NIWA
Taihoro Nukurangi

LakeSPI results for four lakes in the Wellington Region

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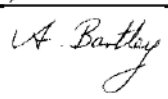
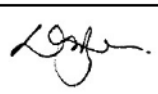
	Formatting checked by:	Alison Bartley
	Approved for release by:	David Roper

Photo: the approaches to Lake Kohangatera (Mary de Winton, NIWA).

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Executive summary

Greater Wellington Regional Council (GWRC) contracted NIWA to survey four lakes in Wellington Region in summer 2016 using LakeSPI (Submerged Plant Indicators). Previously LakeSPI surveys have been carried out for Lakes Pounui, Kohangapiripiri and Lake Kohangatera, with historical submerged vegetation surveys also available for Lake Waitawa. This report presents findings on their current (2016) state and identifies changes in the lake vegetation over time.

Lake Kohangatera was in excellent ecological condition according to submerged vegetation indicators with a LakeSPI Index of 82% in 2016. It has proven to be stable for the last c. 10 years according to LakeSPI. This lake continues to support unusual or rare plant species and submerged vegetation values which are considered nationally outstanding.

Lake Kohangapiripiri had a 'Moderate' lake condition with a LakeSPI Index of 40% in 2016. A natural die-back of native vegetation after fruiting is the major driver of a reduction in lake condition from a 'High' category in 2011, but this lake vegetation will be well positioned to recover.

Lake Pounui fell into the 'Moderate' category for ecological condition with a LakeSPI Index of 38% in 2016. The lake vegetation was dominated by the invasive weed elodea, but still supported a range of native plant communities. Previously in 2011 Lake Pounui scored a LakeSPI Index of 56% and was categorised in the 'High' category for ecological condition. Since then a retraction in the depth to which plants are growing, together with the occurrence of algal blooms indicates poorer long-term water clarity. Greater lake productivity was also suggested by a reduction in the presence of *Isoetes* (listed in New Zealand threat classification) and an increased dominance by elodea.

Lake Waitawa currently has a 'Poor' lake condition with a LakeSPI score of 10%. Submerged vegetation was completely dominated by the invasive weed hornwort. Previously in 2002 the lake vegetation grew twice as deep and still had native vegetation communities, despite the dominance of hornwort. These changes indicate a reduced light climate for submerged plants from long-term poor water clarity, with possible disturbance also from introduced fish.

Recommendations stemming from this report include a check on the expected recovery of Lake Kohangapiripiri vegetation in spring 2016, and resurvey of Lake Kohanagatera after 5 years or earlier if change is suspected. The deteriorating conditions for native vegetation in Lake Pounui are unexpected and are worthy of further investigation. Meantime we suggest efforts to secure the *Isoetes* entity in culture. This lake would benefit from a further LakeSPI survey in 2018 to check on vegetation status. Lake Waitawa would appear vulnerable to a switch to a non-vegetated state, and a continued influence from the weed hornwort might be considered preferable to a phytoplankton dominated state.

1 Introduction

Greater Wellington Regional Council (GWRC) contracted NIWA to survey four lakes in the Wellington Region in summer 2016 using LakeSPI (Submerged Plant Indicators). This bioassessment method harnesses the way submerged plants respond to their growth environment, for example, the extent of the plant depth limit responds to changing long-term water clarity. LakeSPI also captures the degree to which invasive introduced weeds have altered the vegetated littoral zone.

Three scores are generated from LakeSPI; a measure of native vegetation presence, extent and diversity (Native Condition Index), the level of impact by any weed species that may be present (Invasive Impact Index), and an overall score (LakeSPI Index) that combines these values and impacts.

Previous LakeSPI results are available for Lakes Pounui (2011), Kohangapiripiri (2011) and Lake Kohangatera (2011 and 2013). No previous LakeSPI assessment has been made for Lake Waitawa, although detailed submerged vegetation surveys from 2002 NIWA[1] were held by that have been used to generate a retrospective LakeSPI score for this lake.

In this report we present the most recent (2016) results for all lakes to describe their current status. Current status is compared to LakeSPI results for over 250 lakes across New Zealand and regional comparisons are also made. We also report any changes in LakeSPI scores over time (direction and extent).

[1] pre-diquat spray 30th August used for LakeSPI, and post-spray 5th November

2 Survey methods

The LakeSPI survey method (Clayton and Edwards 2006, de Winton et al. 2012) was applied at five previously selected sites in Lakes Pounui, Kohangatera and Kohangapiripiri that were first surveyed in 2011. For Lake Waitawa five representative sites were selected from 13 locations surveyed in August 2002, where divers had attained the depth limit for vegetation (Dugdale and Champion 2002).

Retrospective LakeSPI scores were generated from the Lake Waitawa 2002 data, a 2004 vegetation reconnoitre in Lakes Kohangatera and Kohangapiripiri (Wells and Champion 2004) and a descriptive account of vegetation in Lake Pounui in 1976 (Persse undated, Jellyman 1990). In these cases LakeSPI metrics were extracted from vegetation data, maps and profile diagrams. The 2002 data for Lake Waitawa was sufficient to draw an historical baseline, while results for Lakes Kohangatera and Kohangapiripiri (2004) and Lake Pounui (1976) should be considered indicative only because the surveyed areas was more limited than subsequent application of the LakeSPI method.

Lakes were surveyed over the 15th to 17th of February 2016. The sites were relocated from GPS positions and maps documenting the previous surveys. Appendix A shows the location of sites.

At each site scuba divers scored 11 metrics over a 2 m wide transect from shore to the deepest vegetation limit. Metrics included measures of diversity from the presence of key native plant communities, the depth of vegetation growth, and the extent that invasive weeds were represented.

A complete description of measured characters is given in the technical report at http://lakespi.niwa.co.nz/. An inventory of all plant species encountered was also made (Appendix B).

3 Data analysis

Results were entered to NIWA's LakeSPI database for generation of three indices. The Native Condition Index measures the diversity and extent of native vegetation, the Invasive Impact Index measures invasive weed extent, and these are integrated within an overall LakeSPI Index. Indices are expressed as a percentage of expected pre-European (pristine) state. LakeSPI Index scores place lakes into one of five narrative classes of lake condition, either as Non-vegetated (0%), Poor (>0-20%), Moderate (>20- 50%), High (>50-75%) and Excellent (>75%).

The likelihood of a significant change in lake status over time is based on agreement in the direction and magnitude of change in LakeSPI Indices across all 5 sites. A paired t-test (GraphPad InStat) compared site results from each survey to the same sites at the previous survey to identify change at a significance level of $p < 0.05$.

In addition to statistical significance, the ecological significance of change was assessed using the guidelines below (Figure 1) which give a scale of probabilities for ecologically significant change in lake condition based on change in averaged LakeSPI indices (LakeSPI units as %) over repeated surveys. These guidelines, based on expert judgment, have considered observer-based variation and the response of LakeSPI scores to major ecological events in lakes (NIWA unpublished data).

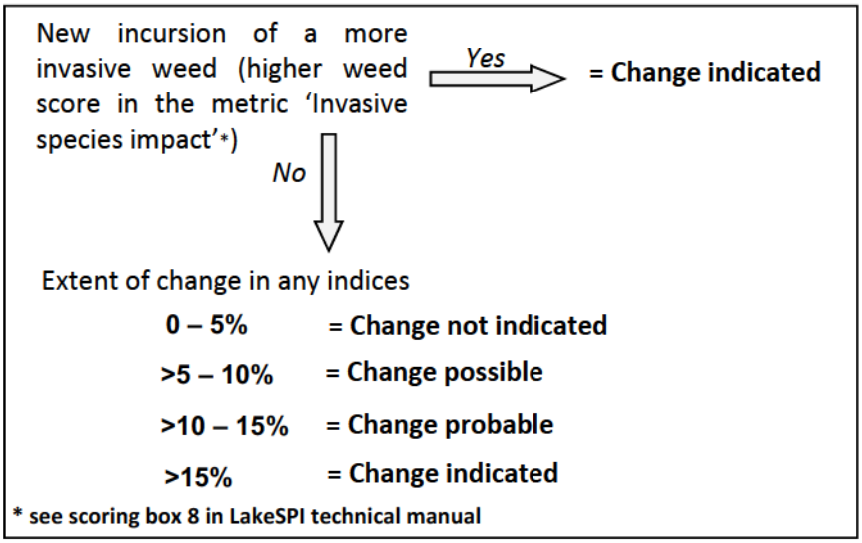

Figure 1: Guidelines for assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.

