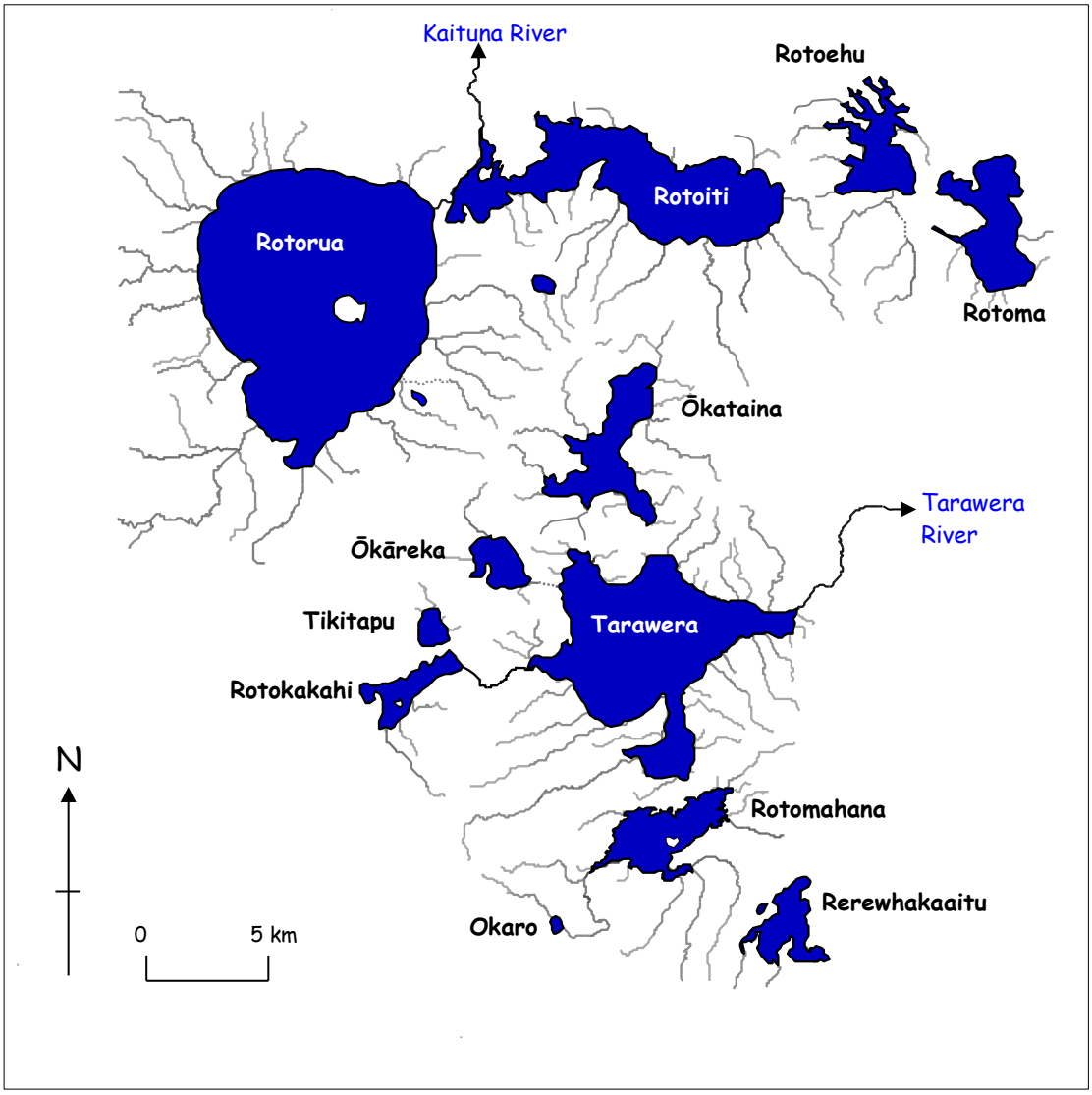


Figure 1: Map showing location of the 12 Rotorua Te Arawa lakes.

In addition to these 12 Rotorua Te Arawa lakes, 3 other lakes (Matahina, Aniwhenua, Pupuwharau) in the Bay of Plenty Region have also been surveyed and results for these lakes can be found on the LakeSPI web reporting website, www.lakespi.niwa.co.nz.

Table 1: Summary of lake characteristics.

Lake	Maximum Depth (m)	Mean Depth (m)	Size (km²)	Catchment Area (km²)
Ōkāreka	33.5	20	3.33	19.6
Ōkaro	18	12.5	0.33	3.9
Ōkataina	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
Rotomāhana	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 Te Arawa 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 Rotomāhana 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 most 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 was recorded from the 1960s to the 1980s (Coffey & Clayton 1988). Land use practices led to

a progressive deterioration in water clarity, reducing the depth to which vegetation grew. There are some exceptions to this general trend with Lake Rotomā retaining a constant maximum vegetated depth limit since the early 1970s, and Lake Rerewhakaaitu with improved water clarity and a corresponding increase in the depth of submerged vegetation.

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 has spread rapidly through most of the Rotorua Te Arawa Lakes, with Lakes Rotomā, Ōkataina and Tarawera likely to have been colonised in the mid to late 1960s (Coffey 1970, Brown & Dromgoole 1977, Clayton 1982). Invasion of the more isolated less used lakes 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 spread to other lakes. The impact of egeria on the Rotorua lakes has been less than expected; in contrast to the impact from hornwort, has exceeded all expectations with this species now ranked as New Zealand's worst widespread submerged aquatic plant pest.

The spread of significant invasive weed species into the remaining Rotorua 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 Rotomāhana 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 with which 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.

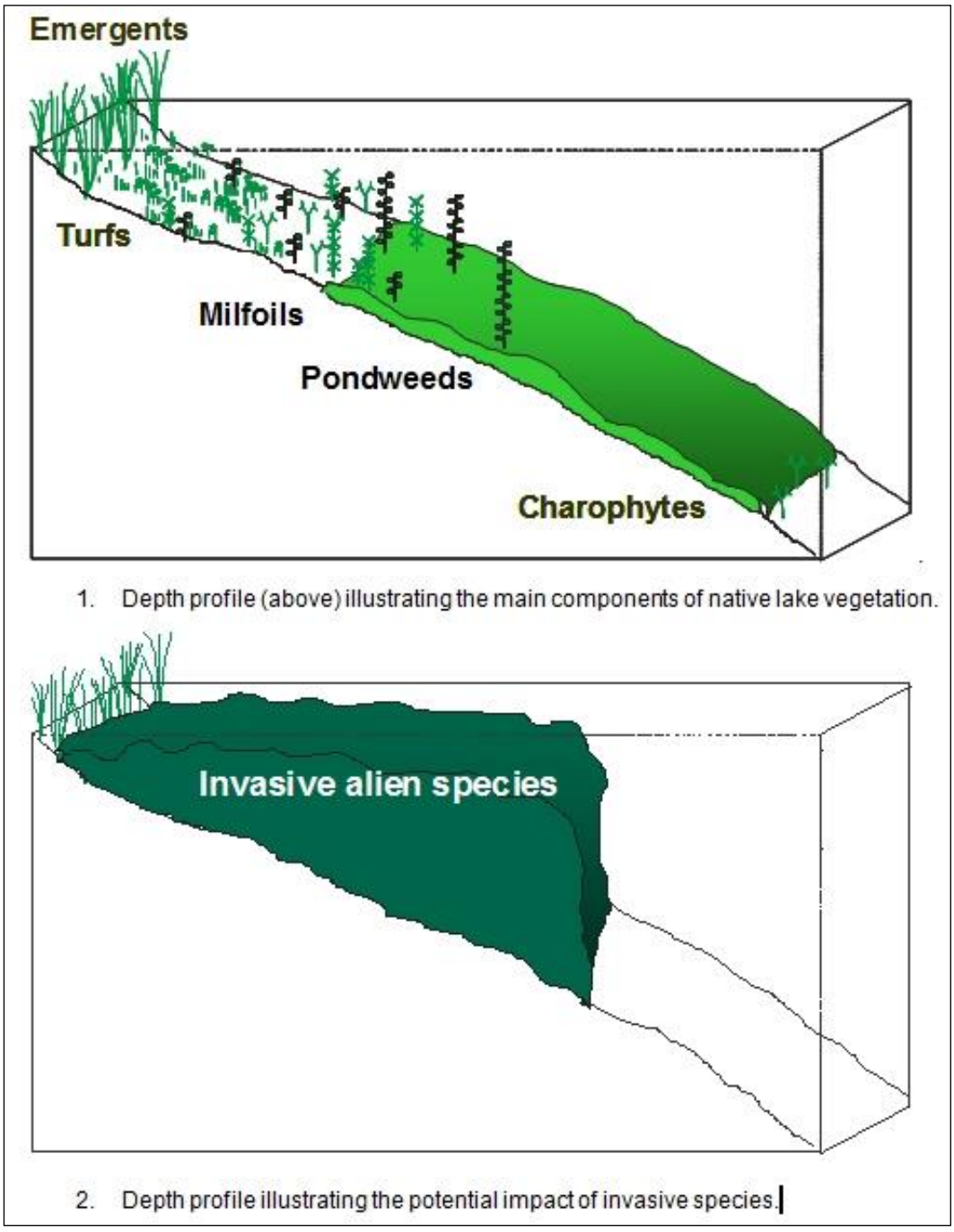


Figure 2: Depth profiles within a lake illustrating the difference between a lake maintaining native plant communities and that which is invaded with invasive weed species.

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 changes in lakes (Clayton & Edwards 2006a). 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%.

An online LakeSPI web reporting system (www.lakespi.niwa.co.nz) enables access to results in a form suitable for lake monitoring and reporting purposes at a national or regional level.

2.2 Lake surveys

The LakeSPI method was repeated at five established baseline sites within each of the six lakes re-assessed this year. Lakes Ōkataina and Rotokakahi were surveyed in March; and lakes Rerewhakaaitu, Rotoehu, Tarawera and Tikitapu in May 2016.

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 assessed for LakeSPI can be found in the LakeSPI user manual (www.lakespi.niwa.co.nz), and includes measures of diversity from the presence of key plant communities, the depth extent of vegetation and the extent that invasive weeds are represented.

2.3 Data analysis

Field survey observations are entered into the NIWA LakeSPI database which calculates the three LakeSPI indices: Native Condition Index, Invasive Impact Index and overall LakeSPI Index.

2.3.1 LakeSPI status

For ease of reporting results, five lake condition categories are used to provide a description of a lake's status based on the LakeSPI Index score:

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

These lake groupings provide a description of a lakes status and support the MfE initiative to ensure national consistency in terminology and reporting allowing for better comparisons of lakes nationally and regionally.

