NIWA
Taihoro Nukurangi

Assessment of the Rotorua Te Arawa lakes using LakeSPI – 2017

Prepared for Bay of Plenty Regional Council

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Cover photo: Lake Rotokakahi.

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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 Ōkāreka, Ōkaro, Rotomā, Rotomāhana, Rotoiti and Rotorua were surveyed in 2017, and Lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu in 2016. This report provides an update of lake ecological condition and discusses the changes evident in LakeSPI indices over a recent time-frame since 2012 (4 to 5 years) and long-term (>25 years).

LakeSPI is a bioassessment method that uses the degree of development by native submerged plants, and level of impact by non-native, invasive weeds to indicate a lakes ecological condition. A LakeSPI Index ranges from 0% (heavily impacted lakes) to 100% (pristine, unimpacted lakes) and provides 5 categories of condition including excellent, high, moderate, poor and the most impaired state of non-vegetated.

The 2016/17 LakeSPI indices for the lakes ranged widely from 19% to 62% with two lakes assessed as being in 'high' condition, eight lakes as 'moderate' and two lakes categorised as in 'poor' condition. Compared to lakes nationally, Rotorua Te Arawa lakes were 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 Rotomāhana was the top-ranked lake, categorised as in 'high' condition. LakeSPI scores had improved since the 2015 survey following an expansion of native vegetation in response to a reduction of invasive weeds in the lake. This reduction in the abundance and extent of egeria and hornwort in the lake is unexplained and may be due to water quality factors.

Lakes Rotomā was also ranked in 'high' condition. This lake has been stable both in recent and long-term time frames due to continued high water quality, but remains vulnerable to potential hornwort invasion.

Eight lakes were in 'moderate' condition. Lake Ōkāreka has shown improvement over the recent time frame on account of efforts by BOPRC to control invasive weeds in the lake. This result is encouraging and shows the benefits of more intensive lake weed management. Lake Ōkaro showed the greatest improvement of any of the lakes following a reduction in the abundance of elodea during the recent 2017 survey and an increase in the depth extent of native vegetation, reflecting improved water quality. This is attributed to intensive restoration efforts in the catchment to reduce nutrient inputs and to in-lake sequestering of phosphates by applying binding agents. LakeSPI results for Lake Tikitapu indicate a stable condition following some recent signs of improvement, however longer-term values show a significant reduction in Native Condition values. Lakes Ōkataina, and Rerewhakaaitu have maintained a stable condition over the recent time frame, but have shown possible signs of deterioration in the latest surveys. A reduction in the depth extent of plant communities at some sites was a concern for Lake Ōkataina and hornwort remains a threat to the future condition of this lake. Lake Rerewhakaaitu showed signs of deterioration on account of increased impact from egeria and lagarosiphon. Lake Rotokakahi showed substantial deterioration over the long-term due to water quality impacts, with no change in invasive weed presence, but more recently LakeSPI scores have stabilised. Results for Lake Rotorua indicate signs of improvement over the longer term with an increase in the depth of native vegetation, but this has been variable in

the past. 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 long term.

Lakes Rotoiti and Rotoehu were categorised in 'poor' condition. They had 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 weed invasion occurred historically (>20 years ago) in Lake Rotoiti, vegetation in Lake Rotoehu has 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 (since 1988). 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 Rotorua Te Arawa lakes continue to be vulnerable to further changes from invasive plants and deteriorating water quality.

It is recommended that additional one-off surveys be completed for all Bay of Plenty lakes even if they have no or limited vegetation. Knowledge of their current condition will provide a better understanding of the region's 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. For Lake Rotoiti, there are a number of lake sectors (e.g., Okawa Bay) that could be monitored separately to establish baselines for monitoring future change. This monitoring would provide improved feedback on attempts to manage Okawa Bay's water quality and invasive weed impacts. It is also recommended that limit and target setting be explored further for the Rotorua Te Arawa lakes in the near future.

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 annually 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 on lakes.

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 Ōkaro, Ōkāreka, Rotoiti, Rotomā, Rotomāhana and Rotorua last assessed in March to May 2017, and also presents results for lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu last assessed in 2016 (Burton 2016).

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 including 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 1-1). Morphological characteristics are given in Table 1.

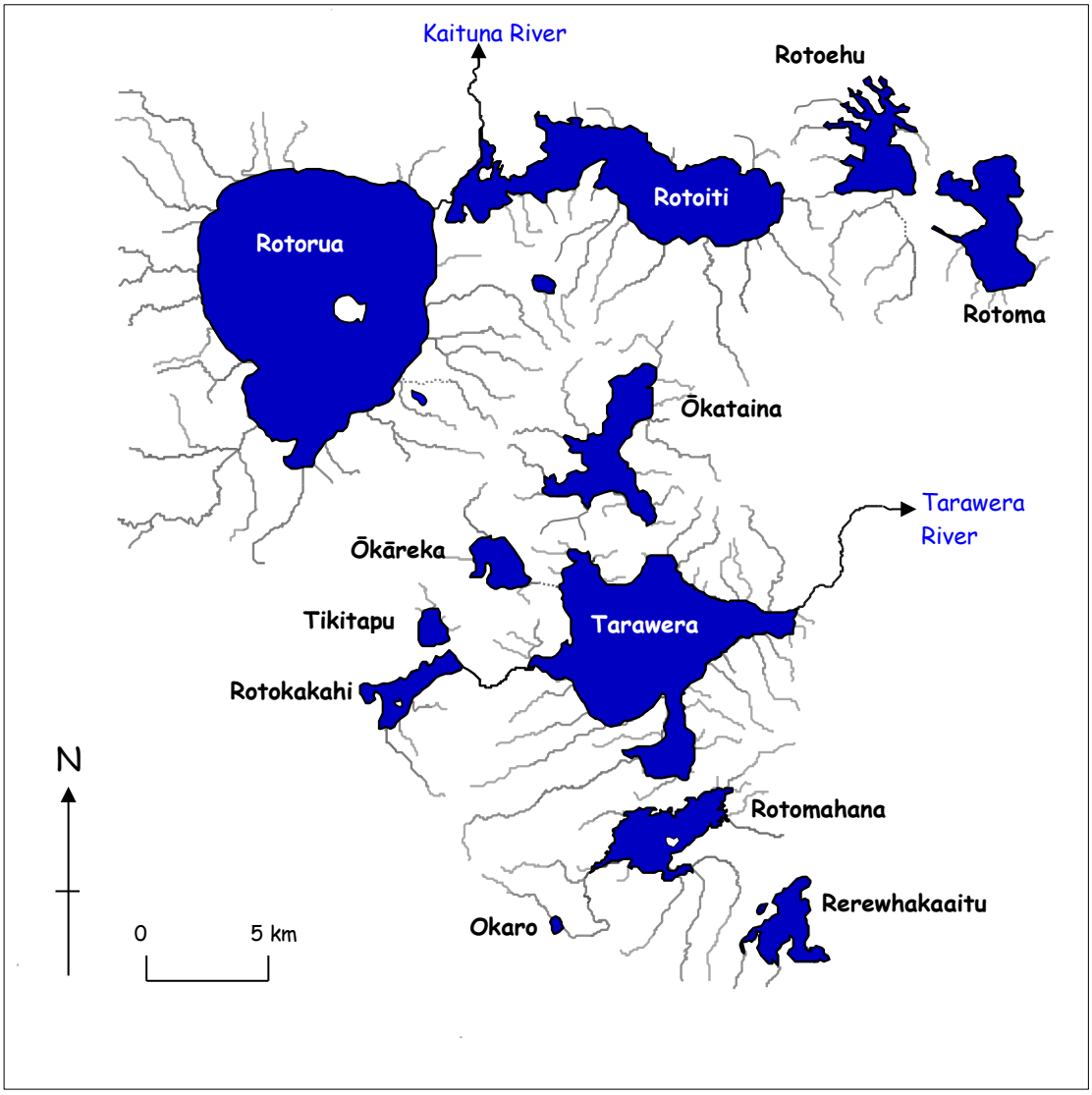


Figure 1-1: Map showing location of the 12 Rotorua Te Arawa lakes.

In addition to these 12 Rotorua Te Arawa lakes, three other Bay of Plenty 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 in manuka scrub. Clearing and planting of *Pinus radiata* forests began in the early 1900s with harvesting 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, and intensification of land use have contributed to nutrient enrichment problems in 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 the introduction of invasive aquatic weeds. 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 maximum vegetated depth close that recorded for the lake in the early 1970s, and Lake Rerewhakaaitu with improved water clarity and a corresponding increase in the depth of submerged vegetation.

The second crucial factor affecting the aquatic vegetation in the Rotorua Te Arawa Lakes is the introduction of a range of invasive plant species (Figure 1-2). 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 1950's 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 by lagarosiphon 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, that has exceeded all expectations justifying its ranking as New Zealand's worst widespread submerged aquatic plant pest (Champion and Clayton 2000).

The spread of significant invasive weed species to the remaining Rotorua Te Arawa Lakes was a gradual 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, attributed to its more remote location and difficult public access, but the discovery of egeria and hornwort around the boat launching area 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 by local hapu through the Lake Rotokakahi Board of Control.

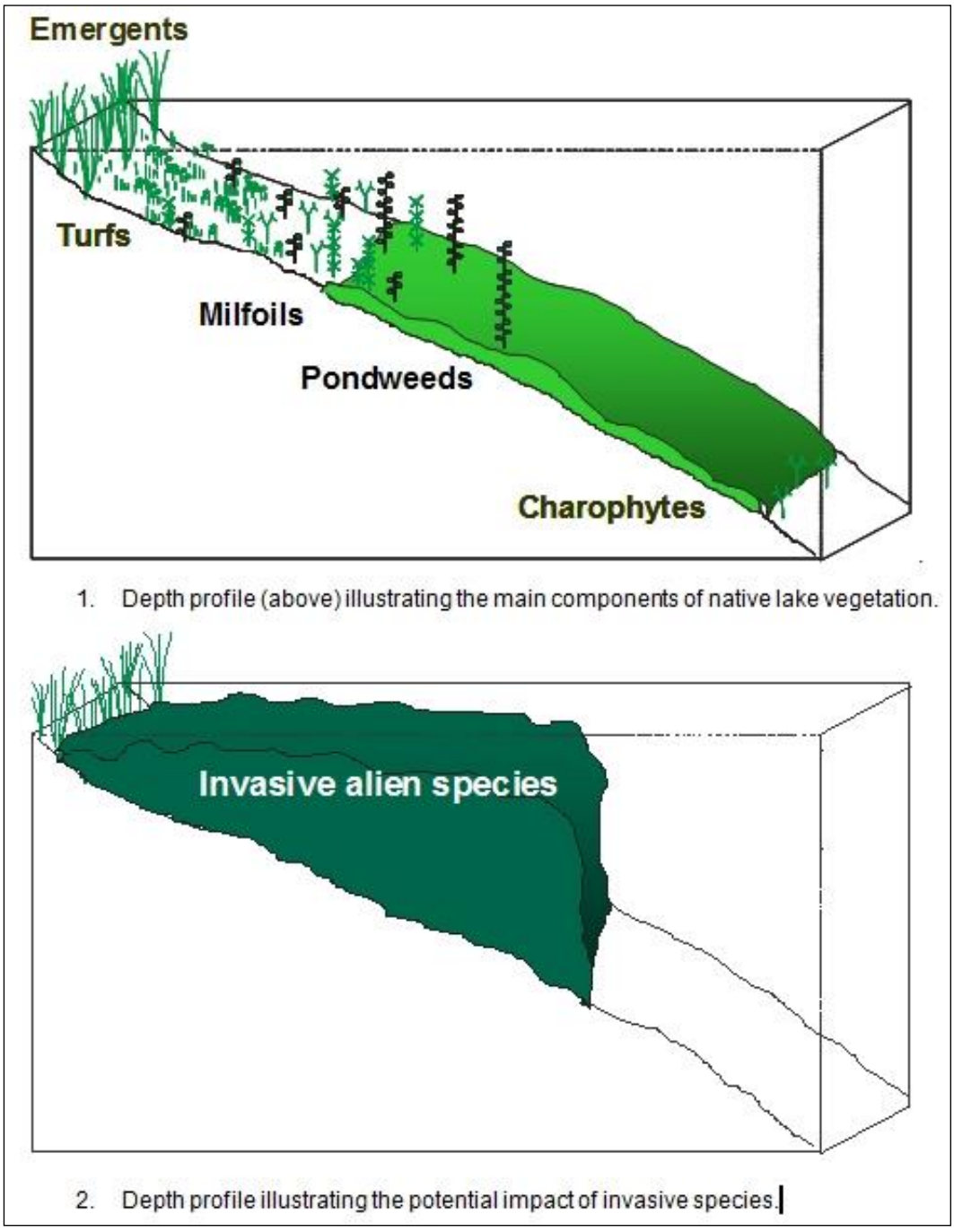


Figure 1-2: Depth profiles within a lake illustrating the difference between a lake maintaining diverse native plant communities and that which is invaded with invasive weed species.

