LakeSPI Assessment of 33 Auckland Lakes: 2017 Update

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November 2017 Technical Report 2017/028

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Table of contents

1 Executive summary

Auckland Council (AC) contracted NIWA to report on the ecological condition of 33 lakes in the Auckland region using LakeSPI (Submerged Plant Indicators). Surveys of the region's lakes have been undertaken since 2008 and historical vegetation surveys have been used where available. Results are updated based on surveys of 10 lakes carried out over the 2017 autumn (March and May). This report collates and reports all LakeSPI information for the Auckland region's lakes.

LakeSPI indices included a 'Native Condition Index' where higher values indicate better lake condition based on the diversity, depth extent and quality of indigenous plant communities; an 'Invasive Impact Index' where higher values show greater impact from invasive weed species and a lower lake condition; and a 'LakeSPI Index' which provides an overall indication of lake condition with higher values indicating better lake condition. LakeSPI indices are expressed as a percentage of a lake's maximum scoring potential to enable comparisons between lakes.

Lakes were categorised into five groups according to the value of the most recent LakeSPI Index and compared with categories for 281 lakes nationally.

Excellent: Only Mangatawhiri Reservoir (Hunua Ranges) had a LakeSPI Index >75% that classifies this water body as in excellent condition according to LakeSPI. Excellent status lakes are under-represented in the region compared to lakes nationally.

High: Lake Rototoa (South Kaipara, previously Ototoa) and the Wairoa and Waitākere Reservoirs had LakeSPI scores of >50-75% which placed them in the high condition category. High status lakes are under-represented in the region compared to lakes nationally.

Moderate: Seven lakes were in the moderate category of >20-50%. These included three Watercare reservoirs, the reservoir at Silver Hill, Little Shag Lake (Te Arai Regional Park), and Lakes Pokorua and Whatihua at Awhitu. The proportion of lakes in this category is similar to lakes nationally.

Poor: Seven lakes scored a LakeSPI Index of >0-20% and were categorised in a poor state according to LakeSPI. These included the addition in 2017 of Lakes Pupuke and the smaller Pehiakura Lake (reduced status), as well as the bigger Pehiakura Lake, Lakes Okaihau, Kuwakatai, Te Kanae, and Kawaupaku. A higher proportion of lakes fall into the poor category compared with lakes nationally.

Non-vegetated: Seven lakes scored a LakeSPI Index of 0% due to the lack of significant submerged vegetation. These included three Watercare reservoirs (Mangatangi, Hays Creek, Upper Nihotupu), Lake Paekawau and the addition in 2017 of Lake Tomarata to other non-vegetated Te Arai lakes (Slipper and Spectacle). A much higher proportion of the region's lakes are non-vegetated compared to lakes nationally.

Non-vegetated, Lakes Kereta, Wainamu and Western Springs, have been stocked with grass carp to control weed. In these situations the LakeSPI metrics do not provide an appropriate measure of their ecological condition. Likewise, extremely shallow dune lakes along the south Kaipara head (Piripoua, Ngakaru) could not be assessed. The assessment of the Lower Nihotupu reservoir was not completed due to a turbid event.

Major constraints identified during the surveys that impact on vegetation development and LakeSPI values included:

- Impacts by invasive submerged weeds (Invasive Impact Index ≥65%) due to dominance by hornwort (*Ceratophyllum demersum*), *Egeria densa*, and/or *Vallisneria australis* in eight lakes.
- Stability of water level. Eight Watercare reservoirs in the Waitākere and Hunua Ranges were influenced by the amplitude, duration and direction of water level change in the year prior to survey. However, the LakeSPI indices reflected the recent stability of water levels during the few months prior to survey. Two lakes had dried since first surveyed (Karaka, Poutoa).
- Poor water clarity in a number of lakes at the time of survey likely contributed to the poor development and depth extent of submerged vegetation (Lakes Slipper, Spectacle, Paekawau, Silver Hills and Hays Creek Reservoir).
- Additional stresses in some lakes were noted in the form of grazing or disturbance by exotic fish (Rototoa, Tomarata).

The most recent changes in the LakeSPI Index were evaluated to provide an indication of stability of lake condition. Both the ecological magnitude of change and statistical tests (possible for 13 lakes) were used to assess stability.

Six lakes showed no statistically significant ($p < 0.05$, paired t-test) or ecologically significant (average change ≤5%) movement in the LakeSPI Index over successive surveys. These were lakes with surveys spanning five to seven years; Rototoa, big and small Pehiakura, Kawaupaku and Kuwakatai. Wairoa Reservoir also showed no significant change over 18 years. Mangatawhiri Reservoir showed a statistically and ecologically significant improvement in the LakeSPI Index over 18 years. Five lakes showed a statistically and ecologically significant deterioration in the LakeSPI Index within five years (Lakes Tomarata, Pupuke and Whatihua) or 18 years (Mangatangi and Cossey's Reservoir). All lakes showed a reduction in condition from the 'pristine' reference condition.

A schedule for LakeSPI monitoring is presented that integrates both the current condition of lakes and the extent and immediacy of threats facing water body condition. Four lakes showing recent deterioration are proposed for reassessment in 2019. Eleven reservoirs last surveyed in 2008 are proposed for survey in 2020. Three stable vegetated lakes should be kept on a five-year cycle, to be resurveyed in 2022. Surveys of seven lower priority vegetated and non-vegetated lakes are proposed for 2025. The final five lakes should be re-investigated following management activities such as grass carp removal, or plantation forest harvest.

2 Introduction

2.1 Study brief

Auckland Council's Research and Evaluation Unit periodically prepares state of the environment (SOE) reports for the Auckland region that require up-to-date information on the condition of the region's lakes. The LakeSPI (Submerged Plant Indicators) survey method to assess the ecological condition of lakes (Clayton and Edwards, 2006) was developed according to Ministry for the Environment (MfE) agreed criteria for freshwater indicators, for the establishment of long-term monitoring for lake SOE reporting, and to monitor changes in lake condition over time. LakeSPI has been favourably reviewed in a report 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' (MfE 2006). The LakeSPI approach has been described (Clayton and Edwards, 2006) and an analysis of results has been published (de Winton et al. 2012). This method has now been adopted by nine Regional Councils and the Department of Conservation (Macdonald et al. 2013). LakeSPI compliments traditional water quality monitoring, such as the Trophic Level Index method (Burns and Bryers, 2000), by providing ecological information. For example, LakeSPI focuses on the littoral edges of lakes where human interaction is the greatest and where impacts from inflowing water quality is most apparent (Clayton and Edwards, 2006).

In recent years AC has contracted NIWA to assess the condition of 33 lakes within the Auckland region using LakeSPI. This report was prepared to provide a 'one-stop' source of LakeSPI information for the region's lakes. LakeSPI scores for each lake are reported (Section 3), accompanied by a brief description of vegetation character, and impacts or threats that may be facing these lakes are outlined. Current LakeSPI scores are collated and ranked in order, together with an explanation of the main characteristics driving each score, while historical and 'pristine' scores are also considered to identify time trends in condition (Section 4). Finally, recommendations are provided on priorities and schedules for future LakeSPI monitoring of lakes based on their apparent stability, value, and perceived threats (Section 5).

2.2 History of lakes of the Auckland region

The Auckland region has approximately 72 water bodies of 1 ha in size or greater (Freshwater Ecosystems of New Zealand geo-database[1]), ranging in size from small ponds to several large flooded valleys which serve as reservoirs for Auckland's reticulated water supply. Lake types in the region can be categorised depending on where they are situated and how they were formed. These types include sand dune lakes along the western and eastern coasts, water bodies of volcanic origin in the city of Auckland and constructed reservoirs for water storage and abstraction, mainly in the Waitākere and Hunua Ranges.

Prior to people arriving in New Zealand, naturally formed lakes would have been in their natural 'pristine' state. Periodic disruption to lake condition would have occurred

[1] http://www.doc.govt.nz/our-work/freshwater-ecosystems-of-new-zealand/

with natural disturbances, such as volcanic activity, flood events or from dynamic dune processes. Changes in lake condition also took place as the lakes aged, with key influences being changing climatic conditions, changes in catchment vegetation and progressive nutrient enrichment associated with increased productivity. Native submerged plant communities were likely present in all natural lake types as evidenced by early botanists. For example, Cheeseman collected six species of native charophyte from Lake Pupuke in 1884 (Wood and Mason, 1977) and Cunningham et al. (1953) reported extensive native plant communities in five coastal dune lakes within the region.

The reservoirs of the Waitākere and Hunua Ranges were dammed from stream valleys between the early 1900s and 1970s. Newly constructed water bodies are often rapidly colonised by submerged plants that are spread from seed by waterfowl, so that vegetation can develop to a similar extent and diversity to natural systems over a relatively short time.

The early history of land settlement, scale of land use change and proximity to a large population centre meant that lakes in the Auckland region have been especially vulnerable to change. Three major factors cause the accelerated decline in ecological condition of lakes: (1) declining water quality; (2) invasive fish species; and (3) invasive plant species.

Declining water quality typically results from the conversion of forested lake catchments to agriculture, exacerbated by drainage of wetlands and removal of lake-margin vegetation, fertiliser application to pasture, and further impacts from farming activities which, collectively, lead to accelerated nutrient enrichment and siltation. The result is increased productivity at an unnatural rate and dominance of phytoplankton over submerged plants so that lakes may ultimately become de-vegetated and turbid.

In recent years there has been widespread liberation of invasive exotic fish such as rudd (*Scardinius erythrophthalmus*) and koi carp (*Cyprinus carpio*), which have contributed significantly to the deterioration in water quality (Rowe 2007) and the decline of submerged vegetation. Juvenile stages of many invasive exotic fish, and some adult stages, feed on zooplankton and so may release planktonic algae from the grazing control exerted by zooplankton (Rowe 2007). Exotic fish also contribute to increased sediment re-suspension in lakes and can reduce plant cover (Rowe 2007). Herbivorous rudd directly graze on submerged vegetation (de Winton et al. 2003), whilst exotic fish are also implicated in preventing the re-establishment of vegetation from propagules, which contributes to the present poor status of many turbid non-vegetated lakes.

Thirdly, there has been extensive invasion of most lakes by submerged weed species that have largely displaced native submerged vegetation. The earliest recorded weed introduction was *Elodea canadensis*, which arrived in New Zealand in the late 1800s and was subsequently spread around much of the country (Chapman 1970). Cheeseman (1886) recorded the early establishment of *Vallisneria australis* (as *V. spiralis*) in Lake Pupuke. Successively more competitive submerged weeds established in New Zealand lakes, firstly lagarosiphon *(Lagarosiphon major)*, then egeria (*Egeria densa*) and hornwort (*Ceratophyllum demersum)*. Their combined effect has led to the virtual loss of submerged native plants from many lakes. Subsequent rapid and wide scale declines in the abundance of weed-dominated vegetation, particularly egeria (Champion 2002), has occurred in fifteen or more New Zealand

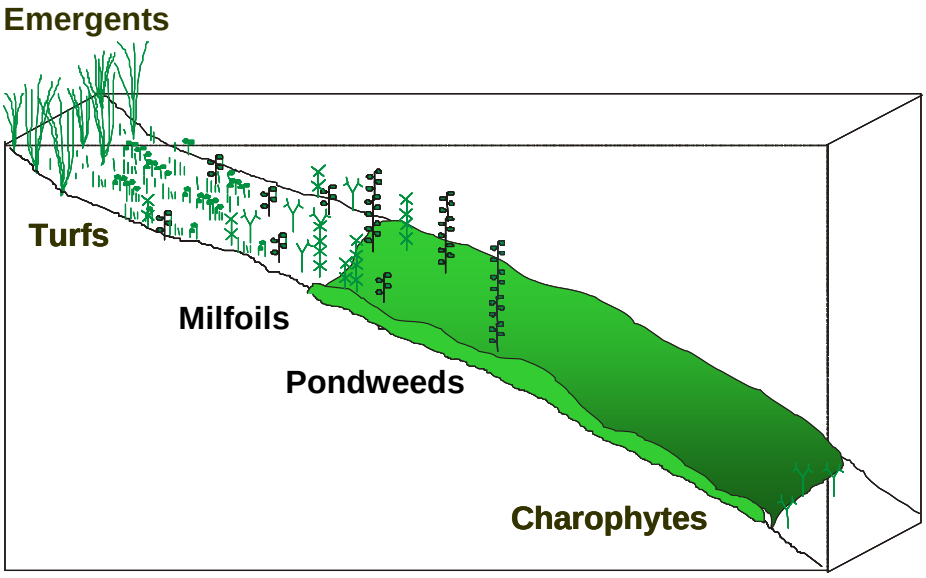
lakes including Lake Wainamu in the Auckland region (de Winton et al. 2007). In non-vegetated lakes, high biomass algal growth or re-suspension of bottom sediments often reduces water clarity to the point where aquatic plants have not re-established.

2.3 Lake vegetation changes

In a pristine state, lakes in the Auckland region would have once contained a diverse range of native plant species to a depth determined by water clarity or the maximum depth of the lake (Figure 1). For very shallow lakes (i.e., <10 m depth) it is likely that plant growth would have occurred across the entire lake bottom at some stage during their development and maturation. Today, there are relatively few lakes in New Zealand that remain in an all-native vegetated state.

Figure 1.

Depth profile illustrating the main components of native lake vegetation.



With the introduction of invasive submerged plant species during the mid-1900s, native plants in most lakes were displaced by invasive weed species, often forming tall monospecific weed beds (Figure 2), which were then especially vulnerable to subsequent decline and dominance by phytoplankton or turbid water conditions (Figure 3). Although invasive species are not favourable in terms of overall lake condition, the presence of any submerged plants in a lake is preferable to none, because they mitigate many of the symptoms of eutrophication (e.g., lock-up nutrients, maintain water clarity, compete with phytoplankton).

Figure 2.
Depth profile illustrating the potential impact of invasive species.

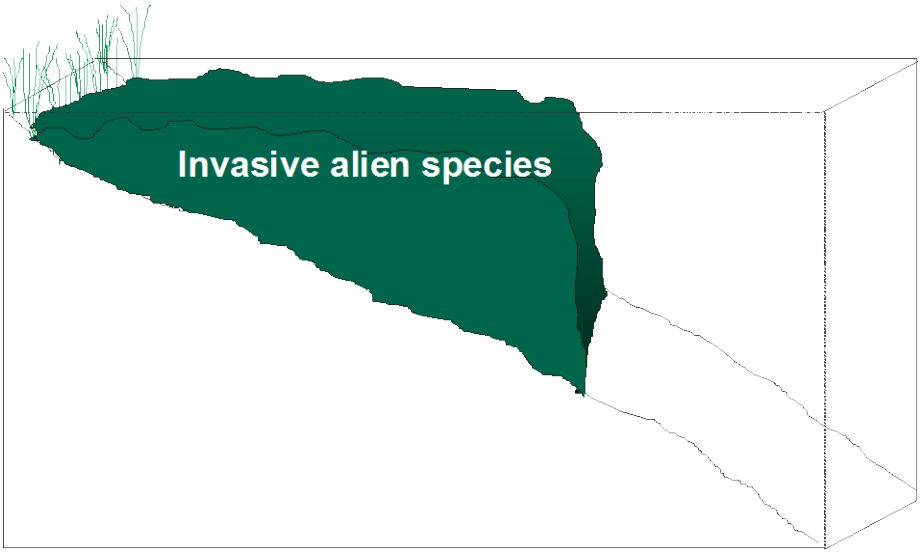
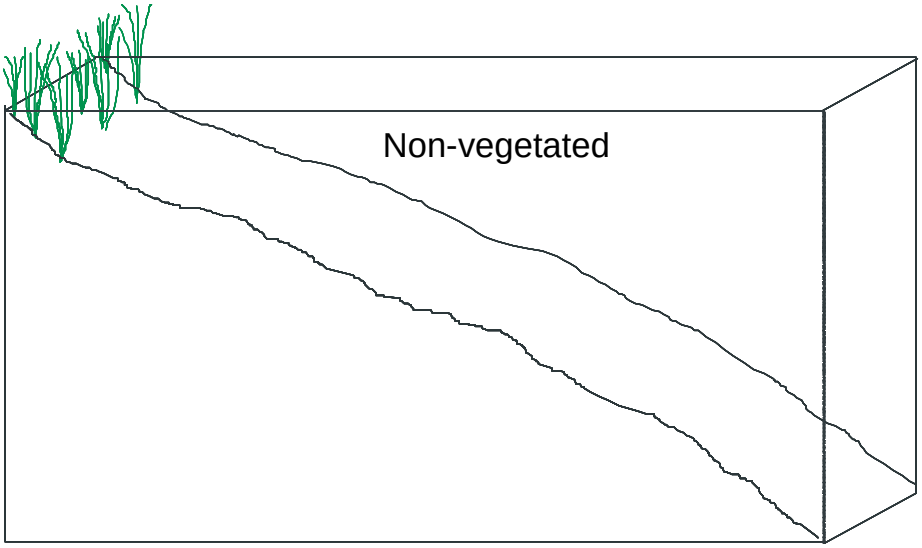


Figure 3.
Depth profile illustrating a non-vegetated lake.