4 Results

4.1 Lake Kohangapiripiri

Lake condition:	Moderate
Stability:	Natural fluctuation
Lake depth:	1.5*

**Maximum depth at time of survey was 1.3 m*

The LakeSPI Index of 40% in 2016 places the lake in the 'Moderate' category of lake condition. At the time of the survey it was apparent that the extent of native vegetation had undergone a major die-back which is reflected in a modest Native Condition Index of 36%. The most abundant plant remaining was the introduced water buttercup *Ranunculus trichophyllus* which formed narrow surface reaching bands along the lake edge and isolated colonies across the centre (Figure 2). This dominance of the remaining vegetation by the weed resulted in a relatively high Invasive Impact Index of 60% (Table 1).

Table 1: LakeSPI results for Lake Kohangapiripiri from surveys in 2016, 2011 (de Winton et al. 2011) and 2004 (Wells and Champion 2004).

Date	LakeSPI Index	Native Condition Index	Invasive Impact Index
2016	40	36	61
2011	63	73	38
2004†	63	70	39

†Indicative only

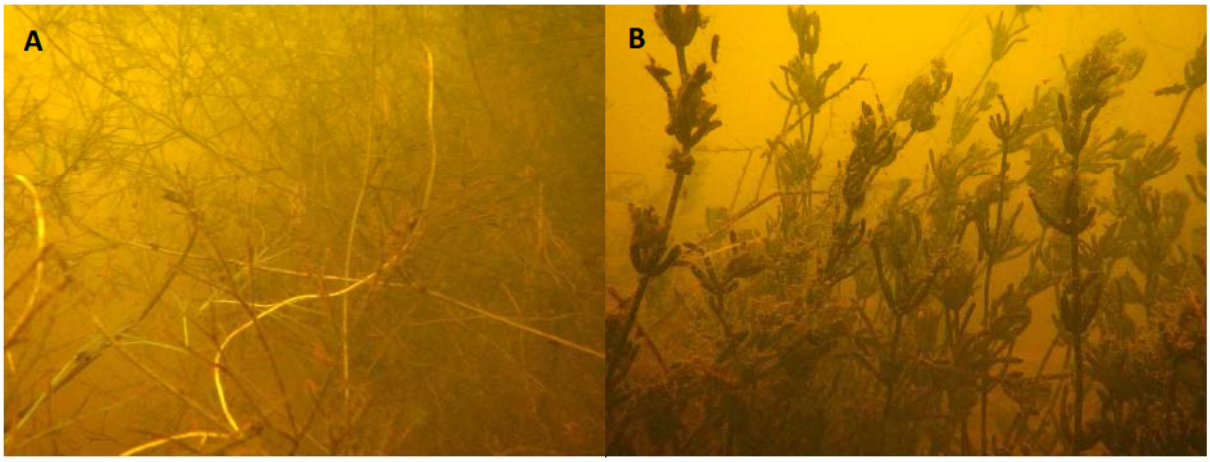

Figure 2: Standing vegetation in Lake Kohangapiripiri in 2016 comprised mostly of A) water buttercup and B) charophyte.

The native charophyte *Chara australis* was also common but did not form high cover beds (Figure 2). Elsewhere there were black fragments of plant stalks on the lake bed (Figure 3A) and large amounts of drift accumulated on and around the reed beds at the lake edge (Figure 3B). The majority of this drift comprised the native pondweed *Potamogeton ochreatus*, which had flowered and produced seed (Figure 4). It is likely that this is a natural senescence phenomenon associated with a strong fruiting response to lower summer 2016 lake levels (Appendix C), and possibly high summer water temperatures. Higher than previously recorded levels of salinity (1,358 µS cm^{-1}) may also have stressed the freshwater species.

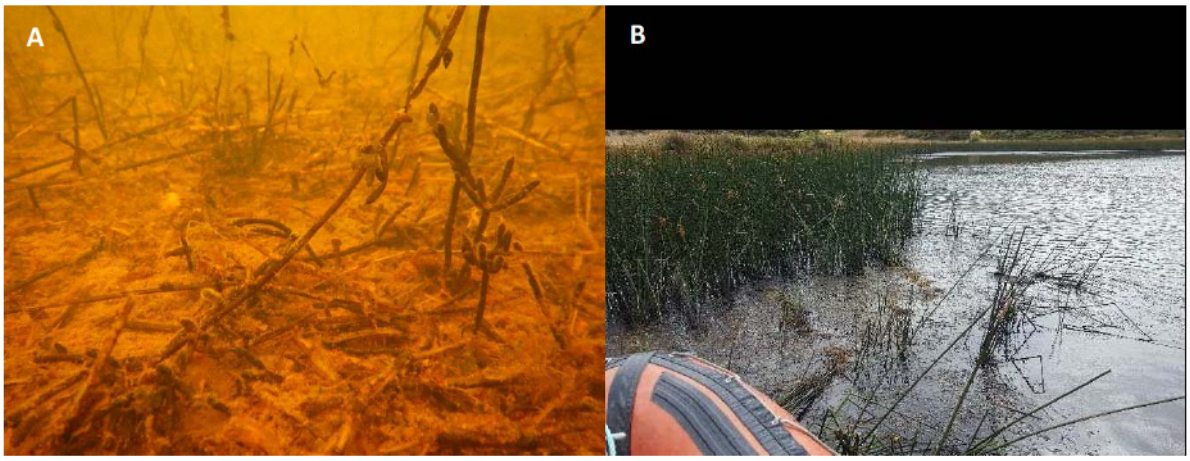

Figure 3: A) Stalks and plant fragments were common across the bed of the lake. B) drift accumulation and disturbance of the fringing beds of reeds.

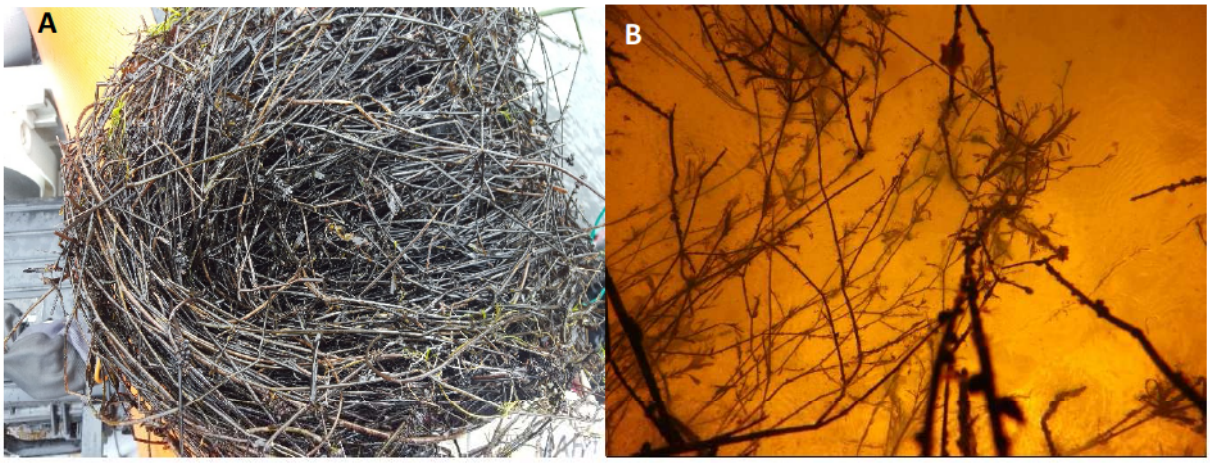

Figure 4: A) Drift commonly included seed heads of pondweed, while B) remaining beds of pondweed (viewed looking upward) had sparse, 'tattered' canopies.

The result of this die-back has been a reduction (although not quite statistically significant) in the Native Condition Index and the LakeSPI Index compared to the 2011 results, with a statistically significant increase in the Invasive Impact Index. It does not appear that the relatively benign weed water buttercup has increased substantially since described in 2011 (de Winton et al. 2011), but it now comprises a proportionally greater part of the lake vegetation due to the reduction in native

plant cover. Based on remnant native plant material and apparent seed load on the distributed drift the vegetation will be well positioned for a recovery.

In 2011 the LakeSPI Index of 63% placed the lake in the 'High' category for ecological condition. Diverse native vegetation extended across most of the lake bed and scored a Native Condition Index of 73%. Only localized beds of the introduced water buttercup were encountered, resulting in an Invasive Impact Index of 38%.

A more limited vegetation survey undertaken by NIWA in 2004 (Wells and Champion 2004) indicated almost identical LakeSPI scores to 2011 (Table 1). Earlier species records (Mason 1950, Moar 1950) also showed a mixture of submerged plants typical of freshwater and brackish water conditions (Appendix B), although the record for *Lamprothamnium macropogon* suggests conditions have been more saline in the past at least in some areas of the lake.

