NIWA
Taihoro Nukurangi

LakeSPI

A method for monitoring ecological condition in New Zealand lakes

Technical Report
Version 2

John Clayton
Tracey Edwards

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Glossary

Aerenchyma	Specialised tissue with air spaces found in submerged angiosperms.
Angiosperm	Flowering vascular plant.
Bryophyte	Refers to mosses and liverworts.
Dystrophic	Refers to lakes rich in humic material and with brown stained water.
Eutrophication	The enrichment of waterbodies by nutrients and organic matter.
Indigenous	Plants that originate naturally from a region or country.
Indicator	An ecological indicator is a measure, or an index of measures, that characterizes an ecosystem or one of its critical components.
Littoral	The zone in a lake that extends from the shore to where rooted plants grow.
Macrophyte	Large plant with multicellular structure.
Oligotrophic	Refers to lakes low in nutrients and organic matter.
Photic depth	The depth of water that light can penetrate to still enable plant growth. This is commonly considered to be around 1% of surface light.
Photosynthetic compensation point	The depth to which light becomes limiting for submerged plant growth.
Photosynthesis	The process by which all plants use light for growth.
Physico-chemical	Refers to the range of physical (e.g., Secchi disc, dissolved oxygen) and chemical (e.g., nutrient concentration, chlorophyll *a*) measurements used to characterise water quality.
Phytoplankton	Microscopic algae that drift suspended in water.
Plankton	Collectively all the microscopic organisms (plants and animals) suspended in water.
Secchi	A 20 cm disc used to measure water clarity by lowering the disc to the point it disappears.
Taxa	Any taxonomic category (e.g., species, genus).
Trophic status	Refers to the nutrient and productivity condition of a waterbody (e.g., oligotrophic or eutrophic).

Executive Summary

Purpose - This report presents a tool for monitoring the ecological condition of New Zealand lakes. The tool, LakeSPI (pronounced ‘Lake Spy’) uses carefully selected features of submerged plant communities to assess the effects of catchment and water management on a lake and the impact of aquatic weed invasion in a lake. Its intended users are lake managers and it provides a relatively quick, cost effective method for monitoring the ecological condition of lakes.

Issue – Historically in New Zealand there has been a reliance on physico-chemical sampling for monitoring the health of lakes. Existing monitoring methods tend to be complex, costly, involve multiple site visits and chemical analysis of water samples. As a result, lake monitoring has often been done irregularly, or not at all. The ecological condition of many lakes has deteriorated significantly before the decline has been recognised and accordingly early opportunities for remedial actions have been lost. As submerged plants are good integrators of change occurring within a lake, they need only be monitored once a year or even less. LakeSPI also provides new information on lake condition with its focus on lake margins where there is greatest public interaction and interest. It is intended that LakeSPI will complement rather than replace traditional lake monitoring methods, as it will facilitate the regular monitoring of a much wider range of lakes than is possible using traditional methods.

Development Process – Development of the LakeSPI method begun in 2000 in line with an MfE iniative to facilitate the implementation of a suite of confirmed indicators for monitoring environmental performance (EPI Programme). LakeSPI was specifically developed to contribute to the implementation of two indicators: (1) change in the biodiversity condition of selected freshwater ecosystems and habitats compared with historic and current baselines, and (2) change in the distribution and abundance of selected plant pests. Initial workshops, stakeholder meetings, field-testing and technical development enabled a range of potential indicators to be investigated. Today the LakeSPI method has been field tested and further refined in more than one hundred lakes throughout New Zealand and the assessed LakeSPI condition of many of these lakes can be viewed using the LakeSPI reporting website – lakespi.niwa.co.nz. LakeSPI presents three indices to describe lake ecological condition. The Native Condition Index captures the native character of lake vegetation while the Invasive Condition Index reflects the degree of invasive impact. Components from each of these two indices are combined to create an overall LakeSPI Index that provides a practical and meaningful measure of lake condition.

Using LakeSPI - The LakeSPI method is designed for use in all lakes apart from those where submerged plant cover is less than ten percent or where environmental conditions (e.g., salinity, acidity) prevent the development of typical submerged vegetation. It involves SCUBA diving at five representative sites within a lake and recording the maximum depth of native and invasive submerged vegetation, the presence of native plant community types, the cover and height of key invasive plant species, the ratio of native to invasive species and the nature of invasive cover. This information is 'scored' to generate numerical values for native condition, invasive condition and overall lake condition.

A simple baseline for lakes has been developed as part of the LakeSPI method. This is based on maximum lake depth and natural differences in clarity and this enables the calculation of a potential maximum score for a lake. LakeSPI scores can be used to monitor trends over time within a single lake and/or for assessing or comparing the ecological condition of lakes within New Zealand. It can contribute directly to reporting of lake environmental trends at the local, regional and national levels. The LakeSPI method can also be applied to historic vegetation survey data for assessing retrospective lake condition changes.

