NIWA
Taihoro Nukurangi

The ecological condition of the Rotorua Lakes using LakeSPI - 2012

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Contents

Tables

Figures

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Executive summary

NIWA was contracted by Bay of Plenty Regional Council (BOPRC) to assess the ecological condition of 12 lakes within the Rotorua Region using LakeSPI (Submerged Plant Indicators). LakeSPI was developed according to Ministry for the Environment agreed criteria for freshwater indicators, for the establishment of long-term reference conditions for Lake State of the Environment reporting and to monitor trends over time. LakeSPI results are presented as a percentage of each lake's maximum scoring potential to enable comparisons between lakes. To identify time trends, each lake has also been assessed using three reference conditions: Pristine condition (lake plant communities in pre-impacted times), Historical condition (described by historical data) and Present day condition (using most recent data).

LakeSPI results show many of the Rotorua Lakes have undergone significant change over the last two decades and continue to be vulnerable to further changes from invasive plants and water quality deterioration. Lakes Tikitapu and Rotokakahi show the biggest change in lake condition over the last 24 years on account of changing water quality or clarity; while the second biggest change to affect the Rotorua Lakes has been from the introduction of invasive plant species.

Present day LakeSPI Indices for lakes in the Rotorua region ranged widely from 17% to 51% and for ease of reporting LakeSPI status, were categorised into five groups according to the value of the LakeSPI Index. One Rotorua lake was assessed as being in 'high' condition, eight lakes as 'moderate' and three lakes were categorised as in 'poor' condition. None of the 12 Rotorua lakes were recorded in the 'excellent' or 'non-vegetated' categories.

Lake Rotoma is classified as being in 'high' condition. This is an exceptional lake and although it appears to maintain high water quality, it remains under serious threat from potential hornwort invasion. This would have a major detrimental impact on the native character and biodiversity value of this lake.

Lakes Rotomahana, Okataina, Tikitapu, Rerewhakaaitu, Okareka, Rotokakahi, Okaro and Tarawera are currently classified as being in 'moderate' condition. Lake Rotomahana, while having the second highest overall status, has undergone some significant changes due to the more recent invasion by egeria and hornwort and is expected to decrease in ranking over time. LakeSPI results for Lake Rotomahana show the largest decline in overall condition recorded in any of the Rotorua lakes over the last 5 to 6 year time frame. Lake Okataina appears to maintain high water quality but the discovery of hornwort in this lake in 2010 poses a serious threat to future lake condition. Lake Tikitapu, while showing a slight improvement in current condition during the recent survey continues in a state of notable decline. Over the last 24 years both Lakes Rotokakahi and Tikitapu have seen a reduction in the diversity and extent of native plant communities present, without any direct change in invasive species presence or increased performance. Lake Rerewhakaaitu has remained relatively stable over this 24 year time frame however the increasing invasive impacts from egeria and changes noted in water quality that are impacting on charophyte depth limits are of concern for the future state of this lake. While the last 8 years has seen the overall condition of Lake Okareka remain relatively stable the recent discovery of hornwort in the

lake in March 2012 raises concern for future condition. As hornwort becomes established in Lake Okareka we can expect it to displace all native charophyte meadows in this lake. Lake Okaro is now classified in 'moderate' condition after a slight improvement in native plant cover and diversity was noted during the recent 2011 survey. Tarawera remains in a stable state and it is not expected to change in the near future since the full impact of hornwort has now taken place.

Lakes Rotoiti, Rotorua and Rotoehu are classified as being in a 'poor' condition. Lake Rotorua is the only lake to have shown a slight increase in lake condition scores over the past 23 years but remains in a poor condition. However, restoration measures on these lakes and others that result in a sustainable improvement in water quality and clarity would be expected to result in improved LakeSPI scores in the future.

Compared nationally, the Rotorua region has no lakes classified as being in 'excellent' condition (representing those close to their maximum potential ecological condition) and only one lake classified as being in 'high' condition. The largest proportion of lakes nationally, including those in the Rotorua Region, fell into the group of lakes classified as being in 'moderate' condition which tended to represent those that are impacted in varying degrees by invasive weeds. A smaller proportion of the Rotorua Lakes and lakes nationally are classified as being in a 'poor' condition and tended to represent those with extensive invasion and dominance by one of the country's worst weeds, hornwort, and/or compromised water quality.

Recommendations made in this report are as follows:

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

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

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

1 Introduction

1.1 Study brief

NIWA was contracted by Bay of Plenty Regional Council (BOPRC) to assess the condition of lakes within the Rotorua Region using LakeSPI (Submerged Plant Indicators); a method that focuses on submerged aquatic plants as indicators of lake ecological condition. The LakeSPI method (Clayton and Edwards 2006a) was developed according to Ministry for the Environment (MfE) agreed criteria for freshwater indicators, for the establishment of long-term baselines for lake SOE reporting, and to monitor trends over time. LakeSPI has been favourably reviewed by MfE describing it as a 'tool offering considerable value to monitor and report on ecological condition' that is 'gaining wide acceptance in New Zealand' (Hamill and Lew 2006). The LakeSPI approach has been described (Clayton and Edwards 2006b) and an analysis of results has been published (de Winton et al. 2012) with the method now applied by agencies in eight regions of New Zealand. LakeSPI compliments traditional water quality monitoring, such as the Trophic Level Index method (Burns et al. 2000), by providing ecological information. For example, LakeSPI focuses on the littoral edges of lakes where human interaction is greatest (Clayton and Edwards, 2006a).

The BOPRC contract specifies assessment of 12 lakes with at least six lakes monitored each year to ensure that any given lake is assessed every two years since 2005. LakeSPI monitoring of the Rotorua lakes using established baseline sites was first completed between September 2003 (Edwards & Clayton, 2003) and March 2005 (Clayton et al. 2005), with data used to estimate three reference conditions for each lake:

1. Pristine condition (lake plant communities in pre-impacted times).
2. Historical condition (described by historical data, including earlier assessments).
3. Present day condition (using most recent data).

This report presents updated results of LakeSPI assessments completed for the 12 Rotorua lakes, with Okaro, Okareka, Rotoiti, Rotoma, Rotomahana and Rotorua last assessed in May or July 2011 (Edwards & Clayton, 2011) and Okataina, Rerewhakaitu, Rotoehu, Rotokakahi, Tarawera and Tikitapu in February or March 2012.

1.2 Study lakes

The lakes assessed in this report are collectively termed the 'Rotorua lakes'. This term refers to the 12 largest lakes in the Rotorua region managed through the Rotorua Lakes Protection and Restoration Action Programme being lakes: Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotokakahi, Rotoma, Rotomahana, Rotorua, Tarawera, and Tikitapu. The location of these lakes is indicated in Figure 1.