2.4 Plants as indicators of lake condition

Submerged plants have a number of advantages that favour 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 physico-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 lake center) 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.

3 Study methods

3.1 LakeSPI

LakeSPI is a bio-assessment tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring trends. Key features of aquatic plant 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 quality of indigenous plant communities. A higher score means healthier, deeper, diverse submerged vegetation.

'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 Index and Invasive Impact Index (inversed) 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, high plant diversity and deeper vegetation extent are taken to represent 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 and Edwards, 2006).

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 https://www.niwa.co.nz/our-science/freshwater-and-estuaries/lakespi-keeping-tabs-on-lake-health/outputs.The LakeSPI method is supported by a web-reporting service found at https://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.

3.2 Reference conditions

To help put the LakeSPI indices into context, each lake has been assessed using three different conditions: Pristine (or potential condition), Historical and Present day.

3.2.1 Pristine condition or potential 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. Characteristics of vegetation structure and species composition are extrapolated from lake vegetation characteristics where given by early botanists (e.g., Cunningham et al*.* 1953), or from un-impacted examples of similar lakes.

In the case of constructed reservoirs a pristine condition is not applicable as in its original state it would have existed as a stream system. In these cases a best potential condition is estimated in a similar way to pristine condition, but based on current reservoir depth. A 'pristine condition' or 'potential condition' reference allows lake managers to better compare present day lake condition with what the lake once would have been, or could be.

3.2.2 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 NIWA's Environmental Information Browser (https://ei.niwa.co.nz/search/fbis). The limitations of source information are considered in these assessments with NIWA's data providing the most reliable and comprehensive information (see information sources below). Reference to historical LakeSPI scores allows changes over the last few decades to be followed.

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.

3.2.3 Present day condition

Present day conditions were 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.

3.3 LakeSPI status

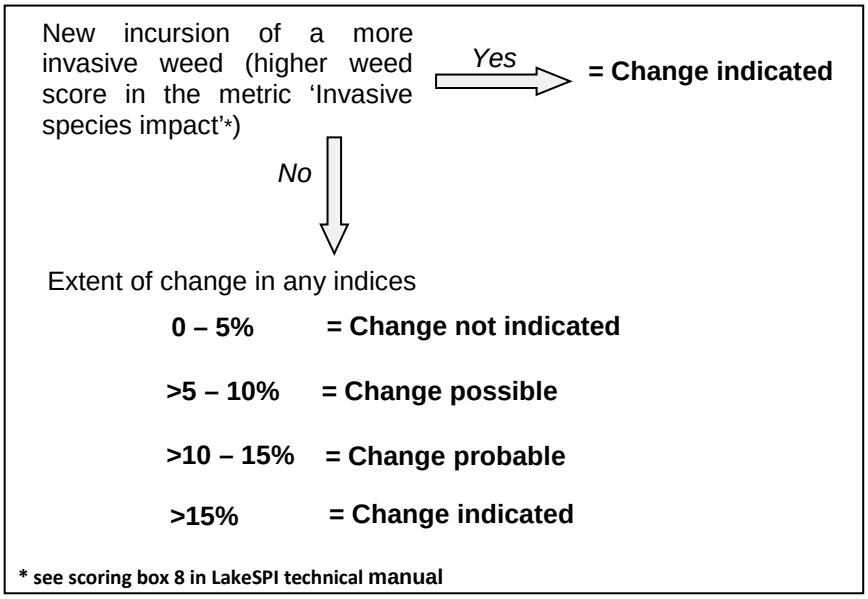
For ease of reporting LakeSPI results, five lake condition categories are used to provide a description of a lakes status at the time of a survey. These categories provide a summary of the data, and allow for comparisons to be made between lakes along a scale of LakeSPI condition according to the LakeSPI Index score:

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

3.4 LakeSPI trends

General guidelines (Figure 4) have been developed by NIWA to give a scale of probabilities for *ecological* change in lake condition with the extent of change in the LakeSPI indices over multiple surveys. These guidelines, based on expert judgment, have considered variation by different observers and the response of LakeSPI scores to major ecological events in lakes.

Figure 4.
Guidelines for assessing the significance of change in LakeSPI Indices over multiple surveys of a lake.



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

3.5 Vegetation description sources

Data for historical LakeSPI assessments have been collected from a variety of sources including published accounts of vegetation. Historical data was obtained from Cunningham et al. (1953), where plant grab samples were used to indicate vegetation

distribution and composition on bathymetrical maps and to note dominant plant species in the text and tables. The limitations of such remote sampling include a level of uncertainty over vegetation detection and lack of information about plant covers; therefore we have made some assumptions based on our knowledge of plant development in lakes of similar vegetation composition.

Unpublished vegetation reports were also used to generate scores, for example, Gibbs et al. (1999) undertook snorkel observations at limited sites for six Auckland lakes that are useful in confirming vegetation presence and changes in composition or weed status.

Historical NIWA macrophyte survey data provides the most reliable data for generating historical LakeSPI scores. Key information on vegetation composition, 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 (NIWA unpublished data).

Present day assessments were generated from recent LakeSPI surveys at these lakes (last 5 years), or if lacking, from surveys conducted specifically for this report (Table 1).

Table 1.

Lake grid reference (New Zealand Transverse Mercator Projection), size, and most recent survey date for 33 lakes assessed in the Auckland region using LakeSPI from surveys carried out specifically for this report or from AC records (Lake Wainamu).

Lake Name	East NZTM	North NZTM	Size (km^2)	Most recent survey date
Cossey's	1787547	5897211	1.132	21/10/2008
Hays Creek	1779564	5895634	0.139	21/10/2008
Karaka	1715596	5947634	0.024	25/02/2010
Kawaupaku	1730005	5915818	0.098	22/05/2017
Kereta	1714422	5949693	0.236	27/02/2012
Kuwakatai	1710982	5956779	0.278	23/05/2017
Little Shag	1747598	5996492	<0.01	25/04/2012
Lower Huia	1739409	5905887	0.470	30/10/2008
Lower Nihotupu	1743462	5908545	0.511	30/10/2008
Mangatangi	1796196	5891451	1.544	21/10/2008
Mangatawhiri	1791615	5894449	1.239	21/10/2008
Ngakuru	1718966	5942560	<0.01	03/11/2005
Okaihau	1728437	5925300	0.057	28/02/2012
Rototoa	1710843	5958624	1.066	24/05/2017
Paekawau	1727957	5927300	0.032	25/02/2010
Pehiakura (Big)	1743356	5883698	0.043	07/03/2017
Pehiakura (Small)	1743468	5883335	<0.01	07/03/2017

Piripoa	1719447	5941811	<0.01	03/11/2005
Pokorua	1744927	5882495	0.259	06/03/2017
Poutoa	1718287	5944643	<0.01	24/05/2017
Pupuke	1757588	5928039	1.038	25/05/2017
Silver Hill	1740040	5988528	0.149	29/10/2008
Slipper	1746657	5995739	0.090	29/10/2008
Spectacle	1746747	5994660	0.438	29/10/2008
Te Kanae	1715290	5951255	0.056	31/10/2008
Tomarata	1748358	5993318	0.144	23/05/2017
Upper Huia	1736672	5908072	0.180	30/10/2008
Wainamu	1730872	5916363	0.150	17/03/2011
Whatihua	1748113	5873293	0.039	06/03/2017
Upper Nihotupu	1739105	5909722	0.102	30/10/2008
Wairoa	1789201	5892920	0.943	21/10/2008
Waitākere	1735885	5914673	0.253	30/10/2008
Western Springs	1753629	5918586	0.074	31/10/2008

3.6 Additional information

Extreme water level fluctuations (i.e., >2 m) can influence vegetation development and depth distribution depending on the amplitude, temporal pattern of change and the timing of vegetation investigations in relation to water level history. Where large fluctuations were known (i.e., Watercare managed reservoirs) we obtained water level data as background information.

Interpreting LakeSPI scores against extreme water level fluctuations can be problematic, especially when fluctuations are of an episodic rather than seasonal pattern. For example, an under estimated LakeSPI score is likely where the speed of lake draw down exceeds the rate that plants respond by colonising downslope. Conversely, LakeSPI scores can be artificially high where rapid water level increase means plants persist at depths beyond their natural survival range. However, where a history of water level change is known it may be possible to correct scores or otherwise acknowledge the direction of possible artifacts.

The presence of coarse fish, particularly herbivorous rudd (*Scardinius erythrophthalmus*) and koi carp (*Cyprius carpio*) were also noted where relevant as these fish are known to have deleterious impacts upon the development of submerged vegetation.

4 Results

LakeSPI results for each lake have been presented in the form of a table identifying the LakeSPI Index, Native Condition Index, and Invasive Impact Index. Indices are presented as a percentage of each lake's maximum scoring potential and can be interpreted as follows:

HIGHER LakeSPI Index = Better lake condition.

HIGHER Native Condition Index = Better lake condition.

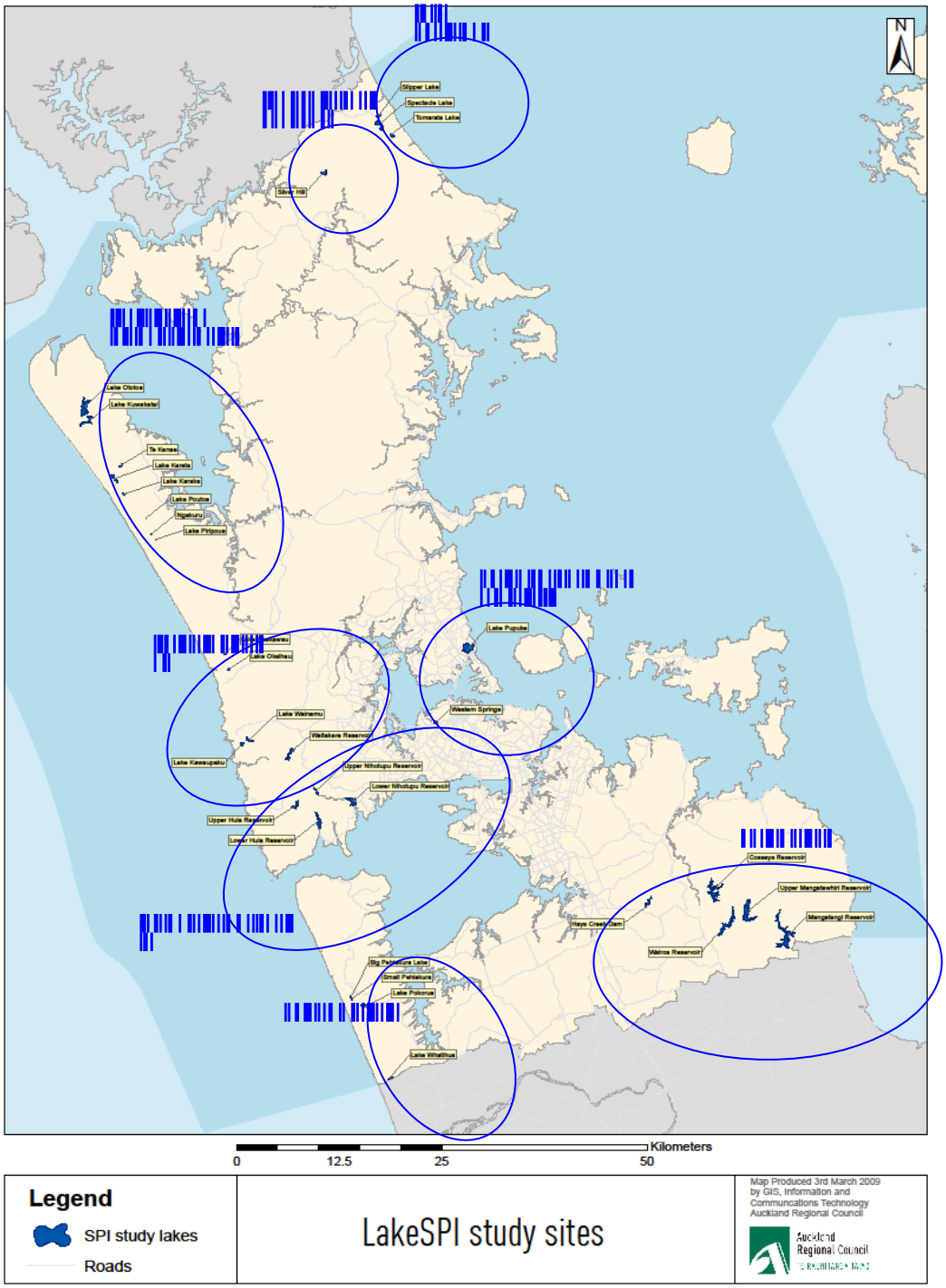
LOWER Invasive Impact Index = Better lake condition.

Descriptions of present day lake condition based on LakeSPI results, together with historic descriptions where available, are presented below by grouping lakes under eight geographical groupings (Figure 5). The Te Arai Lakes include Tomarata, Little Shag, Spectacle and Slipper; the Silver Hill Reservoir is grouped separately; South Kaipara group contains Lakes Rototoa, Kuwakatai, Te Kanae, Kereta, Karaka, Poutoa, Ngakaru and Piripoua; the Muriwai group are Lakes Paekawau, Okaihau, Wainamu and Kawaupaku; Auckland City Lakes are Lake Pupuke and Western Springs; the Waitākere group are Waitākere, Upper Nihotupu, Lower Nihotupu, Upper Huia and Lower Huia Reservoirs; the Awhitu Lakes are Big and Small Pehiakura, Pokorua and Whatihua; and the Hunua group are Cossey's, Hays Creek, Upper Mangatawhiri, Wairoa and Mangatangi Reservoirs. Within each geographical group, lakes are presented in order of decreasing LakeSPI scores.

Species lists based on the most recent survey for each lake are presented in the appendix.

Figure 5.

Geographical grouping of Auckland region lakes.



4.1 Te Arai Lakes

Little Shag Lake

Latest assessment:	**2012**
Lake condition:	**Moderate**
Stability:	**-**
Lake Max Depth (m):	**6**
Lake type:	**Dune**

Little Shag Lake is situated within a catchment of native forest/shrubland and exotic forestry in the newly formed Te Arai Regional Park. Lake waters were strongly coloured with humic substances, but relatively clear. Submerged vegetation was restricted to a narrow, near continuous band around the lake edge. The LakeSPI score of 39% (Table 2) reflected dominance by native charophytes (two common species), but with a major contribution from the exotic weed *Utricularia gibba*.

Evidence suggests *U. gibba* is commonly spread by waterfowl and it has progressively invaded lakes in Northland, Auckland, and the Waikato region, especially lakes isolated from human population and access (de Winton et al. 2009, Compton et al. 2012).

Around the lake margin was commonly a sudd of marginal plants and tall emergents, *Typha orientalis* and *Eleocharis sphacelata*, with the extent of sudds suggesting some seasonal water level fluctuation.

Table 2.

LakeSPI results for Little Shag Lake. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Present day	2012	39	30	54

4.1.1 Silver Hill Reservoir

Latest assessment:	**2008**
Lake condition:	**Moderate**
Stability:	**-**
Lake Max Depth (m):	**13.5**
Lake type:	**Reservoir**

A moderate LakeSPI Index of 30% (Table 3) reflects the restricted depth of vegetation around the lake and presence of the invasive pondweed *Potamogeton crispus*, which dominated at some sites. Overall, pondweeds formed a narrow fringe, extending from the flooded pasture edge at 0.5 m depth to a maximum of 2.1 m depth. Individual, tall-growing clumps of the alien *Aponogeton distachyos* were also present to 2.4 m depth. This irrigation reservoir was constructed in the early 1990s and the submerged vegetation present is comprised of species commonly spread from seed by waterfowl and often dominant in isolated farm dams.

Table 3.

LakeSPI results for Silver Hill Reservoir. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		98	96	0
Present day	2008	30	22	59

4.1.2 Lake Tomarata

Latest assessment:	**2017**
Lake condition:	**Non-vegetated**
Stability:	**Declining**
Lake Max Depth (m):	**6**
Lake type:	**Dune**

The latest 2017 assessment showed the lake has undergone a major vegetation decline since 2012 and currently has a non-vegetated status (LakeSPI Index 0%, Table 4). No submerged plants were detected at four of the five survey sites, with remnants of native charophytes (<1% cover) detected at one site on the western shore. The lake appeared more darkly stained (Figure 6) than previously observed and divers noted disturbance of the bottom sediments that is usually attributed to coarse fish. A continued decrease in kuta (*Eleocharis spacelata*) around wetland margins of the lake was observed, together with some dislodged clumps of other emergent plant species (Figure 6).