2.3.2 LakeSPI stability

Changes in LakeSPI indices over a recent time-frame, taken as since 2011 (i.e., the last four years or three surveys), provide an indication of current stability in lake condition and the direction of any change.

Over longer time frames and multiple surveys, guidelines (Figure 3) based on expert judgement suggest a scale of probabilities for ecologically significant change in lake condition, using averaged LakeSPI indices over repeated surveys. These guidelines have considered variation by different observers and the response of LakeSPI scores to major ecological events in lakes.

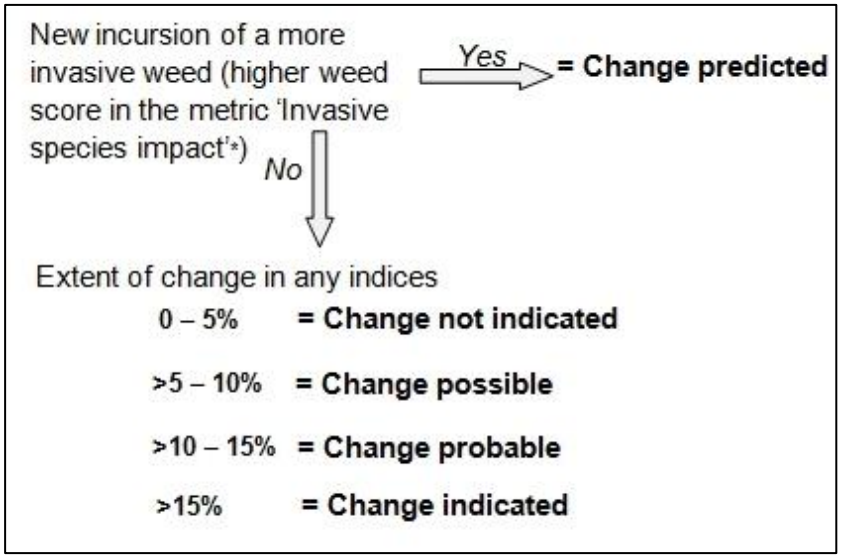


Figure 3: Guidelines for assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.

In addition, the likelihood of an ecologically significant change in LakeSPI scores over time is based on analysis of the direction and magnitude of change in indices across the surveyed sites. A paired t-test (GraphPad InStat) was used to compare site results between surveys at the significance level $p < 0.05$.

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 (2014 or 2015).

Lake	Most recent LakeSPI survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Ōkāreka	03/03/2015	55	53	36	
Rotomā	09/03/2015	54	55	43	High
Rotomāhana	02/03/2015	54	53	37	
Tikitapu	18/05/2016	44	40	46	
Ōkataina	16/03/2016	38	42	67	
Rerewhakaaitu	19/05/2016	31	38	79	
Rotokakahi	17/03/2016	30	29	79	Moderate
Rotorua	03/03/2015	28	33	80	
Ōkaro	02/03/2015	28	22	69	
Tarawera	18/05/2016	25	29	89	
Rotoiti	02/03/2015	20	25	92	Poor
Rotoehu	19/05/2016	19	22	93	

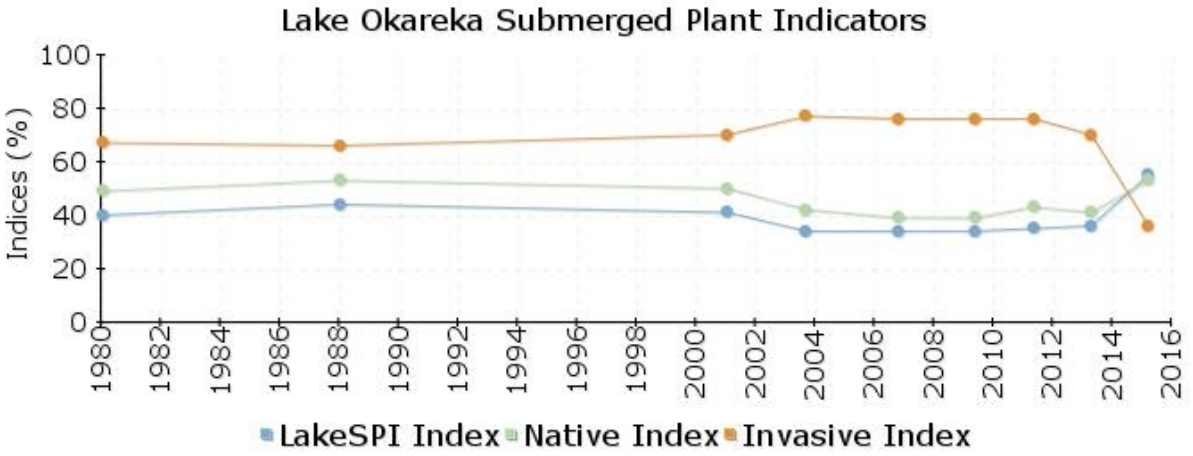
3.1 Lake Ōkāreka

Lake condition: High

Stability: Improving

Lake ranking 1st

Lake Ōkāreka is currently 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).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2015	High	55%	53%	36%
April 2013	Moderate	36%	41%	70%
May 2011	Moderate	35%	43%	76%
May 2009	Moderate	34%	39%	76%
October 2006	Moderate	34%	39%	76%
September 2003	Moderate	34%	42%	77%
January 2001	Moderate	41%	50%	70%
January 1988	Moderate	44%	53%	66%
January 1980	Moderate	40%	49%	67%

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

Recent initiatives by BOPRC to control hornwort (*Ceratophyllum demersum*) in Lake Ōkāreka (Bathgate, 2013) has resulted in native plant communities now forming extensive communities at all LakeSPI sites with a greatly reduced level of impact from invasive weeds. This improvement is reflected by an increase in the Native Condition scores, from 41% in 2013 to 53% in 2015 (Figure 4), almost a halving of the Invasive Impact Index, and an overall improvement in the LakeSPI Index (55%). Egeria, recorded from 3 of the 5 baselines sites in 2013, was not recorded from any of the LakeSPI sites in 2015. Lagarosiphon was still present at all sites in 2015. However, this weed formed only low covers (<10% cover at 4 of the 5 baseline sites) down to a maximum depth of 6.2 m in 2013 in contrast to previous high cover bands of weed growth over the same depth range. As a result native plant communities in the lake have expanded and now Lake Ōkāreka is ranked first in Bay of Plenty Region using LakeSPI.

While hornwort was first reported in the lake in April 2012 it has not yet been recorded at any of the LakeSPI baseline sites. Had hornwort been left un-controlled in Lake Ōkāreka, the LakeSPI scores would almost certainly be decreasing. Hornwort has the ability to occupy an even deeper depth range than egeria with the potential to displace all remaining deep water charophyte meadows in the lake.

A recent report (Burton, 2015de) reviewed the control options for use in Lake Ōkāreka to minimise the impacts of hornwort and other submerged weeds species and found that BOPRC were making use of the most effective control methodologies available.

Historical notes - Prior to the 2015 survey, LakeSPI scores for Lake Ōkāreka had remained stable for some years showing little change in the LakeSPI Index (Figure 4) since 2003. A small increase in the Invasive Impact Index noted at this time resulted from the localised establishment of egeria in the lake which at the time led to a decrease in the LakeSPI Index from 41% in 2001 to 34% in 2003.

Egeria was first reported in Lake Ōkāreka 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 displaced lagarosiphon with taller and denser weed growth and occupies a wider depth range.

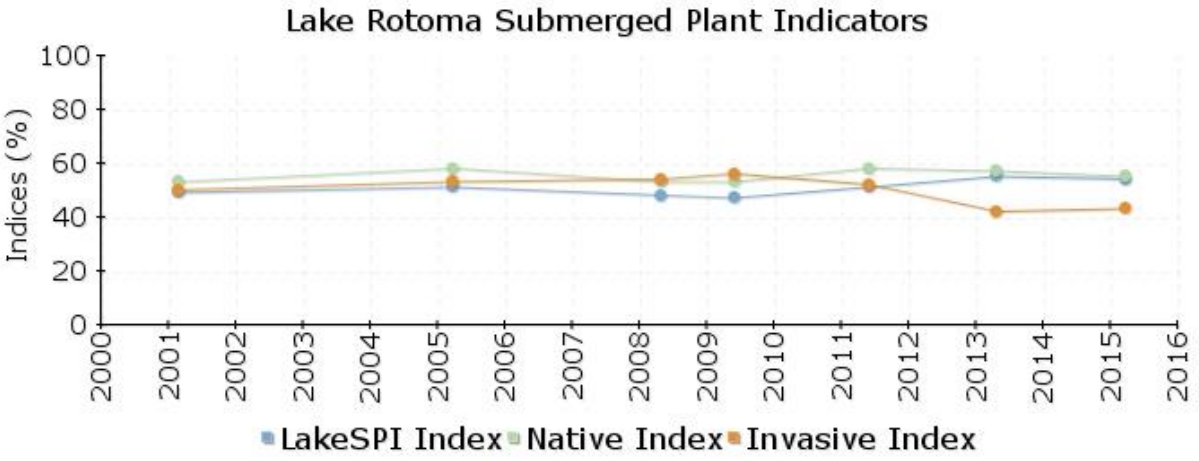
3.2 Lake Rotomā

Lake condition: High

Stability: Stable

Lake ranking: 2nd equal

Lake Rotomā is categorised as being in high ecological condition with a LakeSPI Index of 54% (Figure 5).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2015	High	54%	55%	43%
April 2013	High	55%	57%	42%
May 2011	High	51%	58%	52%
May 2009	Moderate	47%	53%	56%
April 2008	Moderate	48%	53%	54%
March 2005	High	51%	58%	53%
February 2001	Moderate	49%	53%	50%
November 1988	Moderate	50%	52%	47%
January 1973	High	69%	63%	19%

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

LakeSPI scores for Lake Rotomā have remained stable over the last 27 years, from 1988 – 2015. Lagarosiphon is still the dominant invasive plant species in Lake Rotomā, forming high cover beds at 4 of the 5 baseline sites down to a maximum depth of 5.7 m.

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

Historical notes - Lake Rotomā 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 one of the lowest Invasive Impact Indices, 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.