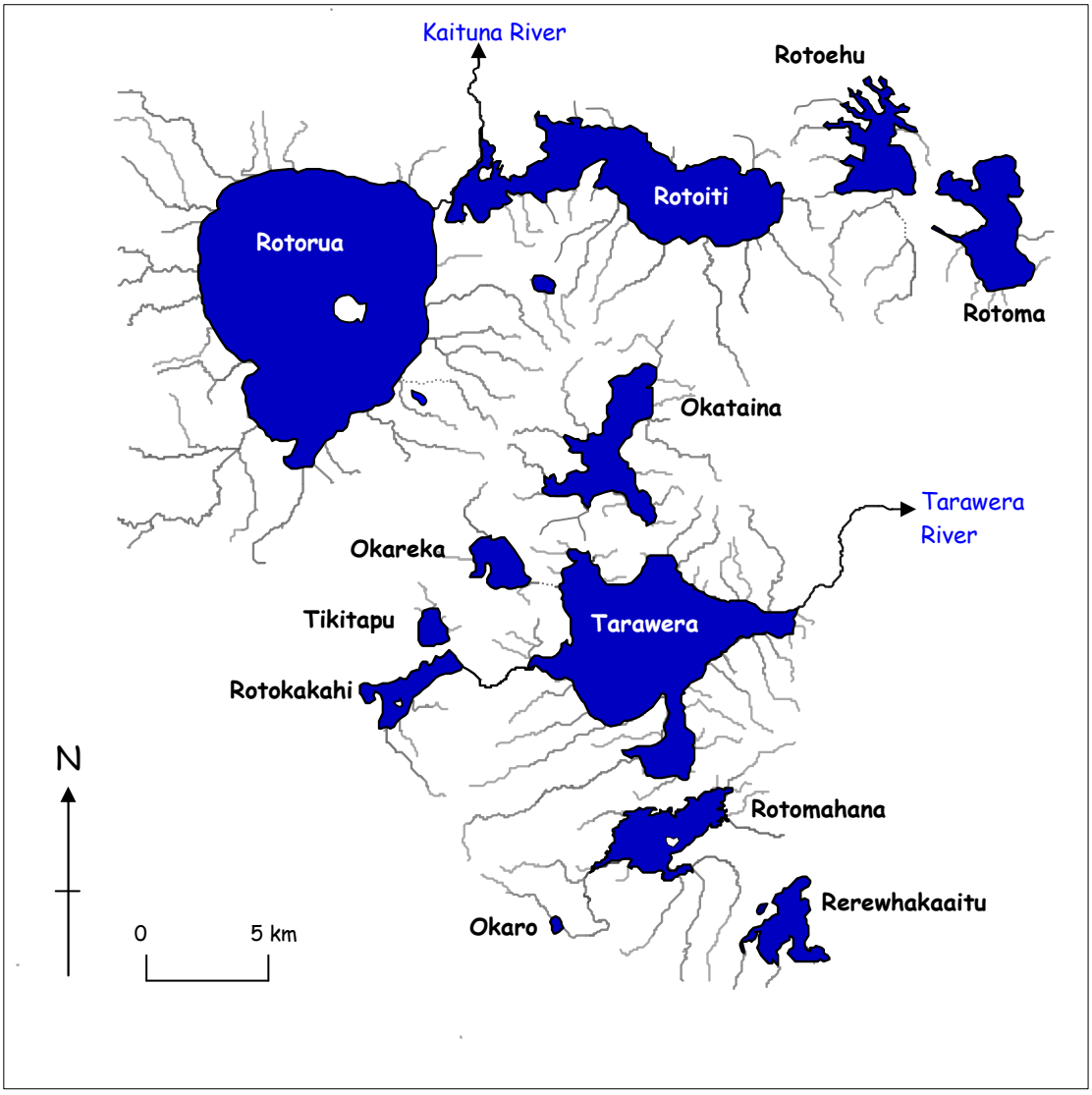

Figure 1: Map showing location of the 12 Rotorua lakes.

Table 1: Summary of lake characteristics.

Lake	Maximum Depth (m)	Mean Depth (m)	Size (km^2)	Catchment Area (km^2)
Okareka	33.5	20	3.33	19.6
Okaro	18	12.5	0.33	3.9
Okataina	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
Rotoma	83	36.9	11.2	27.8
Rotomahana	125	60	9.0	83.3
Rotorua	44.8	11	80.8	508.0
Tarawera	87.5	50	41.7	143.1
Tikitapu	27.5	18	1.5	6.2

1.3 History of the Rotorua Lakes

1.3.1 Geophysical changes

The Rotorua Lakes District contains a diverse range of geologically young water bodies formed from volcanic activity, with the youngest, Lake Rotomahana having been substantially modified and enlarged by the 1886 Tarawera eruption.

Chapman (1970) noted that until the 1900s most of the catchments were densely forested with native trees or covered in manuka scrub. Clearing and planting of *Pinus radiata* forests began in the early 1900s with sawmilling starting around 1940. Farming was slower to prosper on account of “bush sickness” but once the problem of cobalt deficiency was identified and resolved in the mid-1930s, large-scale sheep, beef and dairy farming conversion took place in the late 1940s and 1950s.

Urban development combined with sewage waste disposal, intensification of land uses and tourism have all contributed to nutrient enrichment problems and associated eutrophication of the Rotorua lakes.

1.3.2 Lake vegetation changes

The Rotorua lakes have been significantly affected by changes both in water quality and through the introduction of invasive aquatic plants. Deterioration in the condition of the Rotorua Lakes has been occurring for many years (White 1977, Rutherford 1984, Vincent et

al. 1984). Parallel deterioration in the extent of aquatic vegetation and presence of key native submerged species has also been recorded from the 1960s to the 1980s (Coffey & Clayton 1988). Land use practices have led to a progressive deterioration in water clarity, reducing the depth to which vegetation can grow. There are some exceptions to this general trend of deteriorating water quality and clarity as evidenced by Lake Rotoma, which appears to have retained a constant maximum vegetated depth limit since the early 1970s. Lake Rerewhakaaitu saw a period of improved water clarity and a corresponding increase in the depth of submerged vegetation over earlier investigations.

The second important factor affecting the aquatic vegetation in the Rotorua 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 lakes was *Elodea canadensis*, followed by *Lagarosiphon major*. Elodea is likely to have established in Lake Rotorua during the 1930s, given that the Ngongotaha trout hatchery had 'oxygen weed' in their hatchery around that time and ponds were flushed annually into the Ngongotaha Stream, which flows into the lake (Chapman 1970). By the mid-1950s lagarosiphon had appeared in Lake Rotorua and by 1957 it was recorded in Lake Rotoiti. By the late 1950s major weed problems were apparent in these two lakes, particularly from lagarosiphon. From 1958, large onshore accumulations of weed drift occurred after storms, resulting in an aquatic weed nuisance unprecedented in New Zealand. Lagarosiphon appears to have spread rapidly through many of the Rotorua Lakes, with Lakes Rotoma, Okataina and Tarawera likely to have been colonised in the mid to late 1960s (Coffey 1970, Brown & Dromgoole 1977, Clayton 1982). Invasion of lakes further away from the epicentre of introduction occurred later, with Lake Rerewhakaaitu estimated to have been invaded in the mid-1980s.

Hornwort (*Ceratophyllum demersum*) was first recorded in Lake Rotorua in 1975 and *Egeria densa* in 1983 (Wells & Clayton 1991), and both of these species have continued to spread to other lakes. The impact of egeria on the Rotorua lakes has been less than expected; in contrast to the impact from hornwort, which has exceeded all expectations with this species now ranked as New Zealand's worst widespread submerged aquatic plant pest.

The spread of significant invasive weed species into the remaining Rotorua Lakes is a gradual and on-going process, and there is a strong correlation with boat traffic and lake accessibility, with weed introduction mainly at boat ramps (Johnstone et al. 1985). Lake Rotomahana was the last of the large lakes to remain relatively weed free which had been attributed to its remote location and difficult public access, but the discovery of egeria and hornwort around boat launching areas in 2007 highlights the ease and speed that invasive weeds can establish. Although Lake Rotokakahi is widely impacted by elodea it is now the only well vegetated Rotorua lake to remain free of the worst invasive weed species (lagarosiphon, egeria and hornwort), primarily attributable to its restricted public access due to its sacred status to Te Arawa.