Dark water staining and loss of submerged vegetation has been reported for Northland dune lakes due to mobilised organic matter as result of harvesting of plantation forest in their catchment (Champion 2016). Given the coastal forest belt in the Te Arai area, a similar explanation may be relevant for the significant change in LakeSPI status of this lake. The presence of coarse fish, rudd, tench (New Zealand Freshwater Fish Database) and koi carp (Wells 2016) means that disturbance of submerged vegetation may also have contributed to plant disappearance.

Figure 6.

Left; dark staining suggests light limitation may have contributed to the decline of submerged plants in 2017. Right; a clump of dislodged emergents.

A review of impacts on lake ecology from recreational activities at Lake Tomarata raised the risk of this lake losing submerged vegetation (Wells 2016) based on 'receding macrophyte depth limits and lower native macrophyte covers' and a 'marked declining trend over the three surveys'.

In 2008 the lake had a LakeSPI status of excellent (LakeSPI Index 78%) due to native plant dominance, the absence of invasive weeds, and native charophytes extending around the lake to 3.9 m depth. In 2012 this status had decreased to high status (LakeSPI Index 63%), with loss of vegetation from one site, but no (statistically) significant change discernible in any LakeSPI indices or depth metrics.

Although not directly comparable due to differences in sites, the 1988 survey recorded charophyte vegetation to 6 m depth and generated a similar LakeSPI score to 2008 (Table 4), but was impacted slightly by the presence of the relatively benign weed *Juncus bulbosus*. No submerged vegetation was recorded during a limited investigation in 1999 (Gibbs et al. 1999) with a default LakeSPI Index of 0% (Table 4). Loss of submerged vegetation at that time was attributed to a possible flood event decreasing water clarity and/or grazing by the herbivorous fish rudd (Gibbs et al. 1999) which had been known in the lake since 1975 (Cadwallader, 1978). A reference to loss of the bottom cover of charophyte vegetation in 1989 (Gibbs et al. 1999) proved erroneous, and charophytes were confirmed present in 1989 (ARWB 1990).

Table 4.

LakeSPI results for Lake Tomarata. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Historical data	*1988	77	66	11
	†1999	0	0	0
	2008	78	56	0
	2012	63	45	0
Present day	2017	0	0	0

** site selection was 4 sites only in 1988*
† 1 site only in 1999

4.1.3 Lake Spectacle

Latest assessment:	**2008**
Lake condition:	**Non-vegetated**
Stability:	**Stable**
Lake Max Depth (m):	**7**
Lake type:	**Dune**

Lake Spectacle has not had submerged vegetation on the three occasions it has been surveyed (1988, 1999, 2008), and therefore has received a default LakeSPI Index of 0% (Table 5). In 1999, the lake was reported as having the worst water quality of seven Auckland Lakes assessed (Gibbs et al. 1999) and submerged plants were effectively excluded by low water clarity (<1 m Secchi Disc depth) and floating sudds of marginal vegetation that extended out over 2 m in depth. Herbivorous rudd are known to have been present in this lake since 1979 (FBIS).

Table 5.

LakeSPI results for Lake Spectacle. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Historical data	*1988	0	0	0
	1999	0	0	0
Present day	*2008	0	0	0

** The 1988 result is based on 2 sites, 1999 on 1 site and 2008 on 3 sites.*

4.1.4 Lake Slipper

Latest assessment:	**2008**
Lake condition:	**Non-vegetated**
Stability:	**Stable**
Lake Max Depth (m):	**5.3**
Lake type:	**Dune**

Lake Slipper is connected to Lake Spectacle via a wide drainage channel. Both lakes are likely to have similar water quality issues and like Lake Spectacle, Lake Slipper has been devoid of submerged vegetation during 1988 and 2008 surveys. This has resulted in a LakeSPI Index of 0% (Table 6).

Table 6.

LakeSPI results for Lake Slipper. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
	*1988	0	0	0
Present day	2008	0	0	0

** The 1988 result is based on only 1 site and 2008 2 sites.*

4.2 South Kaipara Lakes

4.2.1 Lake Rototoa (previously Ototoa)

Latest assessment:	**2017**
Lake condition:	**High**
Stability:	**Declining**
Lake Max Depth (m):	**27.5**
Lake type:	**Dune**

In 2017 Lake Rototoa continued to show a high status according to LakeSPI (LakeSPI Index 59%) on account of its primarily native plant communities and deeper vegetation development. A Native Condition Index of 55% (Table 7) reflected widespread native charophyte meadows, together with native pondweeds and beds of emergent plants. The expected expansion by the recent (post 2007) invasive weed hornwort (*Ceratophyllum demersum*) had not eventuated (Figure 7) and the Invasive Impact Index remained similar to 2010. Alien bladderwort (*Utricularia gibba*) also remained limited to amongst the shallow reeds and rushes as in 2010 (Figure 7).

Most recently a slight but significant reduction in the maximum depth extent of plants, from between 11.4 m to 12.2 m in 2010, down to between 9.8 m to 11.5 m in 2017, suggests water clarity has decreased. This is in keeping with lower than previous water transparency noted by divers and the degree of development of blue-green algal coatings on plants (Figure 8). Coarse fish, such as perch, goldfish, rudd and tench are recorded from the lake (New Zealand Freshwater Fish Database), and these represent a potential disturbance pressure on the submerged vegetation (de Winton et al. 2002. Dugdale et al. 2006). Of concern is the level of sediment disturbance usually associated with coarse fish browsing, which was evident near the maximum depth limit of vegetation (Figure 8).

Figure 7.

Left; typically single shoots of hornwort were found amongst reeds in shallow water. Right; alien bladderwort formed local high covers in the shallows

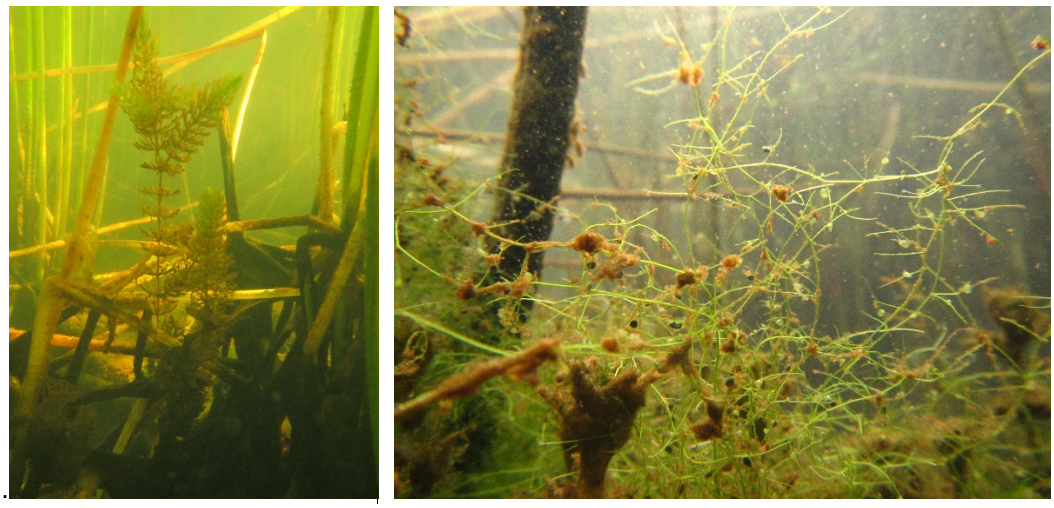


Table 7.

LakeSPI results for Lake Rototoa. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		96	93	0
	1984	74	57	0
	1988	71	51	0
Historical data	2005	70	51	0
	*2007	72	60	8.1
	2010	61	56	27
Present day	2017	59	55	29

** The 2007 survey used different sites to those used in previous years.*

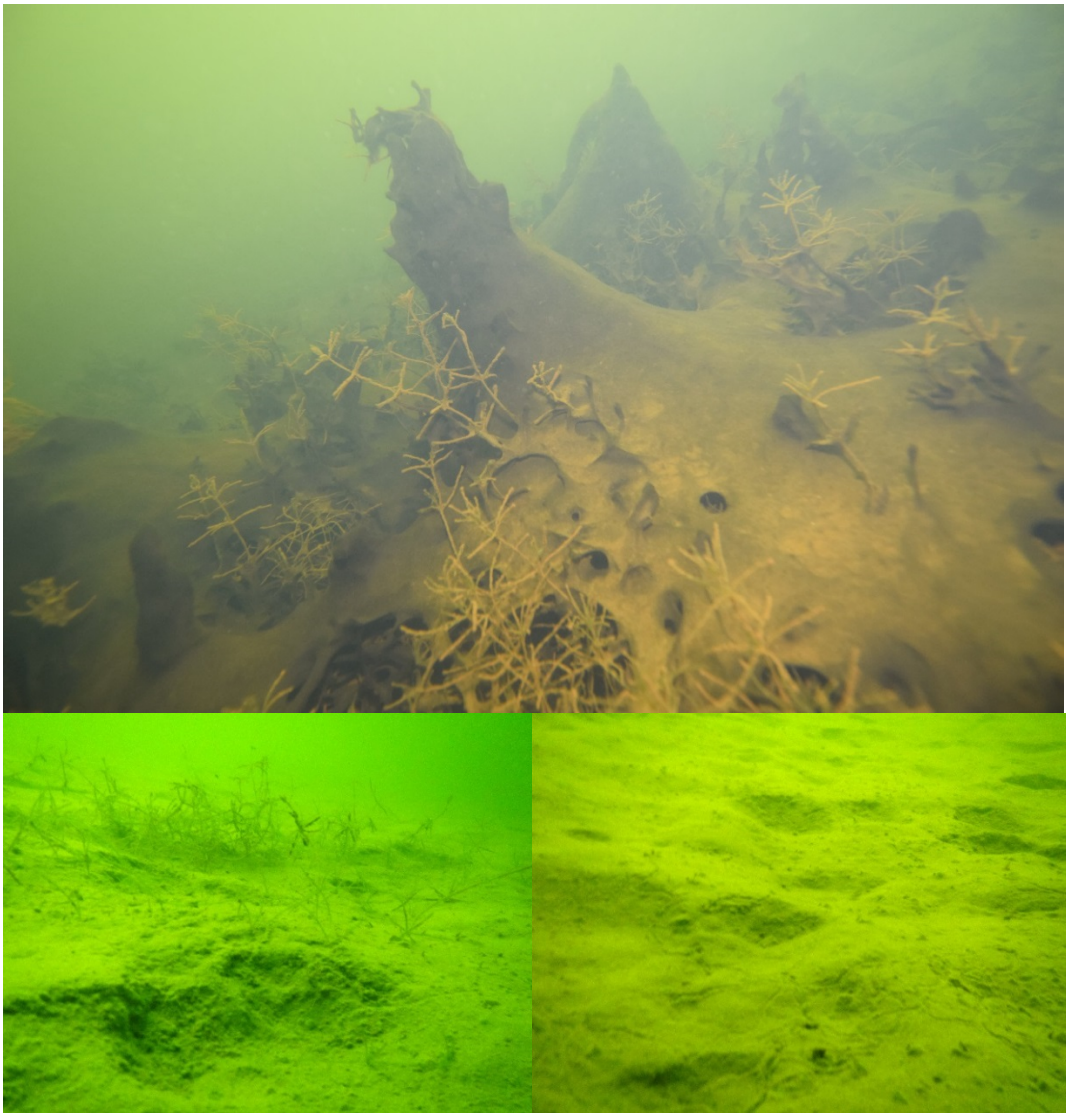
Between 2005 and 2010 there were small but significant changes in all LakeSPI Indices. Firstly there was an extension in the depth limits of native vegetation resulting in a higher Native Condition Index in 2010. Also at this time there was an expansion in alien bladderwort and the newly recorded hornwort leading to an increased Invasive Impact Index. The net result was a slight but significant reduction in LakeSPI Index which has been sustained in 2017.

Previously, the lake would have recorded a high LakeSPI status (70-74%) based on early vegetation survey results from 1984 (Tanner et al. 1986) and 1988 (unpublished NIWA data) (Table 7).

Lack of historical information prior to 1984 has restricted our ability to generate historical LakeSPI scores for earlier survey dates. Cunningham et al. (1953) did not show the presence of submerged species on their 1950 vegetation map for the lake), although a native charophyte was noted as dominant within a sheltered bay. Charophytes were recorded by Green (1975) as abundant along the southern lake edge to depths of 10-15 m so we can only assume that submerged vegetation was present during the 1950 survey but was missed by the plant grab method of sampling employed by Cunningham et al. (1953).

Figure 8.

Top; skin of blue-green algae covers the charophyte bed. Bottom; suspected fish disturbance within and below the deeper charophyte beds.



4.2.2 Te Kanae Lake

Latest assessment:	**2008**
Lake condition:	**Poor**
Stability:	**-**
Lake Max Depth (m):	**18**
Lake type:	**Dune**

The lake at Te Kanae Road had a poor LakeSPI Index (10%) and one of the highest Invasive Impact Indices (96%) reflecting the impact hornwort is having on the lake (Table 8). Hornwort formed beds up to 3 m in height that extended from the margin of emergent plants to a maximum of 6.6 m depth, and drifting shoots from these beds were noted on the lake bed to depths exceeding 12 m. The only other submerged plants seen were a native milfoil and fragments of the invasive weed *Utricularia gibba* at one site only.

Koi, rudd and tench (*Tinca tinca*) have been liberated to the lake (Grant Leighton, landowner, pers comm. 2008) and a large koi, together with signs of sediment disturbance, was observed during the survey. Koi carp are frequently incompatible with significant submerged vegetation on account of direct plant disturbance (Crivelli 1983) and impacts on water quality (Rowe 2007). However, the fact that this lake has dense sandy substrates, and that non-rooted hornwort is less susceptible to physical disturbance, may explain why vegetation destruction has not been severe.

Table 8.

LakeSPI results for Te Kanae Road Lake. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		96	93	0
Present day	2008	10	4	96

4.2.4 Lake Kuwakatai

Latest assessment:	**2017**
Lake condition:	**Poor**
Stability:	**Stable**
Lake Max Depth (m):	**15**
Lake type:	**Dune**

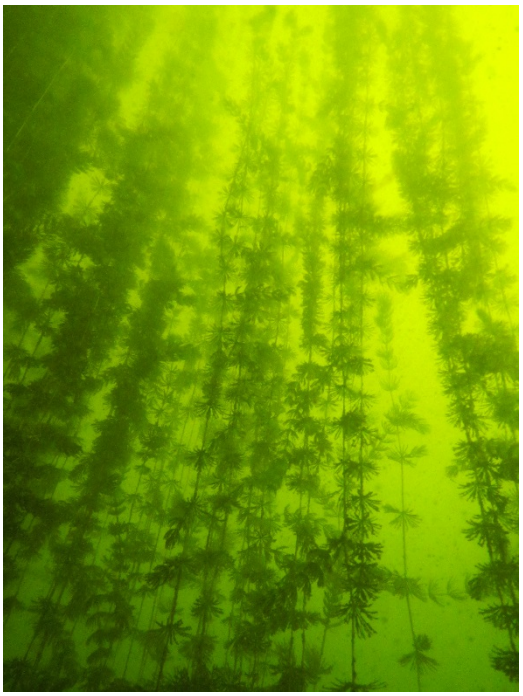
The category of Lake Kuwakatai continues to be poor, with a LakeSPI Index of 8% (Table 9) due to a large impact from the invasive weed hornwort (*Ceratophyllum demersum*). Large hornwort beds extended from the margins to between 6.6 and 7.8 m depth, which in places were up to 5.4 m tall (Figure 9). Emergent marginal plants remained well developed along the northern and eastern shorelines and scattered along the southern shoreline. No native submerged plants were recorded. An algal bloom was noticeable in surface waters at the time of the survey. Large koi carp were observed by divers, and perch, goldfish, tench and rudd are also known from this lake (New Zealand Freshwater Fish Database), but no impacts on hornwort beds were discerned.

Lake Kuwakatai has had a poor status (LakeSPI Index <20%) since 2008 and a correspondingly high Invasive Impact Index of ≥99% (Table 9). Previously only one native submerged plant, *Myriophyllum triphyllum,* was encountered and this was uncommon.

The LakeSPI Index generated from a limited earlier survey in 1999 was lower (4%), as hornwort beds were reported over a more restricted depth range to 2.5 m (Gibbs et al. 1999). Previously, in 1988, no submerged plants were recorded giving a default LakeSPI score of 0%. At this time, the lake waters were described as milky, and emergent plants formed a floating sudd over depths of up to 3 m.

Figure 9.

Tall hornwort beds photographed at their maximum depth limit.