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, more diverse beds.
- 'Invasive Impact Index' – This captures the degree of impact in a lake by invasive weed species. A higher score means more impact from exotic species, which is usually 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 ecological condition. The higher the score the better the condition.

Key concepts driving the LakeSPI method are that native plant species and high plant diversity represent healthier lakes or better lake ecological 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 and regional level.

2.2 Lake surveys

The LakeSPI method was used to assess five established baseline sites within each of the six lakes re-assessed this year. Lakes Ōkaro, Ōkāreka, Rotoiti and Rotomā were surveyed in March, Lake Rotorua in April, and Lake Rotomāhana in May 2017.

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 and composition of invasive weeds 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. They are:

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 change

Changes in LakeSPI indices over a recent time-frame, 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.

Change can also be assessed over longer time frames and multiple surveys. Guidelines (Figure 3) based on expert judgement suggest a scale of probabilities for determining the ecologically significance of 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. The significance for the various levels of change are:

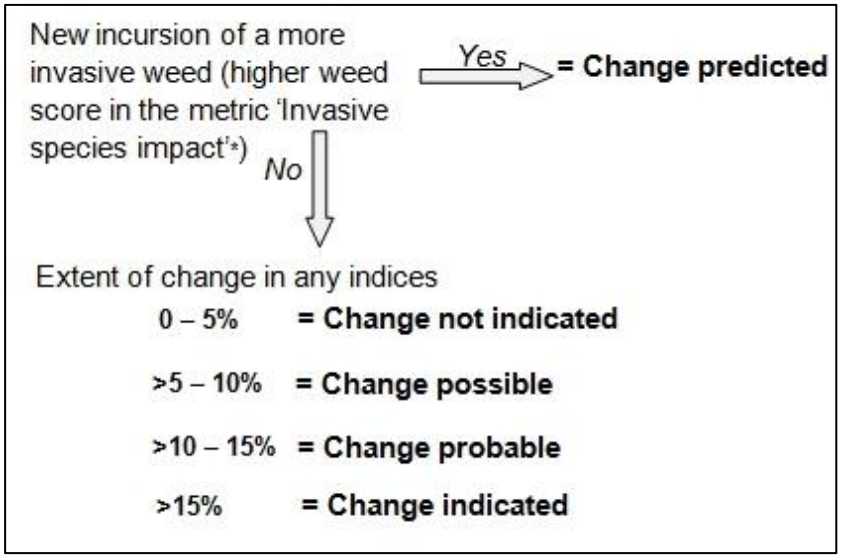


Figure 2-1: Guidelines assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.

In addition, the likelihood of a statistically 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

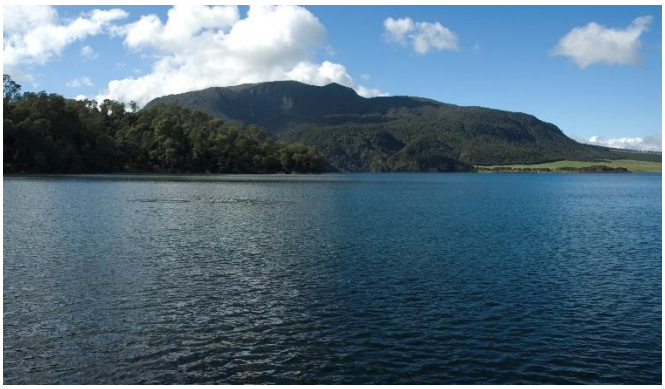
Table 2 presents LakeSPI results for each lake, with the indices presented as a percentage of maximum scoring potential. In the following section the lakes are discussed in order of their LakeSPI scores, beginning with the highest ranked lake.

Table 2: Summary of current LakeSPI indices, for 12 Rotorua Te Arawa lakes in order of their overall lake condition (2016 or 2017).

Lake	Most recent LakeSPI survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Rotomāhana	17/05/2017	62	57	29	High
Rotomā	03/04/2017	52	55	45	
Ōkāreka	04/04/2017	50	56	52	Moderate
Ōkaro	04/04/2017	49	45	39	
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	
Rotorua	10/04/2017	26	27	79	
Tarawera	18/05/2016	25	29	89	
Rotoiti	03/04/2017	19	23	91	Poor
Rotoehu	19/05/2016	19	22	93	

3.1 Lake Rotomāhana

3.1.1 Results



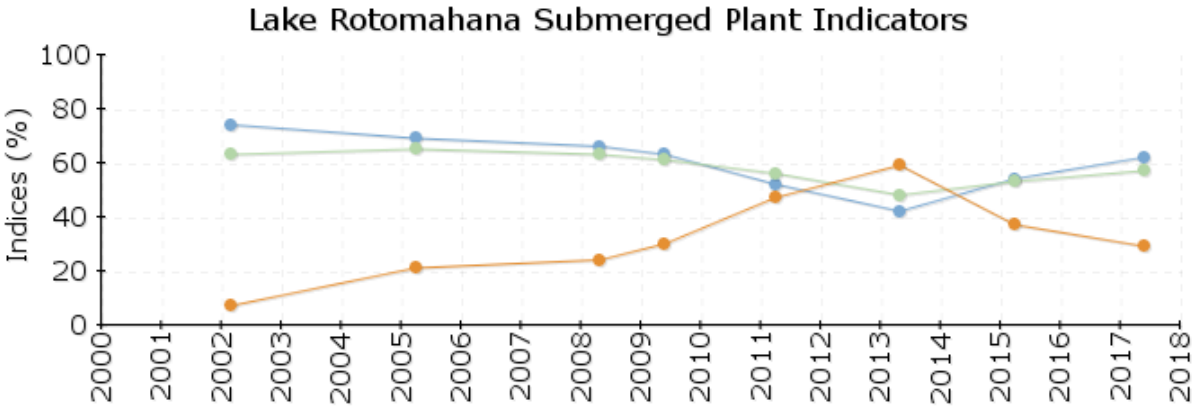
Lake condition: High

Lake ranking: 1st

Lake stability: Stable/improving

Lake maximum depth: 125 m

Max depth of vegetation: 11.5 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
May 2017	High	62%	57%	29%
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 3-1: LakeSPI results for Lake Rotomāhana since 1988.

Lake Rotomāhana is currently the highest ranked lake in the Rotorua region and was categorised in high ecological condition with a LakeSPI Index of 62% (Figure 3-1).

A diverse native plant community was present. Native charophyte communities formed meadows (>75% cover) at four of the five sites to a maximum depth of 9 – 11 m. Charophytes, *Chara globularis* and *Nitella* sp. aff. *cristata* were the most common species observed with *Nitella hyalina* and *Chara*

australis also recorded. Other native plants included milfoils (*Myriophyllum propinquum, Myriophyllum triphyllum*) (Figure 3-2), pondweeds (*Potamogeton ochreatus*, *Stuckenia pectinata*), Ruppia (*Ruppia megacarpa, Ruppia polycarpa*) (Figure 3-3), and three shallow water turf species (*Glossostigma elatinoides*, *Elatine gratioloides* and *Lilaeopsis ruthiana*). A small rush *Eleocharis acuta* was also present on one site growing down to c. 2 m.

Egeria (*Egeria densa*) was recorded from only two LakeSPI sites in the recent survey, forming high covers down to a maximum depth of 8.6 m. The introduced pondweed *Potamogeton crispus* was recorded in low covers from one site. No hornwort (*Ceratophyllum demersum*) was observed from LakeSPI sites in the lake.

During the recent survey, through-water visibility was estimated by divers to be c. 3.0 m, with lower visibility (<1m) in shallower water (c. <4 m) on the south-east side of lake. The ear pond snail (*Radix auricularia*) was present but at lower numbers than had previously been seen in 2015. No koura (freshwater crayfish) or freshwater mussels have been observed in Lake Rotomāhana.

3.1.2 Discussion

An increase in the LakeSPI Index from 54% in 2015 to 62% in 2017 (Figure 3-1) has resulted in Lake Rotomāhana returning to its previous position as the top ranked Rotorua Te Arawa lake.

After remaining relatively stable for some years, Lake Rotomāhana deteriorated following invasion by egeria and hornwort, most noticeable during the 2011 and 2013 surveys (Figure 3-1). Since then however, these weeds have diminished in their abundance and native values and lake condition indices have continued to improve. This improvement is reflected by a reduced Invasive Impact Index, from 59% in 2013 to 29% in 2017 (Figure 3-1), an increase in the Native Condition scores, and an overall improvement in the LakeSPI Index to 62%. Hornwort was not found during the recent 2017 survey at any sites (previously found at two LakeSPI sites in 2013), and egeria was recorded from only two of the five sites it had previously occupied. The reduction in the cover of hornwort and egeria in Lake Rotomāhana is unexplained. There have been no control works carried out in Lake Rotomāhana since 2006 (H. Lass, BOPRC, pers comm). Some lakes do show a boom bust pattern in weed invasion as was documented for egeria in Lake Tarawera, but it is not common. The unusual water quality in the lake may be a driver.

Over the long term (27-29 years) Lake Rotomāhana has shown some of the biggest change in lake condition of the 12 Rotorua Te Arawa lakes resulting mainly from the invasion of egeria and hornwort (Figure 4-1). These weeds not only cause physical and biological changes in the lake's littoral zone, but also impact negatively on lake condition by excluding native plant communities from depths of less than 6-10 metres, with hornwort able to out-grow and smother native vegetation to around 15 metres depth.

Historic notes - Egeria and hornwort were recorded for the first time in 2007. Egeria was found in two areas of the lake, at the north-eastern end and in the south-east embayment, and hornwort fragments were found growing amongst native plants in the southern embayment (Clayton & de Winton, 2007; Scholes and Bloxham, 2008). Subsequent surveys confirmed egeria and hornwort were spreading around the lake with egeria forming high covers at all five LakeSPI sites in the 2011 and 2013 surveys. Hornwort was recorded from two LakeSPI sites in the 2013 survey.

The discovery of the ear pond snail during the 2011 survey, suggests an aquarium or ornamental pond source for egeria, hornwort and the ear pond snail, and possibly a deliberate release is possible based on the coincidental timing.

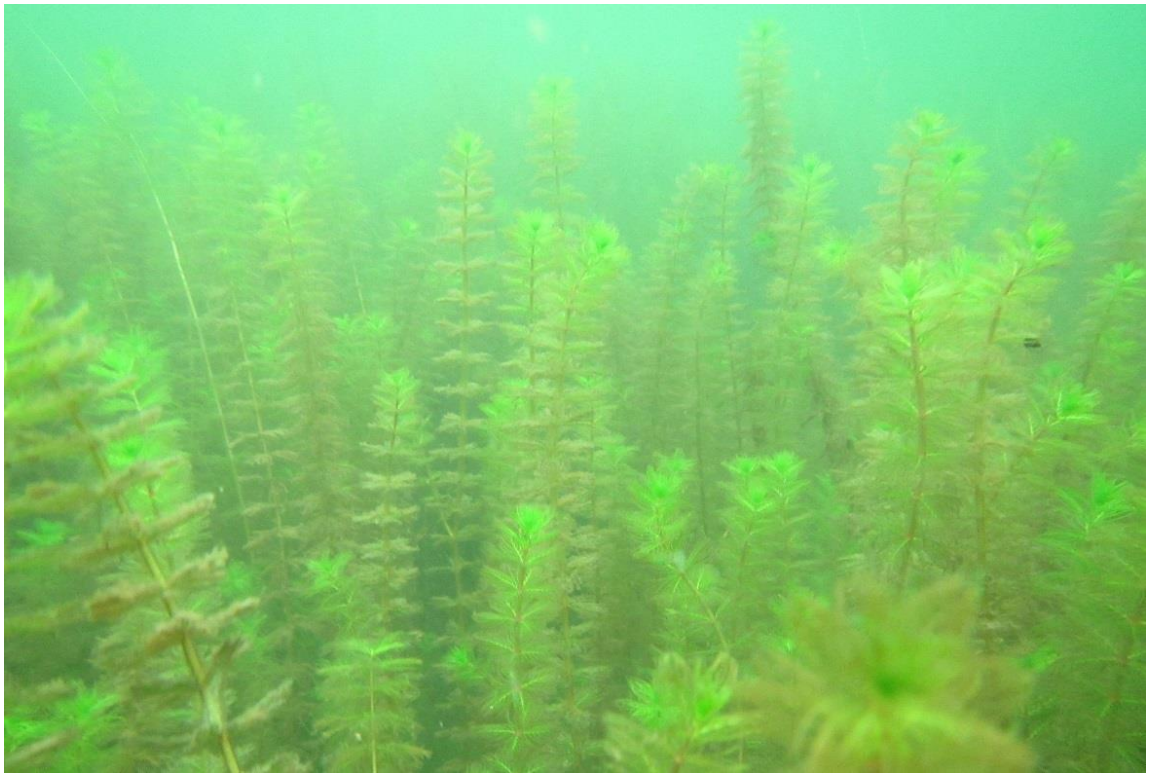


Figure 3-2: Native milfoils (*Myriophyllum triphyllum*) in Lake Rotomāhana.