Similar vegetation elements have been recorded across the 2004 to 2016 surveys (Appendix B), although a more limited range of species was encountered in 2016. Large beds of emergent reeds and rushes encircle most of the lake, with short-growing turf plants present where the emergents are absent or are more open. Tall growing native plants, mostly pondweeds and milfoils grow across extensive areas of lake bed, with charophytes present at usually low covers. Several species are tolerant of saline conditions (e.g., *Zannichellia palustris*), indicating the lake may receive salt spray or periodic overwash from the nearby coastline. Although salinity may have contributed to the dieback in submerged vegetation seen, we would have also expected to see some concurrent dieback in marginal vegetation if this was an extreme salinity intrusion event.

4.2 Lake Kohangatera

Lake condition:	Excellent
Stability:	Stable
Lake depth:	2.3*

**Maximum depth at time of survey was 1.7 m*

In 2016 the LakeSPI Index of 82% (Table 2) indicates the lake is in excellent ecological condition according to submerged vegetation indicators. The lake supported a diverse matrix of native submerged plant species that contributed to a Native Condition Index of 81%. The only invasive weed detected at the survey sites was low covers of elodea (*Elodea canadensis*), which resulted in an Invasive Impact Index of 16%.

Table 2: LakeSPI results for Lake Kohangatera from surveys in 2016, 2013 (de Winton 2013), 2011 (de Winton et al. 2011) and 2004 (Wells and Champion 2004).

Date	LakeSPI Index	Native Condition Index	Invasive Impact Index
2016	82	81	16
2013	87	83	8.1
2011	89	83	5
2004†	72	70	23

†Indicative only

The dominant plant in the southern lake area was lesser horses' mane (*Ruppia polycarpa*) which is known to be tolerant of salinity. Elsewhere in the lake, milfoil (*Myriophyllum triphyllum*) and pondweed (*Potamogeton ochreatus*) were abundant. These plants were accompanied by numerous other submerged species (Appendix B). Nodules of the blue-green algae (*Nostoc* sp.) were common on the plants and lake bed. Similar observations in 2004 (Wells and Champion 2004) were suggested to indicate nitrogen-limitation in the lake.

Despite slight deterioration on the LakeSPI and Invasive Impact Index there were no statistical differences in any of the indices since 2011, indicating a relatively stable lake environment for plants. In 2016 it appears the shallower lake level in summer 2016 (Appendix C) had enabled the entire lake bed to be colonised by plants, where previously (2013 and 2011) some bare areas were encountered.

Two weeds considered more benign than elodea have been recorded in the lake. Appendix B shows *Ranunculus trichophyllus* and *Potamogeton crispus* have been intermittently recorded at very low occurrence, often from outside of the LakeSPI survey sites. These are seed spread species that are transported by waterfowl, unlike elodea which is spread solely by accidental/intentional human activity.

In 1950 a number of the common plant species in NIWA's surveys were recorded by Moar (1950) for Lake Kohangatera and the Gollans Wetland (Appendix B). Although the 1950 survey recorded *Lamprothamnium macropogon*, a charophyte species that generally requires some degree of salinity, this species has not been recorded since (Appendix B).

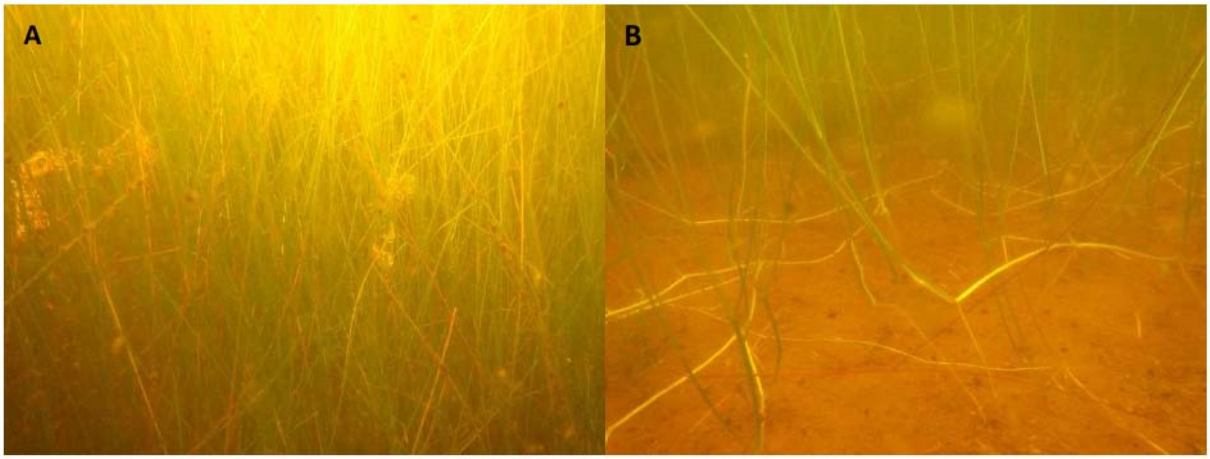

Figure 5: The saline tolerant horses' mane was the dominant plant in the southern part of the lake. A) Dense stand of horses' mane showing active fruiting (see white coils terminating in seed heads), and B) expansion via spreading rhizomes.

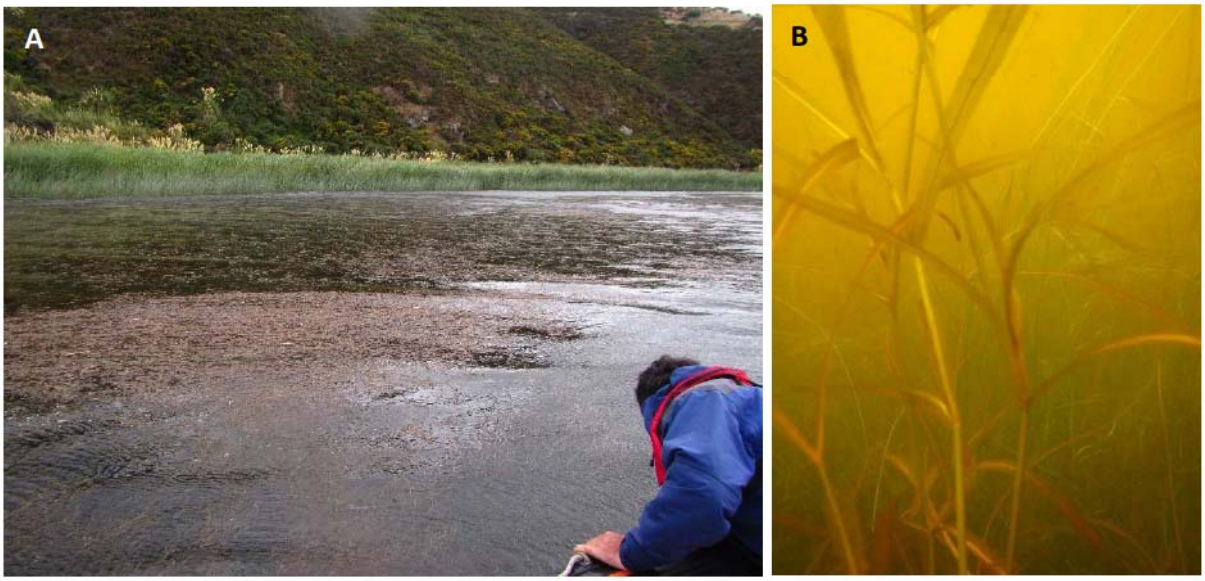

Figure 6: A) Milfoils formed surface reaching bands at some sites, while B) pondweed became more prevalent in the north of the lake.