In 1950, native charophytes were recorded to 4 m depth in the south-east of the lake and less than 2 m depth within the shallow northern arm (Cunningham et al. 1953). A generated LakeSPI Index of 68% based on this historic description reflects a moderate native character, absence of invasive weeds and a modest vegetation depth extent.

Table 9.

LakeSPI results for Lake Kuwakatai. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		96	93	0
Historical data	1950	68	44	0
	*1988	0	0	0
	*1999	4	0	96
	2008	11	5	99
	2012	9	2	99
Present day	2017	8	0	100

** The 1999 results are based only on 1 site. The 1988 result is based on 3 baseline sites.*

4.2.5 Lake Karaka

Latest assessment:	**2010**
Lake condition:	**Dry**
Stability:	**-**
Lake Max Depth (m):	**1.3**
Lake type:	**Dune**

In 2010 Lake Karaka was dry and previous open water areas had been largely colonised by *Cyperus* spp. vegetation. The lake was not assessed using LakeSPI due to the lack of aquatic habitat.

In 2005 submerged plants did not exceed 10% cover in Lake Karaka resulting in a default LakeSPI Index of 0% (Table 10). Only occasional shoots of two species of native pondweeds were recorded to 0.3 m, and extensive areas in shallow water were bare, although diverse and well developed emergent plants fringed the lake (Champion and de Winton 2005).

Table 10.

LakeSPI results for Lake Karaka. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		97	93	0
Historical data	*2005	0	0	0
Present day	2010	0	0	0

** The 2005 survey is based on only 3 sites, and 2010 survey on 2 sites.*

4.2.6 Lake Kereta

Latest assessment:	**2012**
Lake condition:	**Non-vegetated**
Stability:	**-**
Lake Max Depth (m):	**2.3**
Lake type:	**Dune**

Grass carp (*Ctenopharyngodon idella*) were stocked into Lake Kereta over 2008 to 2009 to improve amenity values of the lake. Effects of grass carp grazing of weed beds were not immediately apparent because of the small size and probable high mortality of the fish. However, by the 2012 LakeSPI survey it was estimated that over 99.9% of the previous hornwort beds had been removed. Eradication of hornwort had not yet been achieved, however, with shoots commonly found where fish access was restricted such as amongst dense stems of emergent beds of *Zizania latifolia*. The current non-vegetated status of the lake (Table 11) was a direct result of grass carp stocking and therefore is not indicative of lake ecological condition.

In 2008 the very low LakeSPI Index of 8% (Table 11) resulted from the high level of invasion by hornwort (Invasive Impact Index of 94%), where almost the entire lake bed was covered. A few plants of a native milfoil and charophyte species were limited to a shallow sand bank within the lake.

A LakeSPI Index of 13% was generated from a survey in 1999 (Table 11) which described the extent of hornwort dominance for the first time (Gibbs et al. 1999). Conversely, in 1988 the lake scored highly (70%) due to a vegetation dominated by native milfoils to 1.3 m depth, which was only impacted to a limited extent by the benign invasive weed *Potamogeton crispus* (Invasive Impact Index of 6%). Native vegetation existed until at least the early 1990s (Gibbs et al. 1999). In 1950 the lake was deeper (maximum bathymetry 5 m) with a native vegetation dominated by charophytes, pondweeds and milfoils, recorded to 4 m depth (Cunningham et al. 1953). The corresponding high LakeSPI Index of 85% (Table 11) reflects the extent of native submerged vegetation and lack of any invasive plant at that time.

Table 11.

LakeSPI results for Lake Kereta. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Historical data	1950	85	70	0
	1988	70	47	6
	* 1999	13	15	93
	2008	8	3	94
Present day	†2012	0	0	0

** The 1999 results are based on 1 site. The 1988 result is based on 3 baseline sites.*
†The 2012 result is not indicative of lake ecological condition due to the influence of grass carp present in the lake.

4.2.7 Lake Ngakuru and Piripoua

Latest assessment:	**2005**
Lake condition:	**Not suitable for LakeSPI**
Stability:	**-**
Lake Max Depth (m):	**<1.5**
Lake type:	**Dune**

These lakes were represented by a series of shallow (usually<1.5 m) basins that had a mixture of marginal and submerged plants to <0.3 m depth. These included native milfoils and pondweeds at variable covers (Champion and de Winton 2005). Their shallow nature and the difficulty in distinguishing a true submerged plant community from marginal and ephemeral amphibious species means these lakes are not suitable for the LakeSPI method of assessing ecological condition.

4.2.8 Lake Poutoa

Latest assessment:	**2017**
Lake condition:	**Non-vegetated (dry)**
Stability:	**Unstable**
Lake Max Depth (m):	**1.6 (2005)**
Lake type:	**Dune**

In 2017 the lake was dry and colonized by wooly nightshade and pampas.

In 2005 Lake Poutoa had a LakeSPI Index of 90% (Table 12), the highest LakeSPI Index identified for any of the Auckland lakes and a resultant excellent status. This was a result of a complete vegetation cover by native submerged vegetation in this very shallow lake, with little impact from invasive species. Charophyte meadows together with native pondweeds, grew from 0.8 to 1.5 m depth but were largely excluded from the shallow margins to 1 m depth by *Ludwigia peploides* (Champion and de Winton 2005). The invasive species *Juncus bulbosus* was limited to the margins and had minimal impact on the lake.

In 2010 the water level of Lake Poutoa had dropped by 1.1 m relative to 2005 leaving a remnant basin of 0.5 m depth surrounded by an extensive floating sudd dominated by emergent *Ludwigia peploides*. As a result, two of the three baseline sites extended to only 0.3 m depth and did not record submerged plants, leaving the lake with the default score of 0% (Table 12) and a status of non-vegetated. The third baseline site recorded charophyte meadows and pondweeds to 0.5 m depth. *Utricularia gibba*, recorded for the first time in this lake was commonly entangled with the submerged plants and formed locally high covers amongst the floating sudd.

Lake Poutoa is one of a series of shallow water bodies running along the coastal dunes south from Lake Kereta. This lake together with Lakes Karaka, Ngakaru and Piripoua were marked on recent topographic maps (Map Toaster Topo, Version 4.00.194, 2007) as ‘dry’, although earlier maps (NZMS260 Sheet Q10, Helensville, Edition 1, 1980) showed lakes as a series of basins holding water. Lake Poutoa is likely to have

undergone major changes in water levels over time, which makes it difficult to assign a meaningful LakeSPI score without information on its original bathymetry. The lake is known to dry leaving little open water (J. Bendall pers comm. 2005) and the presence of drowned and emergent dead trees also suggest lower past water levels. Collier (1996) reported the loss of more than 50% of lakes on the South Kaipara Heads attributed to pine transpiration losses and rainfall/groundwater interception.

Table 12.

LakeSPI results for Lake Poutoa. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		97	93	0
Historical data	*2005	90	82	6
	2010	0	0	0
Present day	†2017	-	-	-

** The 2005 survey is based on only 2 sites.*

†The lake was dry in 2017

4.3 Muriwai Lakes

4.3.1 Lake Okaihau

Latest assessment:	**2012**
Lake condition:	**Poor**
Stability:	**Stable**
Lake Max Depth (m):	**9.5**
Lake type:	**Dune**

The latest LakeSPI score of 20% in 2012 suggests the lake is unchanged from the previous (2005) assessment of having a poor ecological condition (Table 13). The dominant submerged plant was hornwort (*Ceratophyllum demersum*), although these beds were not as extensive as before. Egeria (*Egeria densa*) was not re-recorded. Native milfoils, turf plants and sparse charophytes were recorded in shallow water.

Turbid conditions, and possibly the presence of rudd (confirmed in this survey and recorded since 1974; Cadwallader 1978), may account for the poor development of submerged vegetation. Apparent extirpation of egeria from the lake also signals likely stress on submerged plants.

In 2005 the presence of hornwort and egeria (Champion and de Winton 2005) and the somewhat restricted development of submerged vegetation (3.9 m depth), resulted in a LakeSPI Index of 18% (Table 13). Native milfoils and turf plants were also present.

In 1950 Cunningham et al. (1953) recorded native pondweeds and charophytes to depths of 4 m, resulting in the excellent LakeSPI Index of 79% for that time (Table 13).

Table 13.

LakeSPI results for Lake Okaihau. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	91	0
Historical data	1950	79	59	0
	*2005	18	16	80
Present day	2012	20	21	60

**The 2005 results are based on 2 sites*

4.3.2 Lake Kawaupaku

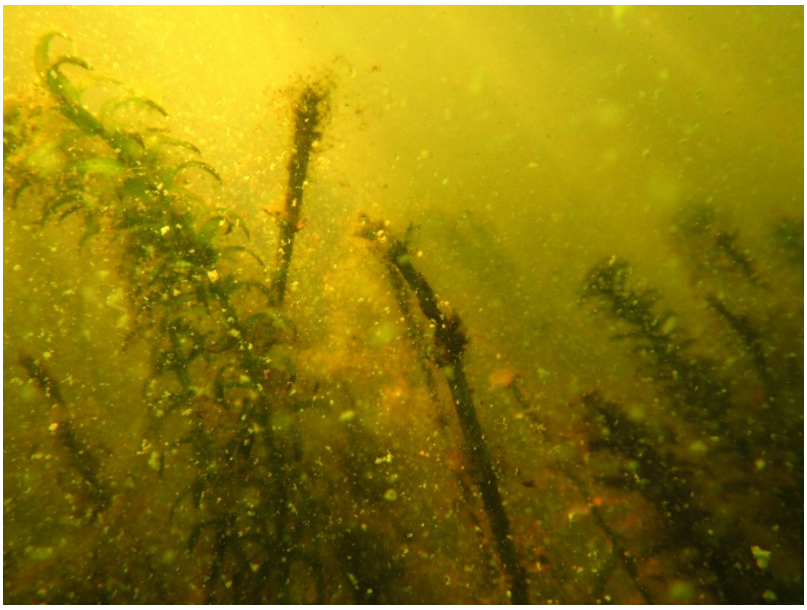
Latest assessment:	**2017**
Lake condition:	**Poor**
Stability:	**Unstable**
Lake Max Depth (m):	**22**
Lake type:	**Dune**

In 2017 the lake had a poor status according to LakeSPI, with a LakeSPI Index of 8% (Table 14). This low score was due to dominance by the weed egeria (*Egeria densa*) as the only submerged plant recorded. Beds were recorded to maximum depths of between 3.3 to 4.5 m. However, egeria was absent at one site which limited the Invasive Impact Index to 70%, but penalised LakeSPI scoring slightly. Egeria shoots tended to have a large burden of algae and detritus (Figure 10) and an algal bloom at the time of the survey would have created further light stress. It was also noted that browsing damage was common on near surface shoots from waterfowl or fish feeding. Herbivorous rudd and benthivorous-feeding tench have been recorded from the lake (New Zealand Freshwater Fish Database). These observations suggest the lake status is unstable and at risk of a wider vegetation decline.

Similar LakeSPI results to 2017 have been recorded since 2004 (Table 14), although the Invasive Impact Index was higher as egeria weed beds were recorded at all sites. During this time the only native submerged plant species seen was one clump of a native charophyte during the 2007 survey, resulting in a low Native Condition Index of 3% (Table 14). Water clarity was observed to be variable with dense algal blooms at times.

Figure 10.

Egeria plants showing a heavy algal burden and signs of grazing.



Prior to the egeria invasion, the submerged vegetation of Lake Kawaupaku in 1971 was dominated by native pondweeds and charophyte meadows to 7 m depth (NIWA unpublished data). Other submerged species recorded included a native turf plant and the minor weed *Otellia ovalifolia*. A high LakeSPI Index of 69% was generated at this time due to the extensive presence of native vegetation and absence of notable invasive weeds. It is of interest to note that the landowner noted that the introduction of egeria coincided with the release of coarse fish (Champion and de Winton 2005).

Table 14.

LakeSPI results for Lake Kawaupaku. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		96	93	0
	*1971	69	49	0
Historical data	†2004	14	0	81
	2007	10	3	89
	2012	10	0	92
Present day	2017	8	0	70

** different sites used in 1971*

† based on only 1 site in 2004

4.3.3 Lake Paekawau

Latest assessment:	**2010**
Lake condition:	**Non-vegetated**
Stability:	**Stable**
Lake Max Depth (m):	**3+**
Lake type:	**Dune**

Although sparse submerged vegetation comprising milfoils and turf plants was locally present at some sites in 2010, overall covers were insufficient to generate a LakeSPI score, giving a default of 0% and a status of non-vegetated (Table 15).

Submerged vegetation was not recorded in 2005 (Table 15), although native milfoils were a component of amphibious marginal vegetation at the extreme lake edge (Champion and de Winton 2005). Poor water clarity with dark-stained and turbid waters was thought to prevent the growth of submerged vegetation. This lake was once infested by the floating weed *Salvinia molesta*, which was detected in 1988 and has since been eradicated (MAF unpublished records). At that time the lake had poor habitat for submerged plants due to shading.

Table 15.

LakeSPI results for Lake Paekawau. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		97	93	0
Historical data	2005	0	0	0
Present day	2010	0	0	0

4.3.4 Lake Wainamu

Latest assessment:	**2012**
Lake condition:	**Non-vegetated**
Stability:	**-**
Lake Max Depth (m):	**15**
Lake type:	**Dune**

The introduction of grass carp (*Ctenopharyngodon idella*) in 2009 has led to a non-vegetated status being recorded for the lake by AC from late 2010 to the time of this report, and so current LakeSPI scores are not indicative of lake ecological condition.

During a 2007 survey egeria (*Egeria densa*) formed a continuous band around the margin of this lake, resulting in a high Invasive Impact Index of 85% and poor LakeSPI Index of 16% (Table 16). High cover beds of egeria formed from the edge of the emergents to 5 m depth, grew to a height of 4.2 m and were surface-reaching in places (de Winton et al. 2007). Native charophytes formed patches between 2.5 and 3.5 m and the invasive weed *Utricularia gibba* formed entangling growths over plants to 2.3 m depth. Additional exotic species were *Myriophyllum aquaticum* and *Otellia ovalifolia* (de Winton et al. 2007).

During the 2005 survey, egeria weed beds had lower covers and extended to a lesser depth of 3.8 m, while native charophyte meadows were common (de Winton et al. 2005b) resulting in a moderate LakeSPI Index of 24%. The 2005 assessment was made at a time when vegetation in the lake was recovering from an extended non-vegetated period from 1999, during which a default LakeSPI value of 0% applied.

Prior to the vegetation decline, a poor LakeSPI Index of 9% generated from 1995 data reflected the greatest impact from egeria (Invasive Impact Index of 93%), when weed beds occupied almost all available habitat in the lake to a depth of 4 m.

In 1991, prior to the establishment of egeria in Lake Wainamu, the submerged vegetation was predominantly native with a shallow zone of native pondweeds and deeper charophyte meadows to 4.5 m depth (Champion 1995). During this time the invasive weed *U. gibba* was widespread but had a minimal impact. The high 1991

LakeSPI Index of 60% reflected the predominantly native character of the lake at that time.

Table 16.

LakeSPI results for Lake Wainamu. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		96	93	0
	1991	60	41	15
	1995	9	0	93
Historical data	1999	0	0	0
	2005	24	22	73
	2007	16	16	85
Present day	*2012	0	0	0

** The 2012 result is not indicative of lake ecological condition due to the influence of grass carp present in the lake.*

4.4 Auckland City Lakes

4.4.1 Lake Pupuke

Latest assessment:	**2017**
Lake condition:	**Poor**
Stability:	**Declining**
Lake Max Depth (m):	**58**
Lake type:	**Volcanic**

In 2017 Lake Pupuke was assessed as in poor condition according to LakeSPI, with a LakeSPI Index of 18% (Table 17). This represents a substantial and significant deterioration since 2012 in both the Native Condition Index and LakeSPI Index. The main cause was a reduction of charophyte meadows from deeper water. There was also a significant retraction of bottom limits of the weeds across all sites compared with previous surveys in 2008 and 2012. Occasional bands of milfoil and shallow water charophytes continued to be recorded.

The Invasive Impact Index had not changed significantly from the previous 2012 survey and the lake continued to be dominated by eelgrass (*Vallisneria australis*) (Figure 11), with pockets of egeria (*Egeria densa*) as the only other invasive weed recorded.

Previously Lake Pupuke had a stable, moderate status over 1985, 2008 and 2012 (Table 17). Eelgrass was dominant. Egeria had fully established after being introduced earlier in the 1980s (Coffey and Clayton, 1987). Other invasive weeds included scattered plants to patches of *Lagarosiphon major*, occasional plants of *Potamogeton crispus*, and the rarely encountered *Elodea canadensis*.

Figure 11.

A diver swims over a bed of eelgrass.

Despite a large number of invasive weed species present over 1985, 2008 and 2012, several elements of native vegetation character were still discernible. Charophyte meadows were found beyond the eelgrass beds to between 8 and 12 m depth, and native milfoils sometimes formed a band in shallow water.