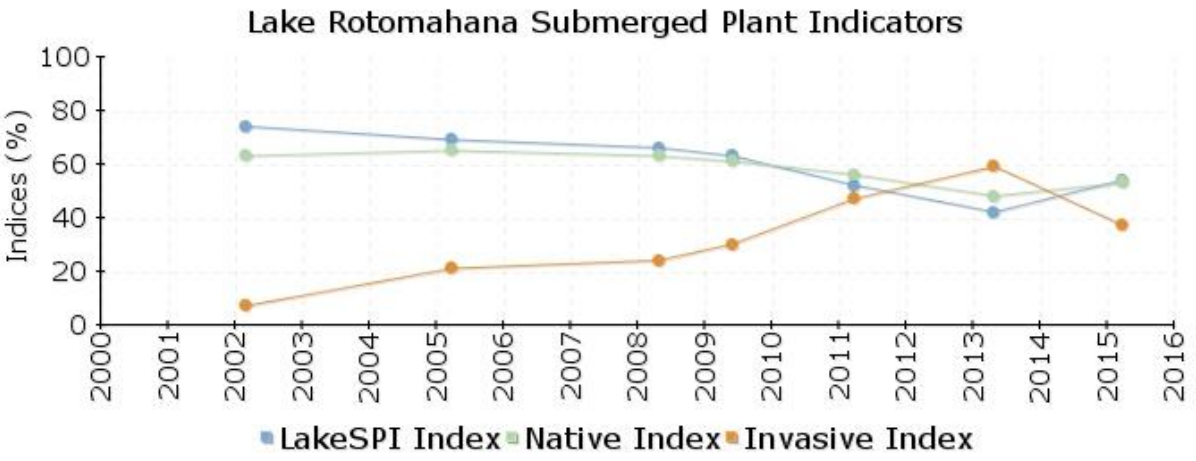
3.3 Lake Rotomāhana

Lake condition: High

Stability: Stable?

Lake ranking: 2nd equal

Lake Rotomāhana is categorised as being in high ecological condition with a LakeSPI Index of 54% (Figure 6).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2015	High	54%	53%	37%
April 2013	Moderate	42%	48%	59%
March 2011	High	52%	56%	47%
May 2009	High	63%	61%	30%
April 2008	High	66%	63%	24%
March 2005	High	69%	65%	21%
February 2002	High	74%	63%	7%
November 1988	High	72%	64%	13%

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

Prior to 2013 Lake Rotomāhana was the top ranked Rotorua Te Arawa Lake according to LakeSPI. For many years it was stable, but showed some deterioration over 2011 to 2013, due to the establishment of egeria and hornwort in the lake. More recently (in 2015), these weeds diminished in their abundance and lake condition improved.

Invasive Impact scores peaked during the 2013 survey (Figure 6). A reduction in the cover of egeria at LakeSPI sites within the lake is unexplained and water quality factors should be explored further. Management programs to control invasive weeds have not been carried out in Lake Rotomāhana since 2006 (H. Lass, BOPRC, pers comm.) so could not have contributed to the decrease in invasive impact values.

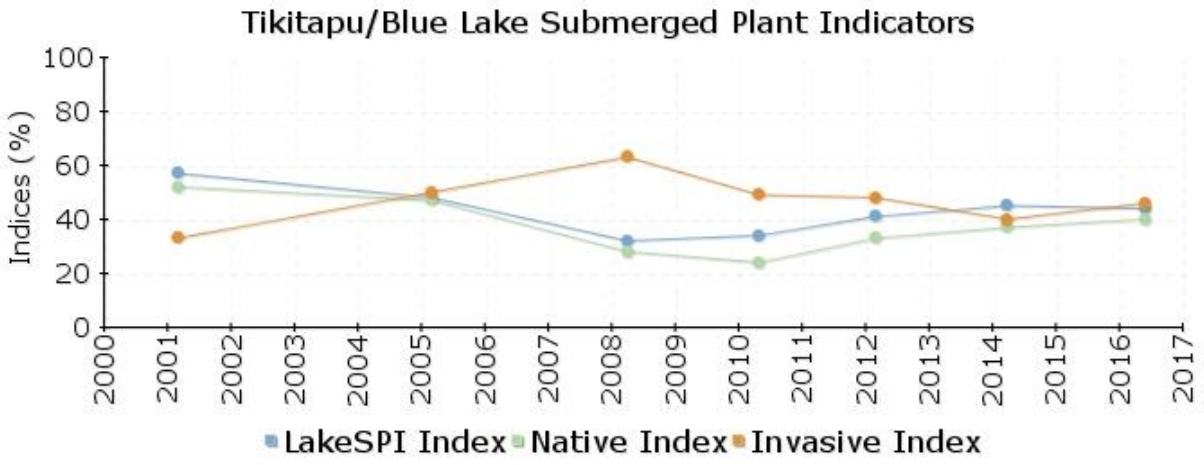
Historic notes - Egeria and hornwort were discovered for the first time in 2007. At this time egeria was found in two areas of the lake, at the north-eastern end and in the southern embayment, while hornwort fragments were found growing amongst native plants in the southern embayment (Clayton & de Winton, 2007; Scholes and Bloxham, 2008). Since then both species have continued to spread around the lake.

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, and possibly a deliberate release.

3.4 Lake Tikitapu

Lake condition:	Moderate
Stability:	Stable
Lake ranking:	4th

Lake Tikitapu is categorised as being in moderate ecological condition with a LakeSPI Index of 44% (Figure 7).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
May 2016	Moderate	44%	40%	46%
March 2014	Moderate	45%	37%	40%
February 2012	Moderate	41%	33%	48%
April 2010	Moderate	34%	24%	49%
March 2008	Moderate	32%	28%	63%
February 2005	Moderate	48%	47%	50%
February 2001	High	57%	52%	33%
November 1988	High	63%	75%	47%

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

Lake Tikitapu is currently in a stable condition. A moderate LakeSPI Index of 44% reflects the presence of native plant communities, with limited impact from the invasive weed lagarosiphon (*Lagarosiphon major*).

Lagarosiphon was recorded from four of the five LakeSPI sites during the 2016 survey forming variable covers to a maximum depth of 4.7 m (Figure 8). Plants however grew to a maximum height of only 1 m and had little impact on native vegetation also occupying the shallow (< 5 m) depth zone.

Native plant communities in Lake Tikitapu included the native milfoil *Myriophyllum pedunculatum* and charophyte species *Nitella pseudoflabellata*, *Nitella leonhardii* and *Chara fibrosa*, which formed low to moderate covers down to a maximum depth of 5.3 m. Beyond this, of particular interest was the continued presence of deep water charophytes occurring from c. 13 – 17 m, at two of the five LakeSPI sites. At one of these sites, charophyte covers exceeded 75% generating a 'charophyte meadow' score which further contributed to a Native Condition Index of 40% (Figure 7). The intermittent and variable nature of these charophytes however, greatly extends the otherwise shallow depth limit of vegetation in Lake Tikitapu, which during the 2016 survey extended from 2.5 – 5.3 m only. For this reason, care must be taken when interpreting any LakeSPI results for this lake as it is recognised for being variable in nature.

At the time of this survey, a thick blue/green algal mat was noted, in places covering the sediment down to c. 16m which can affect macrophyte establishment. Freshwater koura were also observed.

Historic notes – Past records for Lake Tikitapu show 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 particularly variable, with large un-vegetated areas occurring upslope of any deeper charophyte development. This has resulted in a significant reduction in the Native Condition Index from 2008- 2016 (Figure 7) reflecting a decline in the diversity and extent of the native plant communities present. Unlike most other lakes, this reduction has not been due to the impact from new invasive species.

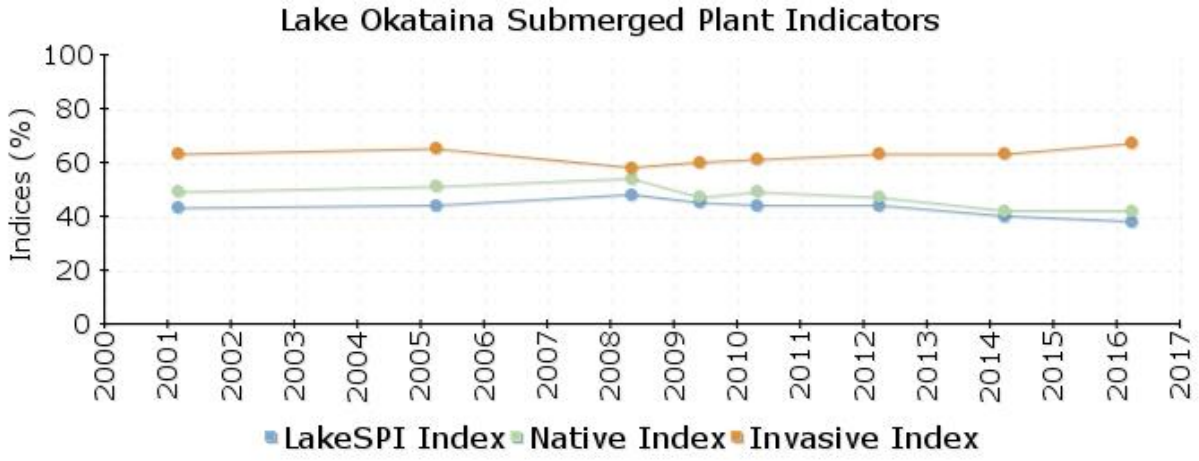
When the water chemistry of Lake Tikitapu was assessed in the early 1970s it had the lowest alkalinity recorded for any of the Rotorua Te Arawa lakes and it also had low sediment and water nutrient levels (McColl 1972). The reported low alkalinity, calcium and silicon levels may explain the on-going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

Figure 8: **Lagarosiphon forms variable covers in Lake Tikitapu,**to a maximum depth of 4.7 m.

3.5 Lake Ōkataina

Lake condition:	Moderate
Stability:	Stable/ possible decline?
Lake ranking	5th

Lake Ōkataina is categorised as being in moderate ecological condition with a LakeSPI Index of 38% (Figure 9).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2016	Moderate	38%	42%	67%
March 2014	Moderate	40%	42%	63%
March 2012	Moderate	44%	47%	63%
April 2010	Moderate	44%	49%	61%
May 2009	Moderate	45%	47%	60%
April 2008	Moderate	48%	54%	58%
March 2005	Moderate	44%	51%	65%
February 2001	Moderate	43%	49%	63%
November 1988	Moderate	47%	53%	57%
April 1981	High	51%	57%	53%

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

A LakeSPI Index of 38% reflects that although Lake Okataina has been impacted on by the invasive weed lagarosiphon (*Lagarosiphon major*), some well-developed native plant communities still persist.

Native charophyte species (*Chara australis*, *Chara globularis*, *Chara fibrosa*, *Nitella sp*. aff. *cristata*) formed meadows (> 75% cover) at four of the five baseline sites during the 2016 survey, growing down to a maximum depth of 11.3 m (Figure 10). A mixed turf plant community, native pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*) and a native milfoil (*Myriophyllum triphyllum*) were also present and contributed to a Native Condition Index of 42% (Figure 9).