Future Directions – Additional indicators for potential incorporation into LakeSPI are under investigation. These include selected benthic macro-invertebrates such as the abundance of koura (native freshwater crayfish) and kakahi (native freshwater mussels), as well as benthic cyanobacteria films immediately below the maximum submerged macrophyte deoth limit.

Chapter 1

1. Forward

1.1 Purpose of this report

The purpose of this report is to:

- Present the rationale for developing the LakeSPI method
- Describe how the method was developed
- Provide a technical account of the concepts behind LakeSPI
- Demonstrate the potential of LakeSPI and benefit for management applications

The intended audience of this report includes scientific users, technical users and managers.

A User Manual providing procedural guidance has also been prepared for the LakeSPI method.

1.2 Summary of the method

WHAT IS LakeSPI?	
LakeSPI	Lake Submerged Plant Indicators (LakeSPI) is comprised of three indices: Native Condition Index, Invasive Condition Index and an overall LakeSPI Index.
Purpose	Assessment of ecological condition of New Zealand lakes.
Biota Sampled	Submerged aquatic plants (macrophytes)
Underlying principles	A lake can be characterised by the composition of native and invasive plants and the depth at which they grow to.

WHAT ARE THE USES OF LakeSPI?	
Uses	To assess, monitor and report on lake ecological condition.
Application	To assist managers in assessing the effectiveness of management activities and to contribute towards regional and national reporting requirements.

SURVEY PLANNING	
Skills	Diving and basic plant identification
Equipment	SCUBA, boat (may be required), field gear (clipboard, pre-printed water proof sheets).
Lake Selection	Any lakes with submerged plants except where salinity, alkalinity, acidity, altitude or size prevents the development of normal submerged vegetation composition. It is not suitable for lakes where submerged plants are rare (i.e., site cover less than ten percent) or non-existent.
Site Selection	Avoid sites affected by unfavourable influences such as stream inflows, steep gradients, exposed shorelines and disturbance areas (boat ramps and weed control areas). Five sites will be sufficient for most lakes.
Timing	Summer and autumn assessments are recommended. Frequency of survey will vary depending on management objectives, a lake's current condition and vulnerability to change.

HOW TO CARRY OUT A LakeSPI SURVEY

Pre-survey	It is useful to investigate previous lake reports, vegetation lists (NIWA Aquatic Plant Database), and a bathymetric map prior to site selection. Surveyors should be familiar with the necessary health and safety guidelines. An equipment checklist is provided.
Field survey	This involves SCUBA diving at five representative sites within a lake and recording various components of native and invasive lake vegetation onto LakeSPI field sheets.

GENERATING LakeSPI SCORES AND INDICES

Site scores	Data captured on the site field sheet is used to generate three LakeSPI scores for an individual site. Separate native condition, invasive condition and LakeSPI scores are generated using scoring parameters, which relate to each vegetation feature being assessed.
LakeSPI indices	A mean of each of the final site scores for native condition, invasive condition and LakeSPI, result in the final indices: *Native Condition Index*, *Invasive Condition Index*, and overall *LakeSPI Index*.

INTERPRETING RESULTS

Native Condition Index	This captures the native character of vegetation in a lake based on diversity and quality of indigenous plant communities. A high 'native condition index' value will represent better lake condition.
Invasive Condition Index	This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species. A high 'invasive condition index' value will represent poorer lake condition.
LakeSPI Index	This is a synthesis of components from both the native condition and invasive condition of a lake and provides an overall indication of a lake's ecological condition.
Lake comparisons	LakeSPI assesses and calculates LakeSPI indices based on a maximum potential score for each lake. This allows dissimilar lakes to be more directly compared.

Chapter 2

2. Introduction

2.1 What is LakeSPI?

LakeSPI (pronounced “Lake Spy”) is a management tool that uses Submerged Plant Indicators (SPI) for assessing the ecological condition of New Zealand lakes and for monitoring trends in lake ecological condition. Key features of aquatic macrophyte 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.
- ‘Invasive Condition Index’ – This captures the invasive character of vegetation in a lake based on the degree of impact by invasive weed species.
- ‘LakeSPI Index’ – This is a synthesis of components from both the native condition and invasive condition of a lake and provides an overall indication of lake ecological condition.

LakeSPI provides a cost effective management tool that is relatively straightforward in its application and relevant for use by lake managers in all lakes where submerged vegetation is present.

A website has been designed to hold LakeSPI survey information and LakeSPI results can be viewed in a user friendly format from lakespi.niwa.co.nz.

2.2 Uses of LakeSPI

The LakeSPI method can be used to provide an overall indication of a lakes ecological and biological condition. It provides an insight into the native and invasive character of a lake and allows for changes in these conditions and overall lake condition to be monitored over time.

