Assessment of the Rotorua Te Arawa lakes using LakeSPI – 2018

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Cover photo: Diver carrying out survey in Lake Ōkataina.

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Executive summary

NIWA was contracted by Bay of Plenty Regional Council (BOPRC) to assess the ecological condition of twelve Rotorua Te Arawa lakes using LakeSPI (Submerged Plant Indicators). Lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokākahi, Tarawera and Tikitapu were surveyed in 2018, and Lakes Ōkāreka, Ōkaro, Rotomā, Rotomāhana, Rotoiti and Rotorua were surveyed in 2017. This report provides an update of lake ecological condition and discusses the changes evident in LakeSPI indices over a recent time-frame since 2013/14 (4 years) and long-term (29-30 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 2017/18 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. Lake Ōkataina maintained a stable condition over the recent time frame. An increase in the depth extent of plants duringing the recent survey is likely a response to higher lake levels at the time of the recent survey. Lakes Tikitapu and Rerewhakaaitu both show signs of deterioration. Deeper growing charophytes previously recorded at depths > 17 m in Lake Tikitapu were not observed during the recent survey and longer-term values show a significant reduction in Native Condition values. Lake Rerewhakaaitu showed signs of deterioration on account of increased impact from egeria and lagarosiphon Lake Rotokākahi 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 Rotokākahi 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 recently developed LakeSPI targets and limits for the Rotorua Te Arawa lakes be included in future reports.

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 twelve 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) and have been surveyed biennially since. Earlier surveys carried out in the 1980's that provide equivilant information on submerged aquatic plants have also been used to generate historical LakeSPI scores.

This report presents updated LakeSPI results for lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokākahi, Tarawera and Tikitapu assessed in March 2018, and also presents results for lakes Ōkaro, Ōkāreka, Rotoiti, Rotomā, Rotomāhana and Rotorua last assessed in 2017 (Burton 2017).

1.2 Study lakes

The lakes assessed in this report are collectively termed the 'Rotorua Te Arawa lakes'. This term refers to the twelve 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 twelve Rotorua Te Arawa lakes include: Ōkāreka, Ōkaro, Ōkataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokākahi, Rotomā, Rotomāhana, Rotorua, Tarawera, and Tikitapu. The location of these lakes is indicated in (Figure 1). Morphological characteristics are given in Table 1-1.

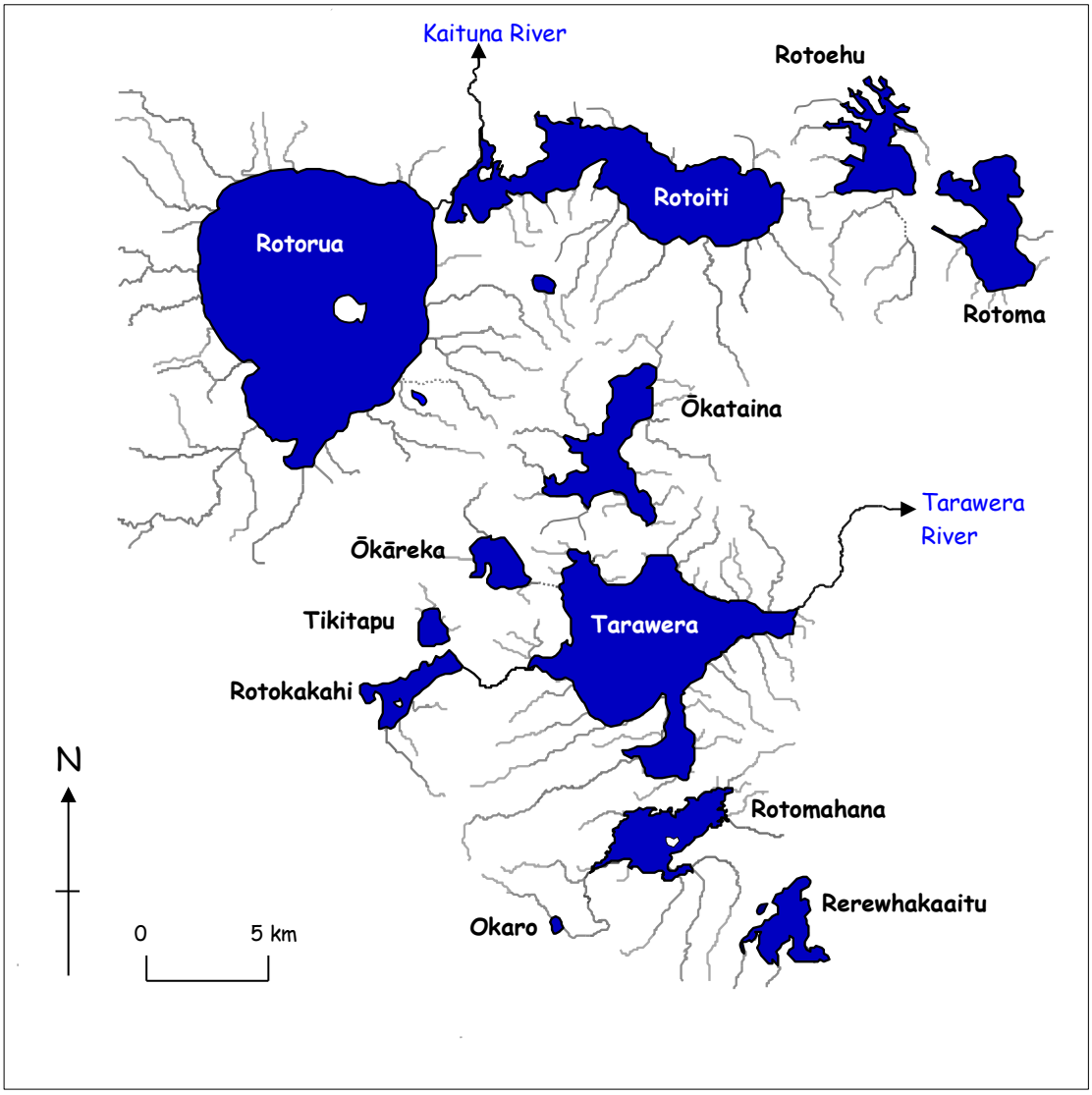


Figure 1: **Map showing location of the 12 Rotorua Te Arawa lakes.**

In addition to these twelve 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 1-1: 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
Rotokākahi	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 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, Wells et al. 1997). 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 Te Arawa Lakes has been less than expected; in contrast to the impact from hornwort, ranked 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, Compton et al. 2012). 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 Rotokākahi is widely impacted by elodea, it is now the only large 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 Rotokākahi Board of Control.

Figure 2: **Four worst invasive submerged weed species in the Rotorua Te Arawa lakes.**

Table 1-2: **Current distribution of invasive submerged weed species in the Rotorua Te Arawa lakes (2018).**

Lake	Elodea	Lagarosiphon	Egeria	Hornwort
Ōkāreka	■	■	■	*
Ōkaro	■			
Ōkataina	■	■		■
Rerewhakaaitu	■	■	■	
Rotoehu	■	■		■
Rotoiti	■	■	■	■
Rotokākahi	■			
Rotomā	■	■		
Rotomāhana	■		■	■
Rotorua	■	■	■	■
Tarawera	■	■	■	■
Tikitapu	■	■		

* Hornwort not recorded in Lake Ōkāreka since 2015.

Study methods

1.4 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.

1.5 Lake surveys

The LakeSPI method was used to assess five established baseline sites within each of the six lakes re-assessed this year. Lakes Ōkataina, Rerewhakaaitu, Rotoehu, Rotokākahi, Tarawera and Tikitapu were surveyed in March 2018.

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.

1.6 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.

1.6.1 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.

1.6.2 LakeSPI change

Changes in LakeSPI indices over a recent time-frame, since 2013/2014 (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:

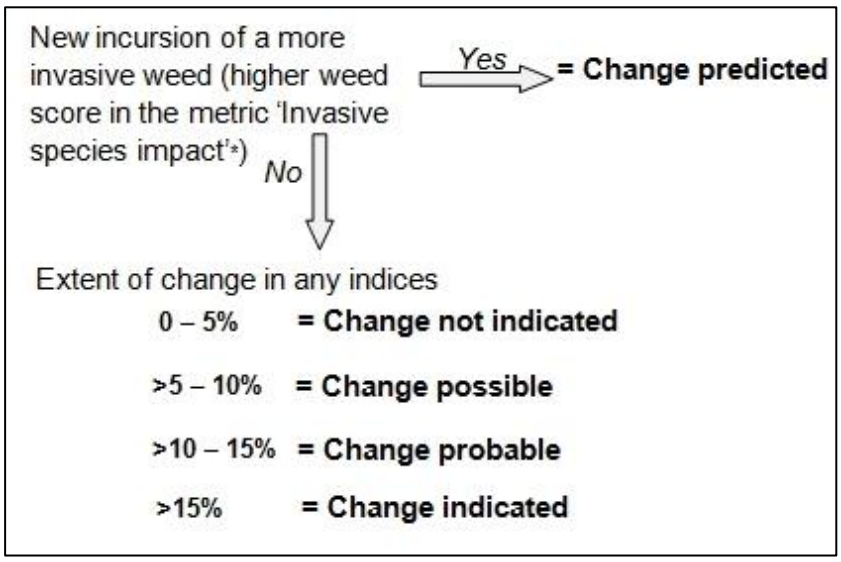


Figure 3: Guidelines assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.

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 $p < 0.05$.

2 Results

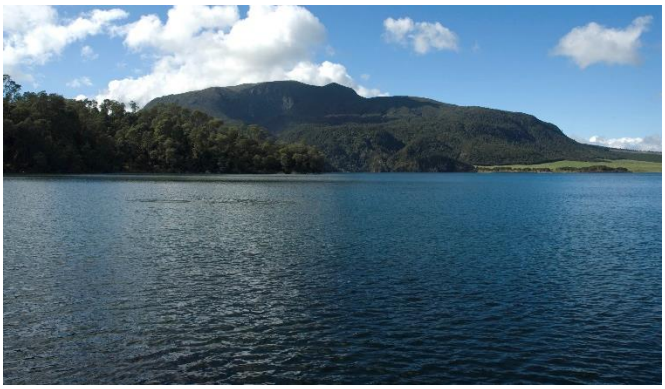
Table 2 presents LakeSPI results for each lake, with the indices presented as a percentage of maximum scoring potential. In the following section the lakes are discussed in order of their LakeSPI scores, beginning with the highest ranked lake.

Table 2-1: Summary of current LakeSPI indices for 12 Rotorua Te Arawa lakes, in order of their overall lake condition (2017 or 2018).