Lagarosiphon remained the dominant invasive species present, forming high cover weed beds (Figure 10) at all five LakeSPI sites generating an Invasive Impact Index of 67% (Figure 9). For the first time at a LakeSPI site, a hornwort (*Ceratophyllum demersum*) plant was recorded at the northern end of the lake, on the western side of the beach (around from boat ramp). Hornwort continues to pose the most serious threat to the future condition of Lake Ōkataina. Should hornwort continue to spread, it is likely that we will see a reduction in LakeSPI scores in the future.

A reduction in the depth extent of plant communities noted during the 2014 and 2016 surveys, did not result in a significant change to LakeSPI scores. Because the lake has no outlet, 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 its maximum depth extent. Nevertheless, if water level changes are slow, the vegetation usually compensates by migrating up and down the slope. BOPRC water level recordings show that lake levels during the 2016 survey were approximately 1.5 m lower than those during the 2014 survey, which could have had a compounding negative influence on LakeSPI scores, with a depth reduction in vegetation noted between the 2012 and 2014 surveys. Over the long-term, LakeSPI scores for Lake Ōkataina have been stable, with only minor fluctuations.

Historic notes –It is most likely that lagarosiphon first invaded Lake Okataina in the late 1960's (Brown and Dromgoole, 1977), so the full impact of lagarosiphon would have already taken place prior to the 1988 survey.

Hornwort was first recorded in Lake Ōkataina in 2007 but it was not until 2009 that the detection of additional drift fragments led to the discovery of a larger hornwort incursion in 2010. Diquat use since this has likely prevented a major impact from hornwort around the lake. Installing a weed cordon has reduced the likelihood of hornwort dispersal from this lake.

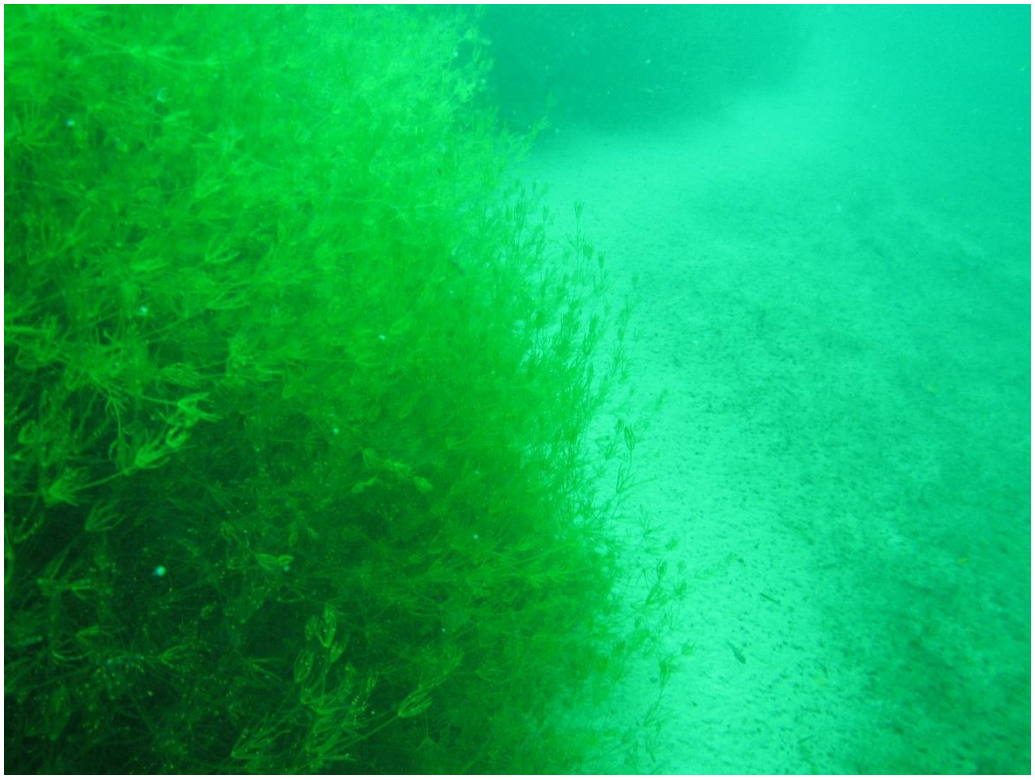


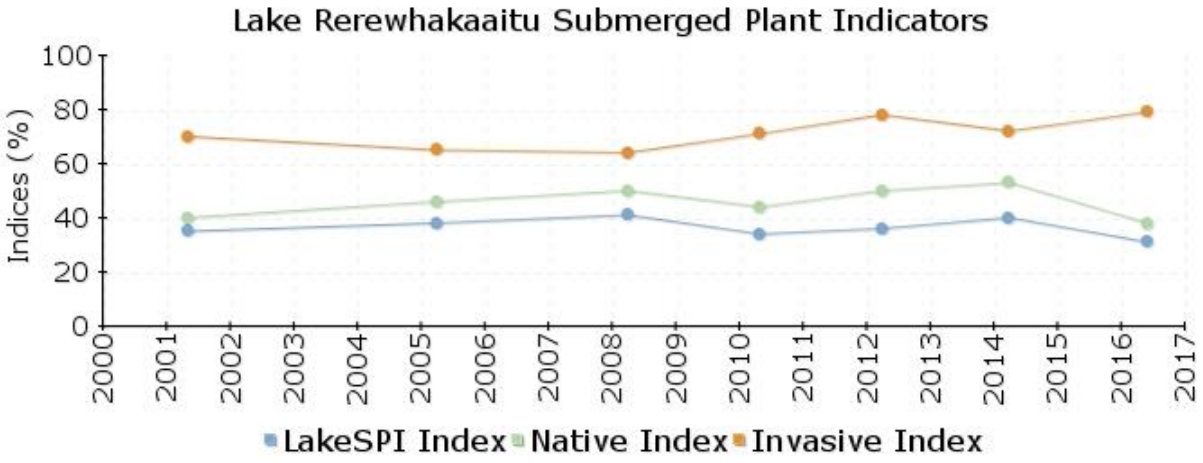
Figure 10: Charophyte meadow growing to a maximum depth 11.3 m in Lake Okataina during the 2016 survey.

Figure 11: Surface reaching bed of lagarosiphon in Lake Okataina.

3.6 Lake Rerewhakaaitu

Lake condition:	Moderate
Stability:	Stable/ possible decline?
Lake ranking	6th

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



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
May 2016	Moderate	31%	38%	79%
March 2014	Moderate	40%	53%	72%
March 2012	Moderate	36%	50%	78%
April 2010	Moderate	34%	44%	71%
March 2008	Moderate	41%	50%	64%
March 2005	Moderate	38%	46%	65%
April 2001	Moderate	35%	40%	70%
November 1988	Moderate	41%	47%	57%
March 1973	High	55%	56%	37%

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

The 2016 survey showed a decline in the overall condition of Lake Rerewhakaaitu from the previous 2014 survey. This result predominantly reflects a significant decline in Native Condition scores, from 53% in 2014 to 38% (Figure 12) during the 2016 survey; following an increase in the overall extent and abundance of the invasive weeds egeria (*Egeria densa*) and lagarosiphon (*Lagarosiphon major).*

An Invasive Impact Index of 79% (Figure 12) is the highest recorded for Lake Rerewhakaaitu. Egeria (Figure 13) continues to spread and is the most dominant invasive species in the lake, present at all LakeSPI sites growing down to a maximum depth of 7.2 m.

Charophyte meadows (>75% cover) were present at four of the five LakeSPI sites during the 2016 survey, one site less than the previous two surveys (2012 and 2014), forming high covers to a maximum depth of 7m. Deep water charophyte meadows mainly consisted of the species *Chara australis*, but other charophyte species included *Nitella pseudoflabellata*, *Nitella sp*. aff. *cristata*, *Nitella leonhardii*, and *Chara fibrosa*. Other native vegetation of note included *Isoetes kirkii*, growing amongst other shallow water turf species, native pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*) and three native milfoil species (*Myriophyllum pedunculatum*, *Myriophyllum propinquum* and *Myriophyllum triphyllum*).

At the time of the survey, a thick cover of algae (Figure 14) was noted covering plants from the lake edge to c. 2 m depth. Freshwater mussels (*Echyridella menziesi*) were also observed.

Historical notes - 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 to 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 following 20 years, to 2008. LakeSPI scores decreased in response to the lagarosiphon invasion, while impacts on the Native Condition Index were partly negated by the improved water clarity and extension in charophyte depth limits.

Egeria further impacted negatively on LakeSPI scores following its introduction and subsequent spread in the 2000's. Egeria was first recorded in Lake Rerewhakaaitu in 2000 (Champion et al. 2006). By 2008, egeria was present at two of the five LakeSPI sites and by the 2010 survey, had spread to all five sites, causing incremental rises in the Invasive Impacts Index to where it is today (Figure 12).

Figure 13: Egeria beds dominated much of the vegetation in Lake Rerewhakaaitu.

Figure 14: Algae covering native plants in Lake Rerewhakaaitu, down to c. 2 m depth.

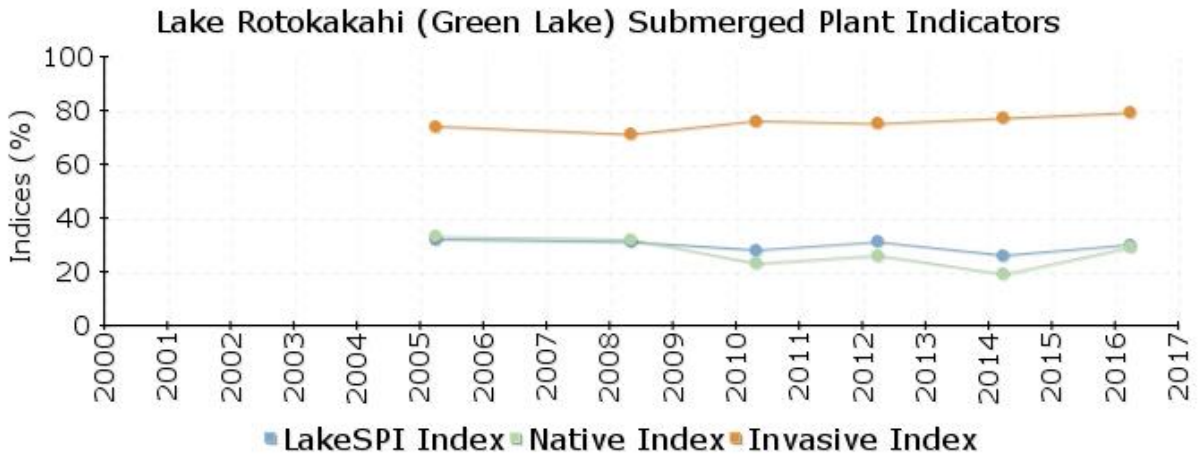
3.1 Lake Rotokakahi

Lake condition: Moderate

Stability: Stable

Lake ranking 7th

Lake Rotokakahi is categorised as being in moderate ecological condition with a LakeSPI Index of 30% (Figure 15).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2016	Moderate	30%	29%	79%
March 2014	Moderate	26%	19%	77%
March 2012	Moderate	31%	26%	75%
April 2010	Moderate	28%	23%	76%
April 2008	Moderate	31%	32%	71%
March 2005	Moderate	32%	33%	74%
November 1988	High	52%	61%	53%

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

Lake Rotokakahi currently appears to be in a stable condition. This follows a small decline in the LakeSPI Index noted in 2014, predominantly due to the absence of native vegetation at one of the five LakeSPI sites. However, the return of native vegetation at this site in the 2016 survey resulted in a recovery of LakeSPI scores close to those previously generated for the lake in 2012 (Figure 15).