Table 17.

LakeSPI results for Lake Pupuke. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		98	97	0
Historical data	1985	26	21	76
	2008	30	35	79
	2012	31	36	77
Present day	2017	18	11	84

4.4.2 Western Springs Lake

Latest assessment:	**2008**
Lake condition:	**Non-vegetated**
Stability:	**-**
Lake Max Depth (m):	**2.9**
Lake type:	**Volcanic**

Western Springs had an almost complete absence of submerged vegetation on account of grass carp (*Ctenopharyngodon idella*) that were stocked in the 1990s to remove weeds. Accordingly, LakeSPI has a limited potential to describe lake ecological condition while grass carp determine vegetation development (Table 18).

Submerged plants were restricted to aquatic mosses, including the 'Nationally Endangered' species *Fissidens berteroi* (Hitchmough 2005), that were growing attached to volcanic rocks used in revetment walls and elsewhere within the lake. *F. berteroi* is locally recorded elsewhere in Auckland City from spring-fed waterways at Onehunga Springs, Meola Creek and Motions Creek which originates from Western Springs Lake (Bodmin and Wells 2009). The rare moss *F. berteroi* is a recent record, however the potential for natural attrition or removal by grass carp is not known.

Western Springs has a long history of weed invasion and weed management. In the mid-1960s the lake was infested by *Salvinia molesta* (Johnstone 1972) and the development of submerged vegetation varied with the degree of invasion by this floating fern until it was eventually eradicated in the mid-1980s. In 1968, when *S. molesta* was actively cleared, egeria (*Egeria densa*) dominated the entire lake and *Elodea canadensis*, native pondweeds, milfoils and a charophyte were recorded to at least 2 m depth (Johnstone 1972). At this time the lake would have had a LakeSPI Index of 29%. In 1980 the lake was still dominated by egeria together with *Potamogeton crispus* (NIWA data).

Table 18.

LakeSPI results for Western Springs Lake. LakeSPI Indices expressed as a percentage of lake maximum potential.

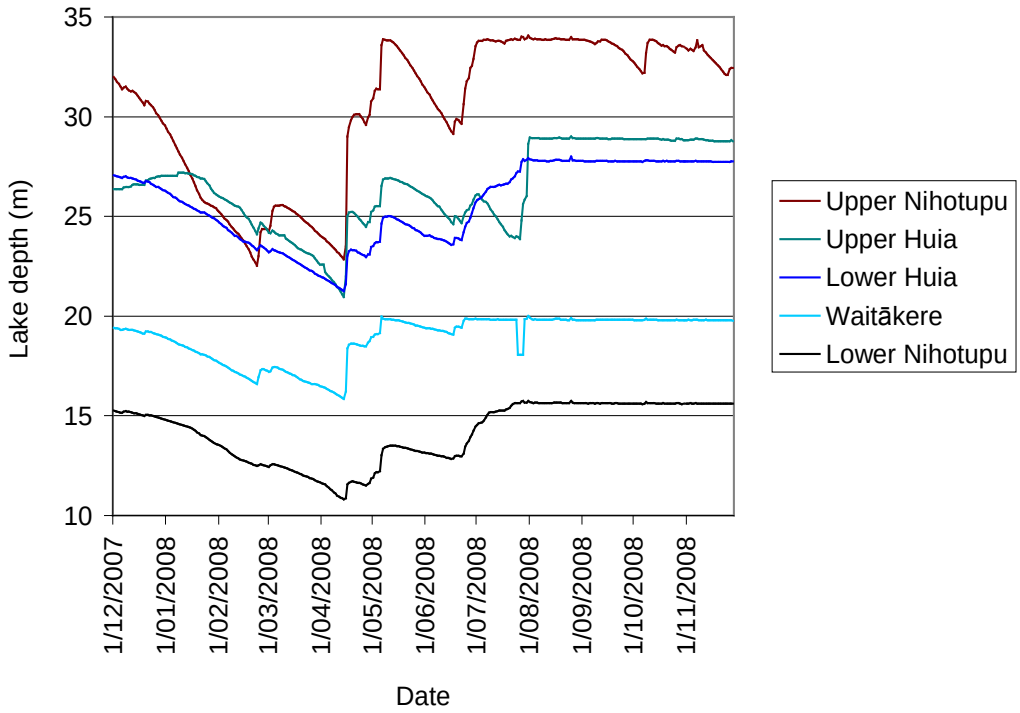
State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Historical data	1968	29	50	78
Present day	*2008	0	0	0

** The 2008 result is not indicative of lake ecological condition due to the influence of grass carp present in the lake.*

4.5 Waitākere Reservoirs

The Waitākere Reservoirs are managed for water supply and typically undergo rapid water level increases driven by precipitation and slower draw-down by water abstraction and evaporation (Figure 12). The range in water levels during 334 days prior to the October 2008 LakeSPI survey showed Upper Nihotupu Reservoir had the greatest fluctuation of 11.5 m, Upper Huia fluctuated by up to 8.1 m, Lower Huia by 6.8 m, Lower Nihotupu by 4.9 m, and Waitākere Reservoir had the lowest fluctuations of 4.1 m (Figure 12). The reservoirs showed a pattern of declining water levels to mid-April 2008 followed by a series of rapid water level increases. Waitākere Reservoir had a period of approximately 6 months prior to the LakeSPI survey when water level was relatively stable. Upper and Lower Nihotupu Reservoirs had a stable period of about 4 months, and Upper and Lower Huia Reservoirs had stable water level period of 3 months prior to the survey (Figure 12).

Figure 12.
Amplitude of water level fluctuations (m) for the Waitākere reservoirs in relation to their depth over the period from 01/12/2007 to 28/11/2008 (Watercare Services Limited data). The LakeSPI survey was in late October 2008.



4.5.1 Waitākere Reservoir

Latest assessment:	**2008**
Lake condition:	**High**
Stability:	**Stable**
Lake Max Depth (m):	**19.7**
Lake type:	**Reservoir**

Waitākere Reservoir was the highest scoring of this group of reservoirs, with a LakeSPI Index of 51% (Table 19) resulting from the presence of extensive charophyte meadows to 6.9 m depth, moderately impacted by a shallow band (<4 m) of the weed *Juncus bulbosus* (Invasive Impact Index of 39%). Patches of native milfoil were also common. Two other invasive weeds observed included one plant of *Ranunculus trichophyllus* and fragments of *Utricularia gibba* stranded on the dam structure outside of the survey sites. All three invasive species are spread by waterfowl. The high cover charophyte meadows began at between 2.5 and 3.8 m depth, within the range of water level fluctuation of 4.1 m and suggesting the 6-month period of stable water levels prior to the survey was sufficient for charophyte expansion.

A LakeSPI Index of 49% was generated from limited data collected in 1982. At this time a diverse charophyte assemblage (four species) was abundant to 3 m depth. A shallower band of native milfoils was recorded to 2.2 m depth, commonly with pondweeds and the invasive weed *J. bulbosus* to 1.5 m.

Table 19.

LakeSPI results for Waitākere Reservoir. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	49	38	33
Present day	2008	51	46	39

** 1982 scores were based on a general reconnoitre*

4.5.2 Upper Huia Reservoir

Latest assessment:	**2008**
Lake condition:	**Moderate**
Stability:	**Stable**
Lake Max Depth (m):	**33.1**
Lake type:	**Reservoir**

The submerged vegetation was dominated by the weed *Juncus bulbosus*, resulting in a high Invasive Impact Index (53%) and moderate LakeSPI Index of 36% (Table 20). Spread from seed by waterfowl*, J. bulbosus* is less invasive than most other submerged weeds, but in the Upper Huia Reservoir it formed the highest covers of any plant species and was recorded to the maximum vegetation depth of 5.5 m. Native milfoils also commonly contributed to the vegetation, but no charophytes were recorded. All submerged vegetation was within the range of water level fluctuations experienced over the preceding year.

An identical LakeSPI Index was recorded in 1982, although native vegetation was more abundant at that time. The submerged vegetation was dominated by native milfoils and the turf plant *Glossostigma* sp. was common to 4 m depth, with *J. bulbosus* described as common to 4.5 m depth. Native pondweeds, and the invasive weed *Ranunculus trichophyllus* were occasional, but charophytes were rare.

Table 20.

LakeSPI results for Upper Huia Reservoir. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	36	33	56
Present day	2008	36	22	53

** 1982 scores were based on a general reconnoitre*

4.5.3 Lower Huia Reservoir

Latest assessment:	**2008**
Lake condition:	**Moderate**
Stability:	**Declining**
Lake Max Depth (m):	**33.5**
Lake type:	**Reservoir**

A LakeSPI Index of 31% (Table 21) reflected the paucity of submerged vegetation, limited depth extent and minor impact by the weed *Juncus bulbosus* (Invasive score 33%). The most common submerged plants were native milfoils, the alien marginal plant *Ludwigia palustris*, and *J. bulbosus*. Highest plant covers were <3 m depth, with the deepest plants recorded at 3.6 m. Charophytes were present but not common. Remains of terrestrial shrubs were recorded to 4.6 m, which is in keeping with the 6.8 m increase in water level over the preceding months and suggests that the submerged vegetation recorded was made up of recently colonised plants.

Data from a limited survey in 1982 suggested a higher LakeSPI Index of 68%. At the time of this survey no invasive weed species were noted, with native charophyte meadows extending to a depth of 3.5 m, native milfoils and pondweeds also common, and one pondweed species recorded to 5 m depth.

Table 21.

LakeSPI results for Lower Huia Reservoir. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	68	47	0
Present day	2008	31	19	33

** 1982 scores were based on a general reconnoitre*

4.5.4 Upper Nihotupu Reservoir

Latest assessment:	**2008**
Lake condition:	**Non-vegetated**
Stability:	**Stable**
Lake Max Depth (m):	**33.9**
Lake type:	**Reservoir**

No submerged plants were recorded from the Upper Nihotupu Reservoir and it received a default LakeSPI Index of 0% (Table 22). The extreme water level fluctuations in this reservoir (11.5 m) are likely to exclude significant vegetation development. Likewise, no submerged species were recorded in 1982 (NIWA data).

Table 22.

LakeSPI results for Upper Nihotupu Reservoir. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	0	0	0
Present day	2008	0	0	0

** 1982 scores were based on a general reconnoitre*

4.5.5 Lower Nihotupu Reservoir

Latest assessment:	**2008**
Lake condition:	**Not assessed**
Stability:	**-**
Lake Max Depth (m):	**18.4**
Lake type:	**Reservoir**

A LakeSPI assessment could not be made in 2008 because of high water turbidity due to a slip in a tributary catchment which severely limited diver observations. Divers were able to confirm the presence of plants to 4 m depth, with apparent bare sediment at 5 m, the deepest extent investigated, however reliable LakeSPI indices could not be generated. Whilst recent water level fluctuations (4.9 m) were amongst the lowest in this group of lakes, additional light stress on plants from high turbidity raises doubts for the survival of deep submerged vegetation.

Limited vegetation data collected in 1982 derived a LakeSPI Index of 46% (Table 23). At this time native charophyte meadows ranged from the lake edge to 2.1 m depth and native milfoils and the invasive weed *Juncus bulbosus* were occasionally encountered stranded above the water level.

Table 23.

LakeSPI results for Lower Nihotupu Reservoir. LakeSPI Indices expressed as a percentage of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	46	29	37
Present day	2008	-	-	-

** 1982 scores were based on a general reconnoitre*

4.6 Awhitu Lakes

4.6.1 Lake Whatihua

Latest assessment:	**2017**
Lake condition:	**Moderate**
Stability:	**Declining**
Lake Max Depth (m):	**11**
Lake type:	**Dune**

In 2017 the lake retained a moderate status with a LakeSPI Index of 41% (Table 24). However, change was apparent in the significantly reduced depth of overall vegetation extent and in the depth of charophyte meadows since the previous survey in 2012. The latest survey showed plants at 10% cover extending to between 5.2 and 6.5 m depth, where 5 years earlier the equivalent depth measure was 7.9 to 9.2 m. Together these resulted in a small but significant reduction in the LakeSPI Index (Table 24).

Egeria (*Egeria densa*) remained the prevalent weed species (Figure 13), being recorded in the lake since at least 1987. Newly recorded, alien bladderwort (*Utricularia gibba*) contributed to a higher Invasive Impact Index in 2017. The weed *Elodea canadensis* continued to have a minor presence in the lake.

Native pondweeds co-dominated the mid to deep vegetation with egeria (Figure 13). However, deeper charophyte meadows seen in 2005 and 2012 were absent in 2017. Native turf plants, emergents and milfoils and mixed charophyte species continued to be recorded from the margins of the lake contributing to a diverse shallow water vegetation (Figure 13).

These latest results reverse the improvement suggested by earlier results over 25 years to 2012 (Table 24), where invasive weed status was stable or declining, native vegetation had improved representation and vegetation depth limits extended slightly. An algal bloom and epiphytic algal growths on plants during the 2017 survey appear to corroborate a reduction in water transparency and increased shading, with subsequent impacts on plant depth limits. Floating plants found at the lake margins included *Azolla pinnata*, *Wolffia australis* and *Ricciocarpus natans*, which suggests high nutrient availability in the waters.

Figure 13.

Left; deeper vegetation of tall egeria and native pondweed. Right; diverse native plants retrieved from shallow lake margins.

A LakeSPI Index of 23% was generated from the survey data of one site in 1987 when the vegetation was dominated by egeria and the deeper charophyte meadows were absent. A much higher LakeSPI Index of 80% is suggested from a 1950 survey by Cunningham et al. (1953), when charophytes were recorded to 8 m depth and invasive weed species were absent.

Lake Whatihua still represents the unusual example of an egeria invaded lake that has retained significant native vegetation values. For example, a total of 10 native submerged species were recorded from this lake in 2005 (Champion and de Winton 2005), 14 species in 2012 and 13 in 2017. Egeria is thought to be most competitive under eutrophic conditions, and the fact that it is co-existing with native species suggests conditions have not been optimal for this weed.

Table 24.

LakeSPI results for Lake Whatihua. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		95	92	0
Historic data	1950	80	63	0
	*1987	23	25	89
	†2005	33	43	81
	2012	48	63	60
Present day	2017	41	52	67

** The 1987 survey is based on 1 site*
†2005 survey is based on 4 baseline sites.

4.6.2 Lake Pokorua

Latest assessment:	**2017**
Lake condition:	**Moderate**
Stability:	**Unstable**
Lake Max Depth (m):	**6**
Lake type:	**Dune**

Lake Pokorua remains in a moderate state according to the LakeSPI Index of 39% in 2017. However, a slight reduction in the impact by invasive weed was observed compared to 2012 (Table 25). Egeria (*Egeria densa*) dominated only the deeper areas of the lake to 2.2 m depth, and did not form closed canopy beds. Meadows of charophytes (Figure 14) occupied a greater proportion of the shallow areas of the lake to depths between 1.5 and 1.8 m, together with open growths of native pondweeds. This native character is reflected by a moderate Native Condition Index of 64%.

Lake Pokorua has fluctuated in ecological condition over time according to the degree of invasion by egeria and, to a lesser extent, the depth of vegetation development. Similar values for LakeSPI Indices were obtained from the 2017, 2012 and 1988 surveys (Table 25), which indicate a moderate ecological condition. At these times vegetation composition was similar to that described for 2017.

Figure 14.

Diver retrieves charophytes to the surface for closer inspection.

In contrast, LakeSPI results for Lake Pokorua in 2005 provided one of the highest scores for the Auckland region, giving a LakeSPI Index of 76% (Table 25). At this time egeria was only locally abundant at one surveyed site (Champion and de Winton, 2005) and occasional elsewhere. Charophyte meadows and native pondweeds dominated to depths of about 3 m, contributing to a Native Condition Index of 82%. The difference in depth extent for significant vegetation of between 2.8 to 3.2 m in 2005 compared to 2.0 to 2.3 in 2017 and 2.3 and 2.5 m in 2012 translated to a big difference in vegetated area in this shallow bowl-like lake. It could be that the temporary improvement in lake ecological condition in 2005 was driven by a prior egeria decline event, with the predominance of native plants reflecting their superior ability to recolonise from seed reserves compared to egeria, which is reliant on vegetative reproduction only.

In 1950 Cunningham et al. (1953) recorded native pondweeds dominant to between 4 and 6 m depth, with charophytes present to between 2 and 4 m depth. Based on this survey data a high LakeSPI Index of 97% was generated reflecting native vegetation that covered much of the bed of the lake. We also note that the lake maximum depth appeared substantially deeper in 1950.

Table 25.