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	
Ōkataina	15/03/2018	44	51	63	
Tikitapu	13/03/2018	32	22	59	
Rerewhakaaitu	14/03/2018	32	40	77	
Rotokākahi	13/03/2018	28	23	79	
Tarawera	14/03/2018	27	32	84	
Rotorua	10/04/2017	26	27	79	
Rotoehu	15/03/2018	20	27	89	Poor
Rotoiti	03/04/2017	19	23	91	

2.1 Lake Rotomāhana

2.1.1 Results



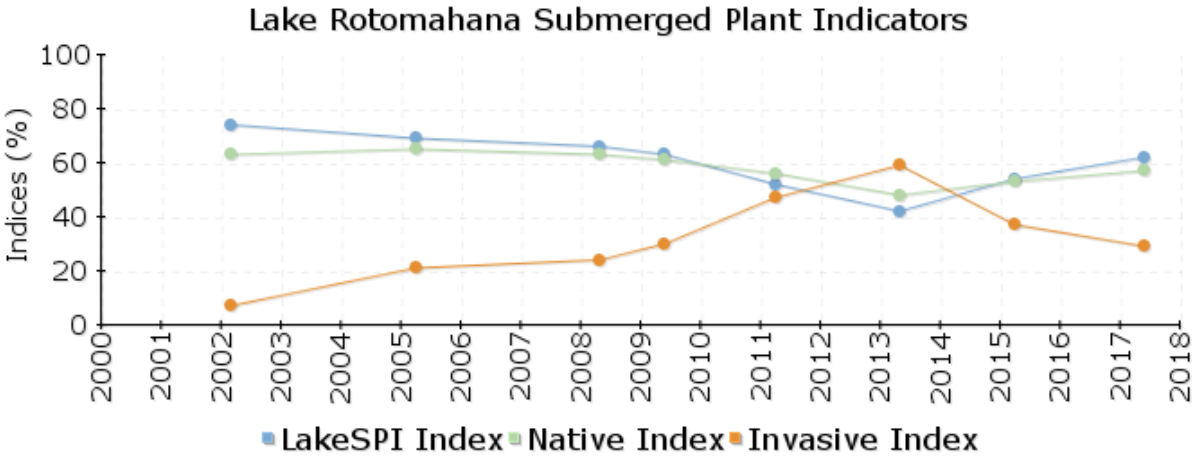
Lake condition: High

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 4: 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 4).

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 5), pondweeds (*Potamogeton ochreatus*, *Stuckenia pectinata*), two ruppia species (*Ruppia megacarpa* and *R. polycarpa*) (Figure 6), and three shallow water turf species (*Glossostigma elatinoides*, *Elatine gratioloides* and *Lilaeopsis ruthiana*). A small sedge, *Eleocharis acuta,* was also present at one site growing down to c. 2 m.

Egeria (*Egeria densa*) was recorded from only two LakeSPI sites, forming high covers down to a maximum depth of 8.6 m. The introduced pondweed *Potamogeton crispus* was present at one site forming low covers. 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 kōura (freshwater crayfish) or kākahi (freshwater mussels) were observed in Lake Rotomāhana.

2.1.2 Discussion

An increase in the LakeSPI Index from 54% in 2015 to 62% in 2017 (Figure 4) 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 4). However, since this time 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 4), 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 a common phenomenon with these species. The unusual, thermally -influenced water quality in the lake may be a factor relating to the performance of these weeds in Lake Rotomāhana.

Over the long term (27-29 years) Lake Rotomāhana has shown some of the biggest changes in lake condition of the twelve Rotorua Te Arawa lakes, resulting mainly from the invasion of egeria and hornwort (Figure 38). 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, might suggest an aquarium or ornamental pond source for egeria, hornwort and the ear pond snail, and possibly a deliberate release based on the coincidental timing.

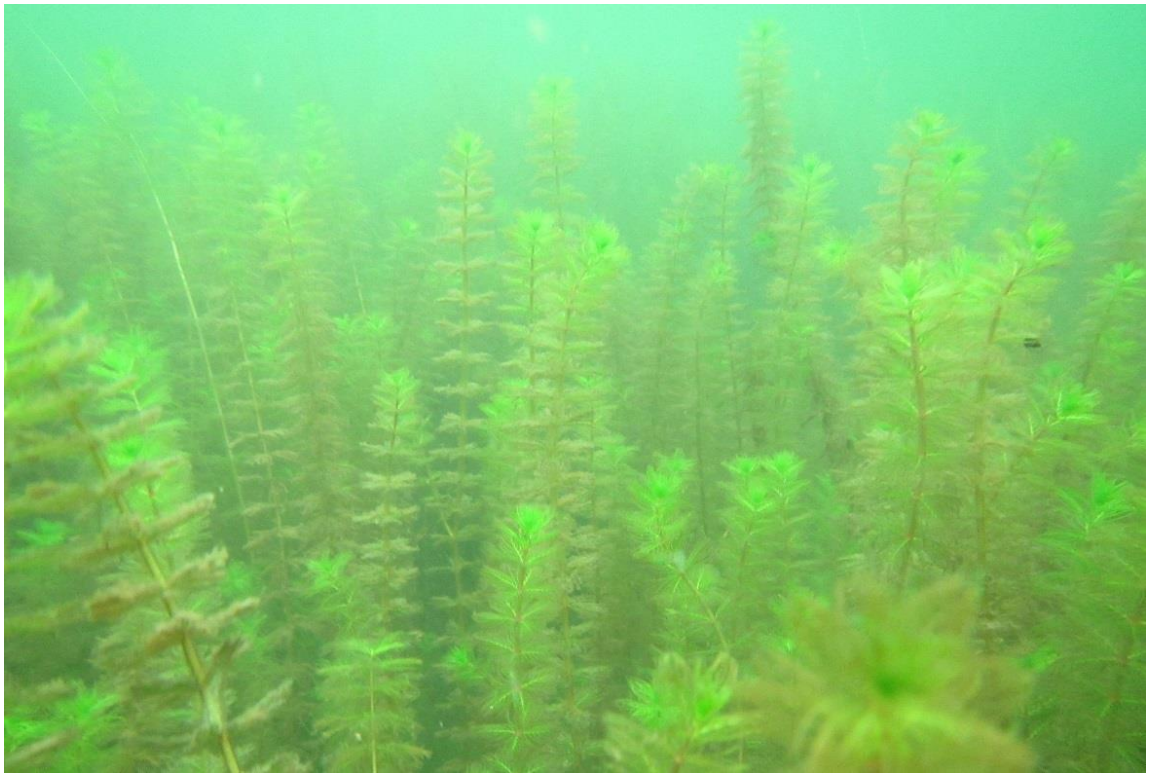


Figure 5: Native milfoil *Myriophyllum triphyllum* in Lake Rotomāhana.

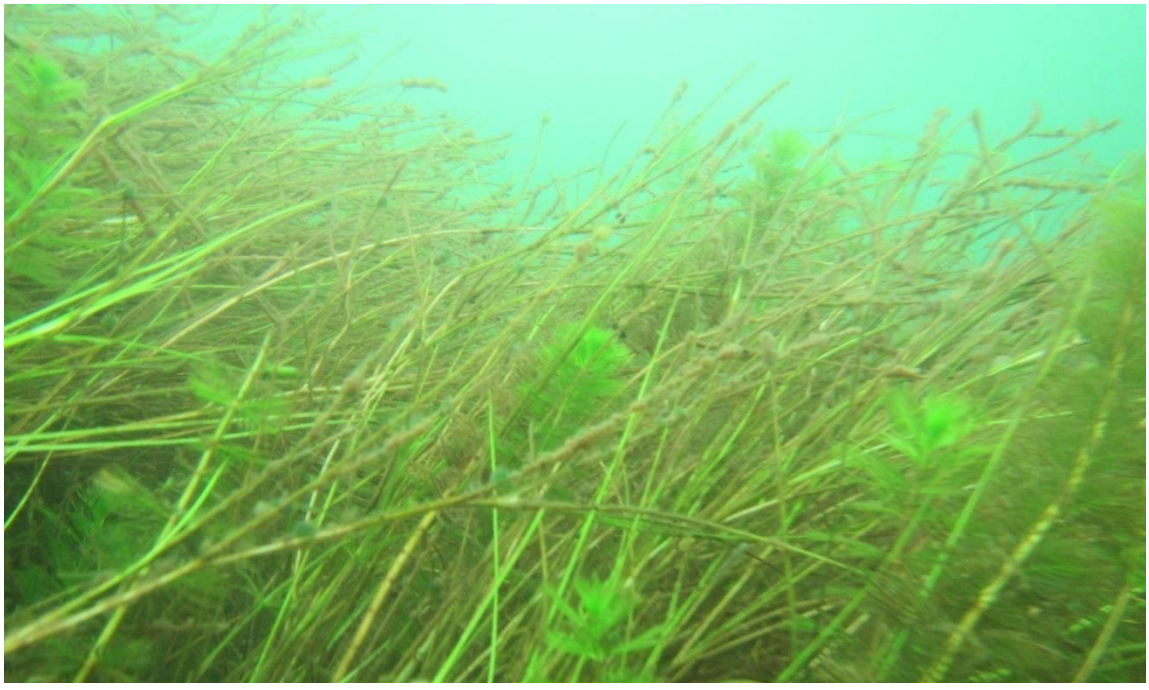
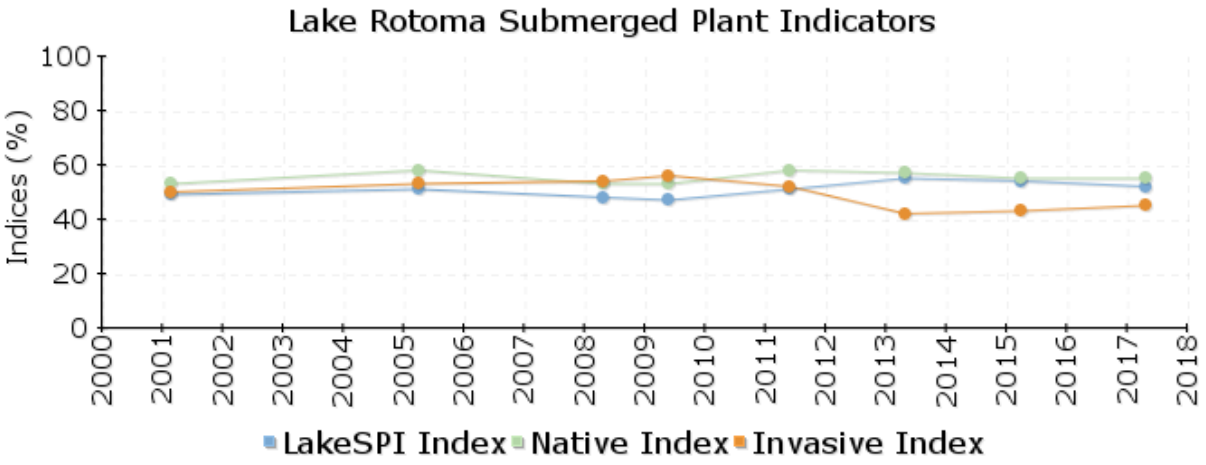


Figure 6: Native *Ruppia megacarpa* in Lake Rotomāhana.

2.2 Lake Rotomā

2.2.1 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 7: LakeSPI results for Lake Rotomā since 1973.

Lake Rotomā was categorised in high ecological condition with a LakeSPI Index of 52% (Figure 7).

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 (Figure 8). 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, and only low covers at a fifth site. 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 9).