Native vegetation in Lake Rotokakahi consisted of a mixed turf community in the shallows (c. < 1 m), which included isoetes (*Isoetes kirkii*). Other native vegetation included two native pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*), two native milfoils (*Myriophyllum propinquum*, *Myriophyllum triphyllum*), and five charophyte species (*Chara australis*, *Chara fibrosa, Nitella hyalina, Nitella pseudoflabellata* and *Nitella sp*. aff. *cristata*). Charophytes extended beyond the extent of invasive weed beds at three of the five LakeSPI sites to a maximum depth of 9.5 m. Charophyte meadows (>75% cover) were observed at 2 of these sites further positively influencing Native Condition scores for the lake.

Elodea (*Elodea canadensis*) was the only invasive species in Lake Rotokakahi during the 2016 survey and formed tall (c. 3 m) high cover weed beds, at all five LakeSPI sites, to a maximum depth of 9.7 m. Small increases in the Invasive Impact scores since 2005 reflect a greater occupancy of the vegetation by elodea as native charophyte meadows declined.

At the time of survey, a brown filamentous algae was observed covering plants in the shallows while a blue/green algal mat was present beyond the maximum depth of plant growth on the sediment. Large numbers of freshwater mussels were also recorded in the lake, mostly in sediments beyond the outer edge of the weed bed at c. 7-9 m depth.

Historical notes - 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 23), with most change taking place prior to 2005 (Figure 15). The LakeSPI Index has reduced from 52% in 1988 to only 30% in 2016, whilst the Native Condition Index has also declined significantly, largely due to a decline in deeper charophyte meadows over this longer-term time frame. This has occurred even though there has been no new invasive species recorded in this lake. Lake Rotokakahi, together with Lake Ōkaro, are the only Rotorua Te Arawa Lakes to remain relatively free of the more invasive weed species.

Overall LakeSPI results for Lake Rotokakahi show a declining condition over the longer term is not due to invasive weeds, but rather due to a decline in Native Condition presumably driven by water quality (RTALP, 2015). Additional observations support this conclusion, with filamentous algae prevalent on submerged vegetation and blue-green algal mats often covering sediments beyond the maximum depth of plant growth, all indicators of enrichment.

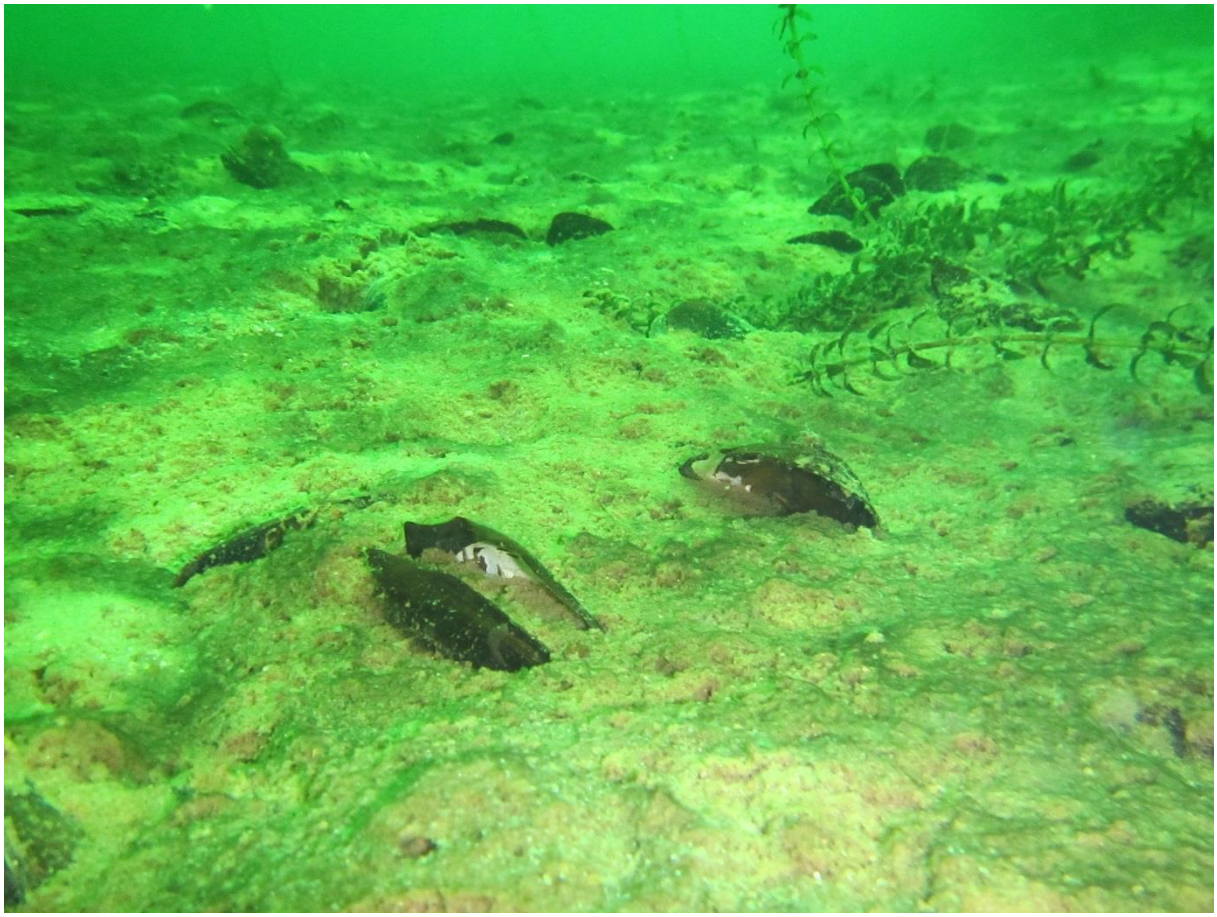


Figure 16: Freshwater mussels present beyond the depth of vegetation in Lake Rotokakahi.

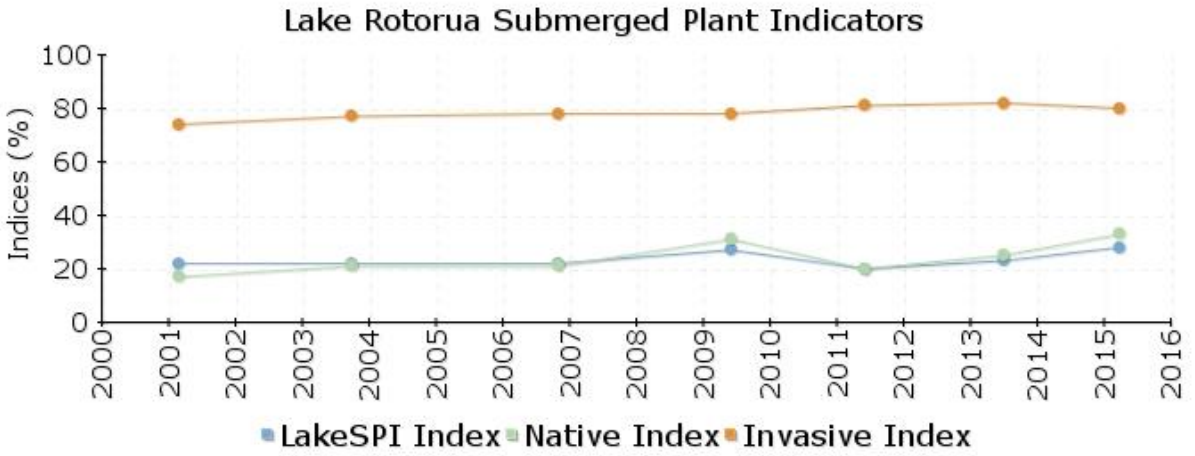
3.2 Lake Rotorua

Lake condition: Moderate

Stability: Stable/Improving?

Lake ranking 8th equal

Lake Rotorua is categorised as being in moderate ecological condition with a LakeSPI Index of 28% (Figure 17).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2015	Moderate	28%	33%	80%
June 2013	Moderate	23%	25%	82%
May 2011	Poor	20%	20%	81%
May 2009	Moderate	27%	31%	78%
October 2006	Moderate	22%	21%	78%
September 2003	Moderate	22%	21%	77%
February 2001	Moderate	22%	17%	74%
January 1988	Poor	18%	21%	90%
January 1982	Moderate	27%	23%	68%

Figure 17: LakeSPI results for Lake Rotorua. LakeSPI Indices expressed as a percentage of lake maximum potential.

Having remained in a stable condition since at least 2003, recent LakeSPI results for Lake Rotorua indicate a slight improvement from 2011 to 2015. This is reflected by an increase in the Native Condition Index from 20% in 2011 to 33% in 2015 (Figure 17), similar to results recorded for the lake in 2009. This improvement in Native Condition was largely due to an increase in the depth of native vegetation at all 5 LakeSPI baseline sites.

Some variability in plant communities year to year can be expected as this lake has a large shallow littoral zone subject to considerable wave action, which can periodically disturb wed beds and shallow turfs. Timing of the surveys in relation to these events may add variability in the longer-term data set.

Historical notes - The early variation in the Invasive Impact Index from 1988 to 2001 was attributable to the 'boom and bust' of egeria, which was first recorded in the lake in July 1983 and by 1988 had established weed extensive beds around most sheltered parts 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 following extensive weed control using diquat in an effort to reduce the water net nuisance and with regular follow up it has never recovered to its former state.