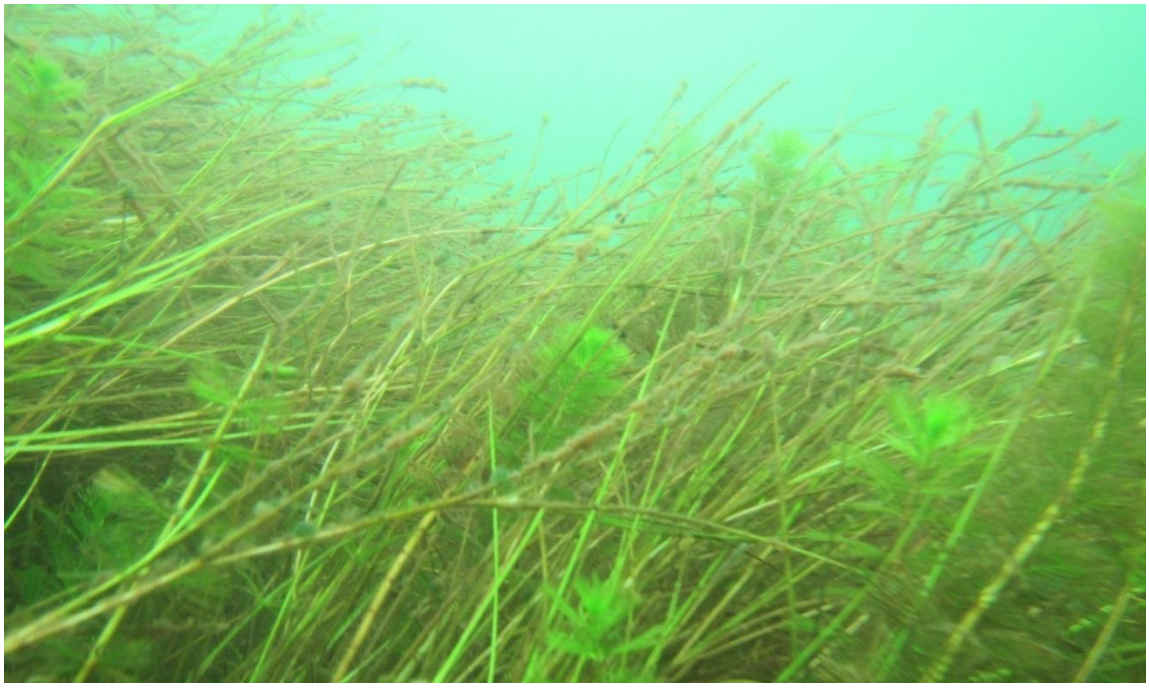
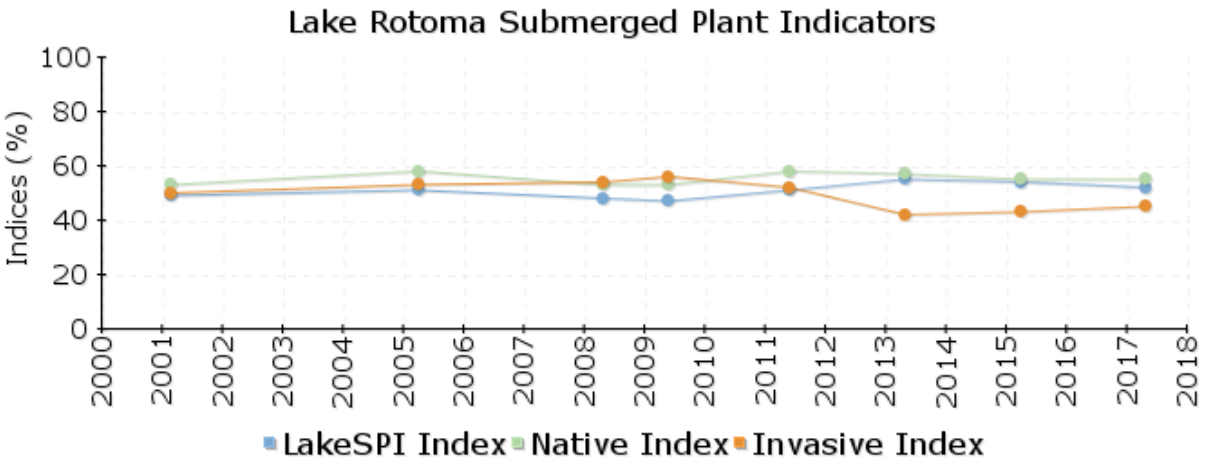


Figure 3-3: Native *Ruppia megacarpa* in Lake Rotomāhana.

3.2 Lake Rotomā

3.2.1 Results

Lake condition:	High
Lake ranking:	2nd
Lake stability:	Stable
Lake maximum depth:	83 m
Max depth of vegetation:	14 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
April 2017	High	52%	55%	45%
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 3-4: LakeSPI results for Lake Rotomā since 1973.

Lake Rotomā was categorised in high ecological condition with a LakeSPI Index of 52% (Figure 3-4).

Native charophyte meadows dominated the submerged vegetation in Lake Rotomā extending down to a maximum depth of 10.5 – 14 m. Six native charophyte species (in order of abundance: *Chara fibrosa*, *Nitella leonhardii*, *Chara australis*, *Nitella hyalina*, *Nitella pseudoflabellata* and *Chara globularis*) were recorded from Lake Rotomā (Figure 3-5). Other native species included a milfoil (*Myriophyllum triphyllum*) and four shallow water turf species (*Glossostigma diandrum*, *Lilaeopsis ruthiana*, *Elatine gratioloides* and *Eleocharis pusilla*) observed from only one site.

Lagarosiphon (*Lagarosiphon major*) was the only invasive weed species observed during the survey and was present at all five LakeSPI sites. It formed high cover weed beds at four of the five sites to a maximum depth of 6.1 m, with low covers at one other. At most sites, it did not grow particularly tall (c. 1.3 m in height), but did grow up to 3 m tall at one site on the northern side of lake (Figure 3-6).

At the time of recent survey, through-water visibility was exceptional and estimated by divers to be >10.0 m. Both freshwater mussels (*Echyridella menziesi*) and koura were observed in the lake.

3.2.2 Discussion

LakeSPI scores for Lake Rotomā have remained stable over the last 29 years, from 1988 – 2017.

The proximity of hornwort in Lake Rotoehu continues to raise concern over the risk of spread to Lake Rotomā, with contaminated boat traffic representing the greatest threat. Invasion by hornwort and egeria would have a major detrimental impact on the native character and biodiversity values of this lake. Hornwort would be capable of displacing all existing native vegetation in Lake Rotomā by forming dense weed beds that would likely extend to the current maximum depth limit of plants as has occurred in Lake Taupo.

Historical notes - Lake Rotomā was retrospectively calculated to have a high LakeSPI score in 1973, which reflected the early stage of lagarosiphon invasion and extensive high cover charophyte meadows in the 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 1988, changes have been minor.

In 1972 an underwater marker buoy was placed at the bottom boundary of submerged plant growth at one of the five LakeSPI baseline sites (J. Clayton, NIWA, pers comm.). This buoy has marked the deepest plant boundary for the last 45 years but could not be found during this recent survey. This buoy has provided good evidence for the stability in water clarity over this time and confirms that the impact of invasive species on submerged vegetation was the key early driver of change in LakeSPI scores.

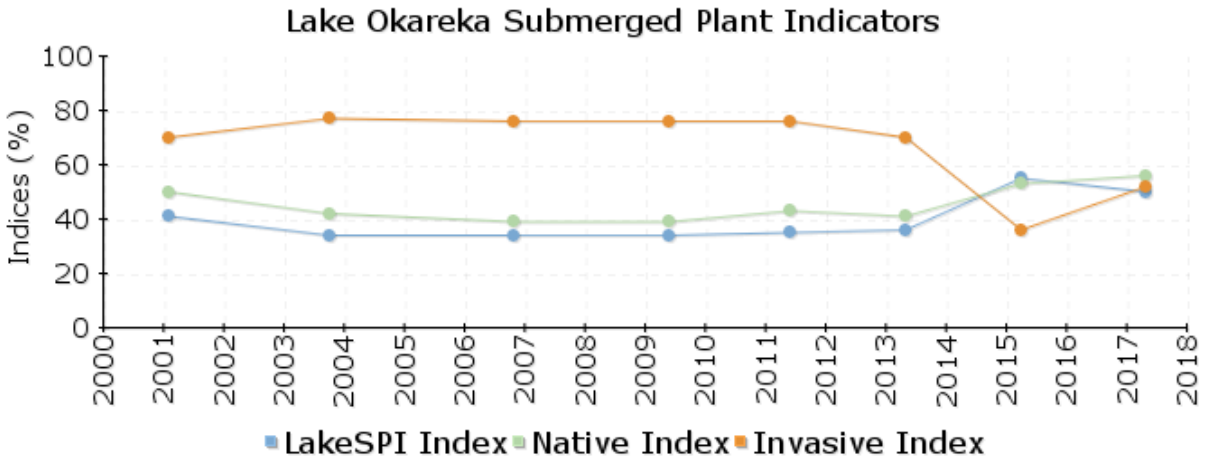
Figure 3-5: Lagarosiphon shoots growing amongst charophyte (*Chara fibrosa*) meadows in Lake Rotomā.

Figure 3-6: Lagarosiphon forming a dense tall weed bed in Lake Rotomā.

3.3 Lake Ōkāreka

3.3.1 Results

Lake condition:	Moderate
Lake ranking:	3rd
Lake stability:	Stable/improved
Lake maximum depth:	33.5 m
Max depth of vegetation:	10 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
April 2017	Moderate	50%	56%	52%
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%

Figure 3-7: LakeSPI results for Lake Ōkāreka since 1988.

Lake Ōkāreka was categorised in high ecological condition with a LakeSPI Index of 50% (Figure 3-7).

A diverse native plant community was present in Lake Ōkāreka with the invasive weed *Lagarosiphon major* (lagarosiphon) having only a moderate impact on native plant covers and extent.

Native vegetation consisted of five charophyte species (*Chara australis*, *Nitella sp. aff. cristata, Chara fibrosa, Chara globularis* and *Nitella pseudoflabellata*), milfoils (*Myriophyllum triphyllum* and *Myriophyllum propinquum*) (Figure 3-8), pondweeds (*Potamogeton ochreatus* and *Potamogeton cheesemanii*), turf species (*Glossostigma diandrum*, *Elatine gratioloides*, *Eleocharis pusilla*, *Lilaeopsis ruthiana* and *Limosella lineata*) and *Isoetes kirkii*. Charophytes formed meadows (>75% cover) at all five LakeSPI sites extending down the profile to an average depth of 8.3 m and a maximum depth of 10 m.

Lagarosiphon was the only invasive species observed at survey sites. It formed variable to high cover weed beds at all sites growing up to 2.5 m tall, and to a maximum depth of 5.2 m.

At the time of the recent survey, through-water visibility was estimated by divers to be c. 6.0 m. Many freshwater mussels (*Echyridella menziesi*) were observed but no koura at this time.

3.3.2 Discussion

Lake Ōkāreka has improved over the last two surveys likely a result of interventions carried out by BOPRC to control invasive weeds in the lake. Repeat diquat treatments targeting areas with hornwort (Bathgate 2013), resulted in the recovery of native plants at all LakeSPI sites during the 2015 and 2017 surveys with a greatly reduced level of impact from invasive weeds. While lagarosiphon was still present at all five LakeSPI sites in 2017, no egeria or hornwort were observed. Egeria has not been recorded in the lake over the last two surveys (2015 and 2017) since the control work was carried out, and hornwort has not been recorded from any LakeSPI sites since its discovery. Hornwort, first reported in the lake in April 2012, can occupy an even deeper depth range than egeria, so should the control program be abandoned for Lake Ōkāreka we would expect to see LakeSPI scores slowly return to previous levels with re-establishment of lagarosiphon and egeria, and then deteriorate further with the continued invasion by hornwort.

Prior to the 2015 survey, LakeSPI scores for Lake Ōkāreka had remained stable for some years showing little change since 2003 (Figure 3-7).