At the time of recent survey, through-water visibility was exceptional and estimated by divers to be >10.0 m. Both kākahi (*Echyridella menziesii*) and kōura (*Paranephrops planifrons*) were observed in the lake.

2.2.2 Discussion

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

The proximity of hornwort (*Ceratophyllum demersum*) in the adjacent 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 Taupō.

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.

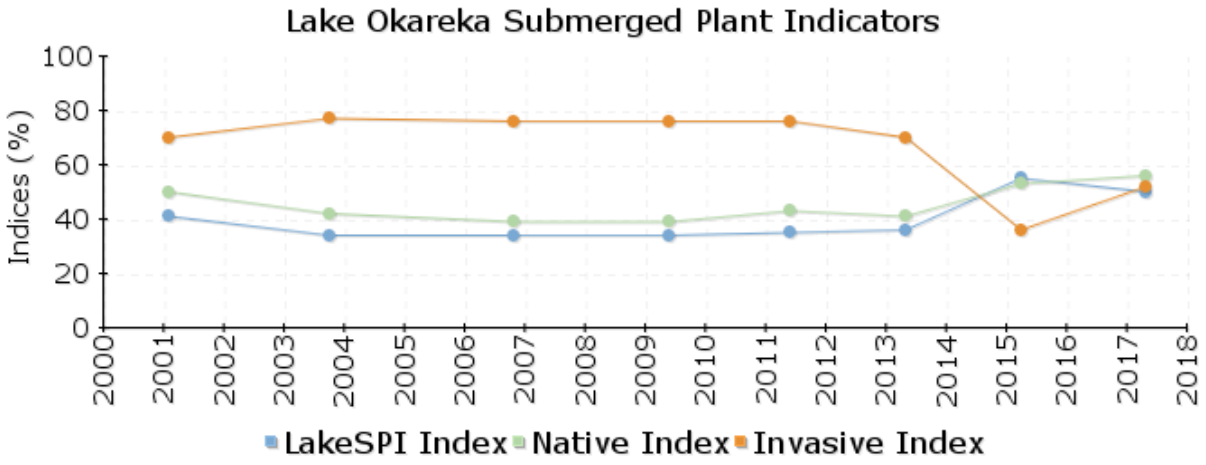
Figure 8: **Lagarosiphon shoots growing amongst charophyte (*Chara fibrosa*) meadows in Lake Rotomā.**

Figure 9: **Lagarosiphon forming a dense tall weed bed in Lake Rotomā.**

2.3 Lake Ōkāreka

2.3.1 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 10: LakeSPI results for Lake Ōkāreka since 1988.

Lake Ōkāreka was categorised in high ecological condition with a LakeSPI Index of 50% (Figure 10).

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 11), 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 kākahi (*Echyridella menziesii*) were observed but no kōura were recorded at this time.

2.3.2 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 (*Ceratophyllum demersum*) (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 (*Egeria densa*) 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 in the lake since 2014 (Hamish Lass, BOPRC, pers. comm.). 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).

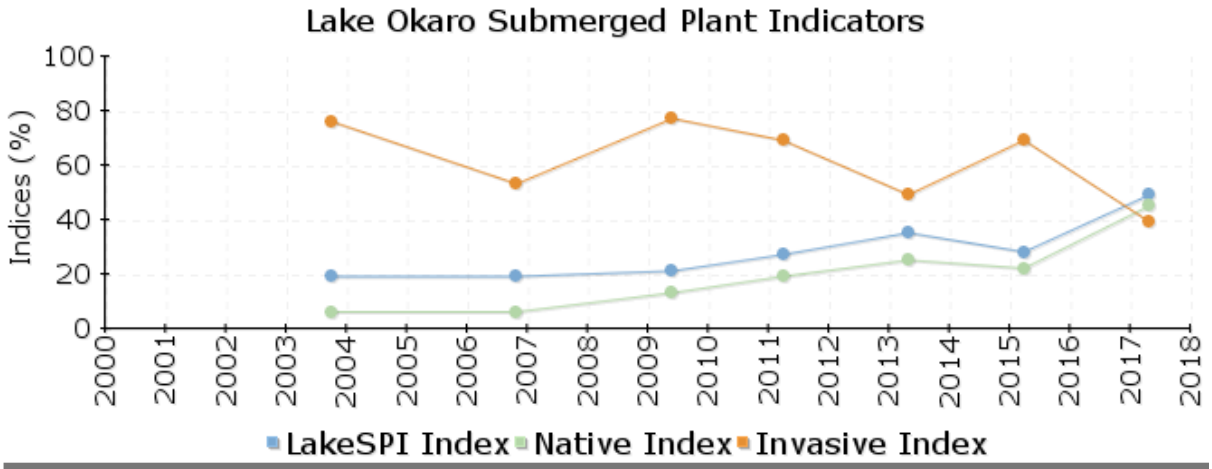
Historical notes - Egeria was first reported in Lake Ōkāreka in 2000 (Clayton et al. 2005). It was not located at any of the five LakeSPI sites during the 2001 survey, but by 2003 it had spread to three sites, and to four sites by 2006. Egeria displaced lagarosiphon with taller and denser weed growth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

Figure 11: Native milfoil, *Myriophyllum triphyllum*, in Lake Ōkāreka. Image on right shows milfoil flowers.

2.4 Lake Ōkaro

2.4.1 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 12: LakeSPI results for Lake Ōkaro since 1982.

Lake Ōkaro was categorised in moderate ecological condition with a LakeSPI Index of 49% (Figure 12).

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 to 5.8 m (Figure 13).

Other native vegetation included three turf species (*Glossostigma elatinoides*, *Glossostigma diandrum* and *Lilaeopsis ruthiana*) (Figure 14), 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 deep.

Elodea (*Elodea canadensis*) 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 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 kōura or kākahi were observed. The ear pond snail (*Radix auricularia*) was present in sparse numbers.

2.4.2 Discussion

LakeSPI results show some significant improvements in the overall condition of Lake Ōkaro over the short and longer-term time frames (1989 to 2017) (Figure 12).

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 12). Dense native pondweed 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 to 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 Rotokākahi, are the only Rotorua Te Arawa Lakes to remain 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.

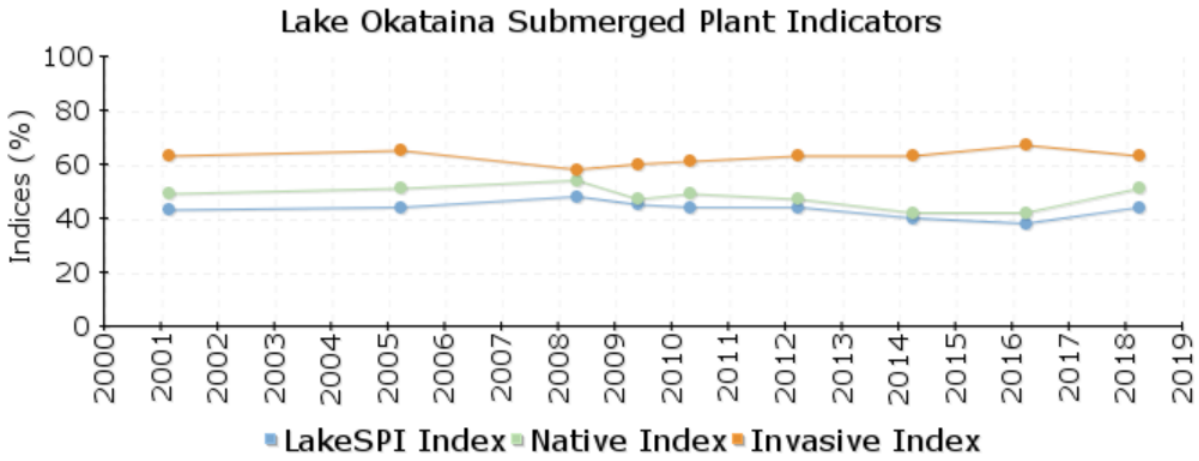
Figure 13: The native pondweed *Potamogeton ochreatus* dominated the vegetation in Lake Ōkaro.

Figure 14: Native low mound submerged plant community in Lake Ōkaro. Photo shows *Glossostigma elatinoides* (spoon shape) and *Lilaeopsis ruthiana* (spikey).

2.5 Lake Ōkataina

2.5.1 Results

Lake condition:	Moderate
Lake ranking:	5th
Lake stability:	Stable
Lake maximum depth:	78.5 m
Max depth of vegetation:	14.3 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2018	Moderate	44%	51%	63%
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 15: LakeSPI results for Lake Ōkataina since 1981.

Lake Ōkataina was categorised in moderate ecological condition with a LakeSPI Index of 44% (Figure 15).

Six native charophytes (*Chara australis*, *Chara fibrosa*, *Chara globularis*, *Nitella* sp. aff. *cristata, Nitella leonhardii, Nitella hyalina*) were recorded within the lake. *Chara australis* was the most prolific of these species forming meadows (> 75% cover) at four of the five sites extending down to a maximum depth of 14.3 m (Figure 16). Native pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*), milfoils (*Myriophyllum triphyllum, Myriophyllum propinquum*) and turf species (*Glossostigma elatinoides*, *Glossostigma diandrum*, *Elatine gratioloides*, *Lilaeopsis ruthiana*, *Ranunculus limosella*) were also recorded.

Lagarosiphon (*Lagarosiphon major*) remained the dominant invasive species in Lake Okataina forming dense weed beds (Figure 16) at all five sites down to a maximum depth of 8 m (Figure 16). No hornwort (*Ceratophyllum demersum*) was observed from LakeSPI sites.

At the time of recent survey, through-water visibility was excellent and estimated by divers to be c. 7 m. Both kākahi (*Echyridella menziesii*) and kōura (*Paranephrops planifrons*) were present. A zone of bare sediment, c. 1 m wide, was observed at three of the five sites extending around the lake margin at a depth of c. 6 – 7 m, between the bottom edge of lagarosiphon weed beds and deeper growing charophyte meadows (Figure 17).

2.5.2 Discussion

Lake Ōkataina remains in a stable condition with only minor fluctuations in the LakeSPI Index over the more recent (4 year) and longer term (30 year) time frames (Figure 15).

An increase in the Native Condition Index from 42% in 2016, to 51% in 2018, largely reflected an increase in the depth extent of plants most likely in response to higher lake levels noted during the 2018 survey. As Lake Ōkataina has no outlet, water levels can vary by several metres, so it is not unusual for water levels to affect the available habitat for submerged vegetation in shallow water, and its maximum depth extent. Nevertheless, when water levels change slowly, the vegetation usually compensates by migrating up and down the slope. In this case, BOPRC water level recordings show lake levels had increased by c. 2 m between the 2016 and 2018 surveys, with most change occurring since March 2017 (BOPRC, 2018). This relatively rapid increase in water level is reflected by a c. 3.3 m increase in the depth extent of native plants, with charophytes recorded to a maximum depth of 14.3 m in 2018, compared to a maximum depth of 11.3 m in 2016. Should water levels remain at this higher level, it is expected that charophytes will adjust by retreating to previous depth limits, in relation to light, with more time.