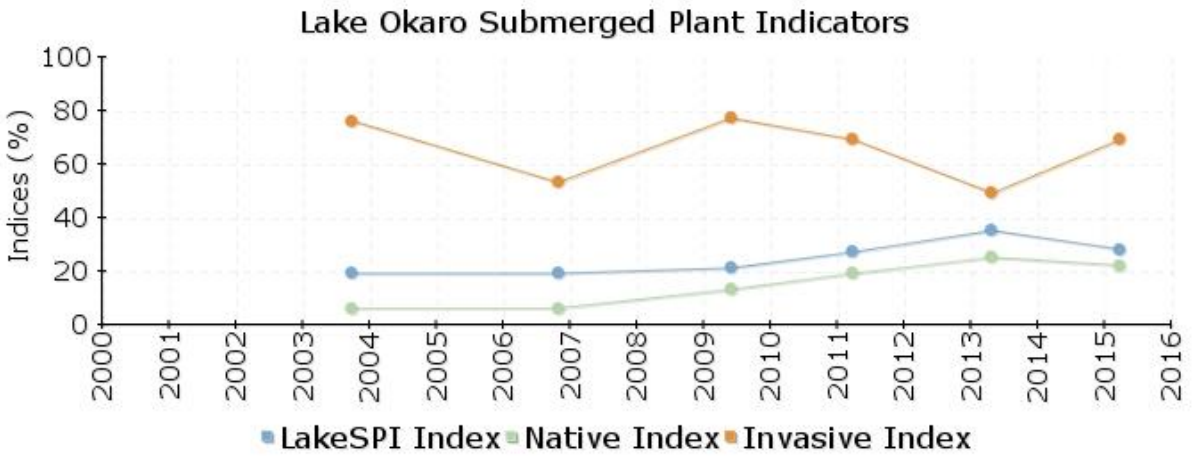
3.3 Lake Ōkaro

Lake condition: Moderate

Stability: Stable

Lake ranking 8th equal

Lake Ōkaro is categorised as being in moderate ecological condition with a LakeSPI Index of 28% (Figure 18).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2015	Moderate	28%	22%	69%
April 2013	Moderate	35%	25%	49%
March 2011	Moderate	27%	19%	69%
May 2009	Moderate	21%	13%	77%
October 2006	Poor	19%	6%	53%
September 2003	Poor	19%	6%	76%
October 1989	Moderate	22%	11%	25%
January 1982	Moderate	31%	29%	67%

Figure 18: LakeSPI results for Lake Ōkaro. LakeSPI Indices expressed as a percentage of lake maximum potential.

The degraded nature of Lake Ōkaro 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 2009 however, suggest a small improvement has occurred in the condition of Lake Ōkaro which has seen it move from a poor ranking to one of moderate condition. This result likely reflects recent efforts by BOPRC to reduce nutrient influx into the lake and nutrient release from hypolimnetic sediments, which probably improved water clarity and gave a positive vegetation response. While these improvements are promising, Lake Ōkaro is still recognised as a highly variable and sensitive lake system.

Elodea is the only invasive species recorded in Lake Ōkaro.

Historic notes - Historically the hypereutrophic nature of the lake has provided an unfavourable habitat for submerged vegetation. This is reflected in the highly variable cover and limited depth range of elodea. On several occasions in earlier surveys we 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.

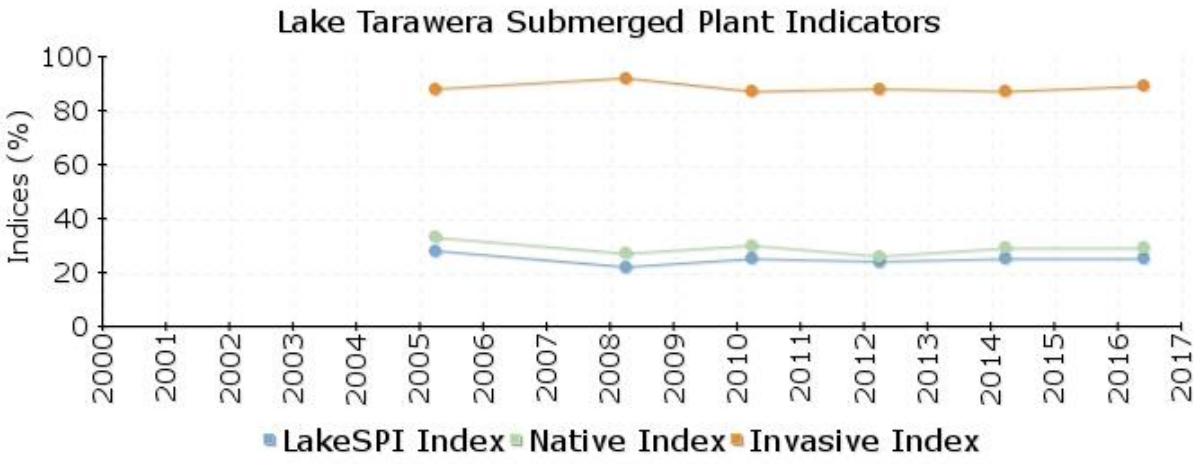
3.4 Lake Tarawera

Lake condition: Moderate

Stability: Stable

Lake ranking 10th

Lake Tarawera is categorised as being in moderate ecological condition with a LakeSPI Index of 25% (Figure 19).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
May 2016	Moderate	25%	29%	89%
March 2014	Moderate	25%	29%	87%
March 2012	Moderate	24%	26%	88%
March 2010	Moderate	25%	30%	87%
March 2008	Moderate	22%	27%	92%
March 2005	Moderate	28%	33%	88%
January 1994	Moderate	41%	50%	70%
November 1988	High	54%	55%	45%

Figure 19: LakeSPI results for Lake Tarawera. LakeSPI Indices expressed as a percentage of lake maximum potential.

Lake Tarawera has remained in a moderate but stable condition since 2008. Prior to this, results showed a significant reduction in the LakeSPI Index from 1988 to 2005 (Figure 19) with the invasion of hornwort (*Ceratophyllum demersum*). Today hornwort dominates the submerged vegetation in Lake Tarawera down to a maximum depth of 13 m, and more recent change has been small since the full impact of hornwort has now taken place.

The invasive weeds *Egeria densa*, *Lagarosiphon major* and *Elodea canadensis* were also present in Lake Tarawera but were of low abundance and had little impact compared to hornwort. An invasive water buttercup, *Ranunculus trichophyllus,* was also locally present.

A Native Condition Index of 29% (Figure 19) reflects some well-developed native plant communities still present in Lake Tarawera (on exposed sites). Five charophyte species were recorded during the 2016 survey (*Chara australis*, *Chara globularis*, *Chara fibrosa*, *Nitella hyalina*, *Nitella sp*. aff. *cristata*), with charophyte meadows (>75% cover) observed at three of the five LakeSPI sites growing to a maximum depth of 8.4 m. Other native vegetation consisted of a mixed turf community in shallower water, two pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*) and two native milfoils (*Myriophyllum propinquum*, *Myriophyllum triphyllum*).

Freshwater mussels and crayfish were both observed in the lake during the 2016 survey.

Historical notes - 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 significantly lower LakeSPI Index of 28% (Figure 19).

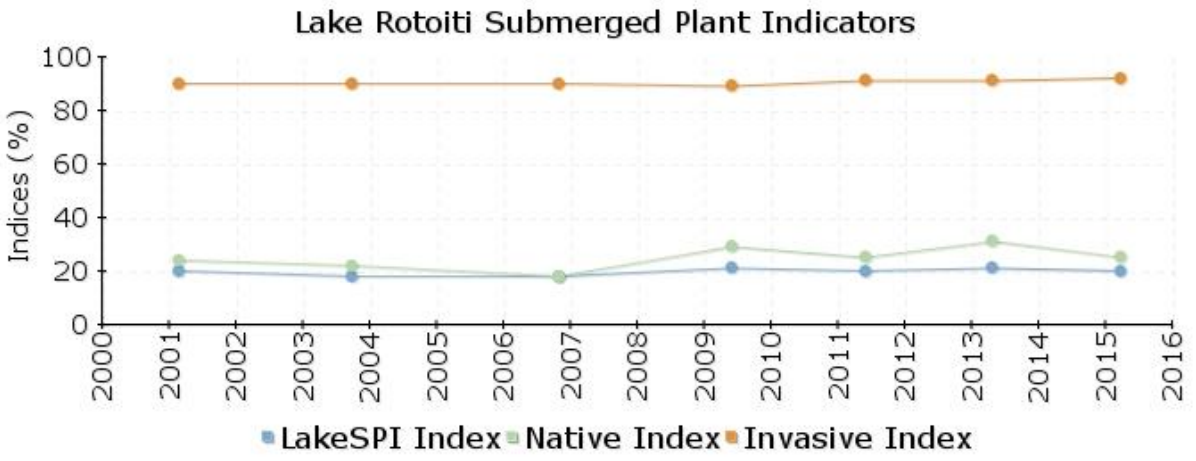
3.5 Lake Rotoiti

Lake condition: Moderate

Stability: Stable

Lake ranking 11th

Lake Rotoiti is categorised as being in moderate ecological condition with a LakeSPI Index of 20% (Figure 20).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2015	Poor	20%	25%	92%
April 2013	Moderate	21%	31%	91%
May 2011	Poor	20%	25%	91%
May 2009	Moderate	21%	29%	89%
October 2006	Poor	18%	18%	90%
September 2003	Poor	18%	22%	90%
February 2001	Poor	20%	24%	90%
January 1988	Moderate	26%	33%	85%
March 1981	Moderate	26%	33%	82%

Figure 20: LakeSPI results for Lake Rotoiti. LakeSPI Indices expressed as a percentage of lake maximum potential.

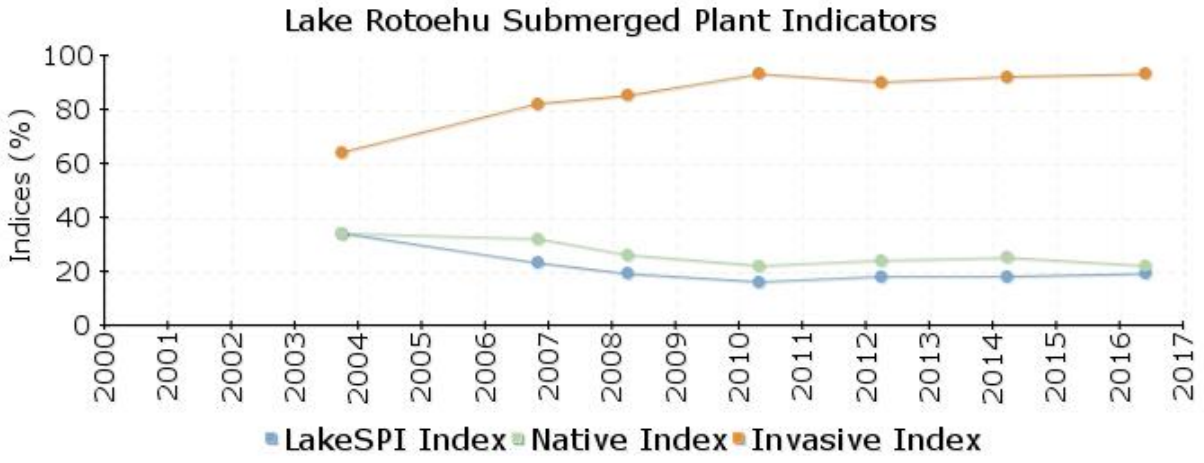
Lake Rotoiti has consistently had one of the highest Invasive Impact Index scores and continued to have one of the lowest LakeSPI Indices recorded for the 12 Rotorua Te Arawa lakes. The development of some deeper charophyte meadows reflected by an increase in the Native Condition scores between 2006 and 2009 have continued to be variable in nature and in 2015, charophyte meadows were recorded from only two of the five LakeSPI baseline sites.