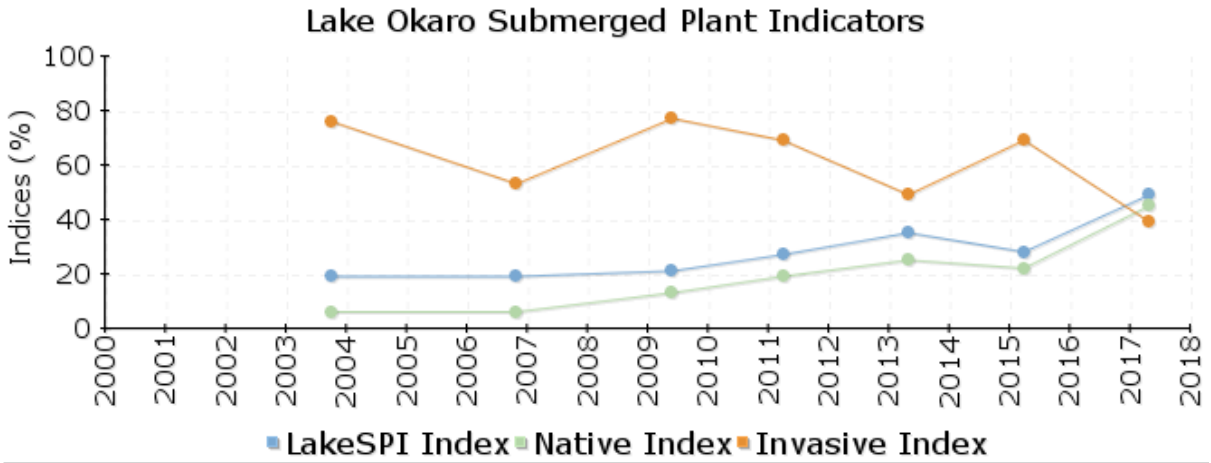
Historical notes - Egeria was first reported in Lake Ōkāreka in 2000 (Clayton et al. 2005). While not located at any of the five LakeSPI sites during the 2001 survey, by 2003 it had spread to three sites, and to four sites by 2006. Egeria displaced lagarosiphon with taller and denser weed growth and occupies a wider depth range.

Figure 3-8: Native milfoils (*Myriophyllum triphyllum*) in Lake Ōkāreka. Image on right shows milfoil flowers.

3.4 Lake Ōkaro

3.4.1 Results

Lake condition:	Moderate
Lake ranking:	4th
Lake stability:	Improving
Lake maximum depth:	18 m
Max depth of vegetation:	5.8 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
April 2017	Moderate	49%	45%	39%
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 3-9: LakeSPI results for Lake Ōkaro since 1982.

Lake Ōkaro was categorised in moderate ecological condition with a LakeSPI Index of 49% (Figure 3-9).

Native plants dominated the submerged vegetation in Lake Ōkaro with the native pondweed *Potamogeton ochreatus* forming high covers (> 75%) at all five LakeSPI sites from the shallows (c. 0.5 m) to depths of 5.2 – 5.8 m (Figure 3-10).

Other native vegetation included three turf species (*Glossostigma elatinoides*, *Glossostigma diandrum* and *Lilaeopsis ruthiana*) (Figure 3-11), three charophytes (*Chara australis*, *Nitella pseudoflabellata* and *Nitella hyalina*) and another pondweed, *Potamogeton cheesemanii*. Two rushes, *Eleocharis acuta* and *Eleocharis sphacelata* were also present growing in water < 0.8 m depth.

Elodea remains the only invasive weed species known in the lake. While it was present at all five sites it did not form a closed cover weed bed and only exceeded a 25% cover at one site. Elodea shoots grew up to 2 m tall and to a maximum depth of 5.2 m.

At the time of recent survey, through-water visibility was estimated by divers to be up to c. 2.0 m. No koura or freshwater mussels were observed. The ear pond snail (*Radix auricularia*) was present in sparse numbers.

3.4.2 Discussion

LakeSPI results show some significant improvements in the overall condition of Lake Ōkaro over the short and longer-term time frames (1989 - 2017) (Figure 3-9).

Since the previous survey the LakeSPI Index has increased from 28% in 2015 to 49% in 2017, reflecting a marked improvement in Native Condition values (abundance and extent) and a corresponding reduction in the invasive Impact scores over this time frame (2015 to 2017) (Figure 3-9). Dense native *Potamogeton* beds overtopped and replaced the invasive elodea beds that had previously dominated the lake, extending down to an increased vegetation depth limit of 5.8 m during the current 2017 survey.

Over the longer time (1982 – 2017) LakeSPI scores have been variable, particularly the Invasive Impact Index, based on the degraded nature of Lake Ōkaro and its fluctuations in water quality. However, small improvements in the LakeSPI scores since 2009 have continued to indicate some positive change in overall lake condition. It is probable that this improvement reflects efforts by farmers and BOPRC in December 2003 to reduce nutrient inflow to the lake and nutrient release from hypolimnetic sediments (Paul et al. 2008), leading to improved water quality and a positive vegetation response.

While these improvements in lake condition are promising, Lake Ōkaro is still recognised as a highly vulnerable lake to weed invasion. Lake Ōkaro, together with Lake Rotokakahi, are the only Rotorua Te Arawa Lakes to remain relatively free of the more invasive weed species.

Historic notes - Historically the hypereutrophic nature of the lake has provided an unfavourable habitat for submerged vegetation. This was reflected in the highly variable cover and limited depth range of elodea. On several occasions in earlier surveys elodea beds were observed to be rooted in shallow water, while from around 2 m depth and deeper all elodea was non-rooted ‘drift’ (J. Clayton, NIWA, pers comm.). This may have coincided with periods of stratification and anoxia or reduced light at or below the thermocline resulting in root death and shoot necrosis.

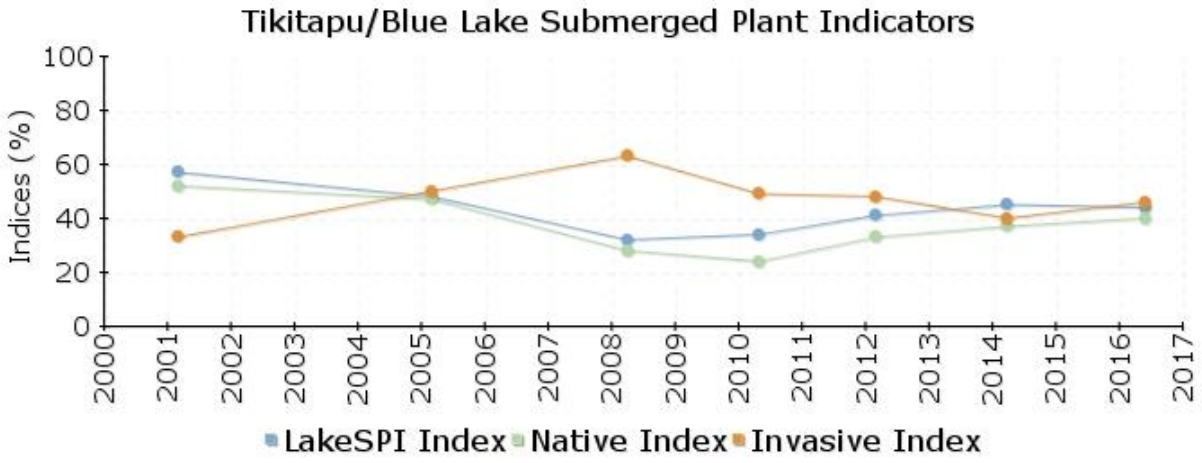
Figure 3-10: The native pondweed *Potamogeton ochreatus* dominated the vegetation in Lake Ōkaro.

Figure 3-11: Native low mound submerged plant community in Lake Ōkaro. Photo shows *Glossostigma elatinoides* (spoon shape) and *Lilaeopsis ruthiana* (spikey).

3.5 Lake Tikitapu

3.5.1 Results

Lake condition:	Moderate
Lake ranking:	5th
Lake stability:	Stable
Lake maximum depth:	27.5 m
Max depth of vegetation:	17.4 m



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 3-12: LakeSPI results for Lake Tikitapu since 1988

Lake Tikitapu was categorised as being in moderate ecological condition with a LakeSPI Index of 44% (Figure 3-12).

Lagarosiphon was recorded from four of the five LakeSPI sites in the 2016 survey forming variable covers to a maximum depth of 4.7 m (Figure 3-13). However, plants grew to a maximum height of only 1 m and had little impact on native vegetation also occupying the shallow (< 5 m) depth zone. The lagarosiphon growth form is unusual in this lake and is likely affected by low nutrient levels in the lake.

Native plant communities in Lake Tikitapu included a short growing native milfoil *Myriophyllum pedunculatum*, and three charophyte species (*Nitella pseudoflabellata*, *Nitella leonhardii* and *Chara fibrosa*) which formed low to moderate covers from 2.5 m down to a maximum depth of 5.3 m. Below this a thick blue/green algal mat was noted covering the sediment down to c. 16 m and may have been excluding charophytes from much of this zone. Beyond this band of vegetation, charophytes were observed at two of the five LakeSPI sites growing from c. 13 – 17 m. Charophyte covers at this depth were variable and exceeded a cover of 75% at one site.

Through-water visibility was estimated by divers to be c. 8 -10 m. Freshwater koura were observed.

3.5.2 Discussion

Lake Tikitapu has been in a stable condition recently according to LakeSPI results. A moderate LakeSPI Index of 44% reflects the somewhat constrained presence of native plant communities, with limited impact from the invasive weed lagarosiphon (*Lagarosiphon major*).

Of interest in Lake Tikitapu is 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%. 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 only 2.5 – 5.3 m. This discontinuity of charophyte growth in relation to light climate is likely the result of a dominant growth of a blue green algal mat on the sediment surface from about 5 m deep and thinning at around 12 m deep. For this reason, LakeSPI results for this lake are variable in nature.

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 3-12) 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 and is not fully explained.

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 3-13: Lagarosiphon forms variable covers in Lake Tikitapu to a maximum depth of 4.7 m..

3.6 Lake Ōkataina

3.6.1 Results

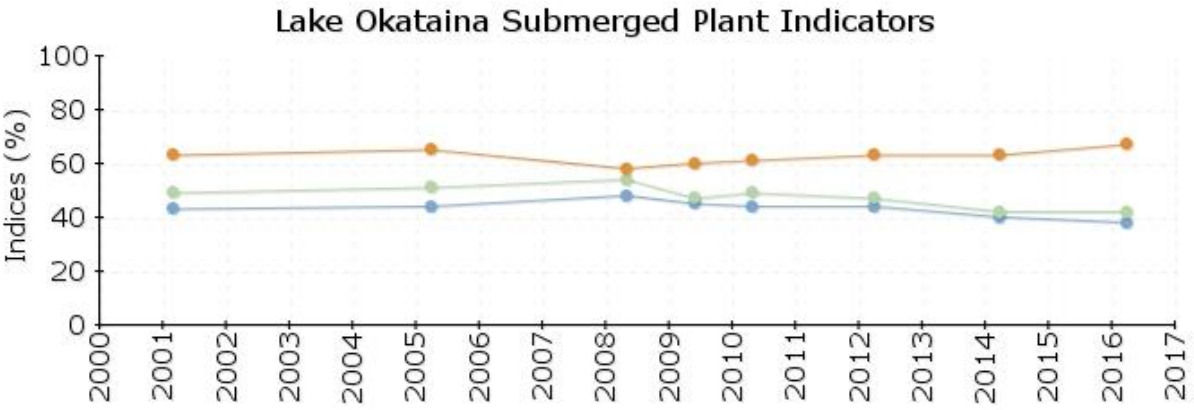
Lake condition: Moderate

Lake ranking: 6th

Lake stability: Stable/declining?

Lake maximum depth: 78.5 m

Max depth of vegetation: 11.6 m



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 3-14: LakeSPI results for Lake Ōkataina since 1981.

Lake Ōkataina was categorised in moderate ecological condition with a LakeSPI Index of 38% (Figure 3-14).

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 3-15). 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 3-14).

Lagarosiphon (*Lagarosiphon major*) remained the dominant invasive species present, forming high cover weed beds (Figure 3-15) at all five LakeSPI sites generating an Invasive Impact Index of 67% (Figure 3-14). 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 (in relation to the boat ramp).

At the time of recent survey, through-water visibility was estimated by divers to be >6.0 m. Both freshwater mussels (*Echyridella menziesi*) and koura were recorded in the lake during the 2014 survey but were not observed during the recent survey.

3.6.2 Discussion

Lake Ōkataina has maintained a stable condition over the recent time frame, but the latest survey shows some possible signs of deterioration with a (non-significant) reduction in the LakeSPI Index from 44% in 2012 to 38% in 2016 (Figure 3-14).

This slight reduction in the LakeSPI Index and increase in the Invasive Impact Index in part reflects the presence of a single hornwort plant for the first time at one of the LakeSPI sites. Hornwort continues to pose the most serious threat to the future condition of Lake Ōkataina. Should hornwort continue to spread, we will see a reduction in LakeSPI scores in the future.

Another reason for the small decrease in LakeSPI scores is likely due to a reduction in the depth extent of plant communities noted during the 2014/2012 and 2016 surveys. 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, to date, 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 then has prevented a major impact from hornwort around the lake. Installing a weed cordon has reduced the likelihood of hornwort dispersal from this lake.