LakeSPI can be used in many ways depending on what the management needs are for individual lakes or for a selection of lakes. The LakeSPI indices will allow lake managers to:

- Assess and compare the ecological condition of different lakes within or between regions.
- Rank the state of lakes in their region and thereby prioritise those most in need of protection, surveillance or management.
- Monitor trends occurring within selected lakes over time.
- Compare current lake condition with indices generated from historical vegetation records
- Make comparisons between dissimilar lakes of different depths and from different regions.
- Provide relevant information for regional and national reporting requirements, including operational monitoring and state of the environment reporting.
- Help assess the effectiveness of catchment and lake management initiatives.

It is intended that LakeSPI complement rather than replace other lake assessment methods. For example, there are many cases where lakes have not been systematically monitored and LakeSPI can provide a simple, cost effective means for allowing mangers to capture information for such lakes under their management.

A list of questions that LakeSPI can help answer and further comparisons between LakeSPI and other monitoring methods can be found in the management application section of this report (Section 9).

Chapter 3

3. Rationale for the project

3.1 Project objectives

LakeSPI was developed as one of various responses to the Environmental Performance Indicators (EPI) Programme coordinated by the Ministry for the Environment. The purpose of the EPI Programme was to implement a set of national environmental indicators for State of the Environment reporting. LakeSPI provides a method for measuring the lakes component of two key indicators; (1) *change in the biological condition for selected freshwater ecosystems and habitats compared with historic and current baselines,* and (2) *change in the abundance and distribution of selected plant pests*.

The project objective for the development team was to design a simple, inexpensive and robust method for monitoring lake ecological condition using submerged plants. The project aimed to provide lake managers with a useful tool requiring only a moderate level of practical and taxonomic skill that was suitable for a range of end user needs (section 3.2).

3.2 Meeting end user needs

The LakeSPI method has been developed to facilitate widespread monitoring of lake ecological condition.

The LakeSPI project originally sought to address two main user needs:

- Provision of tools for monitoring trends in ecological condition of specific lakes. This requires the development of cost-effective measures that allow lake managers to answer a range of questions about the lakes they monitor.
- New Zealand State of the Environment reporting on changes in the ecological condition in New Zealand lakes.

At a more detailed level the project seeks to:

- Provide managers with a means of ranking the state of lakes in their region and thereby prioritise those most in need of protection, surveillance or management initiatives.
- Provide managers with tools that will assist them to monitor the implementation and effectiveness of policies affecting lakes at national, regional and local levels. For example there is a national policy goal to protect the natural character of lakes and their margins (Resource Management Act, s6(a)).
- Provide managers with tools that will assist them to identify appropriate management actions to improve lake management (including catchment) and, where appropriate, facilitate restoration.
- Provide managers with tools that will assist them to monitor the effectiveness of management actions (operational monitoring) for specific lakes or groups of lakes.
- Provide managers with baselines that can be used to provide a historic context for results.
- Contribute to the implementation of the New Zealand Biodiversity Strategy action programme for freshwater ecosystems.
- Contribute directly to the implementation of the Environmental Performance Indicators Programme biodiversity indicators.

At a practical level the project will address the following problems:

- Many lakes have not been surveyed or monitored.
- Traditional methods for measuring water quality require regular sampling on a continuous basis to incorporate seasonal and climatic cycles.
- Present physico-chemical monitoring methods focus on profiles from the centre of the lake rather than lake margins or littoral zones where there is greatest public interaction and interest.
- Present survey methods for monitoring vegetation change are not systematically applied by managers because of the high cost and skill levels required. This means that important trends are not observed and so management opportunities are missed.

3.3 Contributing to the environmental performance indicators programme

New Zealand is a signatory member of the Rio Convention 1992, where Agenda 21 encourages governments to develop, among other things, "indicators of sustainable development". This is to be achieved by: "developing methodologies with a view to undertaking systematic sampling and evaluation on a national basis of the components of biological diversity" and to measure and monitor "the status of ecosystems and establish baseline information on biological and genetic resources, including those in terrestrial, aquatic, coastal and marine ecosystems...". In response the Ministry for the Environment is implementing a Cabinet directive to develop a suite of indicators for monitoring environmental performance (EPI Programme). The Governments objectives for this programme were to:

- systematically measure the performance of environmental polices and legislation
- better prioritise policy and improve decision-making
- systematically report on the state of New Zealand's environmental assets

LakeSPI was specifically developed to contribute to the following indicators in the EPI Programme:

- change in the biodiversity condition of selected freshwater ecosystems and habitats compared with historic and current baselines.
- change in the distribution and abundance of selected plant pests.

LakeSPI may also be able to contribute to the indicator:

- change in lake trophic status (water quality).

Accurate reporting on environmental trends at the local, regional and national level requires the use of an appropriate sampling regime. LakeSPI is sufficiently simple to enable the option of sampling all lakes of interest, especially accessible lakes most at risk from human-induced changes.

3.4 Meeting specific policy requirements

There are a number of policies in legislation and Government strategy documents that affect lake management. Appendix 1 sets out these specific requirements from legislation and other government policies.