Lake Rotoiti has a complex morphometry with areas along the northern shoreline too steep to support submerged vegetation, making them unsuitable for LakeSPI sites. The western end of Lake Rotoiti has in the past been markedly influenced by water from Lake Rotorua and there has been a progressive decline in submerged vegetation extent 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 has reduced water quality impacts in the western part of the lake. However flow-on effects on submerged vegetation are not yet confirmed, but the LakeSPI sites represent the whole lake and not just the western end. 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 overall indicate poor water quality in this lake.

3.6 Lake Rotoehu

Lake condition:	Poor
Stability:	Stable
Lake ranking	12th

Lake Rotoehu is categorised as being in poor ecological condition with a LakeSPI Index of 19% (Figure 21).



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
May 2016	Poor	19%	22%	93%
March 2014	Poor	18%	25%	92%
March 2012	Poor	18%	24%	90%
April 2010	Poor	16%	22%	93%
March 2008	Poor	19%	26%	85%
October 2006	Moderate	23%	32%	82%
September 2003	Moderate	34%	34%	64%
January 1988	Moderate	30%	34%	81%

Figure 21: LakeSPI results for Lake Rotoehu. LakeSPI Indices expressed as a percentage of lake maximum potential.

Hornwort (*Ceratophyllum demersum*) dominates the submerged vegetation in Lake Rotoehu, which continues to have the lowest LakeSPI Index (19%) and the highest Invasive Impact Index (93%) recorded for any of the 12 Rotorua Te Arawa lakes (Figure 21). In 2016 the lake is in a poor, but stable condition, as the full impact of hornwort has taken place.

Hornwort formed dense weed beds up to 3.5 m tall, at all five LakeSPI sites, and grew down to a maximum depth of 8 m. Other invasive species present in Lake Rotoehu include *Elodea canadensis*, *Lagarosiphon major* (although not recorded during the recent 2016 survey), and an invasive pondweed (*Potamogeton crispus*).

Native vegetation in Lake Rotoehu while generally sparse, did still persist, particularly in shallower water less than 2 m deep. Three charophyte species (*Chara australis*, *Chara globularis* and *Nitella hyalina*) were recorded forming high covers (>75%) at three of the five LakeSPI sites, positively contributing to a Native Condition Index of 22% (Figure 21). Other native vegetation included a short turf growing species (*Glossostigma elatinoides*, at only one site), a pondweed (*Potamogeton ochreatus*), and two milfoils (*Myriophyllum triphyllum*, *Myriophyllum propinquum*).

Of particular interest to divers during the recent survey, was the presence of numerous holes, c. 8-10 cm in diameter, at one site on the Western side (Omahota Bay). These holes were in shallow depths of between c. 0.5 – 2 m, and resembled those that are caused by the presence of catfish (*Ameiurus nebulosus*). Surveillance of this area using nets by BOPRC staff following this survey, resulted in no catfish being caught (S.Grayling, BOPRC, pers comm.).

At the time of the 2016 survey, large numbers of freshwater mussels were observed at most sites.

Historical notes – Hornwort was first recorded in Lake Rotoehu at Otautu Bay in December 2004 (R. Mallinson, BOPRC, pers comm.), and by late summer 2005 it had formed extensive weed beds around much of the shoreline. Since 2006, LakeSPI results indicate the negative impact hornwort has had on native submerged vegetation within the lake as it approaches 'habitat saturation'.

The discovery of the ear pond snail (*Lymnaea auricularia*), well established in Omahota Bay during the 2014 survey, is the second record of this invasive snail in the Rotorua Te Arawa lakes.

Figure 22: Hornwort strandings on the shore of Lake Rotoehu in 2016.

4 Discussion

4.1 Changes over time

Changes in LakeSPI indices over the recent time frame (2011 - 2016) have been used to provide an indication of current stability in lake condition and the direction of change (Table 3).

Table 3: Summary for current LakeSPI results for the 12 Rotorua Te Arawa Lakes showing overall condition category, current stability rating, long term changes in condition and an indication of the main impact factors affecting scores.

Lake	LakeSPI Index (%)	Overall Condition	Current Stability (~5 years)	Long term changes (25+ years)	Impact factor
Ōkāreka	55	High	Improved	Change	Weed
Rotomā	54	High	Stable	No Change	Weed
Rotomāhana	54	High	Stable/declining?	Change	Weed
Tikitapu	44	Moderate	Stable	Change	Water Quality
Ōkataina	38	Moderate	Stable/declining?	Change	Weed
Rerewhakaaitu	31	Moderate	Stable/declining?	Change	Weed
Rotokakahi	30	Moderate	Stable	Change	Water Quality
Rotorua	28	Moderate	Stable/Improving?	No Change	Water Quality
Ōkaro	28	Moderate	Stable	Change	Water Quality
Tarawera	25	Moderate	Stable	Change	Weed
Rotoiti	20	Poor	Stable	No Change	Water Quality
Rotoehu	19	Poor	Stable	Change	Weed

Lake Ōkāreka is the only lake to have shown improvement over the recent time frame on account of efforts carried out by BOPRC to control invasive weeds in the lake. While this result is encouraging, should the control program lapse for Lake Ōkāreka we can expect to see LakeSPI scores return to previous levels or deteriorate further with the consequent invasion by hornwort.

Lakes Rotomāhana, Ōkataina, and Rerewhakaaitu maintain a stable condition over the recent time frame, but have shown signs of deterioration in the most recent survey. Lake Rotorua has also remained in a stable condition since at least 2003, however recent LakeSPI results for this lake indicate a slight improvement in lake condition due to an increase in the depth of native vegetation at sites within the lake.

All remaining Rotorua Te Arawa lakes currently appear to be in a stable condition, with little change in scores over the short term, although future change is expected for those at risk from expanding invasive plants (Lakes Rotoma, Ōkataina, Rotokakahi). Longer term, many of the Rotorua Te Arawa Lakes have undergone significant deterioration over the last 25 years (Figure 23).

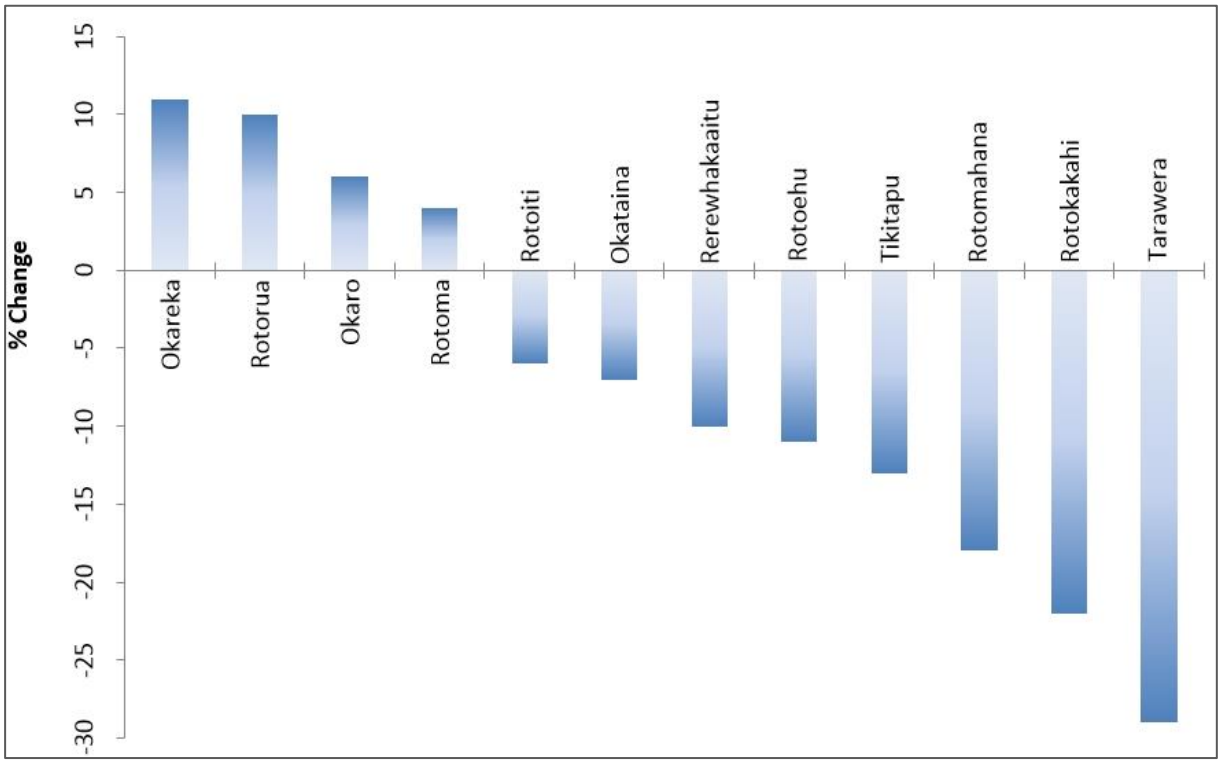


Figure 23: Percentage of change as indicated by the LakeSPI Index over the last 27 years, 1988/1989 to 2015/16.

Lakes Tarawera and Rotomāhana show some of the biggest changes in lake condition over the last 26-28 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 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 taken place, it is not expected to change significantly in the near future. Hornwort is likely at 'habitat saturation' in Lake Rotoehu also. In Lake Rotomahana we can expect to see a further decline in LakeSPI scores if 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 Ōkāreka (detected March 2012) and Ōkataina (detected March 2010). Based on the potential for hornwort to spread within these lakes and its likely impact, we can expect to see a notable decline in the status of Lakes Ōkāreka and Ōkataina in years to come should hornwort continue to spread if it is not controlled.