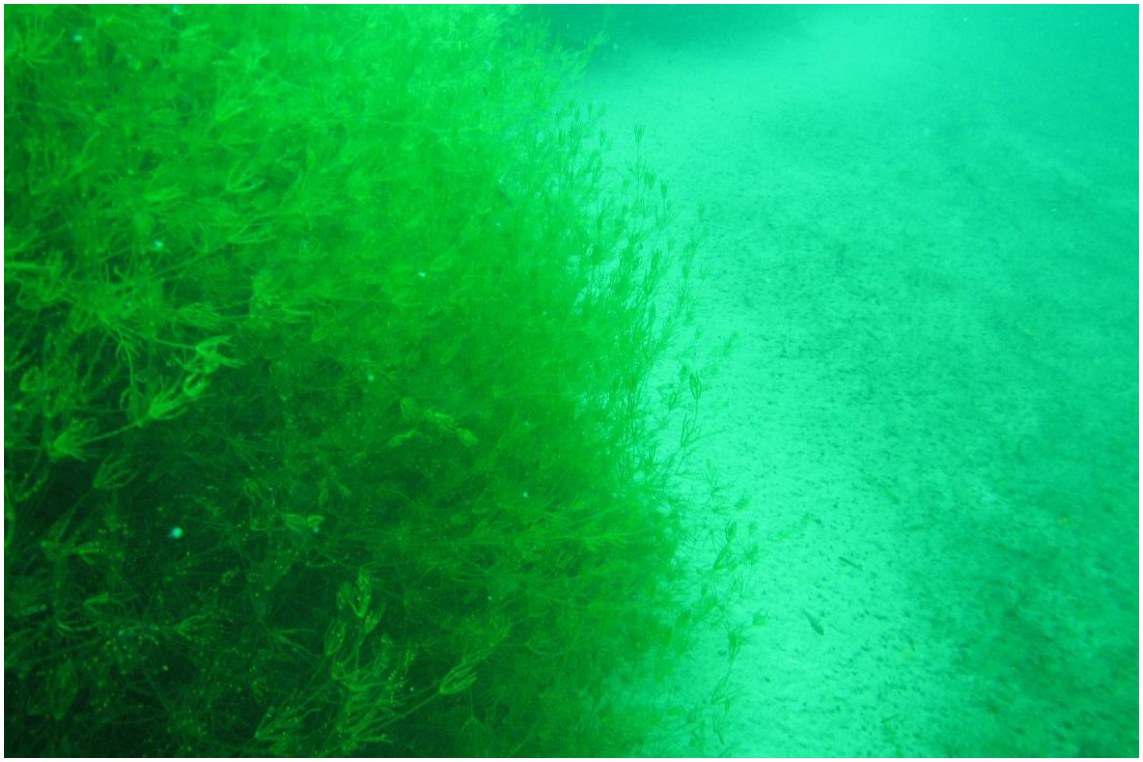


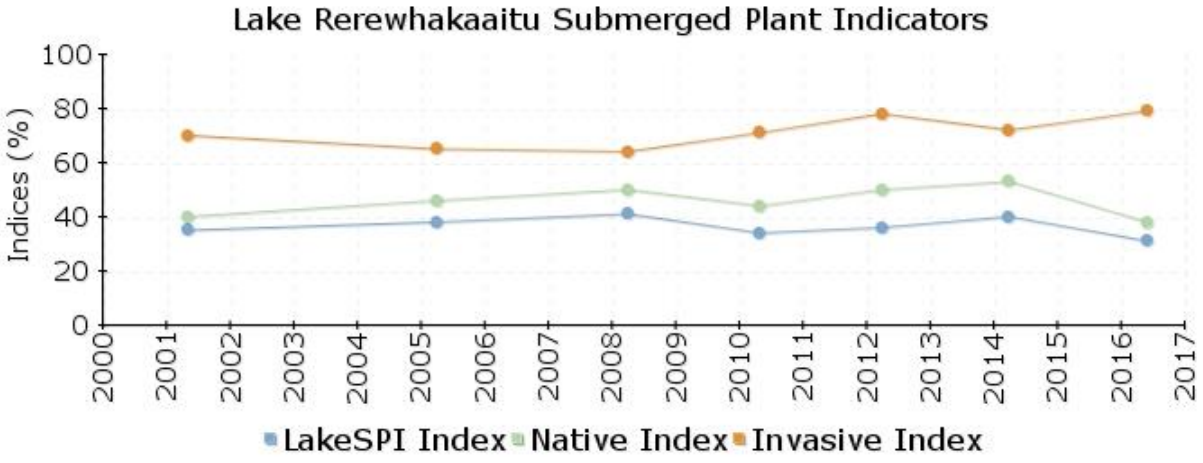
Figure 3-15: Charophyte meadow growing to a maximum depth 11.3 m in Lake Ōkataina.

Figure 3-16: Surface reaching weed bed of lagarosiphon in Lake Ōkataina.

3.7 Lake Rerewhakaaitu

3.7.1 Results

Lake condition:	Moderate
Lake ranking:	7th
Lake stability:	Stable/declining?
Lake maximum depth:	15.8 m
Max depth of vegetation:	7.2 m



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 3-17: LakeSPI results for Lake Rerewhakaaitu since 1973.

Lake Rerewhakaaitu was categorised in moderate ecological condition with a LakeSPI Index of 31% (Figure 3-17).

Dense weed beds of egeria (*Egeria densa*) (Figure 3-18) and in shallower water, lagarosiphon (*Lagarosiphon major*) dominated the vegetation at all five LakeSPI sites extending down to a maximum depth of 7.2 m.

Charophyte meadows (>75% cover) were present at four of the five sites in 2016, one site less than the previous two surveys (2012 and 2014), forming high covers to a maximum depth of 7m. Deeper 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 present included the quillwort *Isoetes kirkii*, native pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*) and three native milfoil species (*Myriophyllum pedunculatum*, *Myriophyllum propinquum* and *Myriophyllum triphyllum*) growing amongst the shallow water turf species.

At the time of the most recent survey, a thick cover of algae (Figure 3-19) was noted covering plants from the lake edge to c. 2 m depth. Through-water visibility was estimated by divers to be c. 4.0 m. Freshwater mussels (*Echyridella menziesi*) were present in the lake.

3.7.2 Discussion

The 2016 survey indicated 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 3-17) in 2016 resulting from an increase in the overall extent and abundance of the invasive weeds egeria and lagarosiphon. An Invasive Impact Index of 79% (Figure 3-17) is the highest recorded to date for Lake Rerewhakaaitu.

Lake Rerewhakaaitu could also be severely impacted by hornwort, if introduced, but the risk is less imminent on account of its greater distance from nearby infestations and relatively low boat traffic. However, it only takes one shoot and even the most remote lake, Lake Rotomāhana, already has it.

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 grew to a maximum depth of 4.5 – 5 m only, 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 3-17). The egeria weed beds in Lake Rerewhakaaitu are currently the tallest, densest, most extensive weed beds we know of in the country.

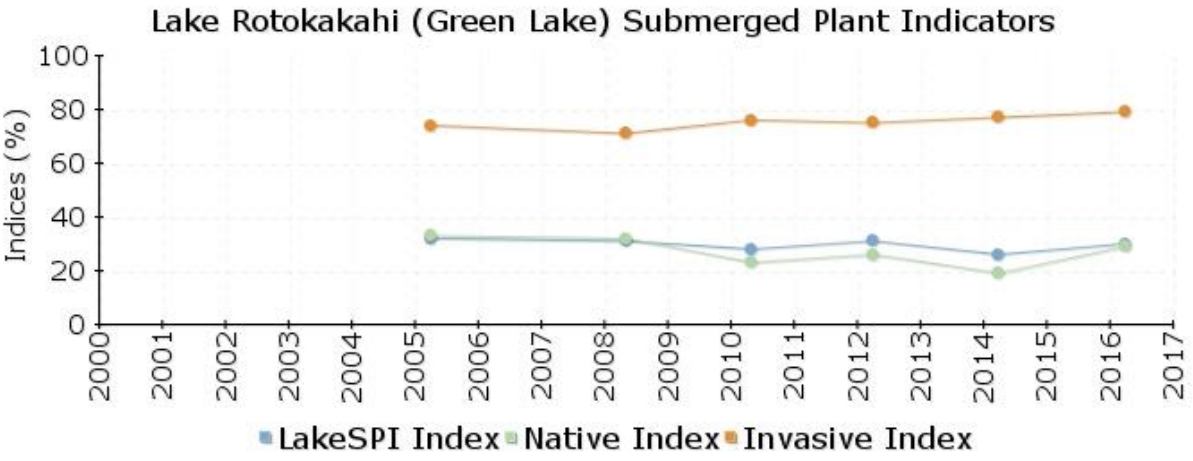
Figure 3-18: Egeria beds dominated the vegetation in Lake Rerewhakaaitu.

Figure 3-19: Algae covering native plants in the shallows (<2 m depth) of Lake Rerewhakaaitu.

3.8 Lake Rotokakahi

3.8.1 Results

Lake condition:	Moderate
Lake ranking:	8th
Lake stability:	Stable
Lake maximum depth:	32 m
Max depth of vegetation:	9.7 m



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 3-20: LakeSPI results for Lake Rotokakahi since 1988.

Lake Rotokakahi was categorised as being in moderate ecological condition with a LakeSPI Index of 30% (Figure 3-20).

Native vegetation in Lake Rotokakahi consisted of a mixed turf community in the shallows (c. < 1 m), which included quillwort (*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 seen during the 2016 survey and formed tall (c. 3 m) high cover weed beds (Figure 3-21), at all five LakeSPI sites, to a maximum depth of 9.7 m.

At the time of survey, a brown filamentous alga 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 (*Echyridella menziesi*) (Figure 3-22) were recorded in the lake, mostly in sediments beyond the outer edge of the weed bed at c. 7-9 m depth.

3.8.2 Discussion

Lake Rotokakahi has been in a stable condition in recent years according to LakeSPI results.

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 (since full lake surveys began in 1988), with most change taking place prior to 2005 (Figure 3-20). 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 therefore likely the result of deteriorating water quality and clarity (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.

Lake Rotokakahi, together with Lake Ōkaro, are the only Rotorua Te Arawa Lakes to remain relatively free of the more invasive weed species.

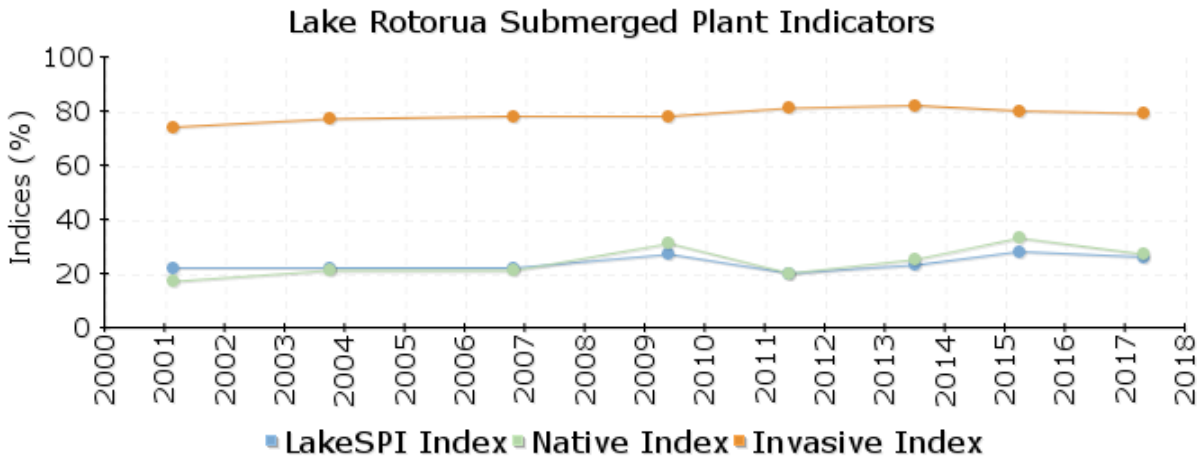
Figure 3-21: Diver swimming through elodea weed bed in Lake Rotokakahi.

Figure 3-22: Freshwater mussels present beyond the depth of vegetation in Lake Rotokakahi at c. 8.5 m.

3.9 Lake Rotorua

3.9.1 Results

Lake condition:	Moderate
Lake ranking:	9th
Lake stability:	Stable
Lake maximum depth:	44.8 m
Max depth of vegetation:	7.2 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
April 2017	Moderate	26%	27%	79%
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 3-23: LakeSPI results for Lake Rotorua since 1982.

Lake Rotorua was categorised in moderate ecological condition with a LakeSPI Index of 26% (Figure 3-23).