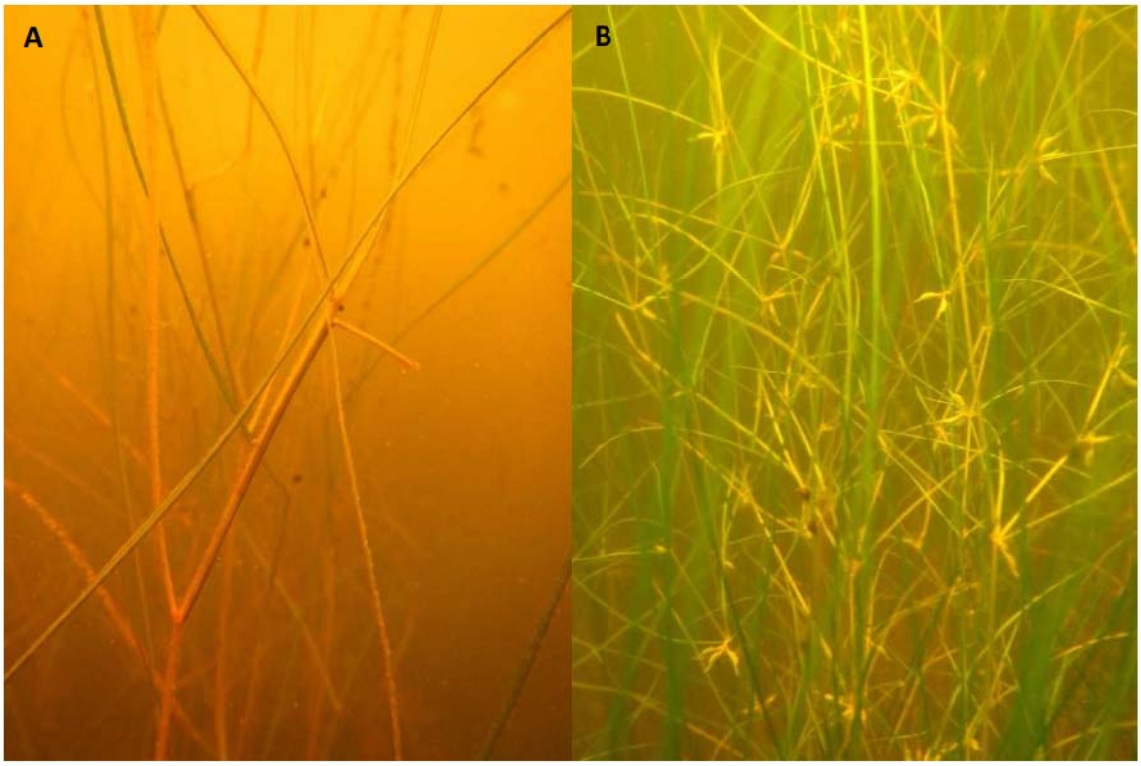

Figure 7: **A) Sago pondweed and B) *Zannichellia* (fruiting) are additional saline tolerant species that are thriving in Lake Kohangatera.**

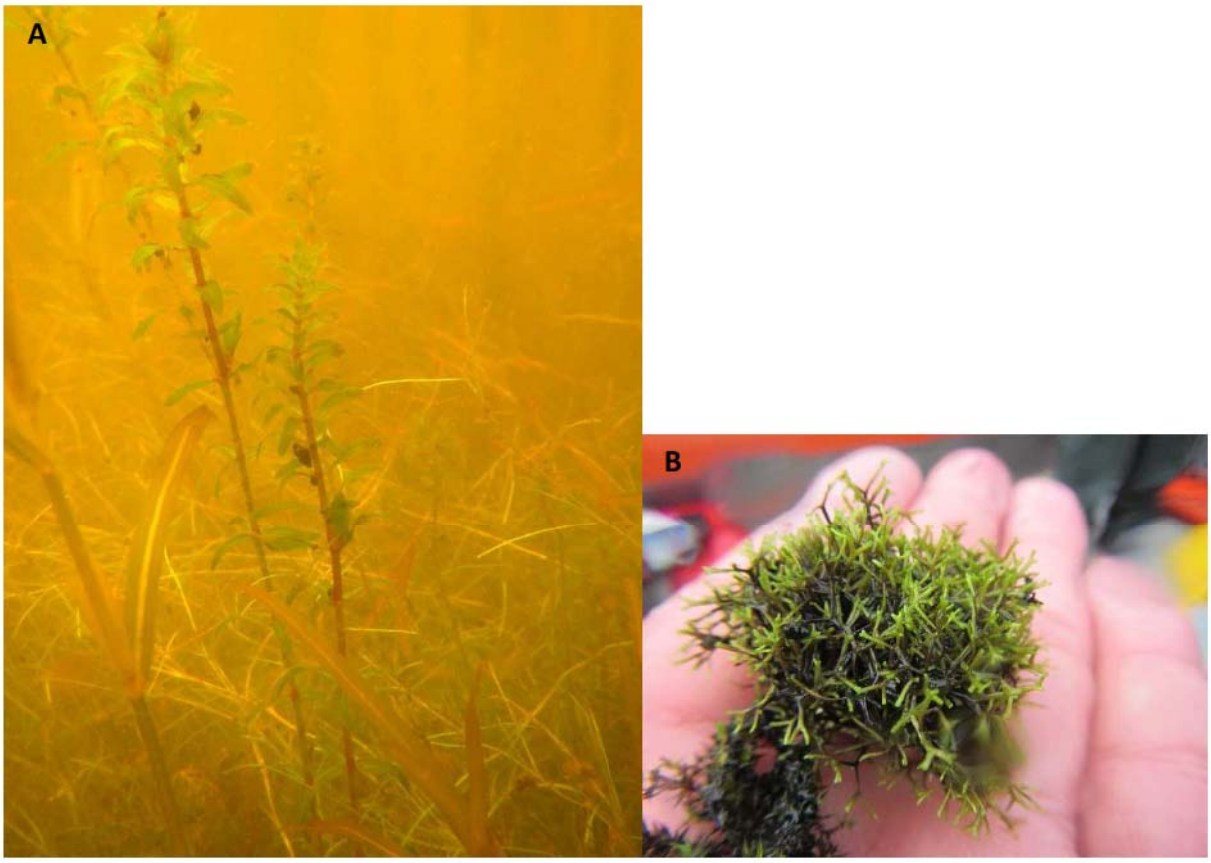

Figure 8: **A) Elodea was a minor component at the shallow edges of the lake, growing amongst pondweed (foreground) and *Lepilaena bilocularis* (pale green), B) *Riccardia* cushion.**

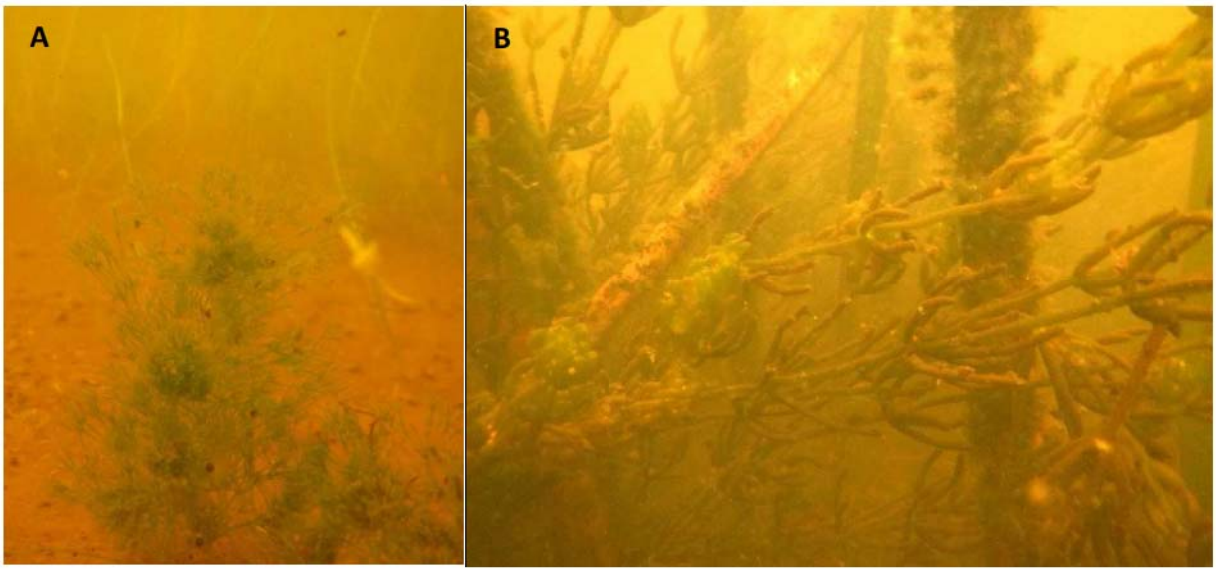

Figure 9: Charophytes included A) sparse but widely distributed *Nitella stuartii* and B) *Chara australis* beds mostly limited to amongst the reeds.

4.3 Lake Pounui

Lake condition:	Moderate
Stability:	Declining
Lake depth:	9.8

Currently, a LakeSPI Index of 38% places Lake Pounui in the 'Moderate' category for ecological condition. A Native Condition Index of 45% reflects the presence of a range of native plant communities, although they were of limited extent (Table 3). The widespread impact from the weed elodea (*Elodea canadensis*) resulted in an Invasive Impact Index of 65%.

Table 3: LakeSPI results for Lake Pounui from 2016, 2011 (de Winton 2011), and indicative values from 1976 (Persse undated, Jellyman 1990).

Date	LakeSPI Index	Native Condition Index	Invasive Impact Index
2016	38	45	65
2011	56	65	44
1976†	52	64	52

†Indicative only

Elodea formed beds that occupied most of the littoral zone in 2016. Although two other invasive weeds were recorded (*Ranunculus trichophyllus* and *Potamogeton crispus*) they were only occasionally encountered and are considered less invasive than elodea.