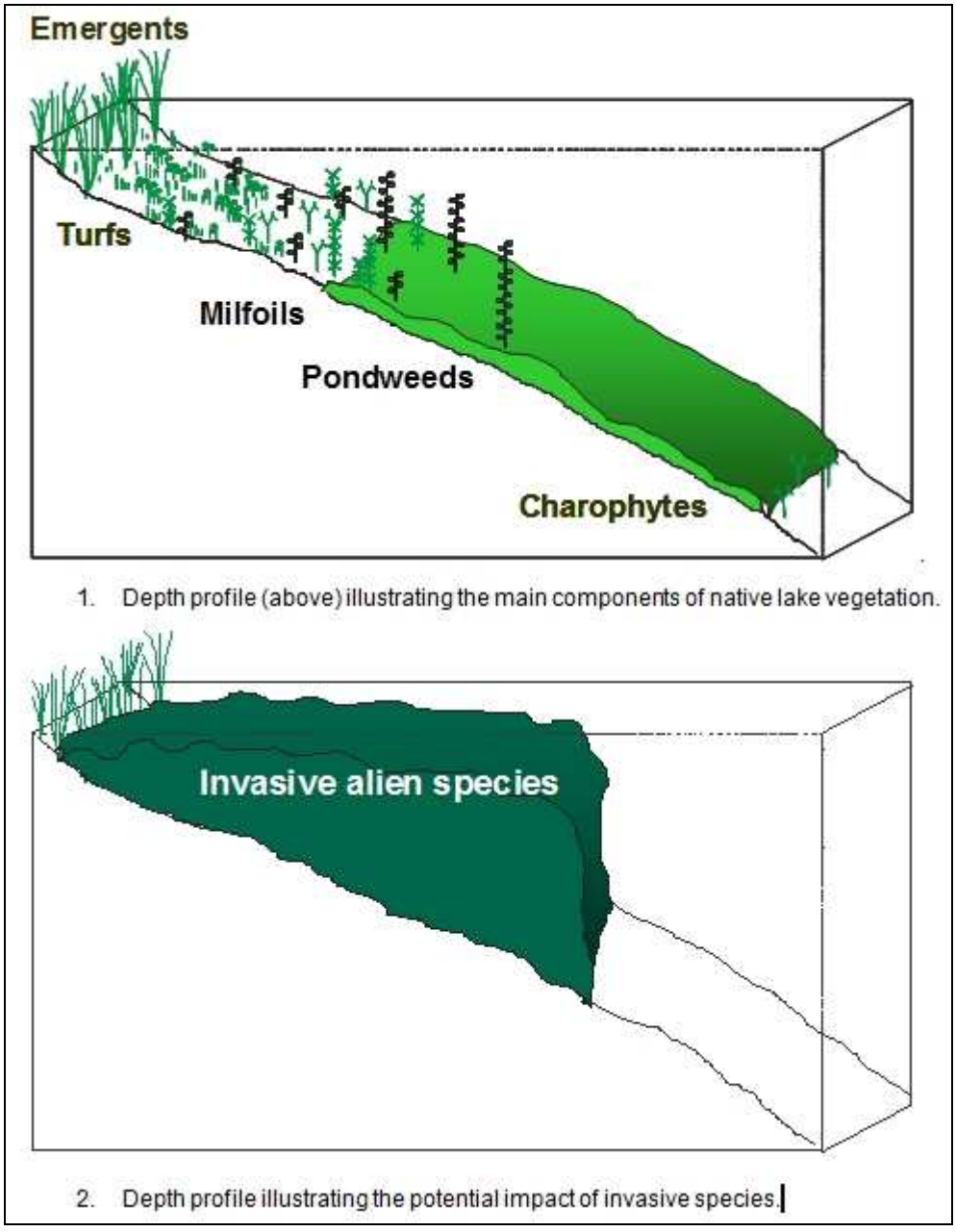

Figure 2: Depth profiles within a lake illustrating the difference between a lake maintaining native plant communities and that which is invaded with invasive weed species.

1.4 Plants as indicators of lake condition

Submerged plants have a number of advantages that favor their use as indicators of lake condition. For example, they are predominantly rooted or anchored to the bed of lakes. They are also macroscopic and perennial in nature, and together these features make them easy to observe, sample and identify. This contrasts with many other biota that can be highly mobile (e.g., fish) or difficult to sample, measure or identify (e.g., plankton).

Submerged plants also effectively integrate the range of environmental conditions supporting plant growth over an extended period of time prior to survey. This contrasts with other physio-chemical methods (e.g., water chemistry and Secchi disc), which may change markedly over short time periods and require frequent measurements throughout the year.

In lakes where the littoral zone (lake margin to maximum plant depth) represents a large proportion of the lake area (e.g., small shallow dune or peat lakes), the open water (or centre lake) condition can have quite different water quality and ecological condition compared to the littoral zone. Given the importance of the littoral zone to the overall ecological state and recreational value of many lakes it is important to monitor the ecological well-being and biological functioning of the littoral zone where submerged plants tend to dominate.

Increased sediment and nutrient loading from catchment activities, and displacement of native vegetation by invasive alien plant species are major influences on lake ecology and condition. The submerged plant indicators used in LakeSPI provide an effective means of assessing these impacts.

2 Study methods

2.1 LakeSPI

LakeSPI is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring trends. Key features of aquatic vegetation structure and composition are used to generate three LakeSPI indices:

- 'Native Condition Index' – This captures the native character of vegetation in a lake based on diversity and extent of indigenous plant communities. A higher score means healthier, deeper, diverse beds.
- 'Invasive Impact Index' – This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A higher score means more impact from exotic species, which is often undesirable.
- 'LakeSPI Index' – This is a synthesis of components from both the native condition and invasive impact condition of a lake and provides an overall indication of lake condition. The higher the score the better the condition.

Key assumptions of the LakeSPI method are that native plant species and high plant diversity represents healthier lakes or better lake condition, while invasive plants are ranked for undesirability based on their displacement potential and degree of measured ecological impact (Clayton & Edwards 2006b).

Because lakes have differing physical characteristics that can influence the extent and type of submerged vegetation, each of the LakeSPI indices are expressed in this report as a percentage of a lake's maximum scoring potential. Scoring potential reflects the maximum depth of the lake to normalise the results from very different types of lakes. A lake scoring full points for all LakeSPI indicator criteria would result in a LakeSPI Index of 100%, a Native Condition Index of 100% and an Invasive Impact Index of 0%.

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

2.2 Reference conditions

To help put the LakeSPI indices into context, each lake has been assessed using three reference conditions: Pristine, Historical and Present day.

1. Pristine condition

Pristine condition describes the best possible condition for a lake, as it theoretically would have been in pre-European times. Because suitable pre-impact submerged vegetation records are not available for most lakes, for the purpose of establishing a pristine reference

we have adopted the limitation posed by lake depth as the maximum scoring potential for lakes. This condition assumes that any lake in a pristine, undisturbed state would have supported a diverse range of submerged plant communities and have had no alien plant species. However, because of the volcanically young history of the Rotorua lakes and impacts from geological events including earthquakes and eruptions along with fluctuating water levels in the last 150 years, the baseline used in this capacity would not be so relevant.

A 'pristine condition' baseline allows lake managers to better compare present day lake condition with what the lake once would (or could) have been.

2. Historical condition

The LakeSPI method can be applied to available historic vegetation survey data. Sources of information include published accounts, unpublished reports, and macrophyte data in FBIS (Freshwater Biodata Information System - fbis.niwa.co.nz). Additional information on the nature of vegetation cover, proportion of native to invasive vegetation and the depth boundary for 10% cover was estimated from examination of the original survey sheets. Reference to historical LakeSPI scores allows changes over the last few decades to be indicated.

Earlier assessments of lakes using the LakeSPI method also provide information on past ecological condition and are included under this reference condition to indicate the direction and rate of change over time.

3. Present day condition

Present day condition was calculated for each lake based on the most recent survey data. These assessments provide managers with information on present condition, a benchmark for monitoring future changes and can help to assess the effectiveness of catchment and lake management initiatives.

2.3 LakeSPI status

For ease of reporting LakeSPI status, five lake condition categories (Excellent, High, Moderate, Poor, and Non-vegetated) have been developed to support an MfE initiative for national consistency in terminology and reporting. These categories provide a description of the lakes status at the time of the survey, and allow for comparisons to be made between lakes along a scale of LakeSPI condition according to the LakeSPI Index score:

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

2.4 Lake stability

Changes in LakeSPI indices over the last five years (or survey that is closest to the five year timeframe) have been used to provide an indication of current stability in lake condition and direction of any change. In this report, the stability of lakes over the five year time frame is indicated either as being stable (±5%), declining (>-5%) or improving (>+5%).

In addition, general guidelines (Figure 3) have now been developed by NIWA to give a scale of probabilities for change in lake condition over longer periods and multiple surveys, using the extent of change in the LakeSPI indices over multiple surveys. These guidelines, based on expert judgement, have considered variation by different observers and the response of LakeSPI scores to major ecological events in lakes.

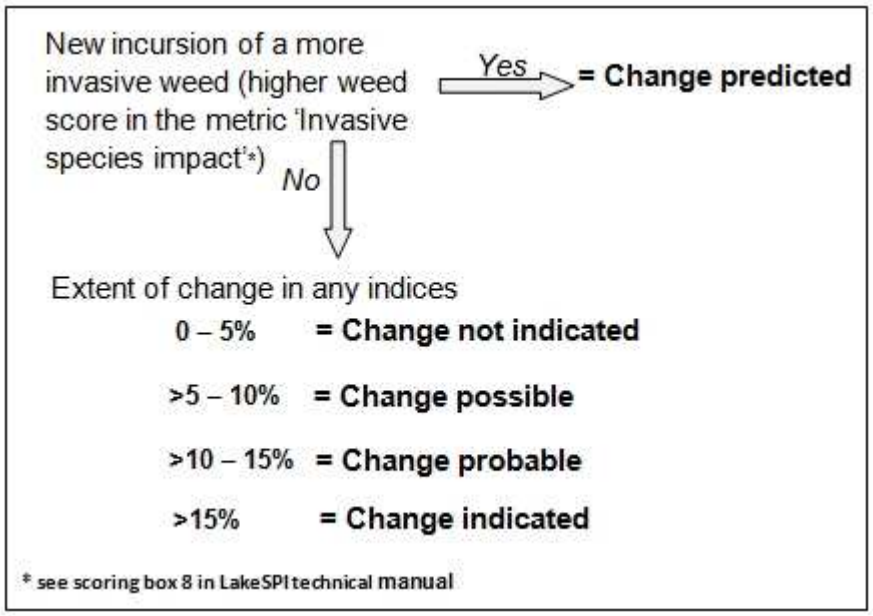

Figure 3: Guidelines for assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.