Egeria (*Egeria densa*) and lagarosiphon (*Lagarosiphon major*) dominated the submerged vegetation in Lake Rotorua but were patchy in nature and distribution (Figure 3-24). While they formed moderate to dense weed beds at all five LakeSPI sites, they were generally low growing (<2 m) but did reach 2.5 m tall at some sites down to a maximum depth of 6.8 m. Elodea (*Elodea canadensis*) was also present from two sites but at low covers. Hornwort has not been recorded from a LakeSPI site in the lake since 2013.

The most prevalent native species in the lake was a charophyte (*Nitella* sp. aff. *cristata*) and pondweed (*Potamogeton ochreatus*) (Figure 3-25) species. Charophytes exceeded a 75% cover at two sites down to the maximum depth of 7.2 m. Other native species included another charophyte (*Chara australis*), milfoil (*Myriophyllum triphyllum*) and a low growing turf species (*Glossostigma diandrum*).

At the time of recent survey, through-water visibility was estimated by divers to be c. 2.0 m. Dense freshwater mussels (*Echyridella menziesi*) were observed at all sites in the lake.

3.9.2 Discussion

LakeSPI scores for Lake Rotorua have shown a statistically significant improvement since the 2011 survey, with the LakeSPI Index increasing from 20% in 2011 to 26% in 2017. This largely reflects an increase in the depth extent of native plants at all sites since 2011, and during the recent 2017 survey, the Native Condition Index had increased from 20% in 2011 to 27% (2017) (Figure 3-23). It is likely that this improvement is the result of efforts by BOPRC to reduce nutrient influx into the lake and nutrient release from hypolimnetic sediments using alum dosing, administered to inflows of Lake Rotorua in 2006 and 2010.

While this improvement is promising, care should be taken when interpreting submerged plant information for this lake. Some variability in plant communities can be expected year to year in lakes like Lake Rotorua that have a large shallow littoral zone subject to considerable wave action from periodic storms that can markedly disturb submerged vegetation. 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. Hornwort was first recorded in the lake in 1975 but has never dominated in this lake, possibly due to long wave fetches (c. 10km) at nearly all sites.

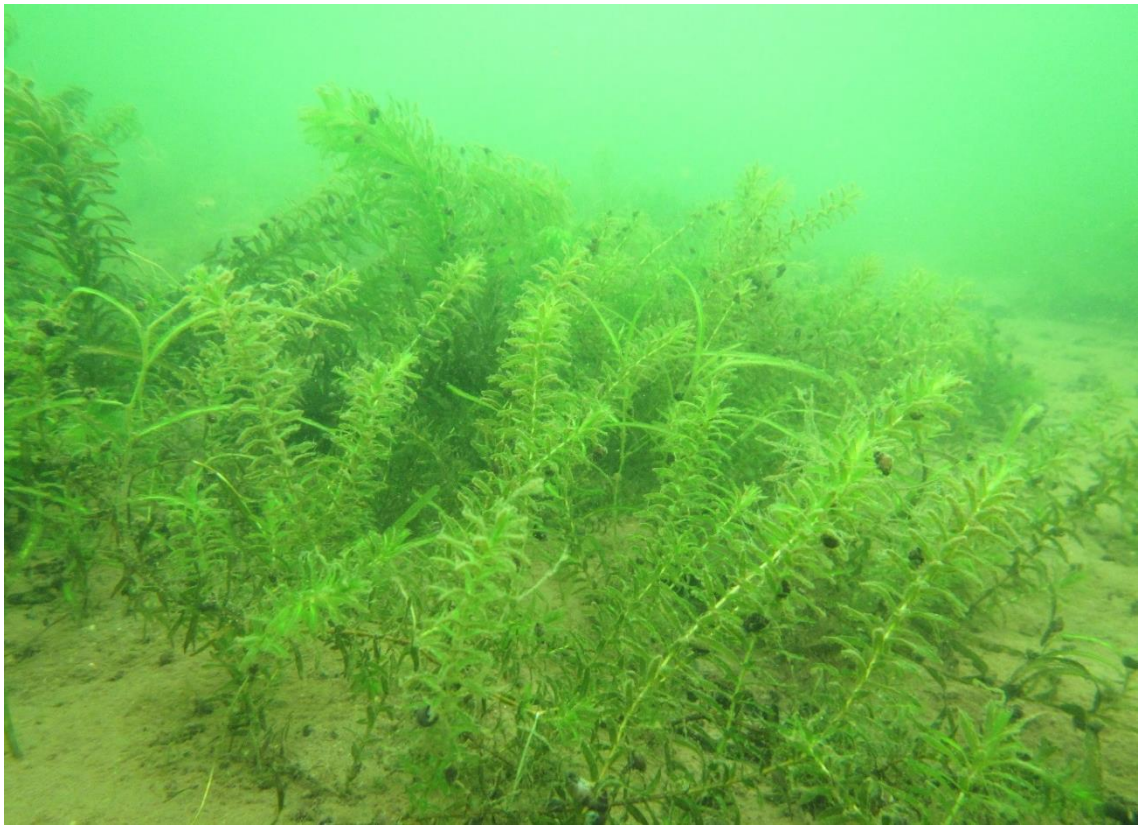


Figure 3-24: Egeria formed variable covers in Lake Rotorua.

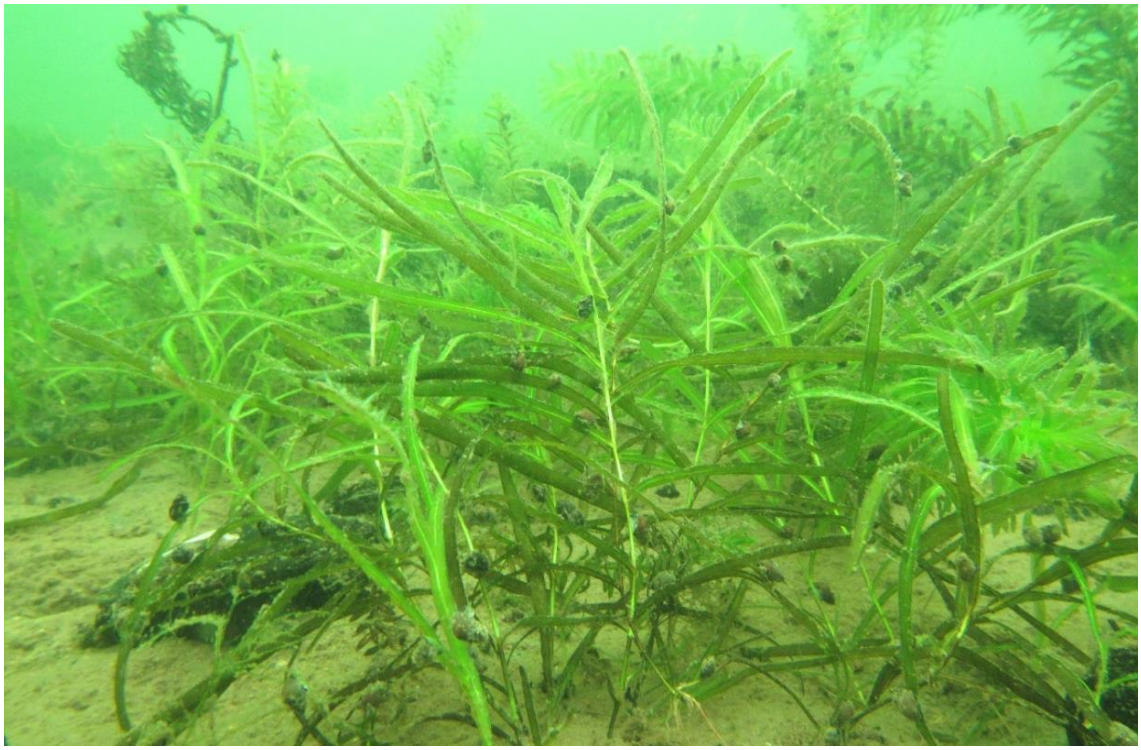
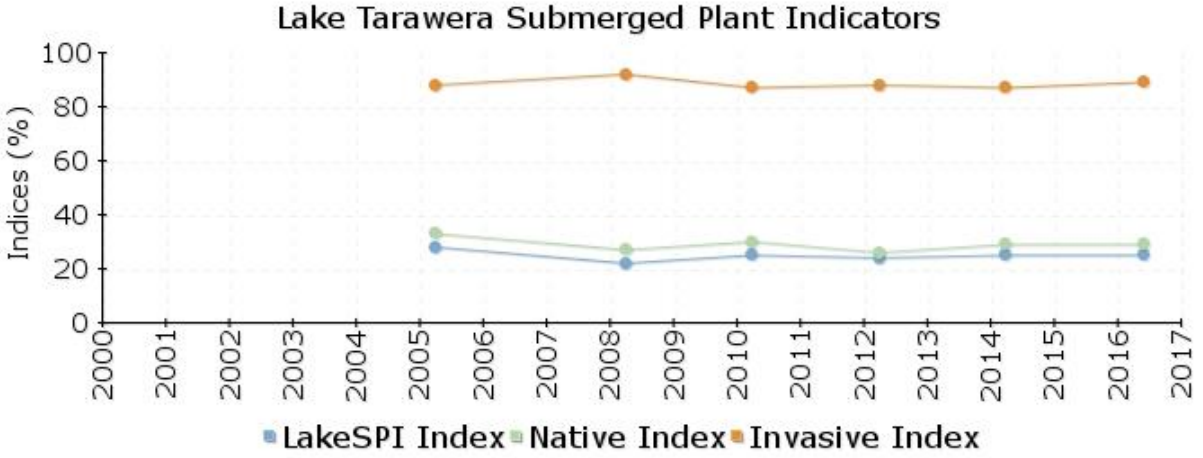


Figure 3-25: Native pondweeds (*Potamogeton ochreatus*) (front of photo) in Lake Rotorua.

3.10 Lake Tarawera

3.10.1 Results

Lake condition:	Moderate
Lake ranking:	10th
Lake stability:	Stable
Lake maximum depth:	87.5 m
Max depth of vegetation:	13.0 m



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 3-26: LakeSPI results for Lake Tarawera since 1988.

Lake Tarawera was categorised in moderate ecological condition with a LakeSPI Index of 25% (Figure 3-26).

Hornwort (*Ceratophyllum demersum*) dominates the submerged vegetation in Lake Tarawera forming dense weed beds up to c. 3 m tall, extending down to a maximum depth of 13 m. The invasive weeds *Egeria densa*, *Lagarosiphon major* and *Elodea canadensis* were also present in the lake but were having minor impact compared to hornwort. An invasive water buttercup, *Ranunculus trichophyllus,* was also locally present.

Five native 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 (*Echyridella menziesi*) and crayfish were both observed in the lake during the 2016 survey.

3.10.2 Discussion

Lake Tarawera has remained in a moderate but stable condition since 2010. Prior to this, the LakeSPI Index from 1988 to 2005 (Figure 3-26) was high then declined 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 the full impact of hornwort has been evident for several years.

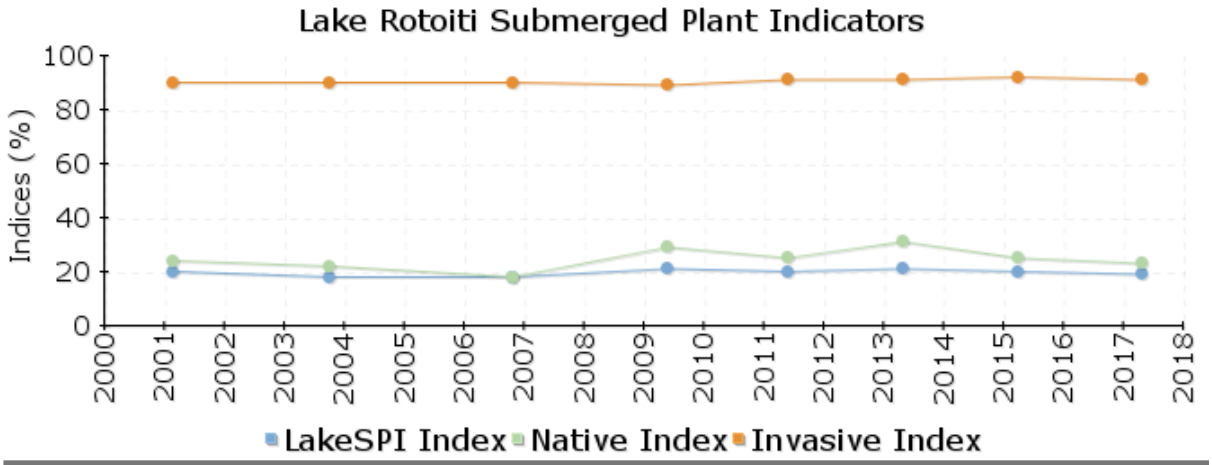
A Native Condition Index of 29% (Figure 3-26) reflects some well-developed native plant communities persisting in Lake Tarawera, particularly on exposed sites unsuited to hornwort.