Submerged native vegetation was dominated by pondweed (*Potamogeton ochreatus*), milfoil (*Myriophyllum triphyllum*) (Figure 10) and charophytes (*Chara australis* and *Nitella* aff. sp. *cristata*) in deeper water (Figure 11). A short-growing turf plant community at shallow shorelines without dense reeds or rushes (Appendix B) included quillwort, *Isoetes kirkii* (Appendix B).

The lake had a dense phytoplankton bloom at the time of the 2016 survey which together with shoreline filamentous algae is suggestive of high nutrient availability in the water column. Observations of abundant snails (*Potamopyrgus antipodarum*) and masses of small sponges also suggest a highly productive lake.

Between 2011 and 2016 there has been a statistically significant reduction in the LakeSPI and Native Condition Index, and an increase in the Invasive Impact Index. Much of this change appears to be from a statistically significant reduction in the depth extent cut-off for native plants from an average of 4.72 in 2011 to 4.04 in 2016. Although this is a relatively small retraction in overall depth (c. 0.5 m) it resulted in a disproportional increase in mid-depth range occupied by elodea.

Isoetes kirkii was also less abundant in 2016 than in 2011, in keeping with likely shading in the shallow zone by abundant growths of filamentous algae (Figure 12). This site is the only remaining

record for the species in the lower North Island (de Winton et al. 2011). Plants from Lake Pounui are genetically similar to plants found in Lake Waikaremoana and Lake Taupo (Hofstra and de Winton 2016) but they displayed a relatively high level of genetic variation in comparison with the other populations (Hofstra and de Winton 2013). Elsewhere in the North Island *Isoetes* has declined in number of sites and population size leading to its designation for New Zealand conservation status as 'At risk, Declining' (de Lange et al. 2013).

The description from 1976 (Persse undated, Jellyman 1990) closely resembled the current vegetation composition (Appendix B). However, apparent changes included a switch in charophyte dominance from *Chara australis* in 1976 to *Nitella* sp. aff. *cristata*, and the first record of *Potamogeton ochreatus* from 2011, when it was the dominant plant.

A macrophyte survey of three sites in 2007 used an underwater viewer and/or grab samples at 5 m intervals (Drake et. al. 2010), which recorded most of the common species found in 2011. However, their records for *Potamogeton cheesemanii*, *Chara fibrosa* and *Nitella hookerii* were not confirmed by the 2011 or 2016 surveys. Because of the methodology employed, we could not generate LakeSPI results from the data collected in 2007.

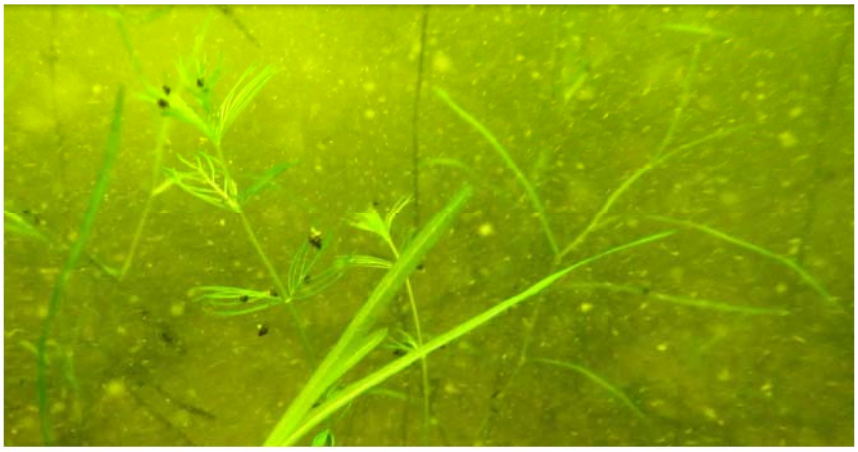

Figure 10: Native pondweed (foreground) and milfoil (behind) contributed to the mid-depth vegetation.

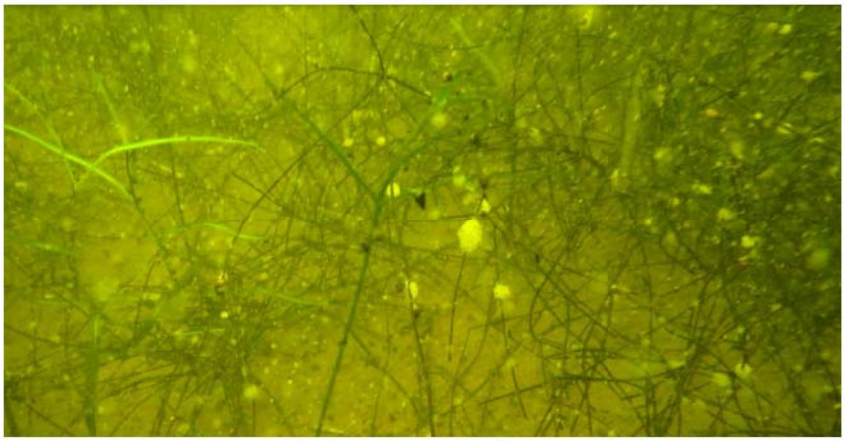

Figure 11: Charophytes dominated the deepest vegetated zone. Note abundant small sponges (larger pale objects).

Figure 12: **Filamentous algae covered the short growing turf community at open shorelines.**

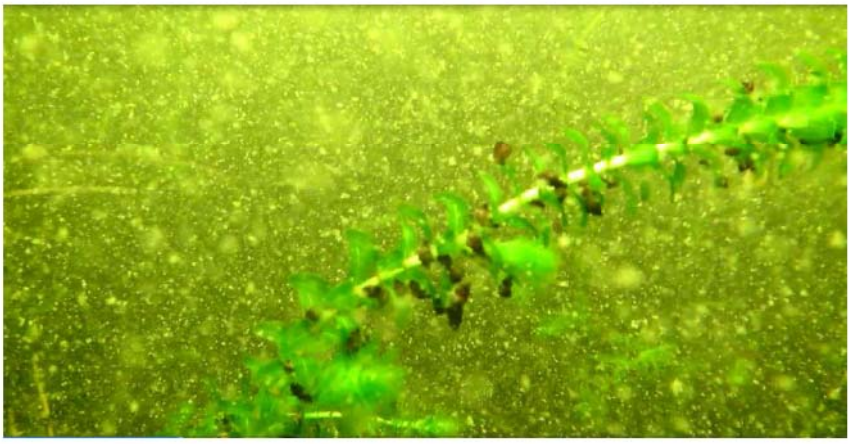

Figure 13: **An elodea stalk supporting numerous snails.**

4.4 Lake Waitawa

Lake condition:	Poor
Stability:	Declining
Lake depth:	7.8*

**Cunningham et al. 1953*

Lake Waitawa currently has a LakeSPI score of 10% (Table 4), which places it in the 'Poor' category for lake condition according to submerged plant indicators. This result is driven by complete dominance of the limited extent of submerged vegetation by hornwort (*Ceratophyllum demersum*) leading to an Invasive Impact Index of 90% and a Native Condition Index of 0%.

Table 4: LakeSPI results for Lake Waitawa from 2016 and 2002 (Dugdale and Champion 2002).

Date	LakeSPI Index	Native Condition Index	Invasive Impact Index
2016	10	0	90
2002	20	24	86

Hornwort was commonly near-surface reaching as a narrow band in shallow water (Figure 14), but had a relatively open growth form across the steeply shelving depth range of 0.4 to 3.1 m. The deeper plants were noticeably spindly, with lengthened internodes suggestive of light limitation. The only other submerged plants seen growing within the lake were also invasive weeds (Appendix B), but all were encountered only occasionally. A phytoplankton bloom noticeably reduced water clarity at the time of the 2016 survey, especially in the surface water layers (Figure 15). Waterlilies (a single cultivar based on flower characteristics) was widespread around the shore (Figure 16) apparently planted to enhance habitat value for introduced fish such as rudd and tench at this popular fishing spot.

In 2002 (prior to weed control works described by Dugdale and Champion 2002) hornwort was already dominant, leading to an invasive Impact Index of 86%. Native pondweeds and charophytes were also commonly recorded at this time, giving a Native Condition Index of 24%. Since 2002 there has been a statistically significant reduction in the depth extent of plants, with an average depth of 2.5 m being half of the average of 5.16 m depth recorded earlier. The loss of native plants has resulted in a statically significant reduction in the Native Condition Index since 2002. The LakeSPI Index had halved by 2016, although this change is not quite significant.

In 1949 (Cunningham et al. 1953) Lake Waitawa was described as having a sparse submerged vegetation comprised of charophytes and a circling band of raupo (*Typha orientalis*).

Figure 14: Near-surface reaching beds of hornwort were commonly present as a band around the lake shore.