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 lakes in order of their overall lake condition (2011 or 2012).

Lake	Most Recent LakeSPI Survey	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall Condition
Rotoma	11/05/2011	51	58	52	High
Rotomahana	11/05/2011	50	53	47	
Okataina	29/03/2012	44	47	63	
Tikitapu	08/02/2012	41	33	48	
Rerewhakaaitu	28/03/2012	36	52	78	Moderate
Okareka	11/05/2011	35	43	76	
Rotokakahi	29/03/2012	31	26	75	
Okaro	31/03/2011	27	19	69	
Tarawera	28/03/2012	24	26	88	
Rotoiti	12/05/2011	20	25	91	
Rotorua	21/07/2011	20	20	81	Poor
Rotoehu	29/03/2012	17	24	90	

3.1 Lake Rotoma

Lake condition: High

Stability: Stable

Lake ranking: 1st

Table 3: LakeSPI results for Lake Rotoma. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		98	97	0
	1973	69	63	19
	1988	54	57	41
Historical data	2001	52	54	44
	2005	52	58	51
	2008	48	53	54
	2009	47	53	56
Present day	2011	51	58	52

Lake Rotoma is the highest ranked lake in the Rotorua region after lake condition values have remained relatively stable over the last 23 years, from 1988 – 2011. In 1973 Lake Rotoma had a high LakeSPI score, which reflected the early stage of lagarosiphon invasion and the extensive high cover charophyte meadows in this lake. By 1988 the Invasive Impact Index had more than doubled, which in turn reduced both the Native Condition Index and LakeSPI score for this lake. Since then, Invasive Impact scores have increased more gradually, with smaller changes occurring to the Native Condition Index or LakeSPI score. As a result this lake presently has the highest Native Condition Index for any of the lakes and one of the lowest Invasive Impact Index which contributes to its high LakeSPI ranking.

In 1972 an underwater marker buoy was placed at the bottom boundary of submerged plant growth at one of the five LakeSPI baseline sites. Despite some water level fluctuations since that time this buoy still accurately marks the deepest plant boundary after almost 40 years, which provides good evidence for the stability in water clarity during this period. This confirms that the impact of invasive species on submerged vegetation has been the key driver of change in LakeSPI scores over that time.

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

3.2 Lake Rotomahana

Lake condition: Moderate

Stability: Declining

Lake ranking: 2nd

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
Historical data	1988	72	64	13
	2002	73	61	7
	2005	70	66	19
	2008	66	63	24
	2009	63	61	30
Present day	2011	50	53	47

After being the highest ranked lake in the Rotorua region for more than 20 years, declining lake condition values have resulted in Lake Rotomahana moving into second position. The LakeSPI Index has declined by 20% since 2005 which is the largest change recorded for any of the 12 Rotorua lakes over this 5 to 6 year time frame and Invasive Impact scores have more than doubled. This is largely due to the recent invasion and continued spread by two of New Zealand's worst aquatic plant species, egeria and hornwort. Discovered for the first time in April 2007, egeria was found to be established in only two areas of the lake, at the north-eastern end and in the southern embayment, while hornwort fragments were found growing amongst native plants in the southern embayment (Clayton & de Winton, 2007; Scholes and Bloxham, 2008). Since then both species have continued to spread, with egeria now present at all 5 LakeSPI baseline sites (2 sites more than in 2009) and forming bands of weed growth down to a depth of 8.5 m. The most recently recorded average maximum depth of vegetation (8.1 m) had reduced by more than 3 m since the 2009 survey when aquatic vegetation was recorded down to an average maximum depth of 11.4 m. This reduction in the depth and extent of vegetation is concerning and as both egeria and hornwort continue to further impact

on the diversity and quality of indigenous plant communities in Lake Rotomahana, we can expect to see the Native Condition Index decline further while the Invasive Impact Index will continue to increase.

Of interest during the recent 2011 survey was the presence of *Lymnaea auricularia* (ear pond snail), recorded for what is believed to be the first time within a natural New Zealand water body. This snail is known from within the aquarium/pond trade and their large numbers and widespread distribution around the lake indicates that they may have been present for some time, perhaps 5 or more years. Their increase in numbers and dispersal around the lake would have likely been much slower than that for egeria and hornwort, which would account for their later discovery. If this proposed timing is correct it suggests that egeria, hornwort and the ear pond snail could all have been introduced at the same time and by means other than boat transfer, such as an outdoor pond overflow or by deliberate release.

3.3 Lake Okataina

Lake condition: Moderate

Stability: Stable

Lake ranking 3rd

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
	1981	51	57	53
	1988	47	53	57
Historical data	2005	44	51	65
	2008	48	54	58
	2009	45	47	60
	2010	44	49	61
Present day	2012	44	47	63

A moderate ecological condition is indicated for Lake Okataina with a LakeSPI index of 44% (Table 5). This score reflects a lake that still maintains some native plant communities while also being impacted on by invasive species. Native charophyte species formed meadows at 4 of the 5 baseline sites, growing down to a maximum depth of 15.6 m. *Lagarosiphon major* remains the dominant invasive species present forming high cover weed beds at most sites generating an Invasive Impact score of 63%.

Hornwort, not yet recorded at any of the 5 LakeSPI sites, continues to pose the most serious threat to the future condition of Lake Okataina. While an established hornwort bed found growing in 2010 (Figure 4) at the south-west end of the lake has since been controlled using diquat and isolated from the rest of the lake by a weed cordon, smaller infestations and fragments currently growing in Oruaroa Bay (south-east end of the lake) are still of concern and control measures continue in this area. Prior to the discovery of significant hornwort weed beds in 2010, one established hornwort plant at the northern end of the lake was successfully eradicated from the lake in 2007. However from 2009 onwards additional fragments were located that suggested a possible established incursion within the lake. The

location of the 2010 find in a popular anchorage site suggests an association with boating activity, while the size of the colony indicates it had been present for some time and subsequent dispersal to other locations within the lake was likely.

In the past 31 years (from 1981 to 2012), LakeSPI scores for Lake Okataina have been reasonably stable, with only minor fluctuations. Care must be taken in interpreting small variations, as the lake has no outlet and water levels can vary by several metres. Although lake level changes tend to be quite slow, they can still affect the available habitat for submerged vegetation in shallow water and the corresponding adjustments in the maximum depth of charophyte colonisation may be slower.

Figure 4: Invasive weed bed of hornwort (*Ceratophyllum demersum*) forming a wall of growth 8 m high and growing down to 12 m depth at the south-western end of Lake Okataina in 2010.

3.4 Lake Tikitapu

Lake condition: Moderate

Stability: Improving

Lake ranking: 4th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
Historical data	1970	70	77	33
	1988	63	75	47
	2005	46	45	50
	2008	32	28	63
	2010	34	24	49
Present day	2012	41	33	48

Lake Tikitapu is categorised as being in moderate ecological condition with a LakeSPI Index of 41% (Table 6). This result indicates that there has been some improvement in the condition of Lake Tikitapu since the last survey, reflected by an increase in Native Condition scores from 24% in 2010 to 33% in 2012. This increase was largely based on the recovery of some sparse deep water charophytes recorded at 2 of the 5 baseline sites growing down to a maximum depth of 18.2 m and 16.6 m respectively. Previously plant growth at these 2 sites was recorded to only a maximum depth of 3.2 m and it is questionable to how sustainable this recent colonisation of deeper plants will be. While no plants were found growing deeper than 3.8 m at the remaining 3 baseline sites, depth records showed a small improvement compared with the last survey in the depth of plant growth and diversity of native plants present.