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 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). But 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 3-26).

3.11 Lake Rotoiti

3.11.1 Results

Lake condition:	Poor
Lake ranking:	12th equal
Lake stability:	Stable
Lake maximum depth:	125 m
Max depth of vegetation:	8.4 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
April 2017	Poor	19%	23%	91%
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 3-27: LakeSPI results for Lake Rotoiti since 1981.

Lake Rotoiti was categorised in moderate ecological condition with a LakeSPI Index of 19% (Figure 3-27).

Hornwort (*Ceratophyllum demersum*) dominated the submerged vegetation forming dense weed beds at all sites, and up to 4 m tall at some sites and extending down to a maximum depth of 8.4 m (Figure 3-28). The invasive weeds *Egeria densa*, *Lagarosiphon major* and *Elodea canadensis* were also present but were having minor impact compared to hornwort.

A diverse native community was present in shallow water (c. <2 m), consisting of charophytes (*Chara australis*, *Chara globularis*, *Nitella* sp. aff. *cristata*, *Nitella hyalina*), pondweeds (*Potamogeton ochreatus* and *Potamogeton cheesemanii*), milfoils (*Myriophyllum triphyllum* and *Myriophyllum propinquum*), turf species (*Glossostigma diandrum*, *Glossostigma elatinoides*, *Eleocharis pusilla*, *Lilaeopsis ruthiana*, *Limosella lineata*, *Elatine gratioloides*), *Ruppia polycarpa* and the New Zealand quillwort *Isoetes kirkii* (Figure 3-29). Charophytes were not observed forming a meadow (>75% cover) at any of the five LakeSPI sites.

At the time of recent survey, through-water visibility was estimated by divers to be c. 5.0 m at the eastern end of the lake. A thick covering of algae was recorded over plants particularly in shallower water (Figure 3-29) at the western end of the lake. Both freshwater mussels (*Echyridella menziesi*) and koura were observed throughout the lake.

3.11.2 Discussion

Lake Rotoiti has consistently had one of the highest Invasive Impact Index scores and continued to have one of the lowest LakeSPI Indices recorded of the 12 Rotorua Te Arawa lakes. It currently remains in “poor” condition. The development of some deeper charophyte meadows that resulted in a slight increase in the Native Condition scores between 2009 and 2015 have continued to be variable in nature and were not present at any of the LakeSPI sites during the recent 2017 survey.

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 and bays of Lake Rotoiti such as Okawa Bay, Wairau Bay and Te Weta Bay (J. Clayton, NIWA, pers comm.). 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 dominated by loose filamentous algae, attached benthic blue-green algal mats and planktonic blue-green algal blooms. There are a number of lake sectors that could be monitored separately to give more detailed feedback on change in these areas. For example, the western end could be compared with the eastern end and a LakeSPI could be done for Okawa Bay alone to provide useful information on attempts to manage this bay’s water quality and invasive weed impacts.

Historical notes - At the time of the 1981 survey hornwort, lagarosiphon and elodea were both having an impact on native plant communities present in the lake.

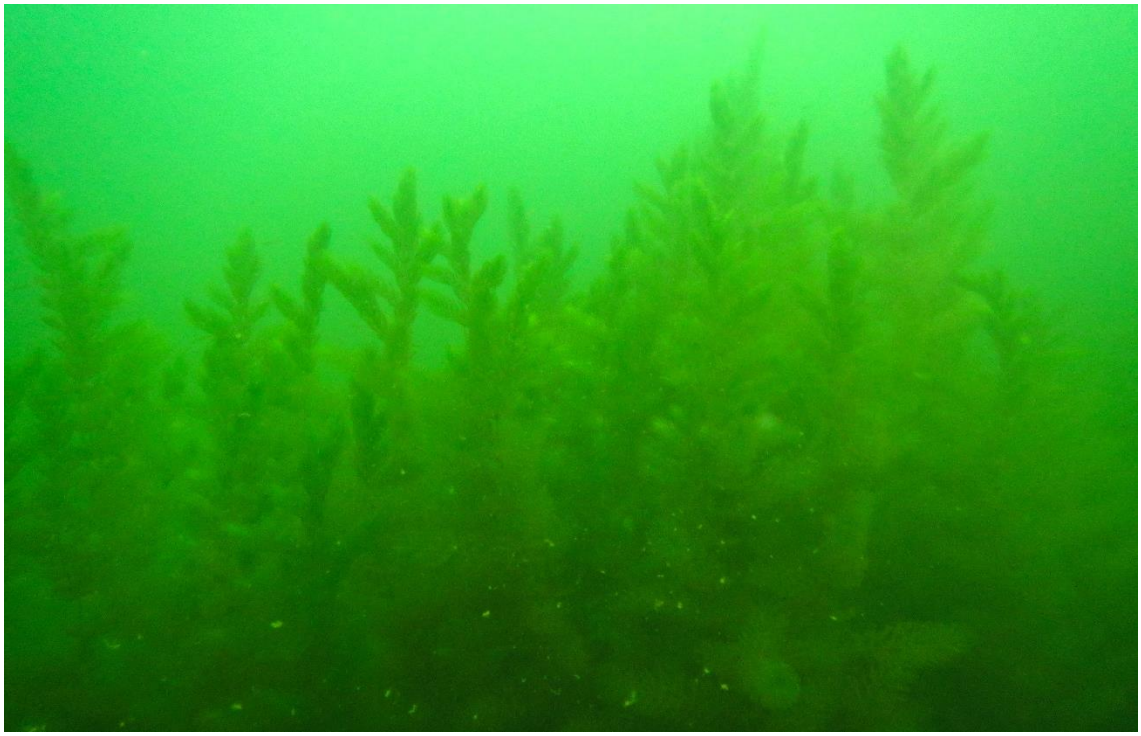


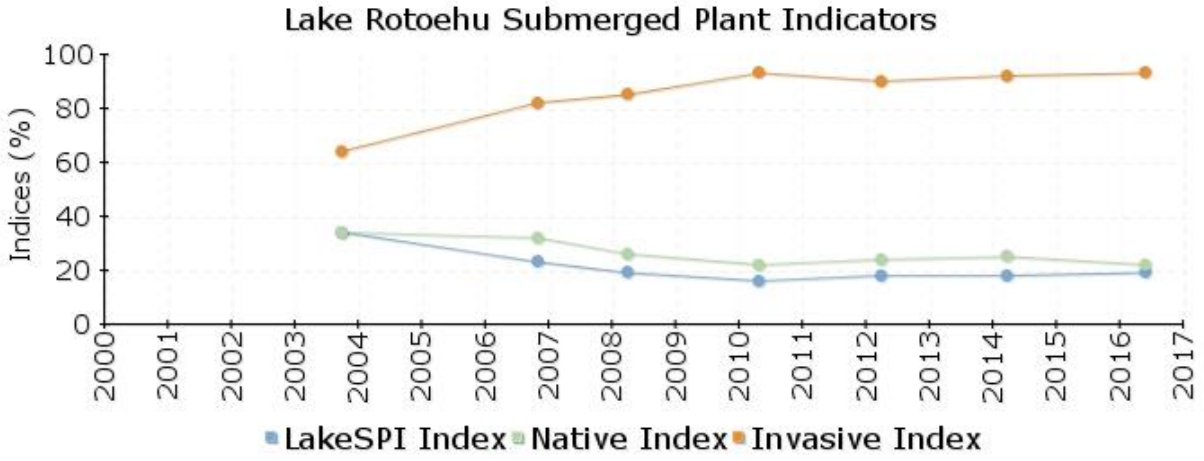
Figure 3-28: Hornwort formed weed beds up to 4 m tall in Lake Rotoiti.

Figure 3-29: A thick layer of algae covers Isoetes growing in the shallows of Lake Rotoiti.

3.12 Lake Rotoehu

3.12.1 Results

Lake condition:	Poor
Lake ranking:	12th equal
Lake stability:	Stable
Lake maximum depth:	13.5 m
Max depth of vegetation:	8.0 m



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 3-30: LakeSPI results for Lake Rotoehu since 1988.

Lake Rotoehu was categorised as being in “poor” ecological condition with a LakeSPI Index of 19% (Figure 3-30).

Hornwort (*Ceratophyllum demersum*) formed extensive 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 was generally sparse and most prevalent in shallow water (<2 m depth). 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 3-30). 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*).

At the time of recent survey, through-water visibility was estimated by divers to be c. 1.5 m. Large numbers of freshwater mussels (*Echyridella menziesi*) were observed at most sites.

3.12.2 Discussion

Hornwort (*Ceratophyllum demersum*) dominated the submerged vegetation in Lake Rotoehu, which continues to have the highest Invasive Impact Index (93%) recorded for any of the 12 Rotorua Te Arawa lakes (Figure 3-30). In 2016 the lake was in a poor, but stable condition (since 2010), as the full impact of hornwort had taken place.

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 very large negative impact hornwort has had on native submerged vegetation within the lake as it approaches ‘habitat saturation’.

The ear pond snail (*Radix auricularia*), was discovered in Omahota Bay during the 2014 survey. This was the second record of this invasive snail in the Rotorua Te Arawa lakes.

Figure 3-31: Hornwort stranding on the shore of Lake Rotoehu in 2016.

4 Discussion

4.1 Changes over time

Regular LakeSPI assessments of the Rotorua Te Arawa lakes since at least 2005, and LakeSPI calculations based on historical lake vegetation records from 1988-89, have allowed for changes in lake ecological condition to be compared over a long-time frame.

Changes in LakeSPI indices over the recent time frame (4-5 years) and longer term (28/29 years), have been used to provide an indication of current lake stability and the direction of current and longer-term change (

Table 3, Figure 4-1).

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
Rotomāhana	62	High	Stable/improving?	Change (-'ve)	Weed
Rotomā	52	High	Stable	No Change	Weed
Ōkāreka	50	High	Stable/Improved	Change (+'ve)	Weed
Ōkaro	49	Moderate	Improved	Change (+'ve)	Water Quality
Tikitapu	44	Moderate	Stable	Change (-'ve)	Water Quality
Ōkataina	38	Moderate	Stable/declining?	Change (-'ve)	Weed
Rerewhakaaitu	31	Moderate	Stable/declining?	Change (-'ve)	Weed
Rotokakahi	30	Moderate	Stable	Change (-'ve)	Water Quality
Rotorua	26	Moderate	Stable	Change (+'ve)	Water Quality
Tarawera	25	Moderate	Stable	Change (-'ve)	Weed
Rotoiti	19	Poor	Stable	Change (-'ve)	Water Quality
Rotoehu	19	Poor	Stable	Change (-'ve)	Weed

4.1.1 Recent change

Lakes Rotomāhana, Ōkāreka and Ōkaro have all shown some improvement in LakeSPI scores over the recent time frame. Lake Rotomāhana has improved following an expansion of native vegetation in response to a reduction in invasive weeds in the lake. This reduction in egeria and hornwort is unexplained and may be due to water quality factors. Lake Ōkāreka has improved over the last two surveys as a result of interventions carried out by BOPRC to control invasive weeds in the lake. This result is encouraging, and documents the benefits of a more intensive weed control programme. Should the control program be abandoned for Lake Ōkāreka we would expect to see LakeSPI scores

slowly return to previous levels and then deteriorate further with the continued invasion by hornwort and re-establishment of lagarosiphon and egeria. Lake Ōkaro has shown improvement based on a reduction in the abundance of elodea during the recent 2017 survey and an increase in the depth extent of native vegetation, reflecting improved water quality as a result of intensive management both in the lake and.

Lakes Ōkataina, and Rerewhakaaitu have maintained a stable condition over the recent time frame, but show signs of deterioration (although not statistically significant) during the most recent survey. Hornwort continues to pose the most serious threat to the future condition of Lake Ōkataina with a single plant found for the first time during the recent survey at a LakeSPI site. A reduction in the depth extent of plant communities at some sites in Lake Ōkataina is also of concern. Lake Rerewhakaaitu showed signs of deterioration on account of increased impact from egeria and lagarosiphon. Egeria forms the most extensive and dense weed beds in this lake we currently know of in New Zealand.

All remaining Rotorua Te Arawa lakes currently appear to be in a stable condition, with minor change in scores over the short term, although future pest plant invasions remain a risk for deterioration for some lakes (e.g., Lakes Rotoma, Rotokakahi).

4.1.2 Long term changes

Changes over the longer-term show many of the Rotorua Te Arawa Lakes have undergone significant deterioration over the last 28/29 years (Figure 4-1).