Key points to note are:

- The requirement in s6 of the Resource Management Act for all those exercising powers and functions under the Act to: recognise and provide for the preservation of the natural character of lakes and their margins (s6(a)); and protect areas of significant indigenous vegetation (s6(c)).
- The New Zealand Biodiversity Strategy freshwater section requires that: management mechanisms adequately provide for the protection of freshwater biodiversity from the adverse

effects of activities on land and water; prevent and control pests that threaten indigenous biodiversity; and restore priority freshwater habitats.

Chapter 4

4. Introduction to New Zealand lake vegetation

4.1 New Zealand lakes – treasures under threat

New Zealand has a warm to cool temperate climate, a moderate rainfall and a wealth of lakes and rivers. The NIWA Aquatic Plant Database has 988 lakes listed that meet the criterion of a lake, being anything larger than 0.5 sq km (Irwin 1975). Additionally there are also numerous smaller water bodies that all contribute to the diversity of 'lake' types found throughout New Zealand. Our lakes are often referred to as the 'crown jewels' of the country. They provide a diversity of beauty and recreational opportunities that are widely advertised in travel promotions and are highly valued by New Zealanders and overseas tourists. They form an integral part of our 'great outdoors' psyche but all too often they are taken for granted.

Prior to the arrival of humans to New Zealand, approximately 78% of the land was forest (Kelly, 1980). Early Polynesians caused widespread fires and from 1840 (start of the main European settlement) forest clearance increased markedly. This was followed by extensive agricultural development including wetland drainage. Today over 90% of New Zealand's original wetlands have been drained and only 23% of New Zealand has an indigenous forest cover (Taylor & Smith 1997).

The impact of changed land use on New Zealand's lakes has been dramatic. The increased nutrient enrichment and siltation has degraded many lakes, especially smaller lakes at low elevations. Water clarity in particular, has decreased due to increasing phytoplankton abundance and suspended inorganic particles. Today, the intensification of agricultural land uses in many locations is exacerbating these effects.

Another impact since the arrival of Europeans, has been the extensive introduction of alien plants and animals. By the 1940's about 500 alien plant species had become established. By March 1998, 2068 alien plants had naturalised (formed self-perpetuating populations) in New Zealand out of the more than 19,000 terrestrial and freshwater introduced plants species currently present (Owen 1998). The invasive spread of uncontrolled alien species has become a major management issue on land and in water.

Alien submerged weeds have had spectacular success in invading New Zealand lakes, particularly members of the Hydrocharitaceae (i.e., “oxygen weed species”) and Ceratophyllaceae families. Adverse changes associated with their establishment are threefold. Firstly, their superior competitive abilities see these weeds exclude and replace native plants, reducing native representativeness and biodiversity values. Secondly, the tall, surface-reaching nature of invasive alien weed beds interferes with recreational uses of waterbodies. Thirdly, economic utility of waterways for hydroelectric generation and water extraction can be compromised.

Historical and current land management practices, and the spread of invasive alien species have resulted in few waterbodies retaining their natural or original indigenous aquatic vegetation.

So just how healthy are our New Zealand lakes and how safe are they from undesirable ecological changes? A common perception is that our most treasured lakes such as Taupo, Wakatipu and Wanaka are clean and clear and will always remain that way. This was the general perception of Lake Tahoe in Utah, USA – one of the clearest known lakes in the world. This lake, although still remarkably clear, has undergone a thirty percent decline in water clarity over a period of twenty-five years and since the late 1960s Secchi disc readings have reduced by 0.37 m yr^{-1} (Goldman 1981, 1988). This has resulted in underwater plants that used to reach exceptional depths on account of pristine water clarity having retracted from depths of 120 m to 80 m (Goldman pers com). Lake Geneva in Switzerland was also a once prized lake for its clarity, but it now suffers frequent algal blooms as a consequence of extended periods of nutrient addition.

These examples provide reminders that our New Zealand lakes are similarly fragile and should not be taken for granted. While many of our large lakes have remained clear because their catchments are in a relatively natural state, there are many lakes that have seen dramatic reductions in water clarity.

Lake Taupo is a high profile, clear-water New Zealand lake, but there are indications that even our large oligotrophic lakes are under threat. Environment Waikato reports that there have been signs of a deterioration in water quality, especially in water clarity. They attribute the decreased water clarity as probably a reflection of increasing levels of plant nutrients that are causing increased phytoplankton algal growth in the water (http://www.ew.govt.nz). Growths of filamentous algae are also having an undesirable impact on various beaches around Lake Taupo each summer. Historical land catchment activities can impose a legacy of unstoppable change for many years. In Lake Taupo, there is a ten to seventy year time lag before the ground water affected by current land use is predicted to reach the lake (Environment Waikato 2002).