Higher lake levels in 2018 also appear to have affected the extent of lagarosiphon growth. In shallower areas, lagarosiphon was observed growing in shallower than usual depths, amongst native charophyte and turf species that typically dominate this shallow water zone (Figure 18). At the deeper limit of lagarosiphon growth, the zone of bare sediment observed running between the bottom edge of the lagarosiphon weed bed and the deeper water charophyte meadows (Figure 17), likely reflects this plants inability to survive (produce or maintain anchorage roots) at hydrostatic pressures reached beyond c. 7 m (Coffey & Chu 1988). Of concern is that these bare areas of sediment may provide the perfect settling ground for the establishment of hornwort shoots.

While a single hornwort plant was recorded from a LakeSPI site (northern end of lake) during the 2016 survey, no hornwort plants were observed from sites during the 2018 survey. Hornwort continues to pose the most serious threat to the future condition of Lake Ōkataina. Should the currently effective hornwort management effort decrease, we will see a reduction in LakeSPI scores in the future.

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.

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

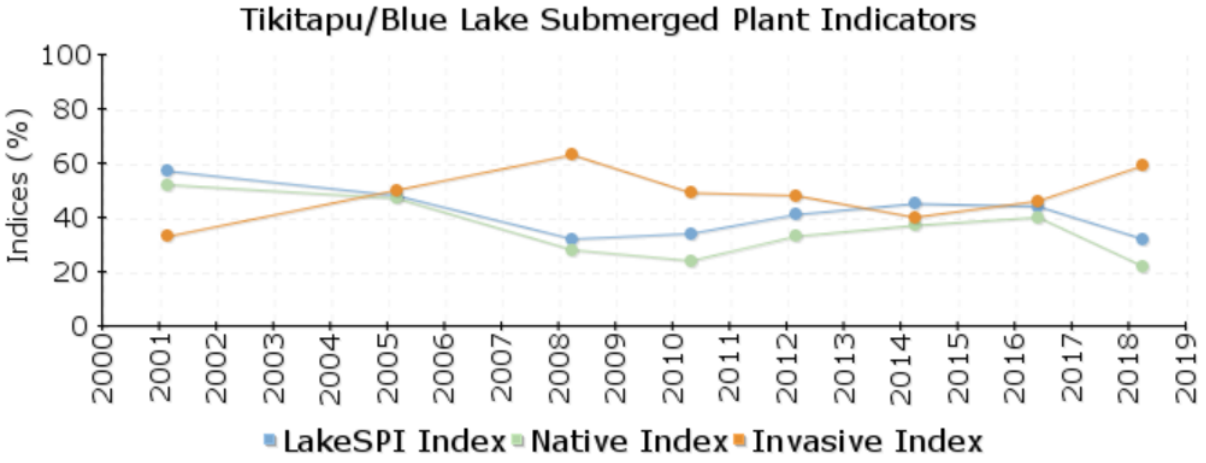
Figure 17: Bare strip of sediment running along the bottom edge of lagarosiphon weed bed in Lake Ōkataina, in response to higher water levels.

Figure 18: Lagarosiphon shoots growing amongst shallow water charophytes in Lake Ōkataina.

2.6 Lake Tikitapu

2.6.1 Results

Lake condition:	Moderate
Lake ranking:	6th equal
Lake stability:	Stable/declining?
Lake maximum depth:	27.5 m
Max depth of vegetation:	6.2 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2018	Moderate	32%	22%	59%
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 19: LakeSPI results for Lake Tikitapu since 1988

Lake Tikitapu was categorised as being in moderate ecological condition with a LakeSPI Index of 44% (Figure 19).

Lagarosiphon (*Lagarosiphon major*) was recorded from four of the five LakeSPI sites in the 2018 survey forming variable to high covers to a maximum depth of 6.2 m (Figure 20). Plants were relatively low growing with an average maximum height of 0.7 m.

Native plant communities included two milfoils (*Myriophyllum pedunculatum*, *Myriophyllum propinquum*), three charophytes (*Nitella* sp. aff. *cristata*, *Nitella leonhardii* and *Nitella pseudoflabellata*) and a turf plant, *Elatine gratioloides*. Charophytes were recorded from all five sites forming low to moderate covers from the shallows (c. 1 m) down to the maximum depth of native plant growth at 6.1 m. No deeper growing charophytes were observed from any of the five sites. Charophyte meadows (>75% cover) were recorded from one site.

Through-water visibility was estimated by divers to be c. 5 m. No kākahi or kōura were observed. A blue/green algal mat was noted covering the sediment beyond the depth of plants.

2.6.2 Discussion

After remaining stable over the more recent time frame (since 2014), the recent LakeSPI results for Lake Tikitapu indicate a probable decline (Figure 3) in overall Lake Condition. The LakeSPI Index has decreased from 44 to 45% in 2014 and 2016, to 32% in 2018 (Figure 19), reflecting a significant increase in the Invasive Impact Index and reduction in Native Condition scores.

While lagarosiphon remains the only invasive species in Lake Tikitapu, it was recorded forming higher covers over a larger depth range in 2018, represented by an Invasive Impact Index of 59%. The average maximum depth of lagarosiphon had increased by 1.5 m since the previous 2016 survey, having a greater impact on native vegetation and contributing to a low Native Condition Index.

A Native Condition Index of 22% is the lowest recorded for Lake Tikitapu since LakeSPI surveys begun (Figure 19) and reflects the absence of deeper growing charophytes from all LakeSPI sites in 2018. Charophytes have been recorded to depths of between 16.2 – 18.5 m from a minimum of two sites since 2012. The presence of deeper growing charophyte communities in Lake Tikitapu have been variable and intermittent between sites and years, greatly extending the otherwise continued shallow depth limit of vegetation. It is possible, that the discontinuity of charophyte growth in relation to light climate in Lake Tikitapu is a result of a dominant 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 continue to be variable in nature.

Longer term, since 1988, LakeSPI results show a significant decline in overall lake condition. Unlike most other lakes, this reduction has not been due to the impact from new invasive species and is not fully explained.

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.

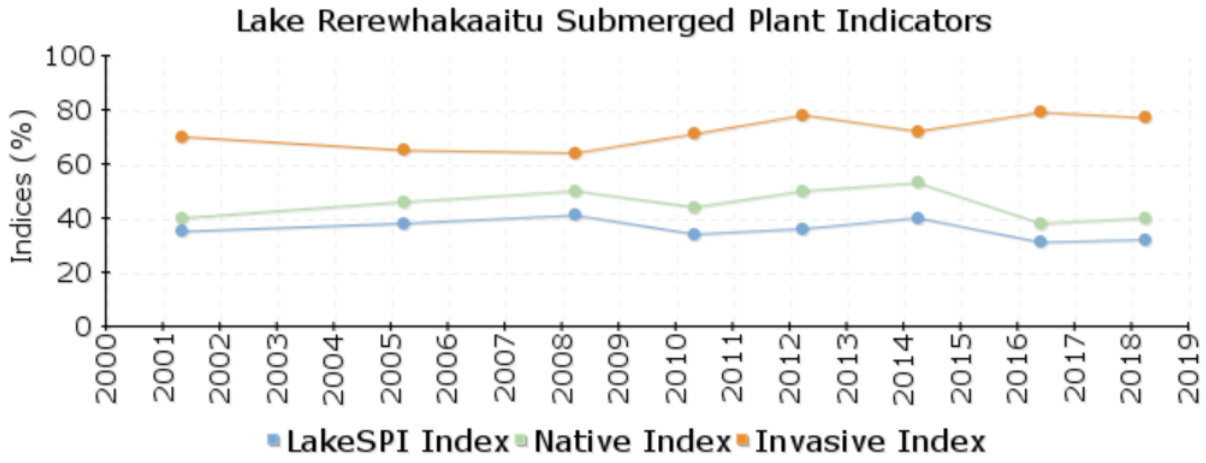
When the water chemistry of Lake Tikitapu was assessed in the early 1970s it had the lowest alkalinity recorded for any of the Rotorua Te Arawa lakes and it also had low sediment and water nutrient levels (McColl 1972). The reported low alkalinity, calcium and silicon levels may explain the on-going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

Figure 20: Lagarosiphon forms variable covers in Lake Tikitapu to a maximum depth of 4.7 m..

2.7 Lake Rerewhakaaitu

2.7.1 Results

Lake condition:	Moderate
Lake ranking:	6th equal
Lake stability:	Stable/declining?
Lake maximum depth:	15.8 m
Max depth of vegetation:	8.5 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2018	Moderate	32%	40%	77%
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%

Figure 21: LakeSPI results for Lake Rerewhakaaitu since 1973.

Lake Rerewhakaaitu was categorised in moderate ecological condition with a LakeSPI Index of 32% (Figure 21).

Dense weed beds of egeria (*Egeria densa*) (Figure 22) and in shallower water, lagarosiphon (*Lagarosiphon major*) dominated the vegetation at all five sites extending down to a maximum depth of 8.5 m. Elodea (*Elodea canadensis*) was also recorded from one site.

Charophyte meadows (>75% cover) were present at all five LakeSPI sites but extended beyond the depth of invasive weed beds at only three sites to a maximum depth of 7.8 m. Deeper water charophyte meadows mainly consisted of the species *Chara australis*, but three other charophyte species were present (*Nitella pseudoflabellata*, *Nitella hyalina* and *Chara fibrosa*). Two further species, *Nitella* sp. aff. *cristata* and *Nitella leonhardii*, recorded in 2016 were not recorded in 2018. Other native vegetation included the quillwort *Isoetes kirkii*, pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*) milfoils (*Myriophyllum pedunculatum* and *Myriophyllum propinquum*) and six turf species (*Elatine gratioloides*, *Eleocharis pusilla*, *Glossostigma diandrum*, *Glossostigma elatinoides*, *Lilaeopsis ruthiana*, *Ranunculus limosella*, *Ruppia polycarpa*).

At the time of the most recent survey, through-water visibility was poor, estimated by divers to be 0.5 - 1.5 m, and there appeared to be a noticeable deterioration in water colour since the previous 2016 survey (Figure 22). No kākahi or kōura were observed.

2.7.2 Discussion

LakeSPI results indicate a possible decline in the overall condition of Lake Rerewhakaaitu over the short-term (4 years), with the LakeSPI Index decreasing from 40% in 2014, to 32% in 2018 (Figure 21). This result predominantly reflects a decline in Native Condition scores, from 53% in 2014 to 40% in 2018 resulting from an increase in the overall extent and abundance of the invasive weeds egeria and lagarosiphon. An Invasive Impact Index of 77% (Figure 21) is close to the highest recorded for the lake.

Egeria and lagarosiphon continue to dominate the vegetation, although, weed beds were noted to be in poorer condition than in previous years, possible due to poor water quality noted at the time of the 2018 survey. Divers recorded though water visibility to be low (< 1.5 m) and water was dark in colour (Figure 22). An increase in the depth extent of invasive weed beds (average c. 1.6 m) between the 2016 and 2018 surveys is likely to reflect an increase in water levels. BOPRC water level recordings show lake levels had increased by c. 2 m over the last year from March 2017 (BOPRC, 2018). However, no similar increase in the depth extent of native vegetation was noted over this same time frame with only a small average increase of c. 0.3 m.