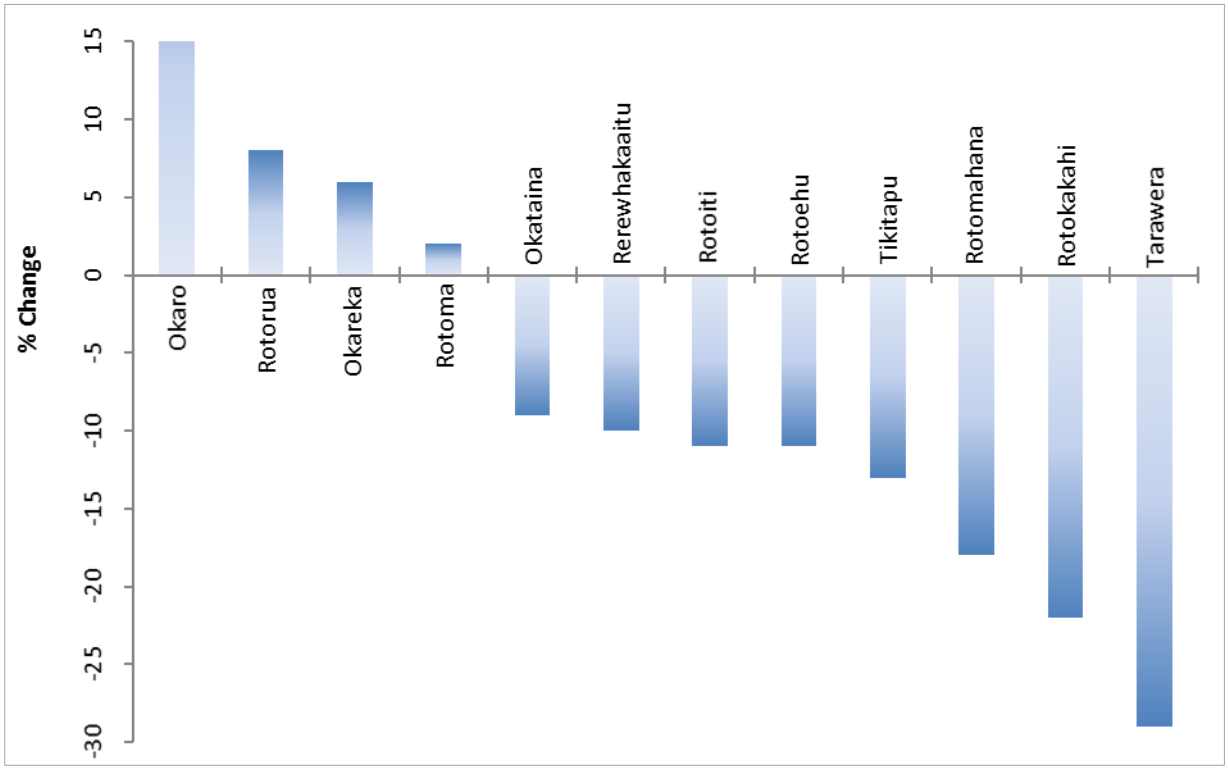


Figure 4-1: Percentage of change as indicated by the LakeSPI Index over the last 28-29 years, 1988/1989 to 2016/17.

Lakes Tarawera and Rotomāhana show some of the biggest changes in lake condition over the last 29 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 Rotomāhana we can expect to see a further decline in LakeSPI scores if hornwort takes hold in this lake 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 Rotomāhana already has it.

The other biggest change affecting the ecological 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 4-1) and since there have been no new invasive species recorded since full lake surveys began in 1988, the changes in this lake are 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 is 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.

Lakes Ōkaro and Rotorua show the greatest amount of positive change signalling some improvement in lake ecological condition over the last 28-29 years. Alum dosing in both lakes in recent years, used to reduce nutrient influx and nutrient releases from hypolimnetic sediments, likely explains the improved water clarity and positive vegetation responses since this time.

4.2 National comparison

Compared with 283 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 two lakes classified as being in 'high' condition (Figure 4-2 & 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.

Note: This comparison is an overview of current LakeSPI Indices for lakes nationally and does not take into account different lake types.

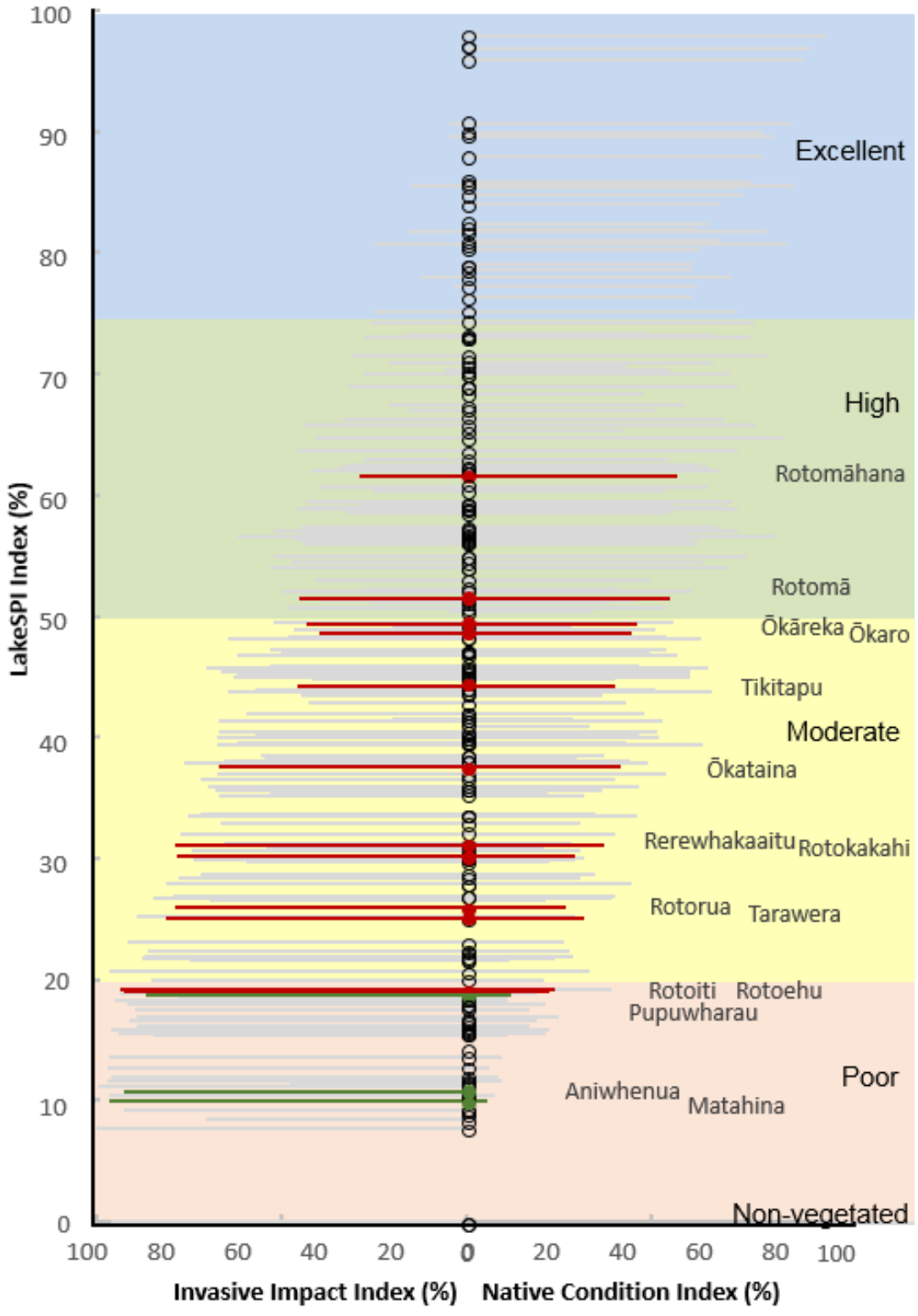


Figure 4-2: Rotorua Te Arawa Lakes (red lines) and 3 other lakes in the Bay of Plenty Region (green lines) are plotted with scores for a total of 283 New Zealand lakes. The most recent LakeSPI scores for lakes for the Rotorua the LakeSPI Index is plotted on the y-axis (points), Native Condition Index 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.

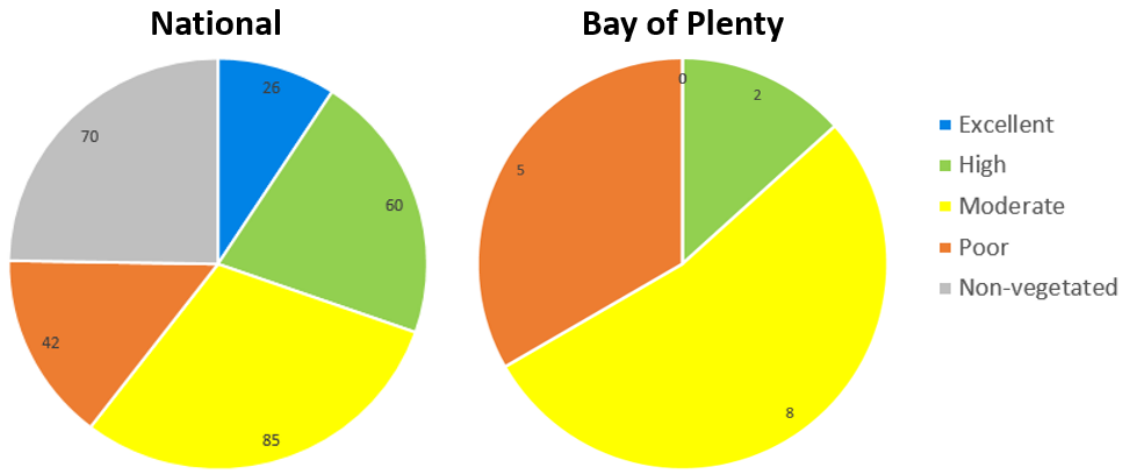


Figure 4-3: Proportion of lakes that fall into each of five categories of LakeSPI Index for the region (15) and nationally (283), with the number of lakes assessed shown in parenthesis.

4.3 LakeSPI key points

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

Lake Rotomāhana

- Overall lake condition high.
- Egeria and hornwort had a reduced impact during the 2015 & 2017 surveys, positively contributing to a high LakeSPI Index.
- Highest Native Condition Index in the region.
- Lowest Invasive Impact Index in the region.

Lake Rotomā

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

Lake Ōkāreka

- Overall lake condition sitting on boundary between moderate and high.
- Improvements based on the recovery of native vegetation following control of invasive weed species in the lake.
- Second highest Native Condition Index.
- Recent invasion by hornwort still poses a serious threat to future condition should efforts to control it be relaxed.

Lake Ōkaro

- Overall lake condition moderate and improving.
- LakeSPI and Native Condition Index scores have improved significantly since the previous survey.
- Improvements based on the abundance of native pondweeds and their maximum depth extent in the lake.
- LakeSPI scores in the past variable due to water quality responses by elodea.
- Does not have any of the three worst invasive species.

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 Ōkaro remain relatively free of all three worst 'high impact' invasive weed species.

Lake Rotorua

- Overall lake condition moderate and showing signs of improvement.
- Egeria remains the dominant invasive species in the lake.

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 recommended that additional one-off surveys be completed for all Bay of Plenty lakes including those with little or no vegetation. Knowledge of their current condition establishes a baseline for future change and will provide a better understanding of the regions diversity of lakes and factors influencing macrophyte presence in the region. Benefits of further long term monitoring can then be considered relative to assessed values and threats for each lake.

For Lake Rotoiti, there are a number of sectors (e.g., Okawa Bay) that could be monitored separately to establish baselines for monitoring future change. This monitoring would provide improved feedback on attempts to manage Okawa Bay's water quality and invasive weed impacts.

It is also recommended that limit and target setting be explored further for the Rotorua Te Arawa lakes in the near future.

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References

Bathgate, S. (2013) 'Draft' Lake Ōkāreka Hornwort Management Plan 2013. Bay of Plenty Regional Council: 19.

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.

Burton, T. (2015) Control methods for invasive submerged plant species in Lake Ōkāreka. Prepared for Bay of Plenty Regional Council. *NIWA Client Report*: HAM2015-022. March 2015: 17.

Burton, T., Clayton, J. (2015) Assessment of the Rotorua Te Arawa lakes using LakeSPI-2015. Prepared for Bay of Plenty Regional Council. *NIWA Client Report*: HAM2015-091. June 2014: 52.

Champion, P., Clayton, J. (2000) Border control for potential aquatic weeds. Stage 1 – Weed risk model. *Science for Conservation,* 141. Prepared for Department of Conservation.

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 Rotomā. *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 Rotomā, 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 Rotomāhana: 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.

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

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

Paul, W.J., Hamilton, D.P., Gibbs, M.M. (2008) Low-dose alum application trialled as a management tool for internal nutrient loads in Lake Ōkaro, New Zealand. *New Zealand Journal of Marine & Freshwater Research,* 42: 207–217.

RTALP (2015) Rotorua Te Arawa Lakes Trophic Level Results – 2015. *Rotorua Te Arawa Lakes Program (RTALP) 6 mthly Report*. Viewed from website: www.rotorualakes.co.nz/vdb/document/1280

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.