Caution must be used however with interpreting the current LakeSPI results for Lake Tikitapu. While the shorter term trend indicating some level of recovery in lake condition is encouraging, the longer term trend continues to show a lake that has deteriorated at an unprecedented rate only recently matched by Rotomahana and Rotokakahi (Figure 5). This decline, unlike that of the other lakes, has not been due to the impact from new invasive

species but from a substantial decline over the last 24+ years in the diversity and extent of the native plant communities present.

Historic records for Lake Tikitapu also confirm a lake that 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. The mean maximum depth of native plant growth at survey sites further decreased from 12.4 m in 2005, 8.8 m in 2008, to only 2 m in 2010.

A notable decrease in the Invasive Impact Index from the 2008 survey is another indicator of the lakes changing condition in Lake Tikitapu. Prior to this 2008 survey a continued increase in Invasive Impact scores occurred due to the existing invasive vegetation having a greater relative impact on overall vegetation status, rather than any new invasive plant introductions or spread of existing invasive plants.

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

3.5 Lake Rerewhakaaitu

Lake condition: Moderate

Stability: Stable

Lake ranking 5th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	92	0
Historical data	1973	55	58	37
	1988	41	48	57
	2005	38	47	65
	2008	41	52	64
	2010	34	45	71
Present day	2012	36	52	78

Lake Rerewhakaaitu is categorised as being in moderate ecological condition with a LakeSPI Index of 36% (Table 7). While LakeSPI scores have remained relatively stable over the last 24 years, particularly between 1988 – 2008, increasing Invasive Impact scores reflect the wider impacts that egeria is now having upon the lake. During the recent 2012 survey, egeria was present at all 5 baseline sites growing to a maximum depth of 7 m. However, an increase in the depth extent of native plants likely due to improved water clarity since the last survey, has to some degree masked the impact that egeria is having on the overall LakeSPI Index. Egeria is expected to have an increased negative impact on overall LakeSPI condition in years to come.

The submerged vegetation of Lake Rerewhakaaitu was first surveyed in 1973 (Chapman and Clayton 1975) at a time when there was government concern over the degree of eutrophication occurring within several of the Rotorua Lakes. This lake was selected as a candidate for catchment restoration. As a base-line to which future changes could be related, a survey was carried out of the marginal and submerged vegetation using scuba and a submarine. A benthic blue-green algal bloom (*Tolypothrix*, *Lyngbya* & *Oscillatoria*) was prevalent around the lake margin and on plants in shallow water. The submerged vegetation

was dominated by native species, with the benign weed *Potamogeton crispus* the only exotic species recorded. None of the problematic 'oxygen weed' species (elodea, lagarosiphon and egeria) or hornwort were present at that time. In 1973 water clarity was low (in water visibility c.1.3 m) and charophytes only grew to a maximum depth of 4.5 – 5 m, with occasional specimens to 5.5 metres.

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

Egeria was first recorded in Lake Rerewhakaaitu in 2000 (Champion et al. 2006). By 2008 egeria was present at 2 of the 5 LakeSPI baseline sites and by the 2010 survey, had spread to all 5 sites, causing an incremental rise in the Invasive Impact score.

3.6 Lake Okareka

Lake condition: Moderate

Stability: Stable

Lake ranking 6th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
	1980	40	49	67
	1988	44	53	66
Historical data	2001	41	50	70
	2003	34	42	77
	2006	34	39	76
	2009	34	39	78
Present day	2011	35	43	76

Lake Okareka currently appears to be in a stable condition indicated by the recent LakeSPI indices showing little change over the last 8 years, from 2003 to 2011. Prior to this however, a 10% decrease in the LakeSPI Index between 1988 and 2003, resulted from a decline in the native plant communities present, indicated by a decrease in Native Condition scores, and an increase in the Invasive Impact Index over the same time frame.

Egeria was first reported in Lake Okareka in 2000 (Clayton et al. 2005). While not located at any of the 5 LakeSPI baseline sites during the 2001 survey, by 2003 it had spread to 3 sites and during the most recent survey it was well established at 4 of the 5 sites. Egeria is expected to continue spreading around the lake, displacing lagarosiphon with taller and denser weed growth and occupying a wider depth range. A hornwort incursion in the lake in March 2012 is of real concern for the future of Lake Okareka. Despite the spread of egeria around the lake, hornwort poses the major threat to Lake Okareka with the potential to reduce the LakeSPI Index even further, by occupying a deeper range than egeria and by displacing all remaining deep water charophyte meadows.

3.7 Lake Rotokakahi

Lake condition: Moderate

Stability: Stable

Lake ranking 7th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
Historical data	1988	52	61	53
	2005	35	36	71
	2008	31	32	71
	2010	28	23	76
Present day	2012	31	26	75

Lake Rotokakahi is currently categorised as being in moderate ecological condition with a LakeSPI Index of 31% (Table 9). Lake Rotokakahi has undergone one of the largest declines in long term lake condition as indicated by LakeSPI for any of the 12 lakes over the same 24 year time period (Figure 5). The LakeSPI Index has shown a 22% reduction from 1988 to 2012, whilst the Native Condition Index has also declined by 39% largely due to a decline in charophyte meadows. This has occurred even though there has been no change in the dominant invasive species (*Elodea canadensis*) in this lake; although the relative impact of invasive presence on overall submerged vegetation has increased. The declining condition of Lake Rotokakahi, like Lake Tikitapu, is not due to invasive weeds but rather a decline in native condition presumably due to a change in water quality. Additional observations support this in Lake Rotokakahi, with filamentous algae prevalent on submerged vegetation and blue-green algal mats often covering sediments beyond the maximum depth of plant growth. These are indicators of enrichment. Nutrient inputs are likely to be entering this lake from the predominantly farmland catchment as well as from sediment nutrient release during summer stratification. A decline in oxygen content in deeper water was noted by David Hamilton in 2010 (Waikato University pers comm.), which is consistent with hypolimnetic nutrient enrichment taking place. Lake Rotokakahi is now the only Rotorua Lake to remain relatively free of significant invasive weed species.

3.8 Lake Okaro

Lake condition: Poor

Stability: Improving

Lake ranking 8th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	89	0
Historical data	1982	31	29	67
	1989	29	15	30
	2003	19	6	76
	2006	19	6	53
	2009	21	13	77
Present day	2011	27	19	69

The degraded nature of Lake Okaro and its wide fluctuations in water quality and clarity account largely for the variation in LakeSPI scores, in particular in the Invasive Impact scores, generated for this lake over the last 29 years. The most recent LakeSPI results, however, are indicating a small improvement in the condition of Lake Okaro and it is now ranked in moderate condition. This result may reflect recent efforts by BOPRC to reduce nutrient influx into the lake and nutrient release from hypolimnetic sediments, which may well be helping to improve water clarity and be resulting in a positive vegetation response.

Over the last 5 years the Native Condition Index has more than doubled to 19% (still the lowest Native Condition value for any of the 12 Rotorua lakes) and the LakeSPI Index has increased by 8% to 27%. While these improvements are promising, care must be taken when interpreting any kind of recovery in the condition of Lake Okaro at this stage as it is still recognised as a highly variable and sensitive lake system.

Elodea remains the only invasive species reported in Lake Okaro and the hypereutrophic nature of the lake continues to provide an unfavourable habitat for submerged vegetation.

This is reflected in the highly variable cover and depth range of elodea, both seasonally and annually. It is also likely to explain root lyses (root death and detachment) in elodea beds from periods of oxygen stress and anoxia. On several occasions in earlier surveys we have observed rooted elodea beds in shallow water, while from around 2 m depth and deeper, all elodea has appeared as non-rooted ‘drift’. This may well coincide with periods of shallow stratification with severe anoxia below the thermocline resulting in root death and shoot detachment.

3.9 Lake Tarawera

Lake condition: Moderate

Stability: Stable

Lake ranking 9th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
Historical data	1988	41	50	70
	1994	22	30	89
	2005	28	33	88
	2008	22	27	92
	2010	25	30	87
Present day	2012	24	26	88

Lake Tarawera remains in a moderate condition and is not expected to change in the near future since the full impact of hornwort has now taken place.