LakeSPI results for Lake Pokorua. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		97	93	0
	1950	97	93	0
Historic data	*1988	37	63	76
	†2005	76	82	23
	2012	37	60	72
Present day	2017	39	64	67

4.6.3 Lake Pehiakura (Small)

Latest assessment:	**2017**
Lake condition:	**Poor**
Stability:	**Declining?**
Lake Max Depth (m):	**5.3**
Lake type:	**Dune**

In 2017 the lake had deteriorated slightly and had a poor status according to a LakeSPI Index of 20% (Table 26). Egeria (*Egeria densa*) remained the dominant plant (Figure 15), with dense beds extending to almost 5 m depth and covering most of the lake bed. The main change from 2005 was a reduction in the remnant native vegetation in the shallows (Figure 15).

The smaller of the two Pehiakura lakes, this lake again appeared to have better water quality than the bigger lake, but an algal bloom was evident (Figure 15).

Earlier, in 2005, a LakeSPI Index of 25% (Table 26) placed the lake at the lower end of a moderate status. Egeria development was very similar to that described in 2017, but a higher Native Condition Index of 25% resulted from covers of native milfoils, turf plants (*Glossostigma* sp.) and a charophyte found in depths <1.3 m between the clumps of emergent reeds (Champion and de Winton, 2005).

Figure 15.

Left; near surface egeria. Right; sparse growths of the charophyte (*Nitella hyalina*).

Table 26.

LakeSPI results for Lake Pehiakura (Small). LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Historical	*2005	25	25	85
Present day	*2017	20	18	85

** Surveys based on 2 baseline sites.*

4.6.4 Lake Pehiakura (Big)

Latest assessment:	**2017**
Lake condition:	**Poor**
Stability:	**Stable**
Lake Max Depth (m):	**10.7**
Lake type:	**Dune**

This lake remains in a poor state according to the LakeSPI Index of 9% in 2017. Egeria (*Egeria densa*) has been the only submerged plant species recorded from all surveys (Figure 16) leading to Invasive Impact Index of ≥89% (Table 27).

Dense weed beds were recorded to a maximum depth of between 4.2 to 4.5 m in 2017, compared to 3.5 to 4.3 m in 2012 and 5.4 m in 2005. A narrow, but almost continuous band of emergent plant species exists around the lake margin (Figure 16).

At the time of the 2017 survey water clarity was poor with a dense algal bloom evident (Figure 16).

Figure 16.

Left; diver records observations amongst the shallow egeria weed bed. Right; algal scums accumulate against the lake margin.

Table 27.

LakeSPI results for Lake Pehiakura (Big). LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Pristine		95	90	0
Historical data	*2005	14	4	89
	2012	10	0	91
Present day	2017	9	0	93

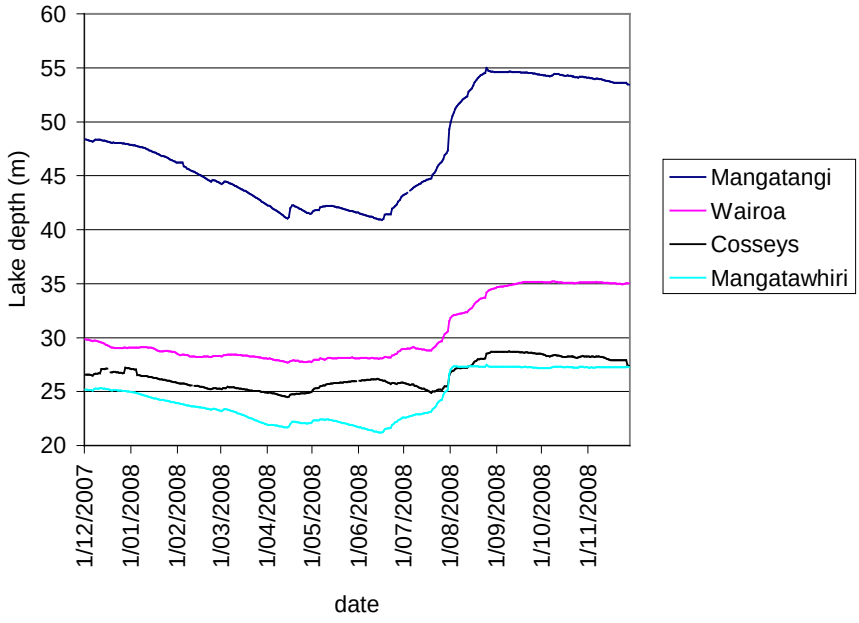
** The 2005 survey is based on 3 baseline sites.*

4.7 Hunua Reservoirs

The Hunua Reservoirs provide water supply to Auckland. With the exception of Hays Creek Reservoir, which has a stable water level, the reservoirs undergo fluctuations driven by precipitation, water abstraction and evaporation. Over the 325 days prior to the October 2008 survey (Figure 17) water levels initially declined slowly to mid-April, stabilised, then rapidly increased from late June (or late July for Cossey's Reservoir) to late August (or early August for Mangatawhiri Reservoir). The subsequent period of stable water level prior to the survey was 2.6 months for Mangatawhiri Reservoir, and 1.8 months for the other reservoirs. The range in fluctuation prior to the survey ranged from 14.1 m for Mangatangi Reservoir, 7.5 m for Wairoa, 6.3 m for Mangatawhiri, and 4.2 m for Cossey's Reservoir.

Figure 17.

Amplitude of water level fluctuations (m) for the Hunua reservoirs in relation to their depth over the period from 01/12/2007 to 28/11/2008 (Watercare Services Limited data). The LakeSPI survey was in late October 2008.



4.7.1 Mangatawhiri Reservoir

Latest assessment:	**2008**
Lake condition:	**Excellent**
Stability:	**Improving**
Lake Max Depth (m):	**35.6**
Lake type:	**Reservoir**

The upper Mangatawhiri Reservoir had the highest LakeSPI ranking of the Auckland region (76%) on account of the depth extent of native charophytes that formed high cover meadows down to 10.4 m depth (Table 28). The shallow edge of these meadows began at 6 m depth, corresponding with the water level rise of 6.3 m recorded prior to the survey. Native milfoils and pondweeds were a minor vegetation component found in shallower depths than the charophyte meadows and no invasive submerged weeds were recorded.

A slightly lower LakeSPI Index of 68% was generated from the 1990 vegetation survey (Table 28), when charophyte meadows were recorded to 6.5 m and native pondweeds to 5 m depth. Using a general description of submerged vegetation in 1982, a similar score of 76% was based on abundant charophytes to 6.2 m and milfoils and pondweeds to 5 m depth.

Table 28.

LakeSPI results for Mangatawhiri Reservoir. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	76	61	0
	1990	68	47	0
Present day	2008	76	61	0

** 1982 scores were based on a general reconnoitre.*

4.7.2 Wairoa Reservoir

Latest assessment:	**2008**
Lake condition:	**High**
Stability:	**Stable**
Lake Max Depth (m):	**40.3**
Lake type:	**Reservoir**

A high LakeSPI Index of 66% (Table 29) resulted from the presence of native plant communities growing down to a moderate depth in the absence of any invasive plant species. Beds of native charophytes began at 6.3 to 7.1 m and extended to 8.6 m depth, with occasional plants recorded as deep as 11.7 m. Native milfoils and pondweeds were sometimes present in mid-depths of 3 to 8.2 m and terrestrial vegetation was noted to 4.4 m depth. An increase in water level of 7.5 m prior to the survey would account for the transition from terrestrial to obligatory submerged plants seen between 4.4 and around 7 m depth.

An identical LakeSPI score was generated from the 1990 survey, when charophyte beds were present from the lake edge to 5.5 m depth. Based on a general description of vegetation in 1982 the lake scored 66%, with pondweeds and milfoils in shallow water to 1.5 m and charophytes common to 3 m depth. At the time of the 1982 survey a rapidly lowering water level (reported at 2 m per day) had also stranded vegetation above the waterline.

Table 29.

LakeSPI results for Wairoa reservoir. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	66	43	0
	1990	68	46	0
Present day	2008	68	47	0

** 1982 scores were based on a general reconnoitre.*

4.7.3 Cossey's Reservoir

Latest assessment:	**2008**
Lake condition:	**Moderate**
Stability:	**Declining**
Lake Max Depth (m):	**35.1**
Lake type:	**Reservoir**

The LakeSPI Index of 49% (Table 30) reflected the largely native vegetation character in Cossey's Reservoir that, although it was low in cover and depth extent, had only minimal impact by invasive *Juncus bulbosus*. The sparse submerged vegetation comprised of native charophytes and milfoils while *J. bulbosus* was present at some of the sites. Submerged plants were recorded to 5.6 m depth although most growth was less than 3.3 m, and inundated terrestrial plants were noted to 2.6 m. The water level increase of 4.2 m prior to the 2008 survey was not clearly reflected in the depth distribution of the submerged vegetation.

A high LakeSPI Index of 71% was generated from a 1990 vegetation survey, driven by greater covers of charophytes that extended to a maximum depth of 7.5 m and the absence of invasive weed species. A high LakeSPI Index of 62% was also generated from a general survey of submerged vegetation in 1982, when charophytes were abundant to 5 m depth, native pondweeds and milfoils common to abundant to 2.5 m, and *J. bulbosus* was occasionally recorded to a depth of 1 m.

The reduction in LakeSPI scores since 1990 (Table 30) reflects a reduction in the covers and depth extent of native submerged plants. This may be related to a dam reconstruction in the early 2000s, which saw reservoir volume reduced by <50% (Watercare Caretaker, pers comm. 2002). Associated water level reduction, desiccation of submerged vegetation, slumping/erosion of aquatic sediment and possible impacts on water clarity might explain the lack of vegetation re-development. Additionally, herbivorous rudd are known to be present in the reservoir (Baker et al.

2008) and have elsewhere been implicated in the removal of native plant material (de Winton et al. 2003).

Table 30.

LakeSPI results for Cossey's Reservoir. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	62	47	15
	1990	71	51	0
Present day	2008	49	28	20

** 1982 scores were based on a general reconnoitre.*

4.7.4 Mangatangi Reservoir

Latest assessment:	**2008**
Lake condition:	**Non-vegetated**
Stability:	**Declining**
Lake Max Depth (m):	**54.6**
Lake type:	**Reservoir**

In 2008 small patches of native charophytes were recorded between 13.1 and 15.4 m depth and native milfoils from 6 to 8.5 m. However, these plants were considered to be remnants of previous vegetation after inundation by a 14.1 m rise in water level prior to the 2008 survey, as it is doubtful these patches would survive the maintenance of high levels recorded over the subsequent three or more months (Figure 7). This together with the sparse nature of plant growth (≥10% cover at only one of three sites investigated) results in a LakeSPI Index of 0% (Table 31).

In 1990 submerged vegetation comprised native charophytes and pondweeds to a maximum depth of 4.5 m. At this time plant cover was not complete due to the steep slopes, unstable sediment and observed wave re-suspension of fine silt. However, the high LakeSPI Index of 64% generated from this survey indicates the native character of vegetation and depth extent of development. A similar score of 62% generated from an earlier (limited) description of vegetation in 1982 also resulted from charophyte meadows recorded to 2.5 m depth and abundant pondweeds to 2 m depth.

Table 31.

LakeSPI results for Mangatangi Reservoir. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Historic data	*1982	62	37	0
	1990	64	39	0
Present day	2008	0	0	0

** 1982 scores were based on a general reconnoitre.*

4.7.5 Hays Creek Reservoir

Latest assessment:	**2008**
Lake condition:	**Non-vegetated**
Stability:	**-**
Lake Max Depth (m):	**20.7**
Lake type:	**Reservoir**

Hays Creek Reservoir received a LakeSPI Index of 0% (Table 32) on account of the low presence of submerged vegetation. Only occasional charophyte plants were encountered at ≤10% cover; below the threshold for generating LakeSPI scores. The low water clarity, with a turbid, 'milky' appearance, suggests light availability restricted submerged vegetation development. However, the presence of koi carp known from the reservoir is implicated both for impacts on water clarity (Rowe 2007) and direct impacts on submerged plants (e.g., Crivelli 1983). In contrast to the other Hunua Reservoirs, Hays Creek had a stable water level (Figure 7).

Table 32.

LakeSPI results for Hays Creek Reservoir. LakeSPI Indices expressed as a % of lake maximum potential.

State	Year	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)
Potential condition		96	93	0
Present day	2008	0	0	0

5 Discussion

5.1 Current lake condition

Lakes of the Auckland region have a wide range of current LakeSPI scores ranging from those that have no submerged vegetation (0%) to a maximum LakeSPI Index of 76% (Table 33, Figure 18).

For the purposes of ranking and discussing these results, the Auckland lakes have been categorised into five lake condition categories (Excellent, High, Moderate, Poor, Non-vegetated) according to their current LakeSPI Index (Table 33, Figure 18). Additionally the lakes have been further divided based on the apparent impacting factor influencing the score. Impacting factors include ‘weed’ invasion (Invasive Impact Index ≥60%), vegetation development limited by ‘water quality’, and/or by ‘water level’ fluctuations (Table 33), impacts from coarse fish disturbance, but also recognize where grass carp have been utilized as a weed control measure.

Table 33.

Summary of current LakeSPI results for assessed lakes with overall condition category and an indication of the main impact factor on scores.

Lake	LakeSPI Index (%)	Native Condition Index (%)	Invasive Impact Index (%)	Overall condition	Impact factor
Mangatawhiri	76	61	0	Excellent	
Wairoa	66	47	0	High	
Rototoa	59	55	29	High	Water Quality/coarse fish
Waitākere	51	46	39	High	Water Level
Cossey's	49	28	20	Moderate	Water Level
Whatihua	41	52	67	Moderate	Weed/Water Quality
Little Shag	39	30	54	Moderate	
Pokorua	39	64	67	Moderate	Weed
Upper Huia	36	22	53	Moderate	Water Level
Lower Huia	31	19	33	Moderate	Water Level
Silver Hill	30	22	59	Moderate	Water Quality
Okaihau	20	21	60	Poor	Water Quality/ Weed
Small Pehiakura	20	18	85	Poor	Weed/Water Quality
Pupuke	18	11	84	Poor	Weed/Water Quality
Te Kanae	10	4	96	Poor	Weed
Big Pehiakura	9	0	93	Poor	Weed
Kawaupaku	8	0	70	Poor	Weed/Water Quality
Kuwakatai	8	0	100	Poor	Weed
Tomarata	0	0	0	Non-vegetated	Water Quality/coarse fish
Hays Creek	0	0	0	Non-vegetated	Water Quality
Mangatangi	0	0	0	Non-vegetated	Water Level
Paekawau	0	0	0	Non-vegetated	Water Quality
Poutoa	-	-	-	Non-vegetated	Water Level (dry)
Slipper	0	0	0	Non-vegetated	Water Quality
Upper Nihotupu	0	0	0	Non-vegetated	Water Level
Spectacle	0	0	0	Non-vegetated	Water Quality
Karaka	0	0	0	Non-vegetated	Water Level (dry)
Poutoa	-	-	-	Non-vegetated	Water Level (dry)
Kereta	0	0	0	Non-vegetated	Grass Carp
Wainamu	0	0	0	Non-vegetated	Grass Carp
Western Springs	0	0	0	Non-vegetated	Grass Carp

5.1.1 Excellent condition lakes

Mangatawhiri Reservoir (Hunua Ranges) was the only lake in the Auckland region that currently qualifies as having an excellent ecological condition (Table 33). However, it is noted that the LakeSPI indices for this reservoir may be slightly inflated because vegetation might not yet have compensated for water level increases prior to the lake survey. Nevertheless, Mangatawhiri Reservoir would still rank the highest out of all the Auckland lakes assessed with scores only likely to change by <10% if meaningful adjustments could be made based on the water level change.

5.1.2 High condition lakes

Three lakes generated a high LakeSPI index (Table 33). These were Lake Rototoa (South Kaipara) and the Wairoa and Waitākere Reservoirs. High LakeSPI indices reflected either substantial native vegetation character (Native Condition Index ≥45%), or the general absence of major impacts from invasive submerged weeds (Invasive Impact Index <40%).

5.1.3 Moderate condition lakes

Seven lakes in the Auckland region were in moderate ecological condition, reflecting differing degrees of impact from invasive weeds. Low impacts from invasive weeds, but also restricted development by native vegetation, were responsible for the scores for three Watercare lakes (Cossey's and two Waitākere Reservoirs) and the reservoir at Silver Hill. Little Shag Lake (Te Arai Regional Park) also had a restricted submerged vegetation development on account of the stained waters and steep sides of this small lake, with the exotic weed *Utricularia gibba* having a significant impact. Two of the Awhitu Lakes (Whatihua and Pokorua) had a strong invasive weed influence, but they also retained elements of native vegetation.