Lake Rotomā remains at high risk of invasion by hornwort, which would have a major detrimental impact on the native character and biodiversity values of this lake.

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. However it only takes one shoot and even the most remote lake, Lake Rotomahana already has it.

The second biggest change affecting the condition of the Rotorua Te Arawa Lakes is water quality. Lake Rotokakahi shows the second biggest change in lake condition over the last 26-28 years (Figure 23) and since there have been no new invasive species recorded since full lake surveys began in 1988, the changes in this lake are likely to be the result of deteriorating water quality and clarity (RTALP, 2015). 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). If the deterioration in this lake was due to the recent pine forest harvest, the lake should recover over the next decade. It is planned to create a native tree buffer zone at the lake margin before the next harvest.

4.2 National comparison

Compared nationally, the Bay of Plenty Region has no lakes classified as being in 'excellent' condition (representing those close to their maximum potential ecological condition) and has three lakes classified as being in 'high' condition (Figure 24 & 20).

A 'moderate' condition category contains the majority of the Rotorua Te Arawa Lakes as is the case 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. Lakes Rotoehu and Rotoiti are the only two Rotorua Te Arawa lakes ranked in this 'poor' category. Three other lakes (Matahina, Aniwhenua, Pupuwharau) surveyed within the Bay of Plenty Region were also in this category.

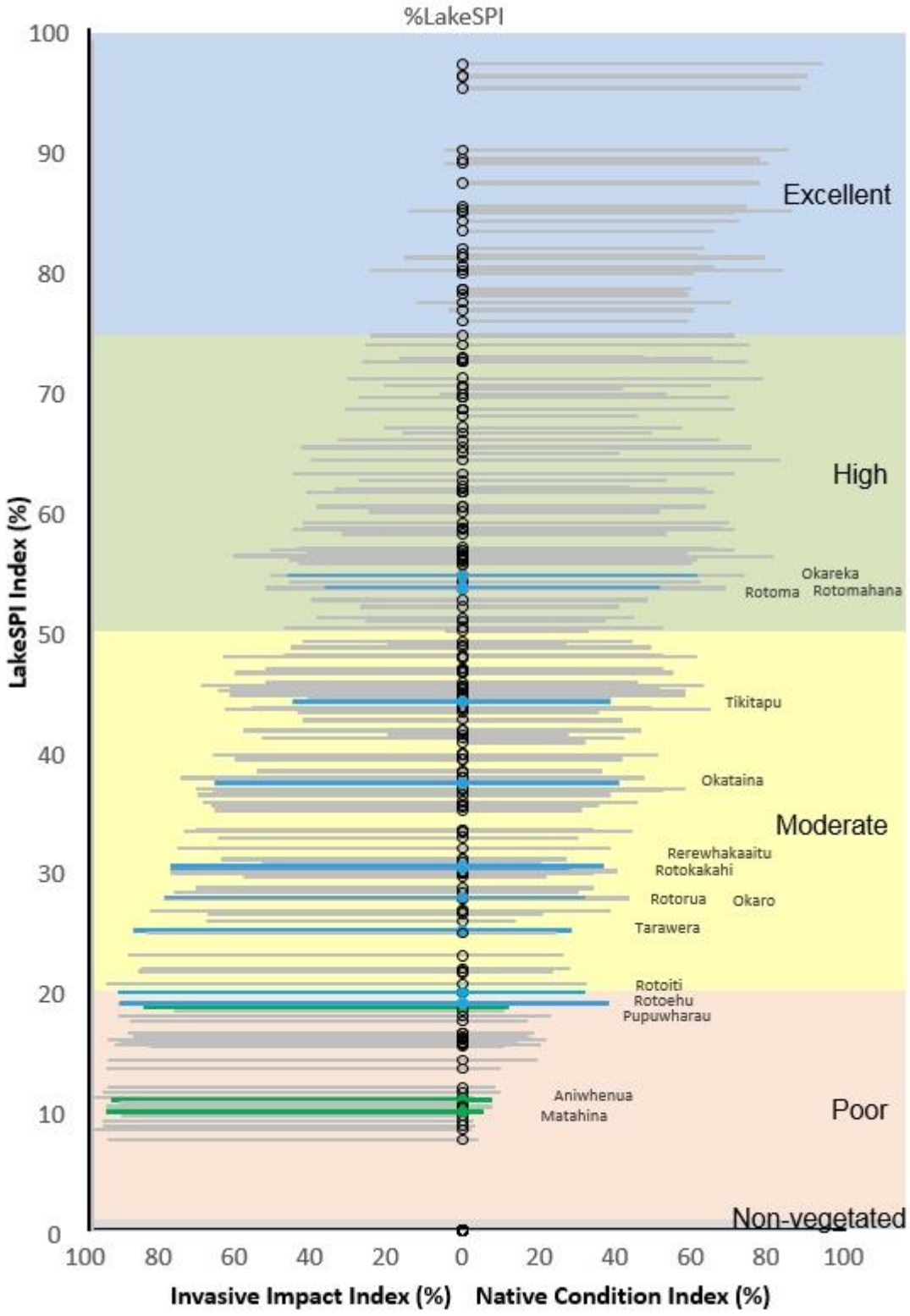


Figure 24: Rotorua Te Arawa Lakes (blue lines) and 3 other lakes in the Bay of Plenty Region (green lines) are plotted with scores for a total of 264 New Zealand lakes. The most recent LakeSPI scores for lakes for the Rotorua the LakeSPI Index is plotted on the y-axis (points), Native Condition Index 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.

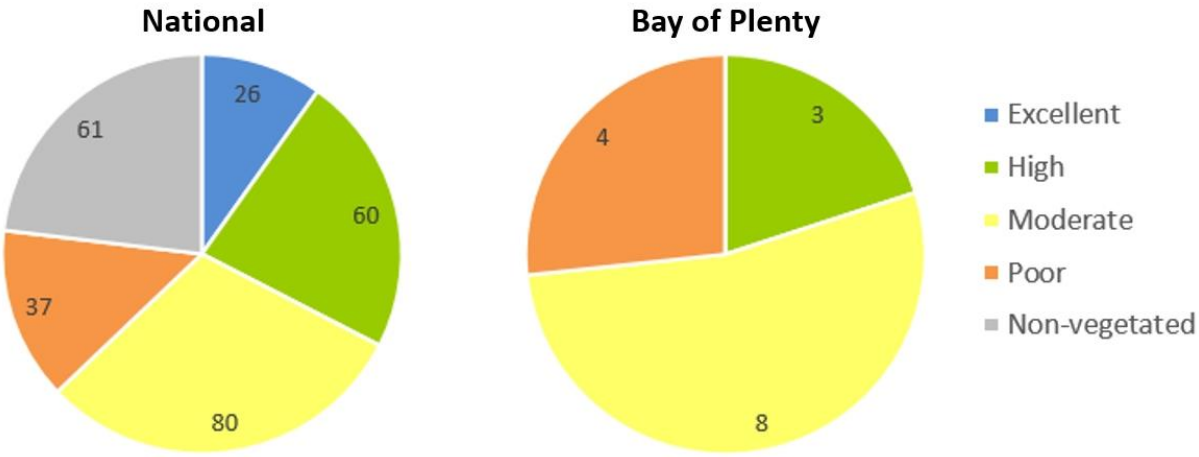


Figure 25: Proportion of lakes that fall into each of five categories of LakeSPI Index for the region (15) and nationally (264), with the number of lakes assessed shown in parenthesis.

4.3 LakeSPI key points

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

Lake Ōkāreka

- Overall lake condition high, for the first time.
- Improvements based on the recovery of native vegetation following control of invasive weed species in the lake.
- Lowest Invasive Impact Index in the region and one of the highest Native Condition Indices.
- Recent invasion by hornwort still poses a serious threat to future condition should efforts to control it be relaxed.

Lake Rotomā

- Overall lake condition high.
- Highest Native Condition Index in the region.
- An exceptional lake and the best example of extensive charophyte meadows.
- Major risk from hornwort invasion that would impact LakeSPI values greatly.

Lake Rotomāhana

- Overall lake condition high.
- Egeria and hornwort had a reduced impact during the 2015 survey.
- High Native Condition Index.

Lake Tikitapu

- Overall lake condition moderate and appears stable.
- Major decline in Native Condition Index and LakeSPI scores over the last 26 years independent of any impact from new invasive species.
- Unusual water chemistry may inhibit impact from present and future invasive species.

Lake Ōkataina

- Overall lake condition moderate and appears stable.
- Hornwort poses a serious threat to future LakeSPI condition.
- High Native Condition Index.

Lake Rerewhakaaitu

- Overall lake condition moderate and stable.
- Early indications raise concern during recent survey for declining Native Condition values due to increased invasion by egeria.
- Invasion potential of egeria may yet further influence LakeSPI Index.
- Moderate risk from hornwort invasion.

Lake Rotokakahi

- Overall lake condition moderate and appears stable.
- Major decline in LakeSPI and Native Condition Index over last 28 years.
- No change in elodea status but Invasive Impact Index reflects greater relative occupation of the remaining vegetation by elodea.
- Now only this lake and Lake Okaro remain relatively free of all three worst 'high impact' invasive weed species.

Lake Rotorua

- Overall lake condition moderate but showing possible signs of improvement.
- Slight variations in Native Condition Index reflect some variability in the development of these communities from year to year.

Lake Ōkaro

- Overall lake condition moderate and stable.
- 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.
- Does not have any of the three worst invasive species.

Lake Tarawera

- Overall lake condition moderate and stable.
- LakeSPI and Native Condition Index scores have declined significantly over the last 28 years.
- Invasion of hornwort primarily responsible for decline in LakeSPI and Native Condition scores.

Lake Rotoiti

- Overall lake condition is poor and stable.
- Has one of the highest Invasive Impact Indices of the Rotorua Te Arawa lakes.
- LakeSPI Index indicates poor water quality.

Lake Rotoehu

- Overall lake condition poor.
- Hornwort has had a major impact and dominates the submerged vegetation.
- Has the highest Invasive Impact Index of the Rotorua Te Arawa lakes.

6 Recommendations

It is recognised by the BOPRC (A. Suren, BOPRC, pers comm.) that there may be merits in investigating other approaches for the use of LakeSPI data (E.g., limit setting) for the Rotorua Te Arawa lakes. NIWA welcomes further discussion with BOPRC to consider the possible options for extending the use of the LakeSPI data as an indicator of overall lake ecological condition.

It is also recommended that additional one-off surveys be completed for all Bay of Plenty lakes even if with no or limited vegetation. Knowledge of their current condition will provide a better understanding of the regions diversity of lakes and factors that influence macrophyte presence in the region. Benefits of further longer term monitoring should then be considered relative to assessed values and threats for each lake.

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