The threats to the condition of Lake Taupo are further highlighted by the impact of invasive alien weeds and especially the relatively recent arrival of *Ceratophyllum demersum* (hornwort). *Ceratophyllum* is displacing native vegetation to depths well below that previously impacted by other invasive weed species. This plant is ranked as one of the highest risk aquatic weed species in New Zealand (Champion & Clayton 2001), and has recently spread from the North Island to the top of the South Island where it threatens the ecological, utilitarian and recreational values of many valuable southern lakes.

Many of New Zealand's lakes have much less buffering capacity against change than a large lake such as Taupo. The high public usage and awareness that has helped focus political and management attention on Lake Taupo is often lacking for other lakes.

The lakes in the Rotorua District present a well-known diversity of treasures and woes. Nutrient enrichment and invasive weed species have adversely affected their natural character. For many years the sewage from Rotorua City was discharged directly into Lake Rotorua with long-lasting consequences for it and the adjoining Lake Rotoiti that receives the waters from Lake Rotorua. Septic tanks still threaten water quality and other values in lakes such as Lake Okareka. Catchment nutrients and effluent have so enriched Lake Okaro that it turns green because of dense algal blooms, while Lake Rotoehu has health warnings in place most of the year on account of toxic algal blooms.

While the water quality in Lake Tarawera is still high, like Taupo, its ecological condition has been significantly degraded by the invasive alien plant *Ceratophyllum*. *Ceratophyllum* has recently displaced much of the remaining indigenous vegetation throughout the lake.

The severe degradation that has taken place in all of the lakes in the Waikato Region is of great concern. Early botanists reported an amazing diversity of native plant species in these shallow lakes (Kirk 1871). Submerged vegetation often extended right across the bottom of these lakes and the water was so clear that this vegetation could be seen from the surface. The small volume of these lakes has made them especially vulnerable to change and there have been three major shifts in their natural character. Firstly there has been a progressive decline in water clarity associated with nutrient enrichment and land disturbance from farming activities in their catchments, including deliberate removal of marginal wetland vegetation. Secondly there has been extensive invasion by submerged weed species that largely displaced native submerged vegetation. Finally in recent years there has been a major decline in submerged vegetation associated with deteriorating water quality and the arrival of pest fish species such as rudd, perch, catfish, tench and koi carp. Pest fish have collectively uprooted plants, disrupted bottom sediments and helped to contribute to the present prevailing status of the many turbid devegetated lakes now found throughout this region. This pattern of degradation experienced in these Waikato Lakes is a legacy likely to be repeated throughout many New Zealand lakes in the future unless public, management and political commitment is focused collectively on preventing such changes.

4.2 A typical vegetation profile

The following is a simplified description of the aquatic vegetation found in most New Zealand freshwater lakes. Generalisations are inevitable, however in this context they are useful in helping to understand and visualise lake vegetation structure.