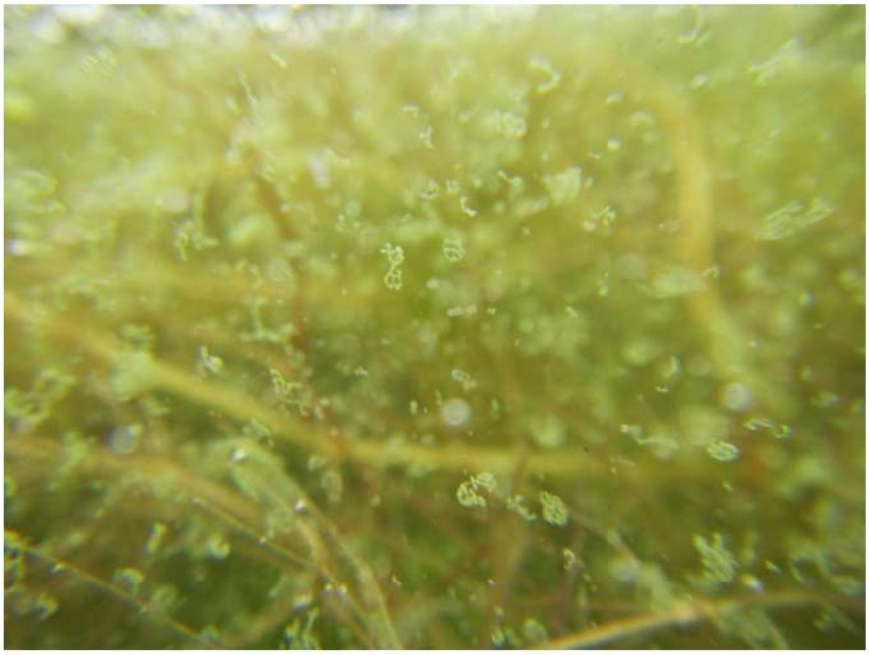

Figure 15: A phytoplankton bloom of chain forming cyanobacteria greatly reduced water clarity at the time of the 2016 survey.

Figure 16: A planted waterlily cultivar was widespread, and jettys provided access for fishermen targeting introduced fish known to be in the lake.

5 Discussion

5.1 Current state

Compared to the LakeSPI index of 259 lakes assessed nationally (Figure 17), Lake Kohangatera was ranked 15th from top in order of ecological condition, Kohangapiripiri was 119th, Pounui was 126th, and Waitawa was 197th.

Lake Kohangatera remains in Excellent condition according to submerged plant indicators with a LakeSPI Index of 82%. This lake continues to support unusual or rare plant species and submerged vegetation values which are considered nationally outstanding (de Winton et al. 2011, de Winton 2013). New Zealand's coastal waterbodies have been heavily impacted by land use changes and the introduction of invasive aquatic species, and Lake Kohangatera is one of the few remaining examples of a little impacted lowland lake.

Lake Kohangapiripiri displayed a low level of vegetation development in 2016. This limited the Native Condition Index and LakeSPI Index that were measured for this lake to a Moderate condition. Although the only invasive weed recorded, water buttercup, was not widely distributed across the bed, it did comprise the majority of the vegetation cover, thereby lowering the LakeSPI score.

Lake Pounui also fell into the Moderate category of Lake Condition according to LakeSPI due to dominance of the vegetation by the invasive weed elodea.

Lake Waitawa was in Poor condition due to the extremely limited development and diversity of submerged plants, which primarily comprised the invasive weed hornwort.

Only five lakes in Wellington Region have been assessed using LakeSPI; the four waterbodies described in this report and the artificial waterbody, Upper Karori Reservoir, which had a 'High' LakeSPI Index of 73.3% (de Winton 2013).

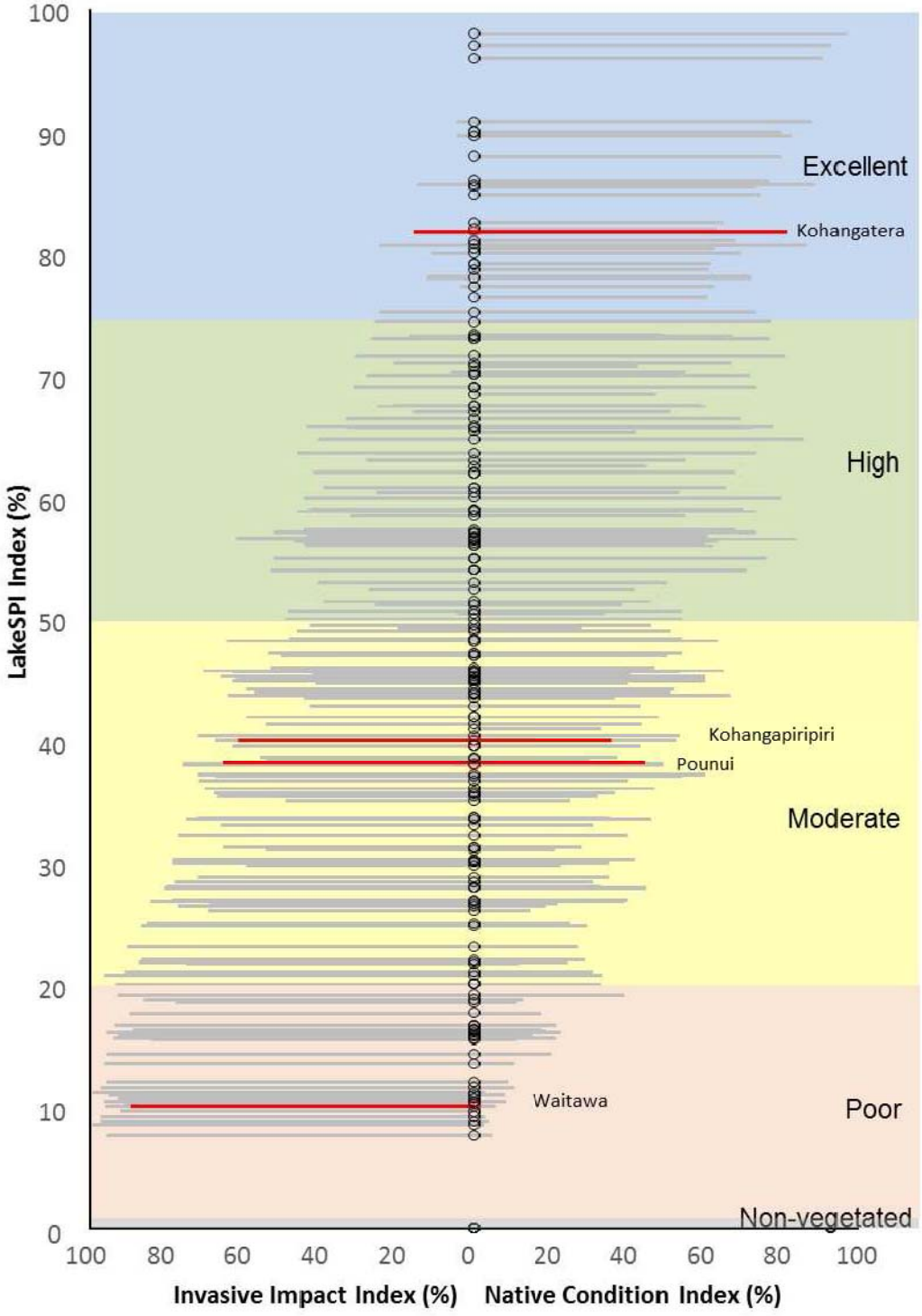

Figure 17: LakeSPI Indices based on the latest results for 259 lakes in grey, showing the scores for the four Wellington lakes as a red line. LakeSPI scores are plotted on the vertical axis, with the Native Condition Index plotted on the right hand horizontal axis, and Invasive Impact Index on the left hand to show the negative influence on LakeSPI scores.

5.2 Changes in LakeSPI Indices

The vegetation of Lake Kohangatera has remained relatively stable during all plant surveys (since 2004). The greatest known threat to the submerged vegetation values of the lake remains the presence of the weed Egeria (*Egeria densa*) upstream in the Gollans Wetland. A delimitation of this weed in 2016 following a herbicide control operation showed biomass has been successfully reduced (de Winton 2016). However, the wetland channel has recently opened-up, which has meant the weed has migrated closer to the lake. Currently there are two sections of thick raupo wetland and one section of open water between the extent of egeria and Lake Kohangatera.