At the time of the 1988 survey, lagarosiphon and elodea were the two dominant invasive weed species in Lake Tarawera. Although hornwort was first recorded in July 1988, it was limited to Kotukutuku Bay near the boat ramp and was not present in any of the survey sites used for LakeSPI. By the time of the 1994 survey, hornwort had spread around much of the lake and had doubled the depth range of invasive vegetation, without displacing lagarosiphon significantly (Wells et al. 1997). The high Invasive Impact Index recorded in 1994 (89%) has remained almost the same and Tarawera has one of the highest Invasive Impact Index scores of the 12 Rotorua lakes. The LakeSPI Index declined by 19% in only 6 years from 1988 to 1994 and has remained low since that time. The Native Condition Index also declined substantially from 1988 to 1994 and has remained low, with hornwort responsible for widespread displacement of almost all the former deep-water charophyte meadows.

3.10 Lake Rotoiti

Lake condition: Poor

Stability: Stable

Lake ranking 10th equal

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
	1981	26	33	82
	1988	26	33	85
Historical data	2001	20	24	90
	2003	18	22	90
	2006	18	18	90
	2009	21	29	89
Present day	2011	20	25	91

Lake Rotoiti has consistently had one of the highest Invasive Impact Index scores and continued to have one of the lowest LakeSPI Indices so far recorded for any of the 12 lakes in this region. Small changes in the Native Condition and LakeSPI values reflect the variable condition of native charophyte meadows (>75% cover) at some baseline sites, growing to a maximum depth of only 3.5 m during the recent survey.

Lake Rotoiti has a complex morphometry with areas along the northern shoreline that are too steep to support submerged vegetation, making them unsuitable for LakeSPI. The western end of Lake Rotoiti has in the past been predominantly influenced from Lake Rotorua inflows and there had been a progressive decline in submerged vegetation in several arms of Lake Rotoiti such as Okawa Bay, Wairau Bay and Te Weta Bay. Construction of the diversion wall to entrain Lake Rotorua inflows down the Kaituna River may see reduced water quality impacts, especially in this area. However flow-on effects on submerged vegetation are not yet clear. Sheltered areas with low water quality are presently often dominated by loose filamentous algae, attached benthic blue-green algal mats and planktonic blue-green algal blooms. The LakeSPI scores indicate poor water quality in this lake.

4.11 Lake Rotorua

Lake condition: Poor

Stability: Stable

Lake ranking 10th equal

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		94	90	0
	1982	27	23	68
	1988	18	21	90
Historical data	2001	22	17	74
	2003	22	21	77
	2006	22	21	78
	2009	27	31	78
Present day	2011	20	20	81

Lake Rotorua is presently in a poor but stable condition similar to that recorded 29 years ago as indicated by LakeSPI. This lake has a large shallow littoral zone subject to considerable wave action, which has the effect of reducing silt build up and helps prevent large surface-reaching weed beds forming around much of the lake margin. The wave washed shallow regions of this lake can support a wide range of native turf-forming species along with shallow water charophyte beds. These shallow plant communities, however, can be ephemeral in nature, especially when subjected to seasonal storms like those that occurred prior to the 2011 LakeSPI survey of Lake Rotorua. As a result charophyte meadows (>75% cover) were present at only 2 of the 5 LakeSPI baseline sites during the 2011 survey, compared to 4 sites in 2009 which resulted in a higher Native Condition Index.

Prior to the recent 2011 survey, the LakeSPI scores and Native Condition Index did not change a lot over the last 27 years from 1982 to 2009. The variable Invasive Impact Index over this same period was attributable to the 'boom and bust' of egeria, which was first recorded in this lake in July 1983 and by 1988 had established weed beds around most of

the lake resulting in a peak Invasive Impact Index of 90%. In 1988 it was estimated that egeria comprised more than 80% of the vegetation in the lake with an area of 440 ha (Wells and Clayton, 1991). In the early 1990s egeria underwent a major decline and has never recovered, which is reflected in the Invasive Impact Index from 2001 declining from the 1988 peak.

3.11 Rotoehu

Lake condition: Poor

Stability: Stable

Lake ranking 12th

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

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		89	88	0
Historical data	1988	33	33	73
	2003	34	34	64
	2006	22	32	82
	2008	18	26	85
	2010	15	22	93
Present day	2012	17	24	90

Lake Rotoehu now has the lowest LakeSPI Index (17%) and one of the highest Invasive Impact scores (90%) recorded for any of the 12 Rotorua lakes (Table 14). This reflects a major infestation of hornwort which has spread through the lake resulting in a halving of the LakeSPI Index since the 2003 survey. Hornwort was first recorded in the lake off Otautu Bay in December 2004 (R. Mallinson, BOPRC, pers comm.) and by late summer 2005 there were extensive weed beds along much of the shoreline. The most recent LakeSPI results show the negative impact hornwort is having on native submerged vegetation within the lake and Lake Rotoehu remains in the bottom group of 3 lakes categorised as being in 'poor' condition.

On a positive note, given the recent history of poor water quality and frequent blue-green blooms, it is quite possible the development of extensive hornwort beds around the margins of this shallow lake may reduce algal blooms by storing nutrients, despite the detrimental impact hornwort will have on littoral condition. Nutrient removal by means of weed harvesting may not only reduce weed impact but also help remove stored nutrients. Out of all the Rotorua Lakes, Lake Rotoehu was the only one estimated to have sufficient harvestable weed biomass to potentially reduce the lake nutrient budget by a beneficial amount (Matheson & Clayton 2002). A total of 600 tonnes of hornwort was harvested and removed

from Lake Rotoehu over a 4 week period from April to May 2008, which equated to removal of 720 Kg of nitrogen and 96 Kg of phosphorous (R. Mallinson BOPRC, pers comm.).

4 Discussion

4.1 Current lake stability

Changes in LakeSPI indices over the last five years (or survey that is closest to the five year timeframe) have been used to provide an indication of current stability in lake condition and the direction of any change (Table 15).

Lakes Tikitapu and Okaro showed some improvement in LakeSPI scores over the 5 year time frame. Both lakes however are recognised as being sensitive and highly variable in nature so care must be taken when interpreting any kind of improvement in these lakes at this stage. Lake Rotomahana, the second highest ranked lake in the Rotorua region, is the only lake currently showing a marked decline in lake condition scores. The LakeSPI Index in Rotomahana has declined by 20% since 2005 which is the largest change recorded for any of the 12 Rotorua lakes over this time frame. This is largely due to the continual spread and impact by two of New Zealand's worst aquatic plant species, egeria and hornwort, in the lake. All remaining Rotorua lakes currently appear to be in a stable condition, with changes in scores of ≤±5%, although future change is expected for those at risk from expanding invasive plants (Lakes Okataina, Rerewhakaaitu, Okareka).

Table 15: Summary of current LakeSPI resultsfor assessed lakes showing overall condition category, current stability rating, long term changes in condition and an indication of the main impact factor affecting scores.

Lake	LakeSPI Index (%)	Overall Condition	Current Stability (~5 years)	Long term changes (>20 years)	Impact factor
Rotoma	51	High	Stable	Change not indicated	-
Rotomahana	50	Moderate	Declining	Change indicated	Weed
Okataina	44	Moderate	Stable	Change not indicated	Weed
Tikitapu	41	Moderate	Improving	Change indicated	Water Quality
Rerewhakaaitu	36	Moderate	Stable	Change not indicated	Weed
Okareka	35	Moderate	Stable	Change possible	Weed
Rotokakahi	31	Moderate	Stable	Change indicated	Water Quality
Okaro	27	Moderate	Improving	Change not indicated	Water Quality
Tarawera	24	Moderate	Stable	Change indicated	Weed
Rotoiti	20	Poor	Stable	Change possible	Water Quality
Rotorua	20	Poor	Stable	Change not indicated	Water Quality
Rotoehu	17	Poor	Stable	Change indicated	Weed

4.2 Long term changes

Longer term, many of the Rotorua Lakes have undergone significant change over the last two decades (Figure 5).