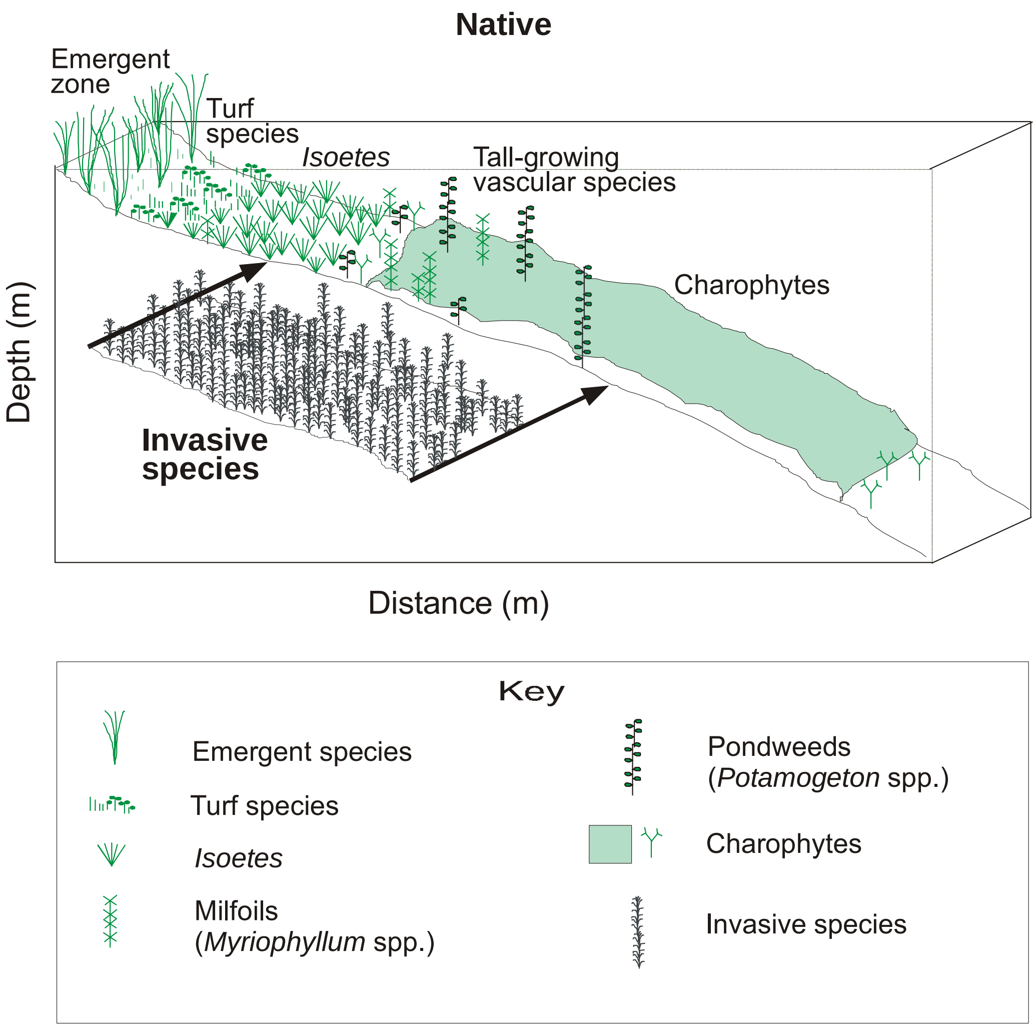


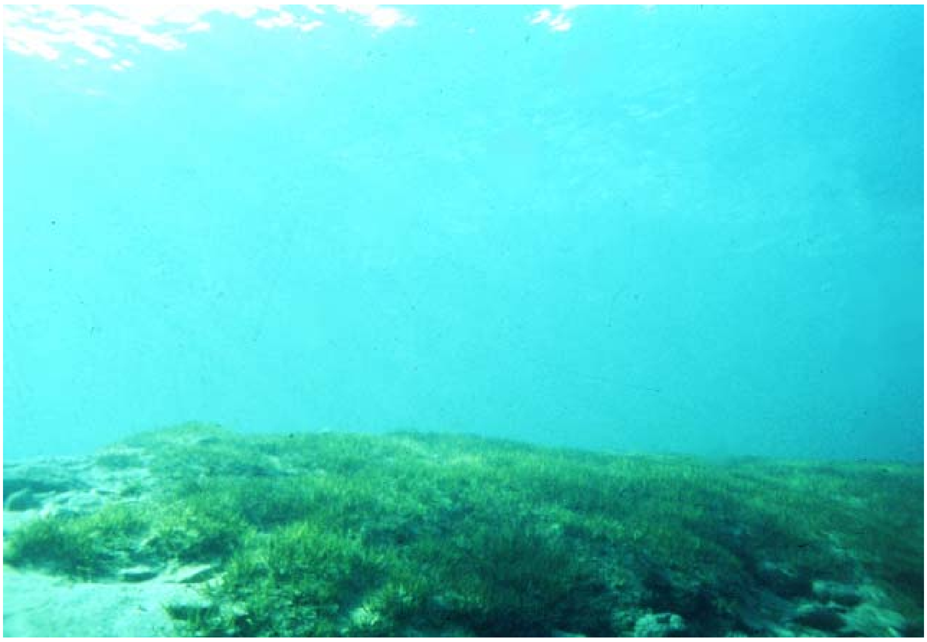
Figure 1. **Depth profile illustrating the main components of native lake vegetation and the region of substitution by invasive species.**

Aquatic plants can be conveniently divided into distinct depth-related community types ranging from the lake margin down to the deepest plant growth where light penetration becomes limiting for plant growth. This can be described in the depth profile drawing (Figure 1), which shows the general vegetation structure of many New Zealand lakes.

Starting at the lake edge the first and most conspicuous community type is the *emergent zone*. This is comprised of a variety of wetland species that tend to be tall growing, erect and occupy the lake margin from just above the water line and can extend out into the water to a depth of around 2 metres. This community is usually only found in sheltered habitats such as around the margins of small water bodies or in protected backwater of larger lakes. In wave-exposed areas this community will be absent.

Emergents growing around margins of Lake Rotoroa (Hamilton Lake)

Turf species (also known as 'low mound [or mixed] community') grow only in shallow water along shorelines of moderate exposure. They can overlap and co-exist with plants in the emergent zone in semi-sheltered habitats or even occupy sheltered shorelines if emergents are absent. There are many different species that contribute to this community type and they all tend to grow as short-stature plants to give the appearance of a grass-like turf. There is one plant (*Isoetes*) that is quite special in this community, since it can grow to greater depths than all other turf species. Normally the turf community only grows down to around 2 or 3 metres depth, whereas *Isoetes* can form a very dense monospecific community down to around 6 metres and sometimes more, especially in the large clear South Island lakes.



Turf species growing in shallow water (Lake Taupo)

Charophytes are a group of native macroalgae that are quite distinctive in that they often form 'meadows' across the bed of a lake. They can grow in shallow water and are often the next common community type to extend beyond either the emergent or the turf zone. They can also extend into deeper water in direct proportion to the water clarity. In clear water lakes they can grow down to depths of 50 metres and they are often the only vegetation type found deeper than the vascular species.