The changed vegetation status in Lake Kohangapiripiri is likely to represent an unusual senescence event in the dominant pondweed (*P. ochreatus*). The shallow nature of this lake after an unusually low lake level in early 2016 (Appendix C) means that pondweeds could synchronously attain the water surface, flower and fruit before naturally dying back. In most lakes (i.e., deeper lakes with a depth gradient), this phenomenon is not so pronounced. Early findings of areas of low vegetation cover (de Winton et al. 2011) may also be keeping with limited senescence events. We would expect a high potential for recovery of native submerged vegetation and recommend that council staff confirm the presence of widespread submerged vegetation in early spring 2016.

The retraction in submerged vegetation depth (and extent) in Lake Pounui indicates a sustained reduction in water clarity which is in keeping with the algal bloom conditions encountered during this 2016 survey and earlier reported anecdotal observations of increased bloom frequency (Perrie and Milne 2012). A shift to higher productivity waters is known to disadvantage isoetes-type plants, for example, algal mats impact on these height-limited plants and higher nutrient concentrations are of limited benefit to Isoetes species that have a slow growth strategy (Smolders et al. 2002). In contrast, nutrient enrichment can advantage elodea-type plants which can escape light limitation by growing upwards and forming a dense canopy close to the water surface. If algal blooms and mats continue we may expect the loss of isoetes and greater dominance by elodea in Lake Pounui.

Increasing nutrient status of Lake Pounui would seem unlikely given the predominantly forested catchments and extensive receiving wetlands. However, lakes with introduced fish, particularly a population of numerous small perch such as documented for Lake Pounui (Jellyman 1980), have a tendency to promote cyanobacterial algal blooms (Smith and Lester 2006, 2007). Moreover, small lakes dominated by introduced fish tend to display poorer water quality than similar lakes without these species (Rowe 2007).

Lake Waitawa has undergone a substantial retraction in the depth extent for submerged vegetation and has lost the native vegetation communities that were recorded in 2002. This indicates a long-term reduction in the light climate for plants. This lake has a history of algal blooms that are fuelled by ongoing internal nutrient regeneration (Perrie and Milne 2012), as well as humic stained water, which together would result in a limited light climate for submerged plant growth.

Lake Waitawa also has multiple introduced fish, with herbivorous rudd, benthivorous tench and common carp known from the lake (Hicks et al. 2006). Combinations of light-limited plant growth and disturbance by introduced fish communities can be expected to supress vegetation (Dugdale et al. 2006) or prevent submerged plant recovery after loss (de Winton et al. 2002). Populations of introduced fish have elsewhere been implicated in the loss of submerged vegetation elements (van Donk and Otte 1996).

Lake Waitawa is considered vulnerable to a 'regime-shift' to a phytoplankton dominated, de-vegetated lake system. Constant blooms of potentially toxin-forming phytoplankton are generally considered as a worse, more intractable problem than dominance by invasive weeds. The LakeSPI method recognises this by scoring non-vegetated lakes lower than lakes that are dominated by invasive weeds.

6 Recommendations

- A check on vegetation development in Lake Kohangapiripiri in early spring 2016 is recommended to confirm recovery is taking place. This check could be undertaken by GWRC staff and would need to be boat-based at 4 to 5 areas away from the outlet but within 10 m distance of the reed bed. The aim would be to confirm native species are present in relative abundance in addition to water buttercup. Photos would help with documentation and possible species identifications.
- Decline in condition of Lake Pounui according to LakeSPI was unexpected. A resurvey using LakeSPI, and a check on the status of Isoetes is recommended in 2018. This lake does not fit the profile of an impacted waterbody prone to algal blooms and warrants further scientific investigation to determine causes.
- Possible trends towards poorer water quality in Lake Pounui are of concern for the outlier population of *Isoetes kirkii* found here, which has disappeared from the Lake Wairarapa complex. We would suggest establishing this entity in culture in case of rapid loss from the lake. For example, NIWA are maintaining a culture of Isoetes plants on behalf of the Lake Omapere Trust, to secure this outlier population after habitat loss.
- Stability shown by Lake Kohangatera suggests frequency of resurvey at intervals of 5 years will be adequate, unless some ecological change is suspected (e.g., entry to the lake by egeria).
- Lake Waitawa is in poor condition according to LakeSPI. However, dominance by an invasive weed such as hornwort is preferable to a non-vegetated condition, where possible beneficial influences of submerged plants are completely lost and the lake remains in a constant state of phytoplankton blooms. Due to the vulnerability of the lake to phytoplankton dominance we would advise against weed management to control hornwort at this time.
- Lakes Kohangatera, Kohangapiripiri and Pounui to date have only recorded relatively benign invasive weeds. Every effort should be made to exclude additional weeds, especially egeria, hornwort or *Lagarosiphon major*, which are capable of completely filling shallow lake systems. Precautions include limiting boat traffic, or ensuring boat hygiene (e.g., Check, Clean, Dry).

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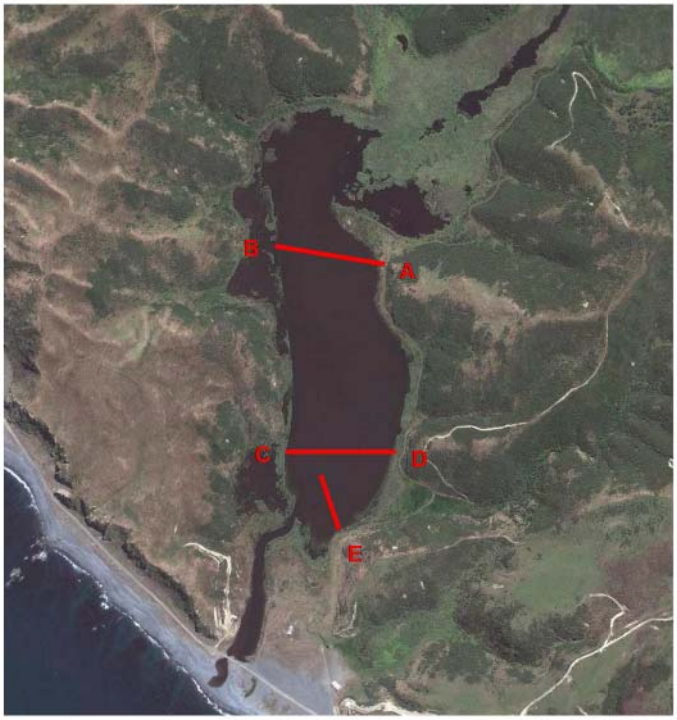
Appendix A Location of LakeSPI sites

Maps and tables show the location of five sites selected for each lake.

Location of five survey sites in Lake Kohangapiripiri.

Lake Kohangapiripiri	NZMG (Easting, Northing)
A	2665574 5981389
B	2665439 5981469
C	2665307 5981245
D	2665474 5981290
E	2665333 5980923



Location of five survey sites in Lake Kohangatera.

Lake Kohangatera	NZMG (Easting, Northing)
A	2666187 5980630
B	2666009 5980606
C	2666068 5980198
D	2666261 5980117
E	2666160 5980030

Location of five survey sites in Lake Pounui.

Lake Pounui	NZMG (Easting, Northing)
A	2687179 5982378
B	2686897 5982278
C	2686380 5982544
D	2686532 5982753
E	2686781 5982828

Location of five survey sites in Lake Waitawa.

Lake Waitawa	NZMG (Easting, Northing)
A	2693527 6051312
B	2693583 6051236
C	2693535 6051066
D	2693388 6051036
E	2693300 6051150

Appendix B Plant species lists

Species list for Lake Kohangapiripiri based on surveys in 1950 (Moar 1950), 2004 (Wells and Champion 2004) 2011 (de Winton et al. 2011) and the current survey (synonyms in parenthesis).