5.1.4 Poor condition lakes

Seven lakes with LakeSPI indices between 8% and 20% were grouped as being in poor condition (Table 33) with most lakes being heavily impacted (Invasive Impact Index >80%) by the major invasive weeds hornwort (*Ceratophyllum demersum*) and/or egeria (*Egeria densa*). These species are amongst the top three ranked submerged plant species in New Zealand for 'weediness' (Champion and Clayton, 2000) and are capable of completely replacing native elements in the vegetation. In the case of Lake Okaihau and Kawaupaku, both poor water clarity and the presence of weed impacted on the lake condition, with possible impacts by coarse fish at these sites also. The small Pehiakura Lake and Lake Pupuke have recently joined this group of poor lakes due to a reduction in the remaining native vegetation diversity. In the case of Lake Pupuke loss of deeper charophyte meadows and a retraction in the main vegetation depth limits suggests a sustained reduction in water quality has occurred.

5.1.5 Non-vegetated lakes

Twelve lakes were categorised as being non-vegetated, as they recorded <10% vegetation cover at most survey sites and therefore scored a LakeSPI Index of 0% (Table 33). Absence of significant vegetation generally indicates a highly impacted lake condition (de Winton et al. 2012) where in most cases water quality issues have created unfavorable conditions for submerged plant growth. However, other impacting factors can also contribute to a non-vegetated condition.

In the three lakes where the management initiative of stocking grass carp to control weeds is responsible for vegetation absence, LakeSPI cannot accurately represent lake ecological condition. This is because the intervention results in a temporary modification of vegetation depth extent and diversity by grass carp, and several of the key assumptions behind the LakeSPI method (see section 2.1) are not met.

Changes in water levels can also impact on submerged plant growth. The Watercare managed lakes, Upper Nihotupu and Mangatangi Reservoirs, had strongly fluctuating levels which precluded significant vegetation growth. Two shallow South Kaipara dune lakes (Poutoa and Karaka) were also impacted by changes in water levels (lowering in this case) and it is unclear as to whether this is a recent hydrologic trend that will threaten the longer-term persistence of these and similar adjacent water bodies.

For the remaining five lakes in this category, it is apparent that water quality is a major constraint for plant growth. Additional stressors in these lakes are likely to be grazing or disturbance by coarse fish. Lake Tomarata (Te Arai) recently joined this group, after earlier indications of vegetation instability.

5.1.6 National comparison

Comparing the categories of lake ecological condition identified for the Auckland region to current LakeSPI Indices for 281 lakes nationally (Figure 18) shows:

- A lower proportion of Auckland lakes fall into the high to excellent category compared to lakes nationally.
- There is a slightly lower proportion of Auckland lakes that fall into the moderate category, compared with nationally.
- There are a higher proportion of lakes in the poor category in the region, which reflects the number of lakes that are extensively invaded by the worst ranked invasive submerged weeds, egeria (*Egeria densa*) or hornwort (*Ceratophyllum demersum*).
- Auckland region has a much higher proportion of lakes which do not possess significant submerged vegetation and are categorised as non-vegetated than is the case nationally.

This comparison is a simplified overview of current LakeSPI Indices for lakes nationally and does not take into account the wide range of lake types sampled. In this regard we note that the high proportion of water supply reservoirs in the Auckland region (11/33 lakes assessed) may influence comparisons. For example, reduced public access for recreational activities in the reservoirs means none are extensively weed invaded,

however, the extent of water level fluctuation undoubtedly contributes to the number of non-vegetated water bodies in the region.

Also, the Auckland region has three water bodies where grass carp have been stocked to manage previously excessive submerged weed issues. Although they are included in this comparison, a LakeSPI assessment does not accurately indicate lake ecological condition in these biologically manipulated lakes.

Figure 18.

The most recent LakeSPI scores for the Auckland region (red lines) are plotted with scores for a total of 281 New Zealand lakes. 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. Five categories of LakeSPI condition are indicated. Lake names are listed in ascending order with the exception of 9 non-vegetated Auckland lakes.

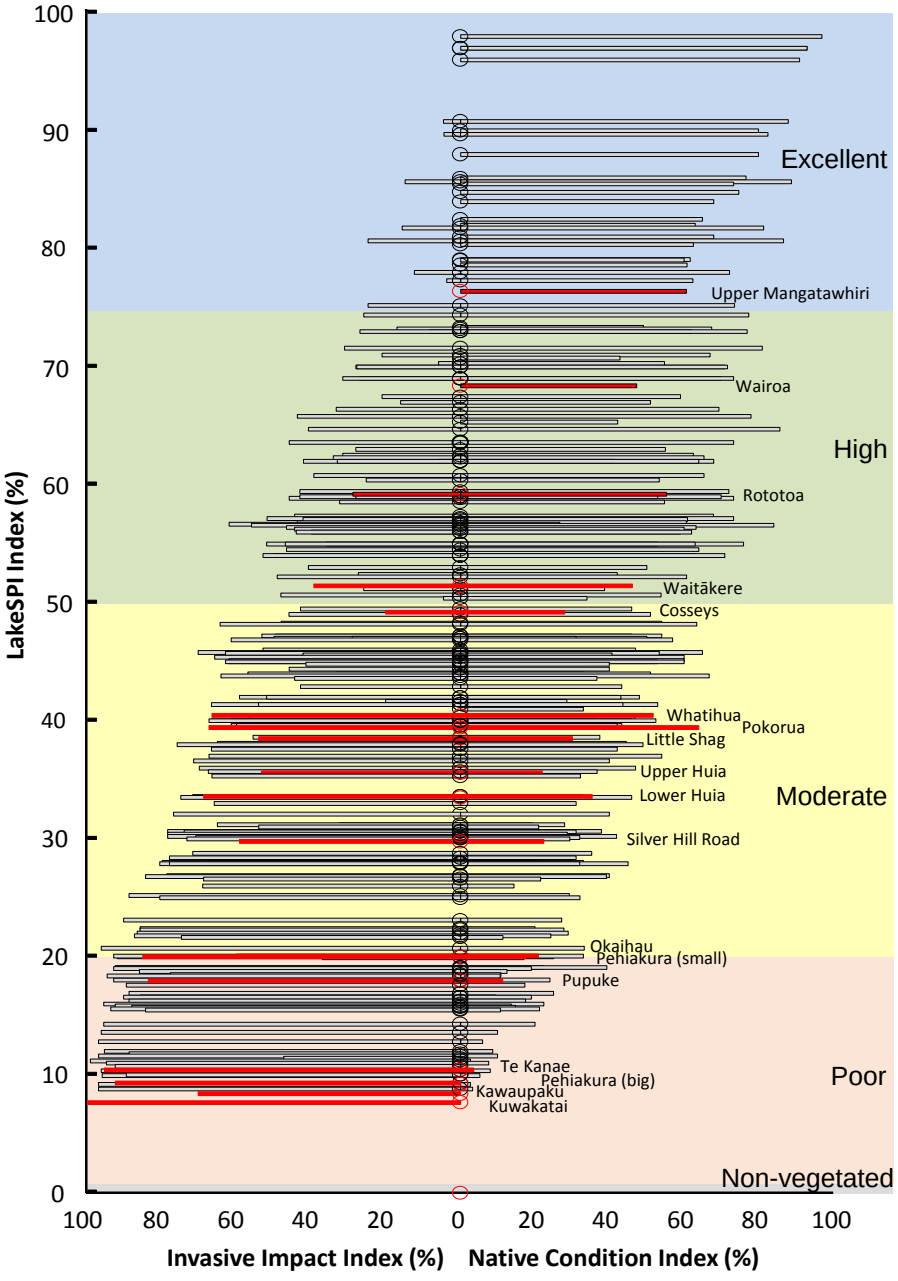
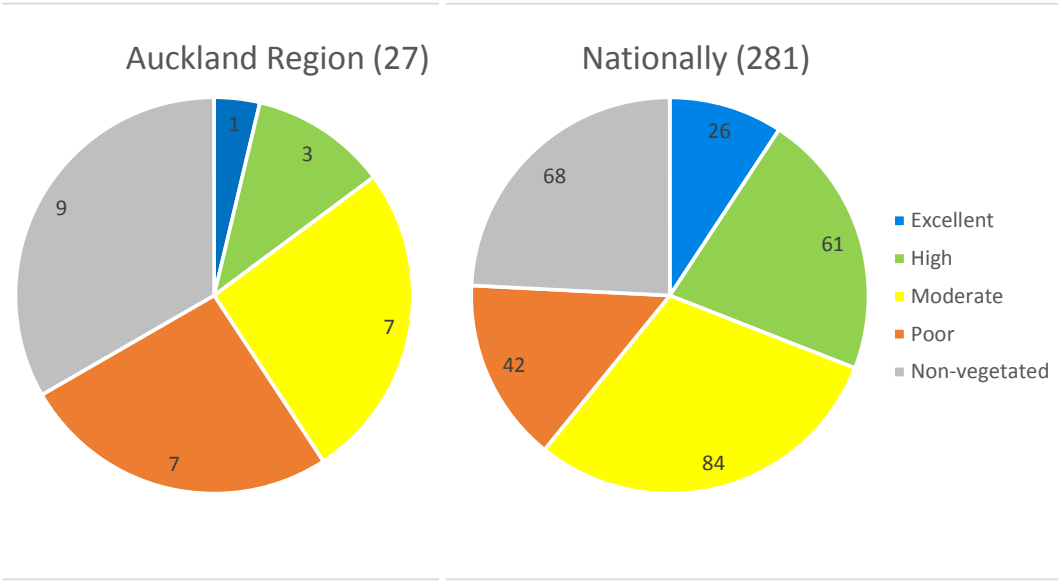


Figure 9.

- Proportion of lakes that fall into each of five categories of LakeSPI Index for the region and nationally, with numbers of lakes assessed shown in parenthesis.



Stability in lake condition

Changes in LakeSPI indices between the last two assessments for each lake have been used to provide an indication of the current stability in lake condition and the direction of any change. We could not assess extremely shallow and dry lakes (four), or lakes that had been surveyed only once (5). Statistical analysis was also undertaken where possible (Table 34).

Of the 21 lakes that were suitable for LakeSPI assessment, ten appeared to be in a stable condition, with changes in scores of ≤5% (Table 34). Another four lakes with changes in scores of ≤5% raised concerns due to observations during the most recent survey of poor plant condition and/or low plant presence in some areas (Kawaupaku, Rototoa, small Pehiakura). Lake Pokorua results remained similar to the last assessment, but together with earlier historical data suggests cycles of change and a somewhat unstable dominance by the weed egeria (*Egeria densa*).The only lake that showed likely improvements in their LakeSPI indices was Mangatawhiri Reservoir, but the depth of native vegetation may have been exaggerated by prior water level increases.

A further 6 lakes showed a declining lake condition (>5% change) between the last two assessments (Table 34). Lake Tomarata had lost its submerged vegetation possibility due to interactions between poor water clarity conditions for plant growth and ongoing disturbance by populations of coarse fish. Lake Pupuke and Whatihua showed a retraction of deeper plant communities that suggests a reduction in long-term water clarity.

The status of Watercare managed water bodies were influenced by the timing of assessments in relation to the temporal pattern of water level fluctuation. In the case of apparent reductions in the condition of Mangatangi, Lower Huia and Cossey's Reservoirs these are driven by the extent and timing of water level fluctuations, and possibly additional factors of water clarity and exotic fish disturbance in the case of Cossey's reservoir (Table 34).

Water level reduction is a threat to the string of smaller lakes (Karaka, Poutoa, Ngakuru, Piripoua) along the South Kaipara Peninsula, with available evidence of higher water levels in the past.

All lakes show deterioration from their likely pristine or potential condition, through to current condition. Vegetation descriptions for five lakes from 1950 (Cunningham et al.1953) gave LakeSPI indices of 10% to 28% lower than pristine state, or an identical score to the pristine state in the case of Lake Pokorua.

Table 34.

Lakes ranked in order of change in LakeSPI Index during the last two assessments, where comparisons are available. * can't compute differences due to identical values.

	Statistical change between last two surveys			Category of change (%)	Change (%)	Stability
Lake	LakeSPI Index	Native Condition Index	Invasive Condition Index			
Mangatangi	-ve	-ve	*	>15	-64	Declining
Tomarata	-ve	-ve	None	>15	-63	Declining
Lower Huia				>15	-37	Declining
Cossey's	-ve	-ve	None	>15	-22	Declining
Pupuke	-ve	-ve	None	>10	-13	Declining
Whatihua	-ve	None	None	>5	-7	Declining
Mangatawhiri	+ve	+ve	*	>5	8	Improving
Pokorua	None	None	-ve (improvement)	≤5		Unstable
Rototoa	None	None	None	≤5		Declining
Big Pehiakura	None	None	None	≤5		Stable
Kawaupaku	None	None	None	≤5		Unstable
Kuwakatai	None	None	None	≤5		Stable
Wairoa	None	None	*	≤5		Stable
Small Pehiakura	*	None	*	≤5		Declining?
Okaihau				≤5		Stable
Paekawau				≤5		Stable
Slipper				≤5		Stable
Spectacle				≤5		Stable
Upper Huia				≤5		Stable
Upper Nihotupu				≤5		Stable
Waitākere				≤5		Stable
Karaka				Dry		Declining
Poutoa				Dry		Declining
Te Kanae				Single survey		

Hays Creek	Single survey
Little Shag	Single survey
Silver Hill	Single survey
Kereta	Grass carp
Wainamu	Grass carp
Western Springs	Grass carp
Lower Nihotupu	Not assessed
Ngakuru	Not suitable for survey
Piripoua	Not suitable for survey

6 Conclusions and recommendations

Priorities for future monitoring of lakes in the Auckland region were considered (Table 35) based on current lake condition, lake stability, any outstanding or special values represented within the lake vegetation, and the perceived extent and immediacy of threats that presented a risk to the future condition of the lakes. For example, higher scoring lakes have a greater potential for deterioration compared to already impacted lakes, so these received a higher priority for future monitoring. Similarly, priority should be given to lakes where there is a tangible risk of future weed invasion based on proximity to weed sources, access to, and usage of lakes, and their vulnerability to further invasion. These factors were considered in detail for ranking Auckland lakes in 2005 (Champion and de Winton 2005), but would require updating according to current lake condition. Non-vegetated lakes have a low risk of invasion due to highly restricted habitat availability for submerged plants, while several lakes already have maximal development of the worst available weed species. At least two lakes (Tomarata and Wainamu) have undergone submerged vegetation decline events, with apparent deterioration in water quality. Risk of vegetation decline is considered highest for heavily invaded water bodies where weed beds occupy much of the water column. Elsewhere vegetation decline has proved especially likely in the case of lakes invaded by *Egeria densa* (Champion 2002), with 26.4% of the New Zealand lakes invaded by *E. densa* subsequently undergoing a de-vegetation event (de Winton et al. 2009).

In setting priorities we have not considered restorative works that have been suggested for several lakes and their catchments. However, we recognise that the proposed schedule for monitoring indicated in Table 35 should be brought forward if a large change is known for any lake or its catchment.

LakeSPI results indicating lake condition can contribute to a prioritisation of the region's lakes for management or for restoration activities. Other information required for such an assessment are the perceived values for lakes (possibly including community/social importance) and the likely threats facing the lakes. The highest priority for management would be those water bodies of high value, that are in good condition (i.e., higher LakeSPI scores, good water quality) which are at greatest risk from identified threats.

Table 35.

Priority ranking for lakes for future monitoring that integrates both the current condition of lakes and the extent and immediacy of threats facing water body condition. A schedule for timing of monitoring for the lakes using LakeSPI is suggested.

Lake	Priority	LakeSPI schedule
Tomarata	Highest	2019
Rototoa	Highest	2019
Pupuke	Highest	2019
Whatihua	Highest	2019
Pokorua	Intermediate	2022
Kawaupaku	Intermediate	2022
Small Pehiakura	Intermediate	2022
Te Kanae	Low-intermediate	2025
Silver Hill Road	Low-intermediate	2025
Big Pehiakura	Low-intermediate	2025
Kuwakatai	Low-intermediate	2025
Cossey's	Low	2020
Lower Nihotupu	Low	Assessment still required
Mangatawhiri	Low	2020
Wairoa	Low	2020
Waitākere	Low	2020
Upper Huia	Low	2020
Lower Huia	Low	2020
Mangatangi	Low	2020
Okaihau	Low	2020
Poutoa	Low	1-2 years following forest harvest
Karaka	Low	1-2 years following forest harvest
Slipper	Low	2025
Spectacle	Low	2025
Paekawau	Low	2025
Upper Nihotupu	Low	2020
Hays Creek	Low	2020
Kereta	Low	Reassess after grass carp are removed
Wainamu	Low	Reassess after grass carp are removed
Western Springs	Low	Reassess after grass carp are removed

6.1 Summary information

To assist in setting priorities, summary information for each lake in ranked priority for monitoring is presented below in bullet point form and includes:

- A conclusion on the current lake condition, and stability (where known).
- The main influences on lake condition.
- Identification of any outstanding or special ecological values.
- Perceived major threats to lake condition and the level of risk of deterioration.