Charophyte meadows (foreground) growing below milfoils. (Note occasional shoots of Lagarosiphon starting to invade charophyte community)

Tall-growing vascular species are comprised mostly of tall-growing angiosperms (flowering plants). There are two commonly recognised native genera *Potamogeton* (pondweeds) and *Myriophyllum* (milfoils). They are often superimposed on top of the two community types discussed above. They tend to have little impact on the density or appearance of the underlying turf species or charophytes because they normally do not grow as a dense community. In fact they may occur at such low densities as to give the appearance of isolated shoots arising from out of a dense ground cover of turf or charophyte vegetation.

Milfoils growing at low density amongst turf species (Isoetes) in Lake Wanaka

The above 'typical vegetation profile' describes **native** community types found widely throughout New Zealand lakes irrespective of lake size. A major deviation arises whenever **invasive** submerged species become established in a lake. All of the main invasive weed species impacting on lake vegetation structure are also tall-growing angiosperms, but they have one distinctive difference from the native milfoils and pondweeds. These invasive species can form extremely dense growths that exclude all other vegetation. They typically occupy the mid-depth range of lakes and are most common from around two to eight metres depth. Although they can grow to a depth of ten metres, their greatest impact tends to be between two to five metres where they are able to exclude most native species. There are several different invasive species present throughout New Zealand, each with their own characteristics (see User Manual for illustrations and details on plant species).

Invasive weed bed (Lagarosiphon major) dominating all other vegetation (Lake Taupo)

Particular features of each of the above community types have been identified and selected as representing useful information about the ecological condition of a waterbody. These features form the basis of the LakeSPI method and are explained in detail in the Section 6.

4.3 Why use submerged plants as lake indicators?

Submerged plants have a number of advantages that favour their use as indicators of lake ecological 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 for an extended period of time prior to sampling. 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 represents a large proportion of the lake area (e.g., Lake Rotorua, North Island) the open water or centre lake condition can be remarkably different to the water quality and ecological condition occurring within 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 focus attention on the ecological well-being and biological functioning of the littoral zone where submerged plants tend to dominate.

Increased sediment and nutrients 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 categorising the extent of these impacts.

Chapter 5

5. Development process

5.1 Technical development

Before the initiation of the LakeSPI project, the Ministry for the Environment held a series of workshops in 1998 in association with science providers, government agencies and regional councils to identify potential biodiversity indicators suitable for New Zealand freshwaters. This was part of the EPI Programme, which initially identified three potential indicators involving the use of freshwater plants:

- "The relative abundance or presence/absence of selected indicator species compared to historic and current baselines". Possible options for assessing this included measuring the relative extent of charophyte meadows, as well as the presence and absence of *Isoetes* and *Myriophyllum* species.
- "Presence and extent of alien plant cover by waterbody eco-type".
- "The number of the ecotypes/water bodies free from alien species".

Initial consideration of the above potential indicators identified two distinct levels of assessment, one being an overview of the status of all lakes in a region (e.g., how many waterbodies are free of alien species?); the other being a more focused statement on the condition of plants within a lake (e.g., relative abundance of suggested indicator species). However in order to address overall lake status it was clear that a method needed to be developed that would characterise key features within each and every waterbody. Conceptual difficulties were also seen in trying to focus on *Isoetes* and *Myriophyllum* as indicator species, since *Isoetes* is not found in many lakes and *Myriophyllum* is very tolerant of diverse water quality and habitats.

After further review, the Ministry for the Environment finally confirmed two key indicators for monitoring environmental performance:

- change in the biodiversity condition of selected freshwater ecosystems and habitats.
- change in the distribution and abundance of selected plant pests

During the development of the LakeSPI project, the first attempt to develop a lake ecological condition indicator using freshwater aquatic plants began with "Boundary Stability and the Extent of Charophyte Meadows". This was considered to be too limited since there are many lakes that have no charophyte meadows.

The next stage was to accept that no single aquatic macrophyte indicator could represent the wide range of lake types and ecological conditions around New Zealand. So in addition to "Boundary Stability and the Extent of Charophyte Meadows", other indicators proposed were: "Sustainability of Invasive Weed Beds", "Seed Bank Status", "A Macrophyte Index" (based on species biodiversity plus information from the three preceding measures), and 'National Species Distribution'. The latter would be derived from the NIWA Aquatic Plant Database.

Following an initial stakeholder workshop in December 2000, the first attempt was made to develop each of these indicators. Emphasis was placed on how to record key information on species biodiversity, extent of charophytes, vegetation boundaries and presence of invasive species. Technical development only addressed aquatic macrophyte attributes within lakes.

Developing measures to meet the project objectives proved to be very difficult. This led to many significant refinements and even major changes in methodology. Some of the initially proposed indicators were set aside because they were impractical, took too long to give results (e.g., Sustainability of Invasive Weed Beds), and required highly specialist knowledge or skills (e.g., Seed Bank Status).