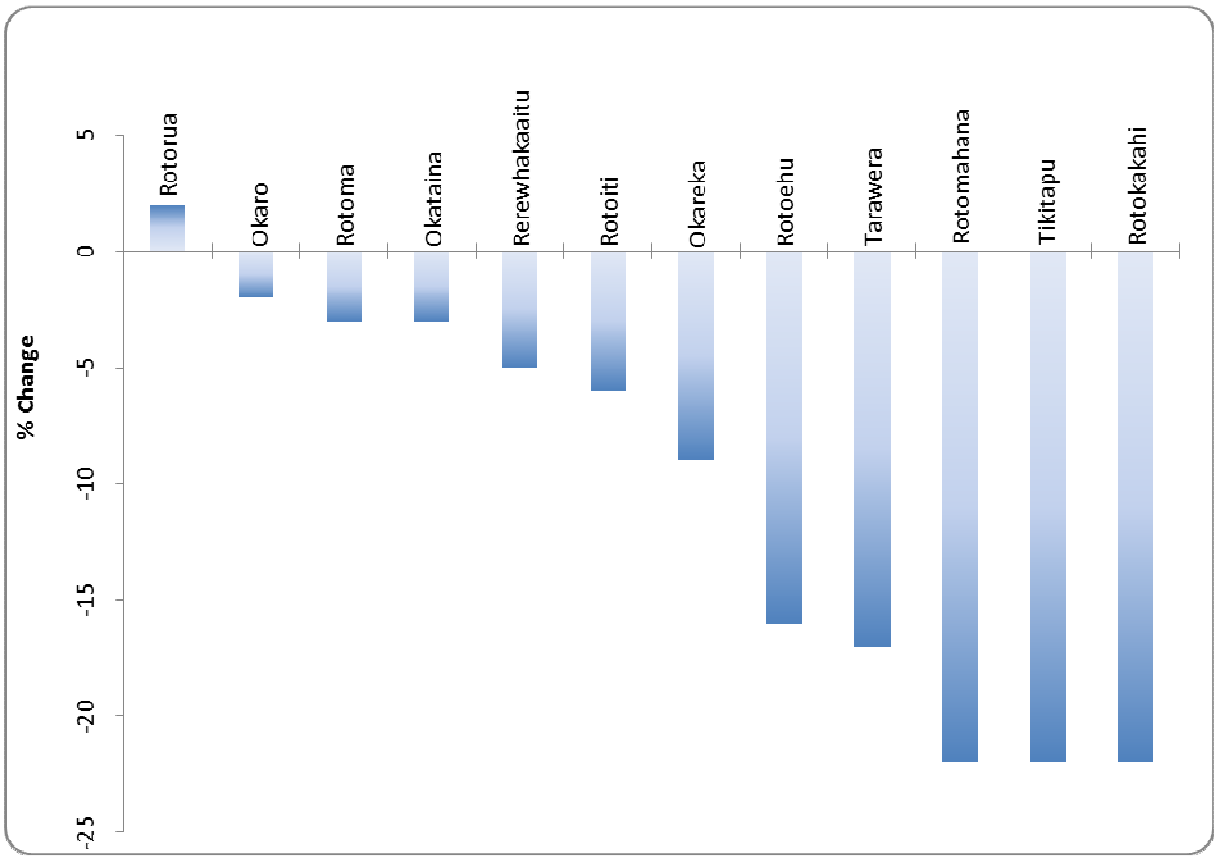

Figure 5: Percentage of change as indicated by the LakeSPI Index over the last 24 years, 1988 to 2011/12.

Lakes Tikitapu, Rotokakahi and Rotomahana show the biggest change in lake condition over the last 23-24 years resulting from a notable reduction in the diversity and extent of native submerged vegetation present in the lakes.

There have been no new invasive species recorded in either of Lakes Tikitapu or Rotokakahi since full lake surveys begun in 1988, so the changes in these lakes are likely to be the result of deteriorating water quality and clarity. Submerged plants are able to integrate long term changes in water clarity and nutrient status over time and often one of the first signs of deterioration is a retraction of the lower depth limit of plant growth (Schwarz et al. 1999). In many lakes the first valuable plant community to disappear is the charophyte meadow that grows into deeper water and this has been the case in Lake Tikitapu. In 1988 Lake Tikitapu supported extensive charophyte meadows at all 5 LakeSPI sites down to a mean depth of 19.5 m. By 2010, charophyte meadows had disappeared and the mean maximum depth of plant growth (inclusive of invasive species) had declined to only 3.6 m. The recent 2012 survey showed some recovery of deeper growing charophytes at 2 of the 5 baseline sites but it is uncertain as to how sustainable this plant community will be.

Next to water quality, the second biggest change affecting the condition of the Rotorua Lakes is the introduction of invasive plant species. Invasive species tend to impact negatively on lake condition by displacing native plant communities to depths of greater than about 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 Lakes and is the dominant invasive species in 2 of these lakes, Tarawera and Rotoehu. Lake Tarawera now remains in a stable state and it is not expected to change significantly in the near future since the full impact of hornwort has now taken place. Hornwort is nearing full impact status in Lake Rotoehu also, although we can expect to see some further decline in LakeSPI scores as hornwort continues to impact negatively on the native vegetation still present. Of most recent concern is the discovery of hornwort for the first time in Lakes Okareka (March 2012) and Okataina (March 2010). Based on the potential for hornwort to spread within these lakes and its likely impact on present vegetation status, if unable to be controlled, we can expect to see a notable decline in the status of Lakes Okareka and Okataina in years to come.

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

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

4.3 National comparison

Compared nationally, the Rotorua Region has no lakes classified as being in ‘excellent’ condition (representing those close to their maximum potential ecological condition) and only one lake classified as being in ‘high’ condition (Figure 6 & 7).

A ‘moderate’ condition category contains the majority of the Rotorua Lakes and contains the largest proportion of lakes nationally. This ‘moderate’ condition group of Rotorua Lakes are representative of those lakes that are impacted in varying degrees by invasive weeds.

A smaller proportion of the Rotorua Lakes and lakes nationally are classified as being in a ‘poor’ condition. This group of lakes tends to represent those with extensive invasion and dominance by one of the country’s worst weeds, hornwort, as is the case for 2 of the 3 Rotorua Lakes ranked in this ‘poor’ category.