Lake Tomarata

- Non-vegetated lake condition declining from high status since the previous survey.
- Current condition from possible adverse catchment events and exotic fish.
- Previously showed signs of instability.
- Risk of invasive weed introduction could remain high.

Lake Rototoa

- High lake condition.
- Expected expansion by hornwort has not eventuated yet.
- Remains a good example of diverse native plant communities.
- Signs of nutrient enrichment (blue-green algal mats) and coarse fish disturbance (reduced plant cover).

Lake Pupuke

- Deteriorated to poor condition due to retraction of vegetation depth limit and loss of deeper charophyte meadows.
- Result suggests recent sustained reduction in water clarity.
- The most immediate threat is hornwort introduction, which elsewhere has proven competitive against *Vallisneria australis,* the dominant weed in Lake Pupuke.

Lake Whatihua

- Moderate lake condition but slight recent reduction in vegetation depth extent.
- The lake recorded a high diversity of native plants despite dominance by invasive *egeria.*
- The lake faces a moderate risk of increased *egeria* dominance, which is more likely if water quality deteriorates in the future.

Lake Pokorua

- Moderate lake condition with apparent cycles of egeria (*Egeria densa*) dominance since 1988.

- Vegetation retains considerable native character.
- Risk of increased egeria dominance with further enrichment.

Lake Kawaupaku

- In poor condition due to almost total invasion by egeria.
- May be vulnerable to a vegetation decline event on account of egeria vegetation, water quality issues and coarse fish disturbance.

Lake Small Pehiakura

- Decline to poor condition due to loss of shallow native vegetation.
- Algal blooms noted.
- Moderate risk of vegetation decline due inherently instability egeria weed beds.

Lake Te Kanae

- Poor lake condition is driven by almost complete invasion by hornwort.
- Level of stability is unknown but a limited catchment area and relatively deep lake depth is likely to buffer the lake against a rapid deterioration.

Silver Hill Reservoir

- Moderate condition on account of significant native vegetation but limited plant development on account of poor water quality and possibly young age of this water body.
- Low to moderate risk of invasion by additional weed species.

Lake Big Pehiakura

- In poor condition due to complete invasion by egeria.
- Moderate risk of vegetation decline due to inherently unstable egeria weed beds.

Lake Kuwakatai

- In a poor lake condition and heavily invaded by hornwort.
- Moderate risk of further deterioration due to a vegetation decline event.

Cossey's Reservoir

- In moderate condition but showing signs of recent deterioration.
- Level of submerged vegetation development restricted despite a more moderate water level regime than other Hunua reservoirs.

- Low risk of rapid deterioration unless an extreme water level regime is adopted.

Lower Nihotupu Reservoir

- Requires an assessment to be made.
- Current condition not known, but risk of rapid deterioration likely to be similar to that assessed for other Waitākere reservoirs (low).

Mangatawhiri Reservoir

- Excellent lake condition with signs of slight improvement.
- High native character without invasive weeds.
- Low risk of rapid deterioration unless an extreme water level regime is adopted.

Wairoa Reservoir

- High lake condition and apparently stable.
- Moderately high native character with absence of invasive weeds.
- Low risk of rapid deterioration unless an extreme water level regime is adopted.

Waitākere Reservoir

- Condition is high and apparently stable.
- Largely native and indicative of good water quality, with only moderate impacts from the current water level regime.
- The reservoir has a low risk of rapid deterioration unless an extreme water level regime is adopted.

Upper Huia Reservoir

- Currently in moderate condition and apparently stable.
- Largely native vegetation, but somewhat restricted development due to relatively recent recolonisation following water level fluctuations.
- Low risk of rapid deterioration unless an extreme water level regime is adopted.

Lower Huia Reservoir

- In moderate condition but signs of deterioration due to invasive weeds and restricted vegetation development from relatively recent recolonisation following water level fluctuations.
- Low risk of rapid deterioration unless an extreme water level regime is adopted.

Mangatangi Reservoir

- Non-vegetated lake condition with deterioration apparent since 1990, however extreme water level fluctuations account for recent change.
- Vegetation re-development is expected (signaling improved lake condition) unless an extreme water level regime is adopted.

Lake Okaihau

- Currently in poor condition with limited vegetation development mostly by invasive weeds.
- Low risk of rapid further deterioration.

Lake Poutoa

- The lake was dry, with loss of all habitat for submerged plants.
- Longer-term status may be linked to plantation forestry rotation status.

Lake Karaka

- The lake was dry, and although it was previously assessed as non-vegetated this change may be taken as deterioration.
- Longer-term threat to hydrology unknown.
- Substantial wildfowl value is recognized on account of diverse marginal emergent vegetation.

Lake Slipper

- Stable in a non-vegetated condition since at least 1988.
- Highly impacted currently so risk of further deterioration is low.
- Changes only likely after amelioration works in the catchment.

Lake Spectacle

- Stable in a non-vegetated condition since at least 1988.
- Highly impacted currently so risk of further deterioration is low.
- Changes only likely after amelioration works in the catchment.

Lake Paekawau

- The lake is stable and non-vegetated, apparently due to water quality restrictions for submerged plant growth.
- Further deterioration is unlikely.

Upper Nihotupu Reservoir

- Non-vegetated but stable.
- Extent of water level fluctuations exclude development of submerged vegetation.

Hays Creek

- Non-vegetated condition.
- Further deterioration unlikely.

Lake Kereta

- Currently non-vegetated after several years of grazing by stocked grass carp. In this case LakeSPI assessments do not accurately indicate lake ecological condition.

Lake Wainamu

- Currently non-vegetated after several years of grazing by stocked grass carp. In this case LakeSPI assessments do not accurately indicate lake ecological condition.

Western Springs

- Currently non-vegetated due to stocking of the herbivorous grass carp as a weed management initiative.
- LakeSPI assessments do not accurately indicate lake ecological condition while grass carp are present.
- A high risk of weed re-introduction will exist following grass carp removal.

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9 Appendix

Species lists for most recent lake surveys, indicating status of species as native or exotic.

Te Arai Lakes

Lake Tomarata 23/05/2017

Apodasmia similis	Native
Machaerina articulata	Native
Nitella sp. aff. *cristata*	Native
Eleocharis sphacelata	Native
Typha orientalis	Native

Little Shag Lake 25/04/2012

Azolla pinnata	Native
Machaerina articulata	Native
Chara australis	Native
Eleocharis sphacelata	Native
Nitella sp. aff. *cristata*	Native
Persicaria decipiens	Native
Typha orientalis	Native
Ludwigia palustris	Exotic
Utricularia gibba	Exotic

Lake Spectacle 29/10/2008

Eleocharis sphacelata	Native
Machaerina articulata	Native
Typha orientalis	Native
Baumea juncea	Native

Lake Slipper 29/10/2008

Machaerina articulata	Native
Machaerina juncea	Native
Eleocharis sphacelata	Native
Typha orientalis	Native

Silver Hills Reservoir 29/10/2008

Aponogeton distachyus	Exotic
Ludwigia palustris	Exotic
Potamogeton cheesemanii	Native
Potamogeton crispus	Exotic
Potamogeton ochreatus	Native

South Kaipara Lakes

Lake Poutoa 24/05/2017
Lake dry

Lake Rototoa 24/05/2017

Typha orientalis	Native
Machaerina articulata	Native
Machaerina arthrophylla	Native
Eleocharis acuta	Native
Eleocharis sphacelata	Native
Apodasmia similis	Native
Ceratophyllum demersum	Exotic
Potamogeton cheesemanii	Native
Potamogeton ochreatus	Native
Ruppia polycarpa	Native
Utricularia gibba	Exotic
Chara australis	Native
Chara fibrosa	Native
Chara globularis	Native
Nitella sp. aff. *cristata*	Native
Nitella leonhardii	Native
Nitella pseudoflabellata	Native

Lake Kuwakatai 23/05/2017

Azolla pinnata	Exotic
Machaerina sp.	Native
Ceratophyllum demersum	Exotic
Eleocharis sphacelata	Native
Ludwigia palustris	Exotic
Persicaria decipiens	Native
Schoenoplectus tabernaemontani	Native
Typha orientalis	Native

Te Kanae Road Lake 31/10/2008

Machaerina articulata	Native
Ceratophyllum demersum	Exotic
Eleocharis acuta	Native
Eleocharis sphacelata	Native
Hydrocotyle sp.	
Ludwigia palustris	Exotic
Ludwigia peploides	Exotic
Myriophyllum propinquum	Native
Persicaria decipiens	Native
Ranunculus amphitrichus	Native
Schoenoplectus tabernaemontani	Native
Typha orientalis	Native
Utricularia gibba	Exotic

Lake Kereta 27/02/2012

Azolla pinnata	Native
Machaerina articulata	Native
Centella uniflora	Native
Ceratophyllum demersum	Exotic
Eleocharis acuta	Native
Glossostigma elatinoides	Native
Isolepis prolifer	Native
Juncus spp.	
Lemna minor	Native
Lotus pedunculatus	Exotic

Ludwigia palustris	Exotic
Ludwigia peploides	Exotic
Myriophyllum triphyllum	Native
Myriophyllum propinquum	Native
Nitella hyalina	Native
Nymphaea sp.	Exotic
Paspalum disticum	Exotic
Schoenoplectus tabernaemontani	Native
Typha orientalis	Native
Utricularia gibba	Exotic
Zizania palustris	Exotic

Lake Karaka 25/02/2010

Isolepis prolifer	Native
Ludwigia palustris	Exotic
Ludwigia peploides	Exotic
Bulboschoenus fluviatilis	Native
Cyperus sp.	
Carex secta	Native
Carex virgata	Native
Myriophyllum propinquum	Native
Hydrocotyle sp.	
Juncus sp.	
Paspalum disticum	Exotic
Polygonum spp.	
Zizania latifolia	Exotic
Eleocharis sphacelata	Native
Eleocharis acuta	Native
Baumea articulata	Native
Typha orientalis	Native
Schoenoplectus tabernaemontani	Native

Lake Ngakuru 3/11/2005

Azolla pinnata	Exotic
Ludwigia palustris	Exotic
Ludwigia peploides	Exotic
Myriophyllum propinquum	Native

Lake Piripoa 3/11/2005

Azolla pinnata	Exotic
Juncus sp.	
Ludwigia palustris	Exotic
Ludwigia peploides	Exotic
Myriophyllum propinquum	Native
Potamogeton cheesemanii	Native
Potamogeton ochreatus	Native

Muriwai Lakes

Lake Okaihau 28/02/2012

Alternanthera philoxeroides	Exotic
Ceratophyllum demersum	Exotic
Eleocharis acuta	Native
Eleocharis sphacelata	Native
Glossostigma elatinoides	Native
Lilaeopsis ruthiana	Native
Ludwigia palustris	Exotic
Myriophyllum propinquum	Native
Myriophyllum triphyllum	Native
Nitella sp. aff. *cristata*	Native

Nitella pseudoflabellata	Native
Nymphaea sp.	Exotic
Schoenoplectus tabernaemontani	Native
Utricularia gibba	Exotic

Lake Wainamu 17/03/2011
See AC records. Samples identified by NIWA included:

Chara australis	Native
Eleocharis sphacelata	Native
Utricularia gibba	Exotic

Lake Kawaupaku 22/05/2017

Egeria densa	Exotic
Typha orientalis	Native
Carex secta	Native

Lake Paekawau 25/02/2010

Eleocharis sphacelata	Native
Glossostigma elatinoides	Native
Isolepis prolifer	Native
Ludwigia palustris c	
Myriophyllum propinquum	Native
Myriophyllum triphyllum	Native
Nymphaea sp.	Exotic
Otellia ovalifolia	Exotic
Typha orientalis	Native
Utricularia gibba	Exotic

Auckland City Lakes

Lake Pupuke 25/05/2017

Chara australis	Native
Egeria densa	Exotic
Myriophyllum triphyllum	Native
Vallisneria australis	Exotic

Western Springs Lake 31/10/2008

Amblystegium riparium	Native
Fissidens berteroi	Native
Iris pseudacorus	Exotic

Waitākere Reservoirs

Waitākere Reservoir 30/01/2008

Centella uniflora	Native
Chara australis	Native
Eleocharis acuta	Native
Eleocharis sphacelata	Native
Juncus bulbosus	Exotic
Ludwigia palustris	Exotic
Myriophyllum propinquum	Native
Nitella sp. aff. *cristata*	Native
Nitella leonhardii	Native
Nitella pseudoflabellata	Native
Potamogeton cheesemanii	Native
Potamogeton ochreatus	Native
Ranunculus trichophyllus	Exotic

Upper Huia Reservoir 30/10/2008

Machaerina sp.	Native
Centella uniflora	Native
Glossostigma elatinoides	Native
Juncus bulbosus	Exotic
Ludwigia palustris	Exotic
Myriophyllum propinquum	Native
Myriophyllum triphyllum	Native
Potamogeton ochreatus	Native
Typha orientalis	Native
Unidentified moss	

Lower Huia Reservoir 31/10/2008

Callitriche sp.	
Centella uniflora	Native
Eleocharis sphacelata	Native
Galium palustre	Exotic
Glossostigma elatinoides	Native
Juncus bulbosus	Exotic
Ludwigia palustris	Exotic
Myriophyllum propinquum	Native
Nitella sp. aff. *cristata*	Native
Nitella pseudoflabellata	Native
Potamogeton cheesemanii	Native
Zannichellia palustris?	Native

Upper Nihotapu Reservoir 30/11/2008

Lower Nihotupu Reservoir 30/11/2008

Ludwigia palustris	Exotic

Awhitu Lakes

Lake Pokorua 06/03/2017

Chara australis	Native
Chara globularis	Native
Egeria densa	Exotic
Elodea canadensis	Exotic
Eleocharis sphacelata	Native
Myriophyllum triphyllum	Native
Nitella sp. aff. *cristata*	Native
Potamogeton ochreatus	Native
Typha orientalis	Native
Ludwigia peploides	Exotic
Ludwigia palustris	Exotic
Persicaria decipiens	Native
Glossostigma elatinoides	Native

Lake Whatihua 0603/2017

Chara australis	Native
Chara fibrosa	Native
Chara globularis	Native
Egeria densa	Exotic
Eleocharis acuta	Native
Eleocharis sphacelata	Native
Elodea canadensis	Exotic
Glossostigma elatinoides	Native
Lilaeopsis ruthiana	Native

Limosella lineata	Native
Ludwigia palustris	Exotic
Myriophyllum triphyllum	Native
Nitella hyalina	Native
Persicaria decipiens	Native
Potamogeton cheesemanii	Native
Potamogeton ochreatus	Native
Utricularia gibba	Exotic
Azolla pinnata	Exotic
Ricciocarpus natans	Native
Wolffia australis	Native

Lake Small Pehiakura 07/05/2017

Egeria densa	Exotic
Glossostigma elatinoides	Native
Spirodela punctata	Native
Myriophyllum triphyllum	Native
Nitella hyalina	Native
Azolla pinnata	Exotic

Lake Big Pehiakura 07/05/2017

Machaerina articulata	Native
Elodea canadensis (drift)	Exotic
Schoenoplectus tabernaemontani	Native
Typha orientalis	Native
Carex secta	Native
Apodasmia similis	Native

Hunua Reservoirs

Mangatawhiri Reservoir 21/10/2008

Centella uniflora	Native
Chara australis	Native
Eleocharis sphacelata	Native
Galium palustre	Exotic
Juncus sp.	
Ludwigia palustris	Exotic
Myriophyllum propinquum	Native
Nitella aff. *cristata*	Native
Potamogeton cheesemanii	Native
Potamogeton ochreatus	Native

Wairoa Reservoir 21/10/2008

Carex sp.	
Chara australis	Native
Myriophyllum propinquum	Native
Nitella sp. aff. *cristata*	Native
Nitella pseudoflabellata	Native
Potamogeton cheesemanii	Native
Potamogeton ochreatus	Native

Cossey's Reservoir 21/10/2008

Centella uniflora	Native
Galium palustre	Exotic
Glossostigma submersum	Native
Juncus bulbosus	Exotic
Juncus sp.	

Ludwigia palustris	Exotic
Myosotis sp.	
Myriophyllum propinquum	Native
Myriophyllum propinquum	Native
Nitella sp. aff. *cristata*	Native
Nitella pseudoflabellata	Native
Ranunculus flammula	Exotic

Mangatangi Reservoir 21/10/2008

Chara australis	Native
Myriophyllum propinquum	Native
Nitella sp. aff. *cristata*	Native

Hays Creek Reservoir 21/10/2008

Nitella sp. aff. *cristata*	Native

Find out more: phone 09 301 0101, email rimu@aucklandcouncil.govt.nz or visit aucklandcouncil.govt.nz **and knowledgeauckland.org.nz**

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Te Kaunihera o Tāmaki Makaurau