While charophyte meadows (>75 % cover) persisted at all five LakeSPI sites in shallow water, deeper growing meadows were recorded from only three sites in 2018, one site less than in 2016, and two sites less than in 2014. Should deeper water charophytes continue to disappear from this deeper depth zone, we can expect to see Native Condition scores for Lake Rerewhakaaitu decline further in the future.

Lake Rerewhakaaitu still remains at risk from hornwort (*Ceratophyllum demersum*). While the risk is assessed as relatively low because of its distance from surrounding infestations and relatively low boat traffic, it only takes the introduction of one shoot to initiate a new weed invasion. If introduced, hornwort could have a severe impact on existing vegetation.

Over the longer term (30 year) time frame, LakeSPI results indicate a significant decline in the overall condition of Lake Rerewhakaaitu on account of invasion by lagarosiphon and egeria.

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.

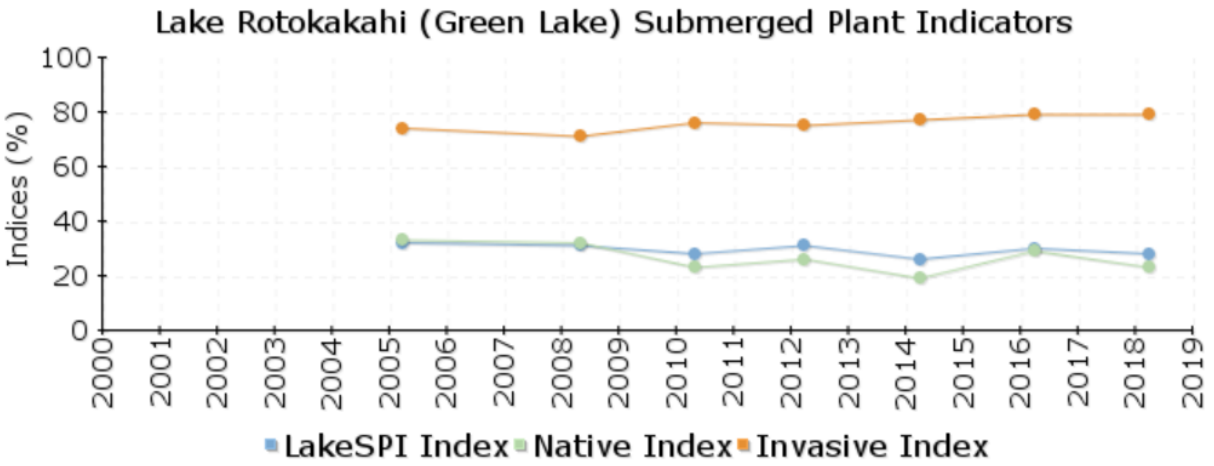
Egeria further impacted negatively on LakeSPI scores following its introduction and subsequent spread in the 2000's. Egeria was first recorded in Lake Rerewhakaaitu in 2000 (Champion et al. 2006). By 2008, egeria was present at two of the five LakeSPI sites and by the 2010 survey, had spread to all five sites, causing incremental rises in the Invasive Impacts Index to where it is today (Figure 21). Egeria weed beds remain the tallest, densest, most extensive weed beds we know of in New Zealand.

Figure 22: Egeria beds dominated the vegetation in Lake Rerewhakaaitu. Photo on left in 2016, right 2018.

2.8 Lake Rotokākahi

2.8.1 Results

Lake condition:	Moderate
Lake ranking:	8th
Lake stability:	Stable
Lake maximum depth:	32 m
Max depth of vegetation:	8.8 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2018	Moderate	28%	23%	79%
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 23: LakeSPI results for Lake Rotokākahi since 1988.

Lake Rotokākahi was categorised as being in moderate ecological condition with a LakeSPI Index of 28% (Figure 23).

Native vegetation in Lake Rotokākahi 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*), three native milfoils (*Myriophyllum pedunculatum*, *Myriophyllum propinquum*, *Myriophyllum triphyllum*), and four charophyte species (*Chara australis*, *Nitella hyalina, Nitella pseudoflabellata* and *Nitella sp*. aff. *cristata*). Charophytes were present at all five sites but formed charophyte meadows (>75% cover) at only two sites in shallow water (< 2 m) (Figure 24). *Chara australis* was recorded growing beyond the extent of invasive weed beds at three sites to a maximum depth of 9.2 m but at only low to moderate covers.

Elodea (*Elodea canadensis*) was the only invasive species in Lake Rotokākahi. It was surface reaching in places and formed tall (c. 3.5 m) weed beds at all five sites to a maximum depth of 8.8 m (Figure 25).

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 kākahi (*Echyridella menziesii*) were recorded in the lake, mostly in sediments beyond the outer edge of the weed bed at c. 7-9 m depth.

2.8.2 Discussion

Lake Rotokākahi has been in a stable condition in recent years according to LakeSPI results (Figure 23).

Lake Rotokākahi has undergone one of the largest declines in lake condition as indicated by LakeSPI for any of the twelve lakes over the long-term (Figure 38), with most change taking place prior to 2005 (Figure 23). The LakeSPI Index has reduced from 52% in 1988 to only 28% in 2018, whilst the Native Condition Index has also declined significantly, largely due to a decline in deeper charophyte meadows over the longer-term time frame. This has occurred even though there have been no new invasive species recorded in the lake, therefore, likely the result of deteriorating water quality and clarity (RTALP, 2018). 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 Rotokākahi, together with Lake Ōkaro, are the only Rotorua Te Arawa Lakes to remain relatively free of the more invasive weed species.

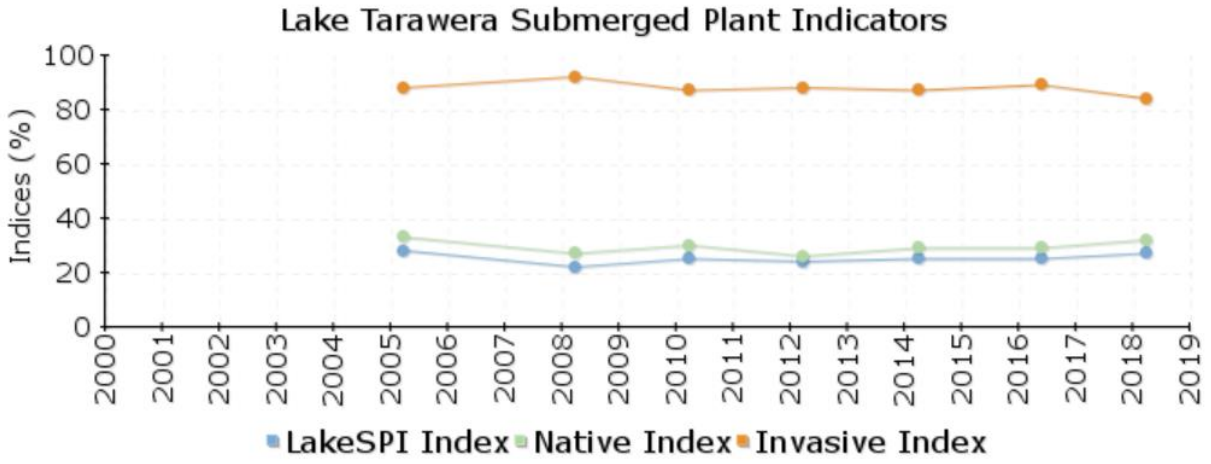
Figure 24: Charophyte meadow growing in shallow water in Lake Rotokākahi.

Figure 25: Diver swimming over surface reaching elodea weed bed in Lake Rotokākahi.

2.9 Lake Tarawera

2.9.1 Results

Lake condition:	Moderate
Lake ranking:	9th
Lake stability:	Stable
Lake maximum depth:	87.5 m
Max depth of vegetation:	12.8 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2018	Moderate	27%	32%	84%
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 26: LakeSPI results for Lake Tarawera since 1988.

Lake Tarawera was categorised in moderate ecological condition with a LakeSPI Index of 27% (Figure 26).

Hornwort (*Ceratophyllum demersum*) dominates the submerged vegetation in Lake Tarawera forming dense weed beds up to c. 2 m tall, extending down to a maximum depth of 12.8 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 even more minor invasive species, water buttercup (*Ranunculus trichophyllus*), was also locally present (Figure 27).

Six native charophyte species were recorded during the 2018 survey (*Chara australis*, *Chara globularis*, *Nitella hyalina*, *Nitella* sp. aff. *cristata*, *Nitella leonhardii*, *Nitella pseudoflabellata*), with charophyte meadows (>75% cover) observed at three of the five sites growing to a maximum depth of 6 m. Other native vegetation consisted of a mixed turf community in shallower water, pondweeds (*Potamogeton cheesemanii*, *Potamogeton ochreatus*) and milfoils (*Myriophyllum propinquum*, *Myriophyllum triphyllum*). A small native buttercup *Ranunculus amphitrichus*, was also recorded from one site (Figure 28).

At the time of survey, underwater visibility was estimated by divers to be c. 5 m. Kākahi (*Echyridella menziesii*) were recorded at most sites. Kōura, observed in 2016, were not seen in 2018.

2.9.2 Discussion

Lake Tarawera has remained in a moderate but stable condition since 2010. Prior to this, the LakeSPI Index from 1988 to 2005 (Figure 26) was high then declined with the invasion of hornwort. Today hornwort dominates the submerged vegetation in Lake Tarawera down to a maximum depth of 12.8 m, and the full impact of hornwort has been evident for several years.

A Native Condition Index of 32% (Figure 26) reflects some well-developed native plant communities persisting in Lake Tarawera, particularly on exposed sites unsuited to hornwort bed formation. A small, but statistically significant, decrease in the Invasive Impact Index from 89% in 2016 to 84% in 2018, was mostly due to an increase in the extent of native vegetation. Higher native, and correspondingly lower invasive ratio scores were recorded in 2018 at three of the five sites. The maximum height of weed beds was also reduced at three sites further influencing the Invasive Impact Index.

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 26).

Figure 27: Four invasive species in Lake Tarawera. Hornwort (bottom left), egeria (top left), lagarosiphon (top right), *Ranunculus trichophyllus* (bottom right).