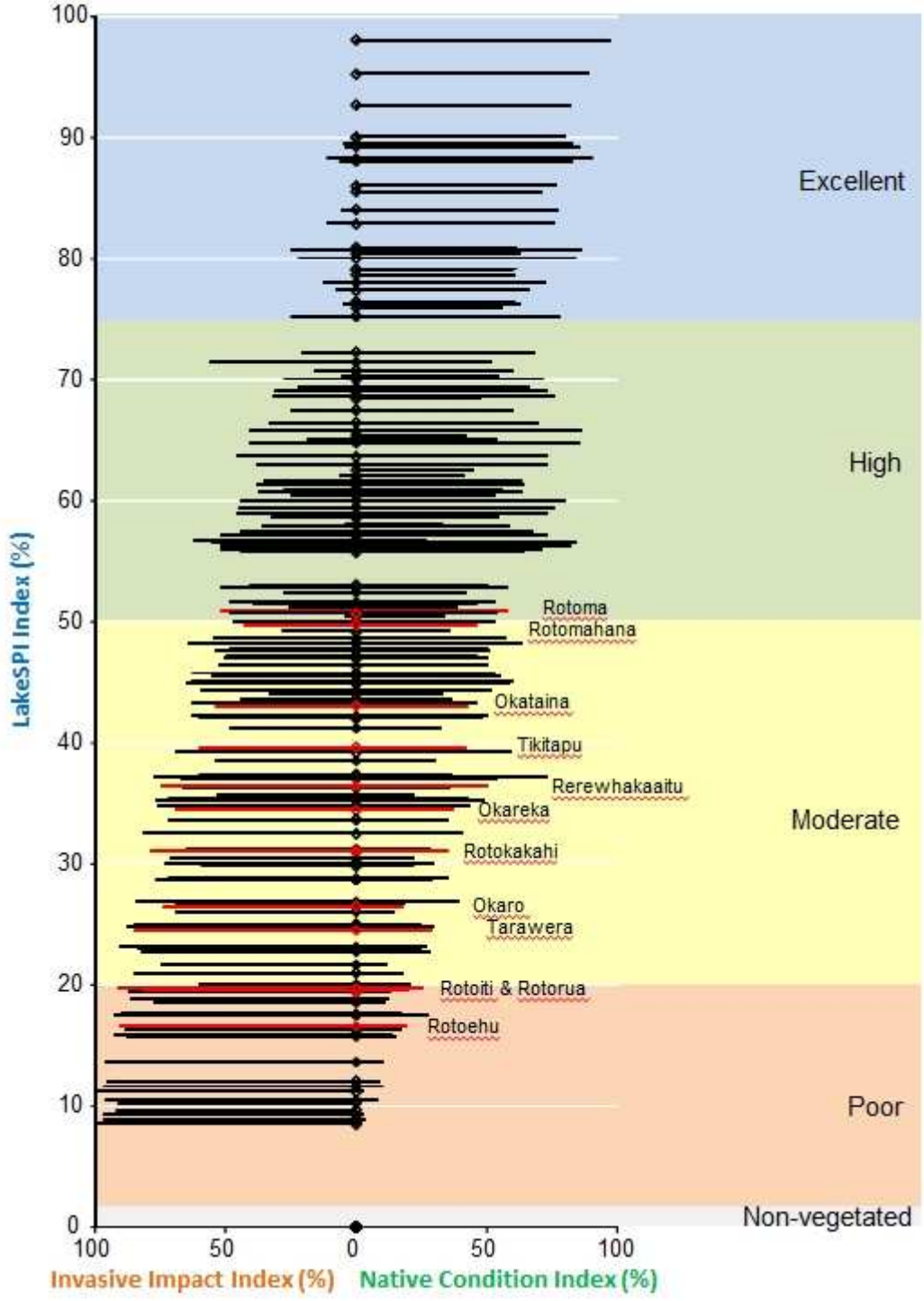

Figure 6: The most recent LakeSPI scores for the Rotorua Lakes (red lines) are plotted with scores for a total of 221 New Zealand lakes. The LakeSPI Index is plotted on the y-axis (points), Native Condition Index as lines to the right and Invasive Impact Index lines to the left of the x-axis. Five categories of LakeSPI condition are indicated by labelled colour bands.

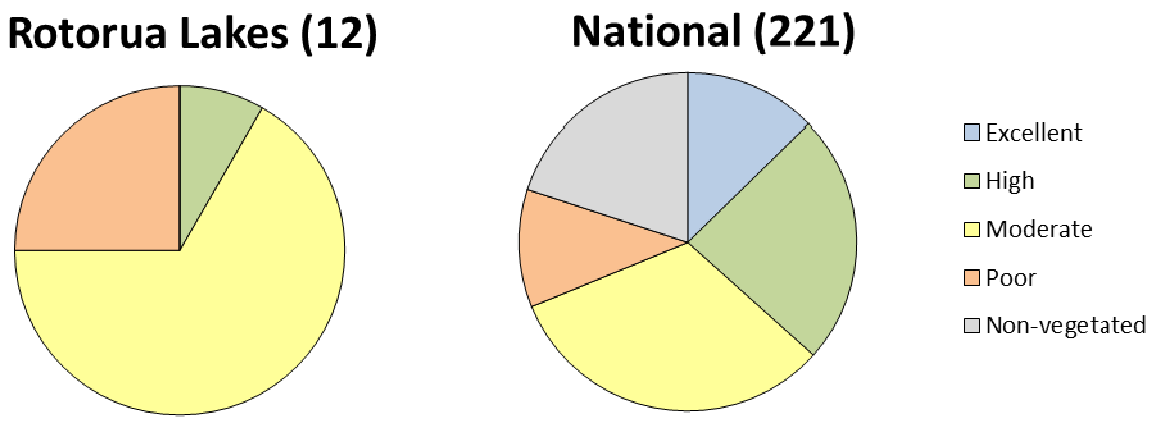

Figure 7: Proportion of lakes that fall into each of five categories of LakeSPI Index for the region and nationally, with number of lakes assessed shown in parenthesis.

5 Conclusions

LakeSPI results have provided valuable inter-lake comparisons and show many of the Rotorua Lakes have undergone significant change over the last two decades while continuing to be vulnerable to further changes from invasive plants and water quality deterioration over the short term (last 5 years). As well as providing a cost effective monitoring tool for regional and national reporting requirements, LakeSPI information can also be used to prioritise management objectives such as for surveillance strategies, appropriate protection measures for high value lakes and potential restoration objectives for degraded lakes.

Present day LakeSPI Indices for lakes in the Rotorua region ranged widely from 17% to 51% and for ease of reporting LakeSPI status, were categorised into five groups according to the value of the LakeSPI Index. One Rotorua lake was assessed as being in 'high' condition, eight lakes as 'moderate' and three lakes were categorised as in 'poor' condition. None of the 12 Rotorua lakes were recorded in the 'excellent' or 'non-vegetated' categories.

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

Lakes Rotomahana, Okataina, Tikitapu, Rerewhakaaitu, Okareka, Rotokakahi, Okaro and Tarawera are currently ranked as being in 'moderate' condition. Lake Rotomahana has shown the largest decline in lake condition over the last 5-6 year time frame of any of the Rotorua lakes. This is largely due to the introduction and spread of invasive species which has recently seen the Invasive Impact Index more than double. Lake Okataina and Okareka have remained relatively stable. However, the recent discovery of hornwort in Okataina (since 2010) and Okareka (2012) poses a serious threat to the future stability and condition of these lakes. Lake Rerewhakaaitu has remained relatively stable however the increasing invasive impacts from egeria and changes noted in water quality that are impacting on charophyte depth limits are of concern for the future state of this lake. Lake Tikitapu showed a slight improvement during the recent survey based on the recovery of some sparse deeper growing charophytes species at 2 of the 5 sites. Over the longer term however Lake Tikitapu continues in a state of notable decline on account of changing water quality although there have been no new invasive species since the first full lake survey in 1988. Lake Rotokakahi also continues to appear in a state of decline due to water quality issues. Over the last 20 years, both Lakes Rotokakahi and Tikitapu have seen a reduction in the quality and extent of native plant communities present, without any direct change in invasive species presence or performance. A slight improvement was noted in scores for Lake Okaro during the 2011 survey and it is now classified in 'moderate' condition. This reflects an increase in native plant cover and diversity, and a corresponding decrease in invasive plant covers during the recent survey. Lake Tarawera also falls into this 'moderate' condition category and its condition is not expected to change in the near future since the full impact of hornwort has now taken place.

Lakes Rotoiti, Rotorua and Rotoehu are classified as being in a 'poor' condition and are not expected to move from this position in the near future. Lake Rotorua is the only lake to have shown a slight increase in lake condition scores over the past 23 years (Figure 4) but

remains in a poor condition. Lakes Rotoiti and Rotoehu also remain classified as in 'poor' condition, however, restoration measures on these lakes and others that result in a sustainable improvement in water quality and clarity would be expected to result in improved LakeSPI scores in the future.

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

Lake Rotoma

- Overall lake condition high and appears stable.
- LakeSPI scores stable with the highest Native Condition Index and one of the lowest Invasive Impact Index in the region.
- An exceptional lake and the best example of extensive charophyte meadows.
- Major threat from hornwort invasion.

Lake Rotomahana

- Overall lake condition now moderate and declining.
- Recent invasion by egeria and hornwort having a significant impact.
- High Native Condition Index and lowest Invasive Impact Index of any Rotorua lake.

Lake Okataina

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

Lake Tikitapu

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

Lake Rerewhakaaitu

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

Lake Okareka

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

Lake Rotokakahi

- Overall lake condition moderate and stable.
- Major decline in LakeSPI and Native Condition Index over last 20 years.
- No change in elodea status but invasive impact accentuated by decline in native plant communities.
- Now the only Rotorua lake (with the exception of Okaro) to remain relatively free of the worst 'high impact' invasive weed species.

Lake Okaro

- Overall lake condition moderate and variable (currently showing some improvement).
- Unstable LakeSPI scores due to variable water quality and seasonal response of elodea. Possible signs of some improvement following lake restoration measures.
- Has the lowest Native Condition Index for any of the Rotorua lakes.

Lake Tarawera

- Overall lake condition moderate and likely to be stable in the immediate future.
- LakeSPI and Native Condition Index scores have declined significantly within the last 22 years.
- Invasion of hornwort primarily responsible for decline in LakeSPI and Native Condition scores.

Lake Rotoiti

- Overall lake condition poor.
- Has the highest Invasive Impact Index of the Rotorua lakes.
- LakeSPI Index indicates poor water quality.

Lake Rotorua

- Overall lake condition poor and variable.
- Only Rotorua lake to have shown a slight increase in lake condition scores over the past 22 years.

Lake Rotoehu

- Overall lake condition poor and declining.
- Recent invasion by hornwort is having a major impact.
- Has one of the highest Invasive Impact indices of the Rotorua lakes.

6 Recommendations

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

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

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

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