LakeSPI plant community	Species	Taxonomic Authority	1950	2004	2011	2016
Emergents	*Apodasmia similis* (*Leptocarpus similis*)	(Edgar) B.G. Briggs & L.A.S.			✓	
	Schoenoplectus tabernaemontani (*S. validus, Scirpus lacustris*)	(Gmel.) Palla	✓	✓	✓	✓
	Typha orientalis (*T. angustifolia*)	C.B. Presl.	✓		✓	✓
	Eleocharis acuta	R. Br.			✓	
Turf plants	*Crassula kirkii*‡	(Allan) A.P. Druce et Given		✓	✓	
	Elatine gratioloides	Cunn.		✓	✓	
	Glossostigma cleistanthum	W.R. Barker			✓	✓
	Glossostigma elatinoides	Benth.	✓	✓	✓	
	Glossostigma submersum (*G. diandrum*)	Petrie			✓	
	Lilaeopsis novae-zelandiae	(Gand.) A.W. Hill		✓	✓	✓
	Limosella lineata	Gleuck	✓		✓	
	Ranunculus limosella	Kirk		✓	✓	
Milfoils	*Myriophyllum triphyllum* (*M. elatinoides*)	Orchard		✓	✓	
	Myriophyllum propinquum	A. Cunn.		✓	✓	
Pondweeds	*Potamogeton ochreatus*	Raoul		✓	✓	✓
	Potamogeton cheesemanii	A. Bennett	✓	✓		
Charophytes	*Chara australis* (*C. corallina*)	Brown	✓	✓	✓	✓
	Lamprothamnium macropogon (*L. papulosum*)	(A. Braun) J.L. Ophel	✓			

LakeSPI plant community	Species	Taxonomic Authority	1950	2004	2011	2016
	Nitella hyalina	(DC.) Ag.	✓		✓	
	Nitella pseudoflabellata	A. Br.			✓	
	Nitella stuartii	A. Br.			✓	
Invasive species	*Ranunculus trichophyllus*	Chaix		✓	✓	✓
Brackish species	*Ruppia polycarpa* (*R. spiralis*)	R. Mason	✓		✓	
	Zannichellia palustris	L.			✓	
	Lepilaena bilocularis†	Kirk	✓	✓		
Other species	*Azolla filiculoides* (*A. rubra*)	Lam.	✓		✓	
	Centella uniflora	(Colenso) Nannf.		✓		
	Centipeda aotearoana	N.G. Walsh			✓	
	Hydrocotyle novae-zelandiae	Kirk		✓	✓	
	Isolepis prolifer	(Rottb.) R.Br. (1810)			✓	
	Lemna minor	L.	✓		✓	
	Ludwigia palustris	(L.) Elliott		✓	✓	
	Ranuculus macropus	Hook. f.	✓			

†Classified as Nationally vulnerable according to the New Zealand Threat Classification (de Lange et al. 2013).
‡Classified as Naturally uncommon according to the New Zealand Threat Classification (de Lange et al. 2013).

Species list for Lake Kohangatera based on surveys in 1950 (Moar 1950), (Wells and Champion 2004), 2011 (de Winton et al. 2011), 2013 (de Winton 2013) and the current survey (synonyms in parenthesis).

LakeSPI plant community	Species	Taxonomic Authority	1950	2004	2011	2013	2016
Emergents	*Apodasmia similis* (*Leptocarpus similis*)	(Edgar) B.G. Briggs & L.A.S.	✓		✓	✓	✓
	Eleocharis acuta	R. Br.	✓				
	Schoenoplectus tabernaemontani (*S. validus*, *Scirpus lacustris*)	(Gmel.) Palla	✓	✓	✓	✓	✓
	Typha orientalis	C.B. Presl.	✓	✓	✓	✓	✓
Turf plants	*Crassula kirkii* ‡	(Allan) A.P. Druce et Given		✓			
	Glossostigma cleistanthum	W.R. Barker		✓	✓	✓	✓
	Glossostigma elatinoides	Benth.	✓	✓	✓		✓
	Lilaeopsis novae-zelandiae	(Gand.) A.W. Hill	✓	✓	✓	✓	✓
	Limosella lineata	Gleuck			✓	✓	
Milfoils	*Myriophyllum triphyllum* (*M. elatinoides*)	Orchard		✓	✓	✓	✓
	Myriophyllum propinquum	A. Cunn.	✓			✓	
Pondweeds	*Potamogeton cheesemanii*	A. Bennett	✓	✓			✓
	Potamogeton ochreatus	Raoul	✓	✓	✓	✓	✓
	Stuckenia pectinata (*Potamogeton pectinatus*) ‡	(L.) Boerner)			✓	✓	✓
Charophytes	*Chara australis* (*C. corallina*)	Brown	✓*		✓	✓	✓
	Chara globularis	Thuill.			✓	✓	✓
	Lamprothamnium macropogon (*L. papulosum*)	(A.Braun) J.L. Ophel	✓*				
	Nitella hyalina	(DC.) Ag.			✓	✓	✓
	Nitella pseudoflabellata	A. Br.			✓		
	Nitella stuartii	A. Br.			✓	✓	✓

LakeSPI plant community	Species	Taxonomic Authority	1950	2004	2011	2013	2016
Invasive species	*Elodea canadensis*	Michaux			✓	✓	✓
	Potamogeton crispus	L.		✓			✓
	Ranunculus trichophyllus	Chaix		✓		✓	
Brackish water	*Lepilaena bilocularis* †	Kirk			✓	✓	✓
	Zannichellia palustris ‡	L.		✓	✓	✓	✓
	Ruppia polycarpa (*R. spiralis*)	R. Mason	✓	✓	✓	✓	✓
Other	*Azolla filiculoides* (*A. rubra*)	Lam.		✓	✓	✓	
	Callitriche petriei	R. Mason		✓	✓	✓	
	Isolepis prolifer	(Rottb.) R.Br. (1810)		✓	✓		
	Lemna minor	L.		✓		✓	
	Ludwigia palustris	(L.) Elliott	✓			✓	
	Triglochin striata	Ruiz Lopez et Pav.			✓		
Bryophytes	♈*Riccardia* sp. *?R furtiva* (NZ) / *R. reducta* (Australia) group?	L.			✓	✓	✓
	₸*Drepanocladus aduncus*					✓	✓
Rhodominaceae	Red algae?					✓	

† Classified as Nationally vulnerable according to the New Zealand Threat Classification (de Lange et al. 2013).

‡ Classified as Naturally uncommon according to the New Zealand Threat Classification (de Lange et al. 2013).

♈Rodney Lewington, pers comm. 2011.

₸ Owen Spearpoint, pers comm. 2013

Species list for Lake Pounui based on surveys in 1976 (Persse undated, Jellyman 1990), 2007 (Drake et al. 2010), 2011 (de Winton et al. 2011) and the current survey (synonyms in parenthesis).

LakeSPI plant community	Species	Taxonomic Authority	1976	2007	2011	2016
Emergents	*Schoenoplectus tabernaemontani* (*S. validus*)	(Gmel.) Palla			✓	✓
	Typha orientalis	C.B. Presl.	✓	✓	✓	✓
Turf plants	*Crassula sinclairii*	(Hook. f.) A.P. Druce & D.R.			✓	
	Glossostigma elatinoides	Benth.	✓		✓	
	Glossostigma cleistanthum	W.R. Barker			✓	✓
	Glossostigma submersum (*G. diandrum*)	Petrie	✓			
	Elatine gratioloides	Cunn.			✓	
	Lilaeopsis novae-zelandiae	(Gand.) A.W. Hill	✓		✓	✓
	Limosella lineata	R. Br.	✓			
Isoetes	*Isoetes kirkii* *	A. Braun	✓	✓	✓	✓
Milfoils	*Myriophyllum triphyllum* (*M. elatinoides*)	Orchard	✓	✓	✓	✓
Pondweeds	*Potamogeton ochreatus*	Raoul			✓	✓
	Potamageton cheesemanii			✓		
Charophytes	*Chara australis* (*C. corallina*)	Brown	✓		✓	✓
	Chara fibrosa	Ag. ex Bruz., em. R.D.W.		✓		
	Nitella sp. aff. *cristata*				✓	✓
	Nitella pseudoflabellata	A. Br.	✓		✓	
	Nitella hookerii	A. Br.		✓		
	Nitella stuartii	A. Br.			✓	

LakeSPI plant community	Species	Taxonomic Authority	1976	2007	2011	2016
	Nitella hyalina	(DC.) Ag.				
Invasive species	*Elodea canadensis*	Michaux	✓	✓	✓	✓
	Ranunculus trichophyllus	Chaix	✓			✓
	Potamogeton crispus	L.	✓		✓	✓
Other species	*Lemna minor*	L.	✓			
	Azolla filiculoides (*A. rubra*)	Lam.	✓			

* Classified as At Risk, Declining according to the New Zealand Threat Classification (de Lange et al. 2013).

Species list for Lake Waitawa based on surveys in 2002 (Dugdale and Champion 2002) and the current survey (synonyms in parenthesis).

LakeSPI plant community	Species	Taxonomic Authority	2002	2016
Emergents	*Eleocharis sphacelata*	R. Br.	✓	
	Typha orientalis	C.B. Presl.	✓	✓
Pondweeds	*Potamogeton ochreatus*	Raoul	✓	
Charophytes	*Nitella* sp. aff. *cristata*		✓	
Invasive species	*Elodea canadensis*	Michaux		✓
	Egeria densa			✓
	Ceratophyllum demersum	L.	✓	✓
	Potamogeton crispus	L.	✓	✓

Appendix C Lake Level graphs

Water level (mm) for Lake Kohangapiripiri showing a low level event preceded the 2016 survey compared to the previous summer 2011 survey (source GWRC).

Water level (mm) for Lake Kohangatera, showing a low spring to summer level in 2015/16 compared with previous summer surveys in 2011 and 2013. This followed a sustained high water event in mid-2015 that resulted in a likely coastal barrier breach (source GWRC).