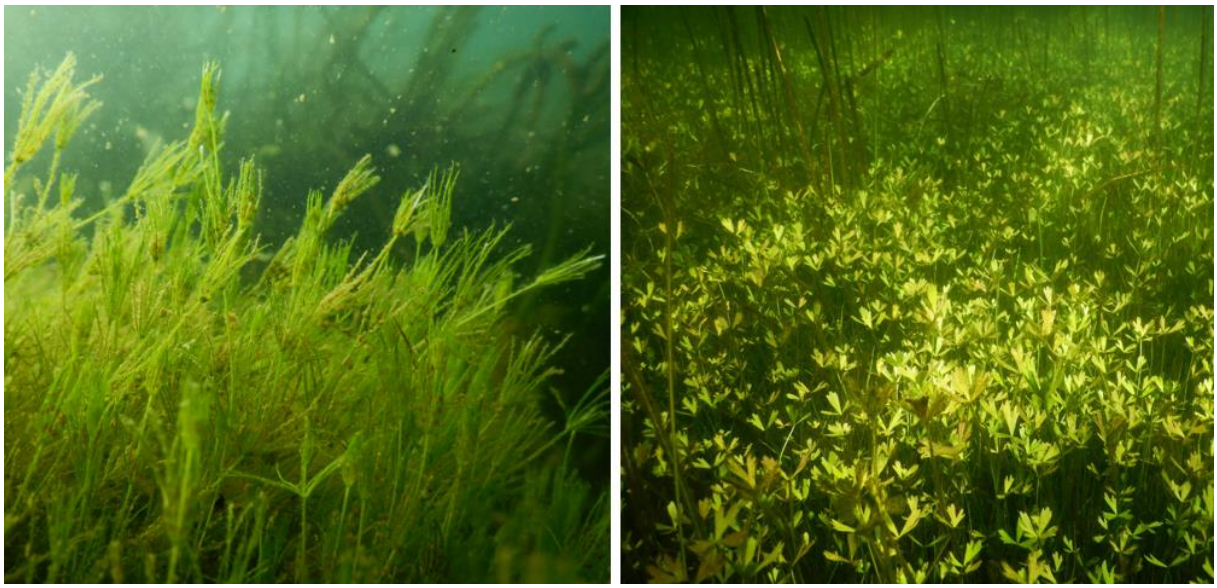
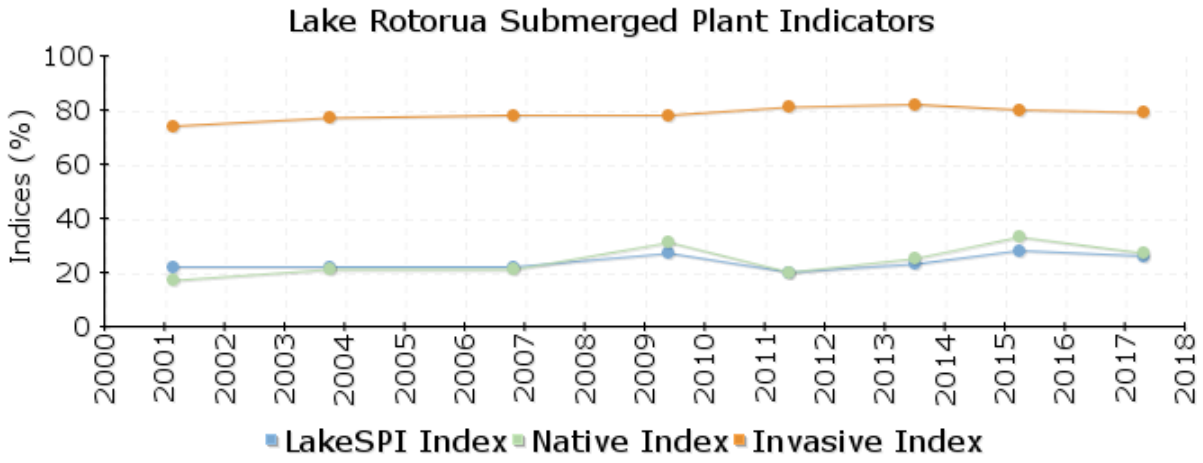


Figure 28: Native charophyte, *Chara globularis* (left), and *Ranunculus amphitrichus* (right) in Lake Tarawera.

2.10 Lake Rotorua

2.10.1 Results

Lake condition:	Moderate
Lake ranking:	10th
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 29: LakeSPI results for Lake Rotorua since 1982.

Lake Rotorua was categorised in moderate ecological condition with a LakeSPI Index of 26% (Figure 29).

Egeria (*Egeria densa*) and lagarosiphon (*Lagarosiphon major*) dominated the submerged vegetation in Lake Rotorua but were patchy in nature and distribution (Figure 30). 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 31) 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 kākahi (*Echyridella menziesii*) were observed at all sites in the lake.

2.10.2 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 29). 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 habitat provided by egeria beds for nuisance blooms of the invasive water net alga (*Hydrodictyon reticulatum*) and, with regular herbicide follow up, it has never recovered to its former state. Hornwort (*Ceratophyllum demersum*) was first recorded in the lake in 1975 but has never dominated in this lake, possibly due to its highly exposed nature, with long wave fetches (c. 10 km) at nearly all sites.

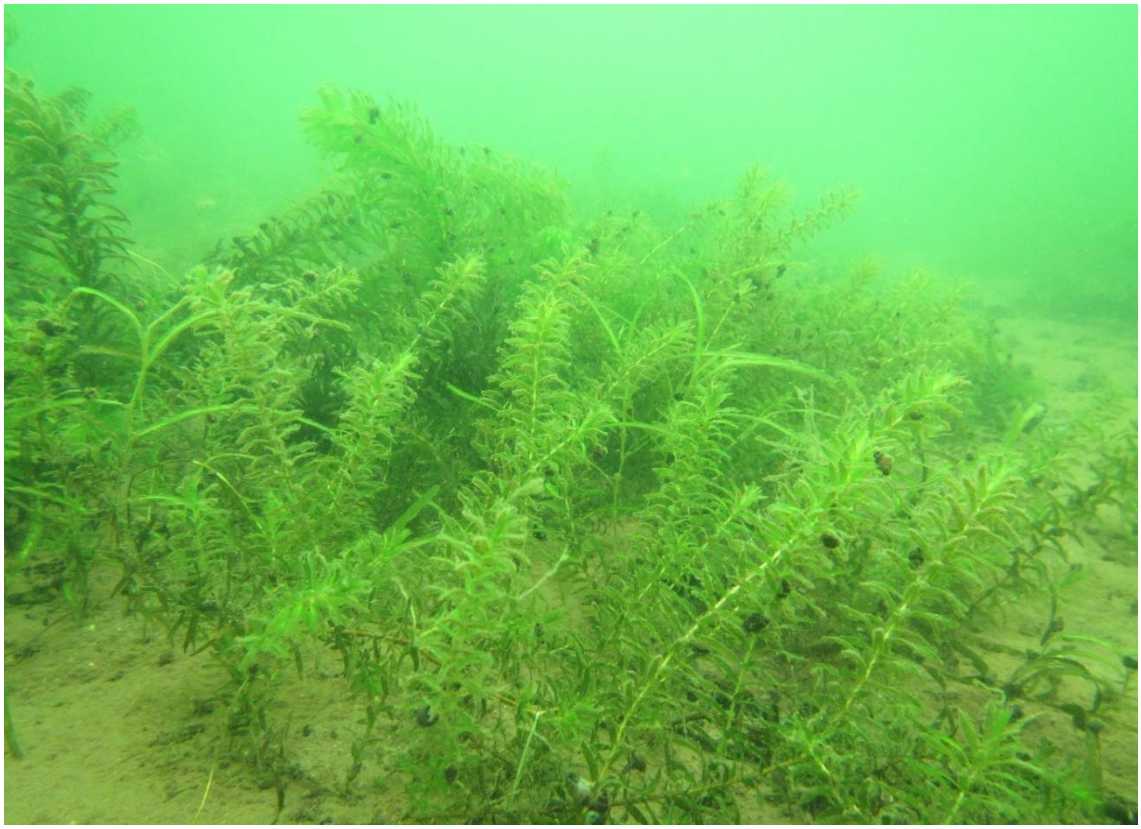


Figure 30: Egeria formed variable covers in Lake Rotorua.

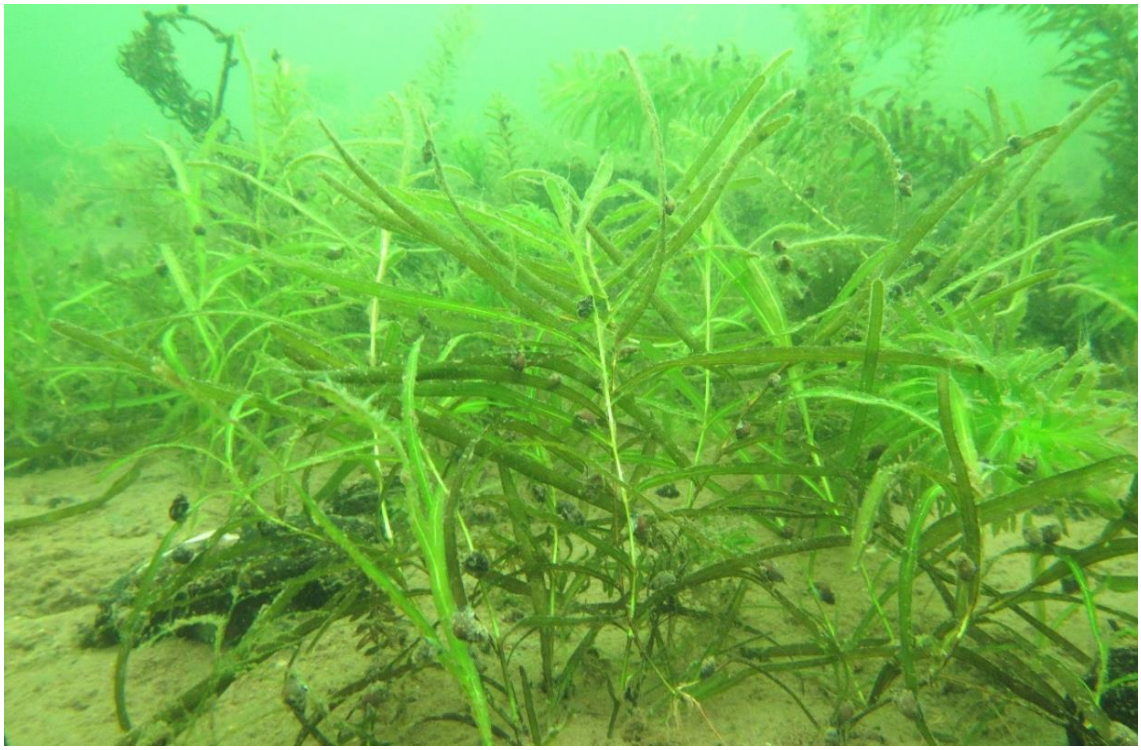
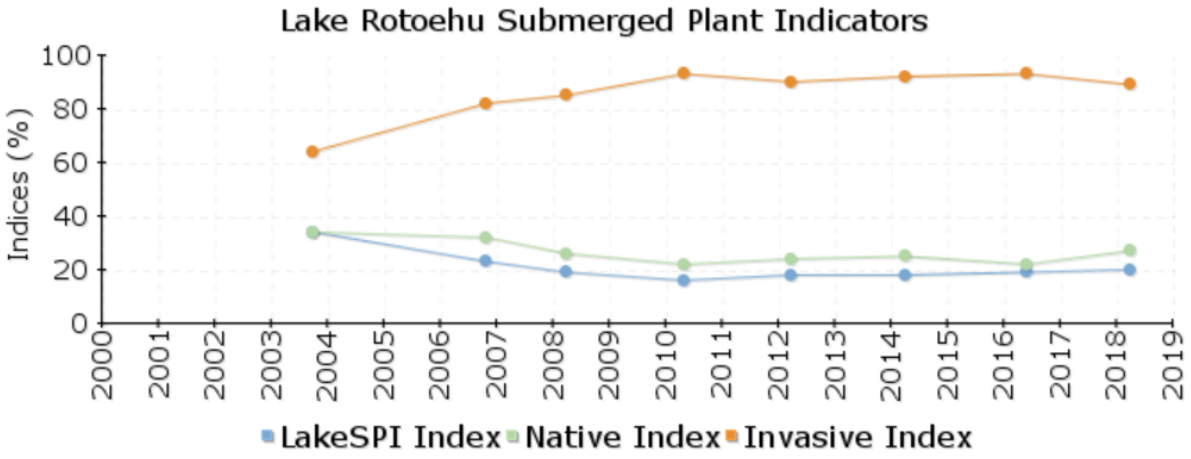


Figure 31: Native pondweeds (*Potamogeton ochreatus*) (front of photo) in Lake Rotorua.

2.11 Lake Rotoehu

2.11.1 Results

Lake condition:	Poor
Lake ranking:	11th
Lake stability:	Stable
Lake maximum depth:	13.5 m
Max depth of vegetation:	8.0 m



Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
March 2018	Poor	20%	27%	89%
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 32: LakeSPI results for Lake Rotoehu since 1988.

Lake Rotoehu was categorised as being in “poor” ecological condition with a LakeSPI Index of 20% (Figure 32).

Hornwort (*Ceratophyllum demersum*) formed extensive dense weed beds up to 2.5 m tall, at most LakeSPI sites, and was recorded down to an average maximum depth of 4.7 m, and maximum depth of 8 m. Other invasive species present in Lake Rotoehu included *Elodea canadensis*, *Lagarosiphon major* (although not recorded during the previous two surveys), and an invasive pondweed (*Potamogeton crispus*).

Native vegetation was generally sparse and most prevalent in shallow water (<2.5 m depth). Three charophyte species (*Chara australis*, *Chara globularis* and *Nitella* sp. aff. *cristata*) were recorded forming high covers (>75%) in shallow water (< 2.5 m) at three of the five LakeSPI sites. Other native vegetation included two short growing turf species (*Glossostigma elatinoides, Lilaeopsis ruthiana*), a pondweed (*Potamogeton ochreatus*), and milfoil species (*Myriophyllum triphyllum*).

At the time of recent survey, a thick cyanobacteria bloom was present on the lake affecting two of the five LakeSPI sites (Figure 33). This bloom (Figure 33) prevented a visual assessment of the vegetation at one of the five LakeSPI sites. Instead, previous data recorded for this site during the previous 2016 survey was verified using a grapnel and sonar equipment. Kākahi (*Echyridella menziesii*) recorded from most sites in 2016, were not observed in 2018.

2.11.2 Discussion

Lake Rotoehu has remained in a poor, but stable condition (since 2010) as the full impact of hornwort invasion in the lake has taken place. Hornwort (Figure 34) dominates the submerged vegetation in Lake Rotoehu, which continues to have one of the highest Invasive Impact Indices (89%) recorded for any of the twelve Rotorua Te Arawa lakes (Figure 32).

Native vegetation was generally sparse and most prevalent in shallow water (<2.5 m depth). Charophyte meadows recorded at three sites in shallow water (< 2.5 m), positively contributed to a Native Condition Index of 27% (Figure 32).

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

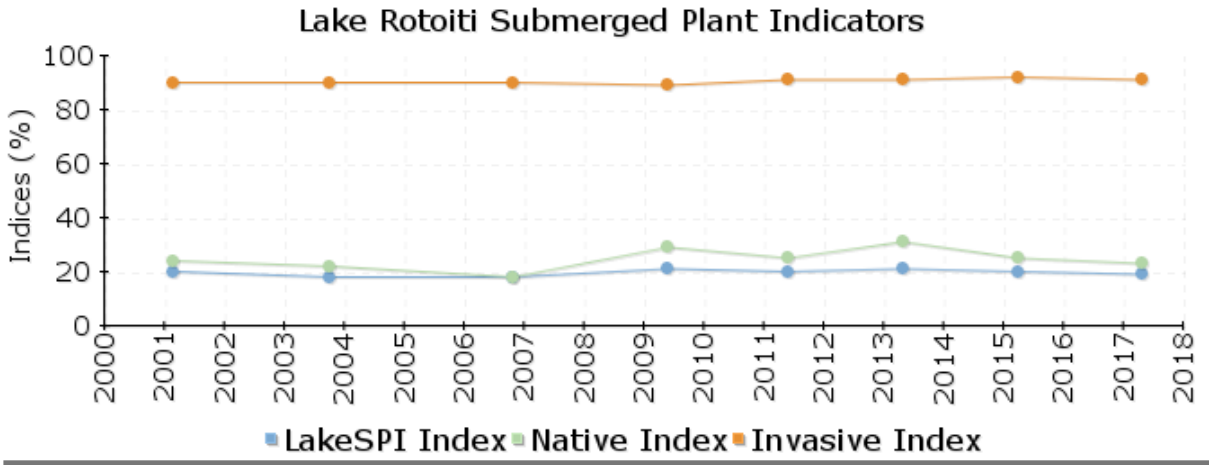
Figure 33: Cyanobacteria bloom in Lake Rotoehu, March 2018.

Figure 34: Surface reaching hornwort in Lake Rotoehu, 2018.

2.12 Lake Rotoiti

2.12.1 Results

Lake condition:	Poor
Lake ranking:	12th
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 35: LakeSPI results for Lake Rotoiti since 1981.

Lake Rotoiti was categorised in moderate ecological condition with a LakeSPI Index of 19% (Figure 35).

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 36). 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 37). 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 37) at the western end of the lake. Both kākahi (*Echyridella menziesii*) and kōura (*Paranephrops planifrons*) were observed throughout the lake.

2.12.2 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 twelve 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 been markedly influenced by water from Lake Rotorua in the past 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, with increased colonisation depths with increasing water clarity are not yet reported. However, the current LakeSPI sites represent the whole lake and not just the western end. There are a number of lake sectors/discrete bays that could be monitored separately to give more detailed assessment of 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 as a baseline to compare future management activities.

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

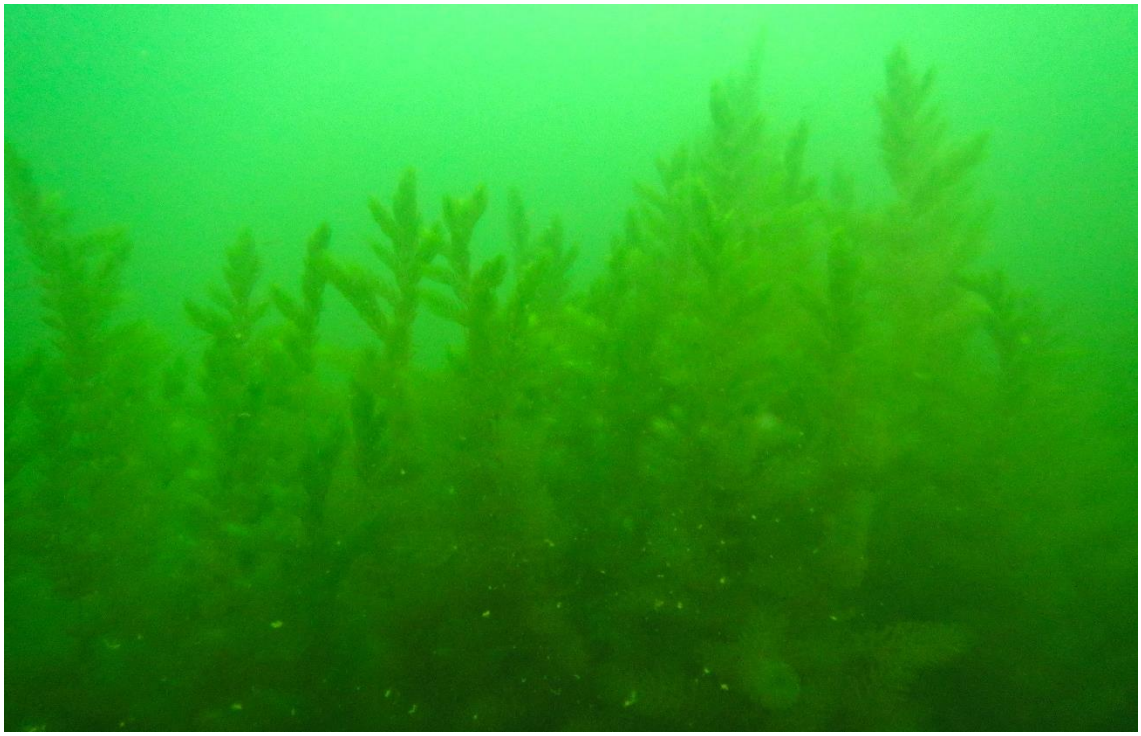


Figure 36: Hornwort formed weed beds up to 4 m tall in Lake Rotoiti.

Figure 37: A thick layer of algae covers Isoetes growing in the shallows of Lake Rotoiti.

3 Discussion

3.1 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 (29/30 years), have been used to provide an indication of current lake stability and the direction of current and longer-term change (Table 3-1, Figure 38).

Table 3-1: 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	Moderate	Stable/Improved	Change (+'ve)	Weed
Ōkaro	49	Moderate	Improved	Change (+'ve)	Water Quality
Ōkataina	44	Moderate	Stable	Change (-'ve)	Weed
Tikitapu	32	Moderate	Stable/declining?	Change (-'ve)	Water Quality
Rerewhakaaitu	32	Moderate	Stable/declining?	Change (-'ve)	Weed
Rotokākahi	28	Moderate	Stable	Change (-'ve)	Water Quality
Tarawera	27	Moderate	Stable	Change (-'ve)	Weed
Rotorua	26	Moderate	Stable	Change (+'ve)	Water Quality
Rotoehu	20	Poor	Stable	Change (-'ve)	Weed
Rotoiti	19	Poor	Stable	Change (-'ve)	Water Quality

3.1.1 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 cease in 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 to improve water quality, both in the lake and catchment. The marked difference in submerged vegetation was the increase in vegetated bottom limits and the proliferation of tall, dense native pondweed beds that have overtopped and replaced the invasive elodea beds that previously dominated the lake.

Lakes Rerewhakaaitu and Tikitapu both showed signs of deterioration (although not statistically significant) over the most recent time frame. Lake Rerewhakaaitu showed signs of possible 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. Lake Tikitapu showed probable signs of deterioraton resulting from the loss of deeper growing charophytes recorded from LakeSPI sites in the lake. However, the presence of deeper growing charophyte communities have been variable and intermittent in nature between sites and years in Lake Tikitapu so care must be taken when interpreting changes over the more recent (4 year) time frame.

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, Rotokākahi).

3.1.2 Long term changes

Changes over the longer-term show many of the Rotorua Te Arawa Lakes have undergone significant deterioration over the last 29/30 years (Figure 38).

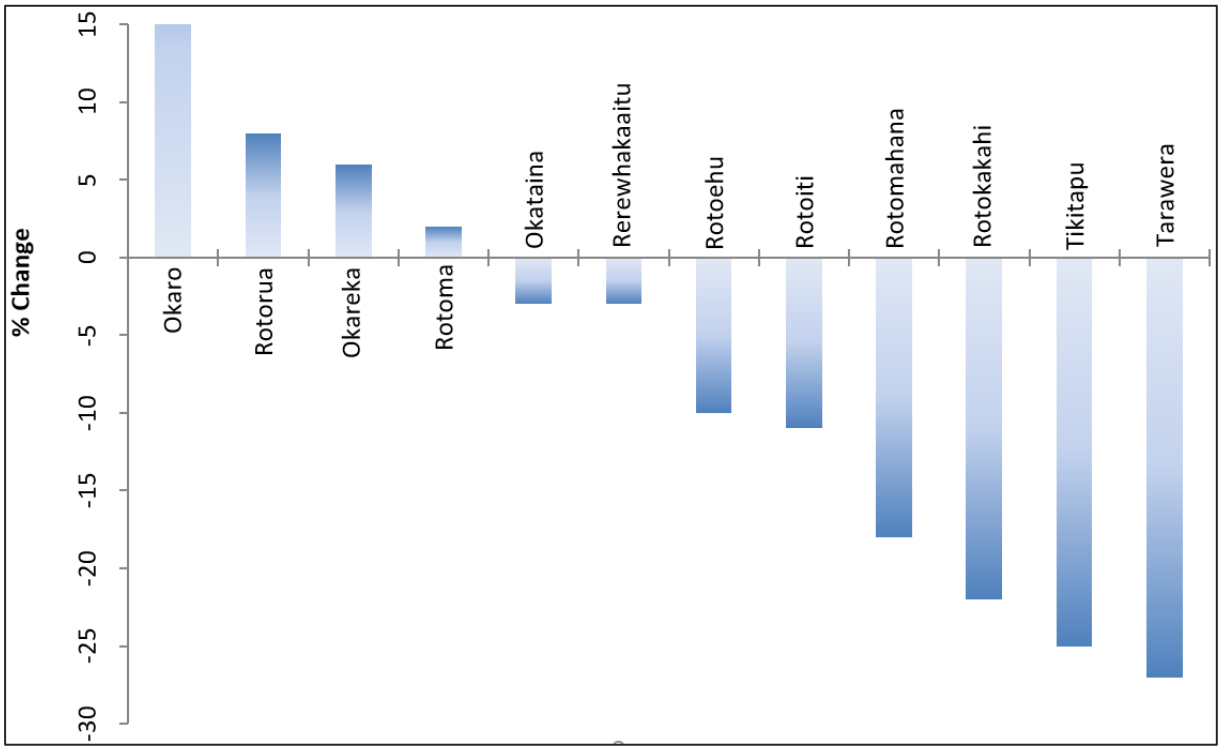


Figure 38: Percentage of change as indicated by the LakeSPI Index over the last 29-30 years, 1988/1989 to 2017/18.

Lakes Tarawera and Rotomāhana show some of the biggest changes in lake condition 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 zone, 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 to 10 metres with the worst of these invasive species, hornwort, able to smother native vegetation up to 15 metres depth.

Hornwort is present in seven of the twelve 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 unless deterioration of water quality impacts on the submerged vegetation. 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 occupies 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 current control activities fail to prevent continued spread of hornwort.

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 levels. However, it only takes one shoot and hornwort has already been introduced to the most remote lake, Lake Rotomāhana.

The other biggest change affecting the ecological condition of the Rotorua Te Arawa Lakes is water quality. Lake Rotokākahi shows the second biggest change in lake condition over the last 26 to 28 years (Figure 38) 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 29 to30 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.

3.2 National comparison

Compared with 283 lakes 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 39 & 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 all lakes nationally and does not take into account different lake types.

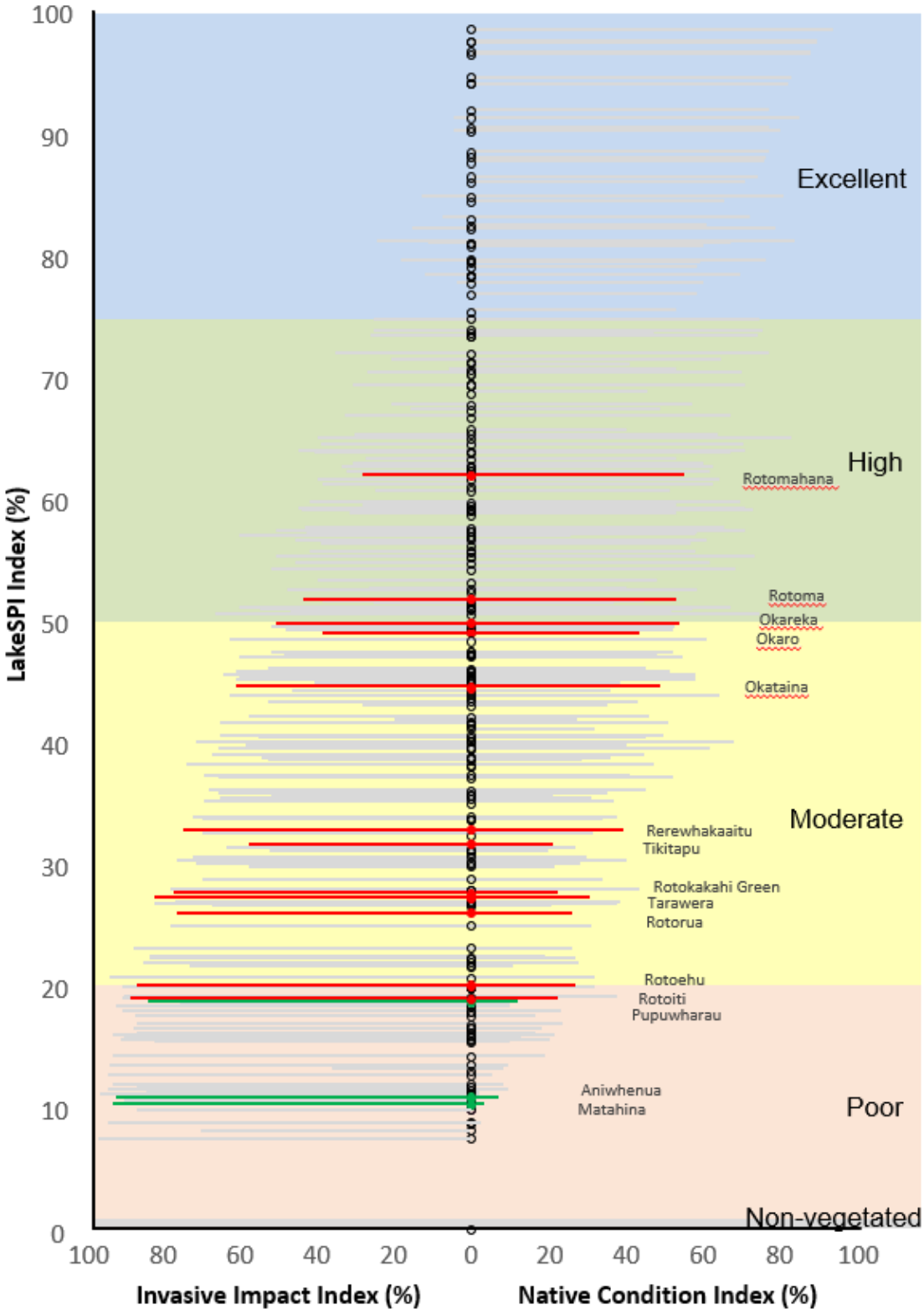


Figure 39: Rotorua Te Arawa Lakes (red lines) and 3 other lakes in the Bay of Plenty Region (green lines) are plotted with scores for a total of 283 New Zealand lakes. The most recent LakeSPI scores for lakes for the Rotorua the LakeSPI Index is plotted on the y-axis (points), Native Condition Index 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.

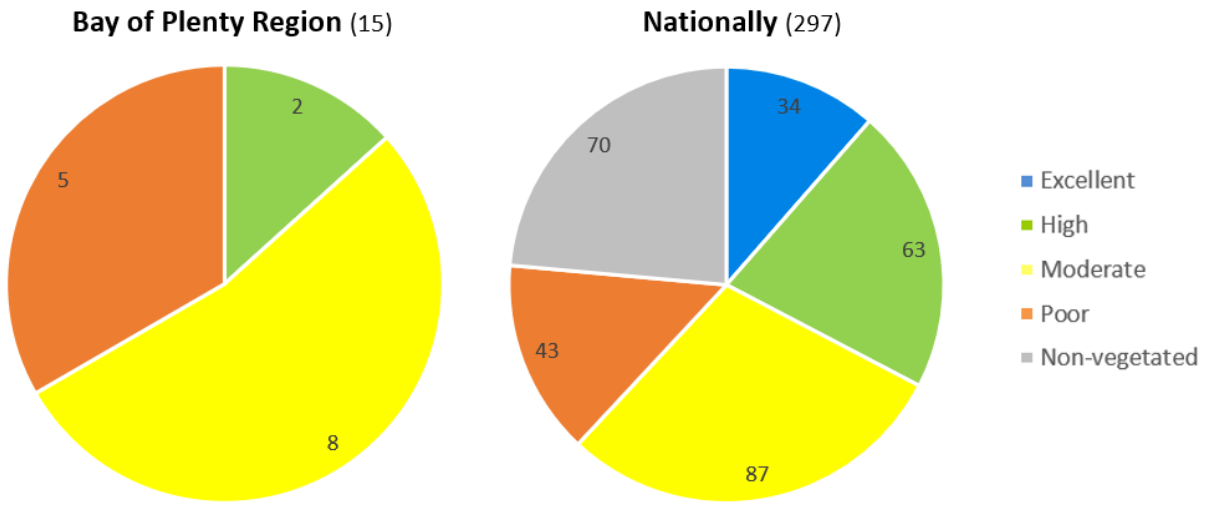


Figure 40: Proportion of lakes that fall into each of five categories of LakeSPI Index for the region (15) and nationally (283), with the number of lakes assessed shown in parenthesis.

3.3 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 Ōkataina

- Overall lake condition moderate and appears stable.
- High Native Condition Index reflects increase in depth extent of charophytes.
- Dense lagarosiphon weeds beds present at all five sites.
- Hornwort poses a serious threat to future LakeSPI condition should it spread.

Lake Tikitapu

- Overall lake condition moderate and showing signs of decline.
- No deeper growing charophytes recorded at LakeSPI sites in 2018.
- 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 Rerewhakaaitu

- Overall lake condition moderate and showing signs of decline.
- Declining Native Condition values due to increased invasion by egeria.
- Poor water quality observed by divers in recent survey.
- Moderate risk from hornwort invasion.

Lake Rotokākahi

- 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.
- This lake and Lake Ōkaro remain the only Rotorua Te Arawa lakes to have none of the 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 the second highest Invasive Impact Index 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 and second lowest Native Condition Index of the Rotorua Te Arawa lakes.

5 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 baseline values and assessed 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 recently developed LakeSPI targets and limits for the Rotorua Te Arawa lakes be included in future reports.

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