One aspect that was tested and reluctantly abandoned was whether the 'health' or 'condition' of individual aquatic macrophytes could be reliably described and used as a measurement of vegetation status or even lake health. This proved too problematic on account of temporal and spatial variation within lakes and the subjective nature of scoring 'plant health'.

Despite the use of established aquatic vegetation survey methods (Clayton 1983) to characterise over 100 New Zealand lakes, as well as extensive knowledge on community structure and variation between lakes, it has proved difficult to capture known vegetation information in a simpler or less technical way compared to traditional and more specialised survey methods.

A breakthrough came when attempts to describe community structure were replaced with methods focusing on describing ‘native condition’ and ‘invasive condition’. Combined with this new initiative was the development of concepts and methods on how each of these two factors contributed to overall ‘lake condition’.

A parallel initiative to use the NIWA Aquatic Plant Database for recording and reporting on national aquatic plant species distribution is continuing.

5.2 Consultation with stakeholders

The Sustainable Management Fund application was lodged with active support from a selection of agencies involved in lake management as noted in the acknowledgments. The first stakeholder workshop was held in December 2000. Management agency needs and constraints were discussed, including the utility of the proposed methodology for monitoring lakes of particular interest. A summary of workshop proceedings was distributed after the workshop and a report on the first year’s progress was distributed to a wider stakeholders group in July 2001.

The project was introduced to a wider audience at a special half-day workshop associated with the New Zealand Limnological Society conference held in November 2001. A scientific paper on the project was also presented at the main conference. This paper introduced the concept of what was being called a "Lake Condition Index". One important outcome from the feedback received was to change the name of this index to the "Lake Submerged Plant Indicator Index". This clarified that the index was focusing on submerged plants rather than all components of lake biota.

Stakeholder assistance during field-testing and method development included a team from Environment B.O.P in the Rotorua Lakes (February 2001 and February 2002), Environment Waikato in the Waikato lakes (February 2001), and Horizons MW in the Manawatu sand dune lakes (November 2001). Field-testing was extended to the South Island lakes (March 2001) to cover a wider range of lakes than would otherwise have been possible.

A three-day peer review workshop and field-testing programme was held in February 2002. This involved a total of 12 people from NIWA, Environment B.O.P and Pacific Eco-Logic. The workshop addressed the rationale, concepts, field and analysis methodologies. Workshop participants included both those who had been involved throughout the process of developing LakeSPI, as well as people who had not been involved previously. Feedback and questions were wide-ranging and provided essential fine-tuning for the methodology. A number of lakes were surveyed to test comparability between different observers. Two teams then SCUBA dived at 16 sites in Lake Tarawera to test the use of the method in a complex lake.

Further field testing occurred in Lake Waikaremoana in Te Urewera National Park in March 2002 using a refined field survey form incorporating all the points raised at the February workshop.

Key regional council and DoC feedback during the development process included:

- They would like to be able to use the method to monitor lakes not previously monitored and therefore the method needs to be sensitive enough to pick up impacts from invasive species and indicate the overall condition of the lake.
- They would like a separate index that expressly addresses water quality as part of the suite of indices associated with LakeSPI. This will be looked at further during implementation of the method.
- It is essential for them to identify the context (reference condition or maximum potential score) for each lake to be able to assess how badly impacted a lake is (i.e., whether it is in good or bad condition) and whether action is needed.
- They thought the index provided a simple analysis that can be presented to councillors and local communities. They would like version two to include a simple graphing package for illustrating LakeSPI results.
- They supported the identification of additional alien plant species to provide a better continuum between lake plant communities containing only indigenous species to those completely dominated by invasive alien plants.
- The need for the methodology to be consistent and free from ambiguities.

5.3 Consultation with Iwi

Local hapu were consulted about trials and, in some cases to allow access (e.g., Lake Taharoa). Presentations were made to several Iwi organisations including the Office of Te Runanga o Ngai Tahu and Te Arawa Maori Trust Board.

Many matters relating to lake management and measuring the changes in lakes were discussed at these meetings. Although each Iwi had a different perspective, key points raised included:

- An interest in using the proposed methods for monitoring condition trends of lakes in their rohe.

- A concern about the condition of lakes in their rohe, especially those that are declining.
- A strong interest in what is happening to culturally significant harvestable biota, especially koura, freshwater mussels, flax and raupo. Te Arawa are especially concerned about the decline in the harvest of koura from the Rotorua Lakes.
- A concern about the impacts of alien biota in lakes.
- A desire to be actively involved in lake management including setting management goals for all aspects of lakes including water quality, plant communities and fauna.
- A strong interest in lake restoration. This includes identifying appropriate targets for various attributes in lakes of particular interest. The use of individual lake benchmarks for providing context for LakeSPI was strongly supported as part of helping to identify appropriate restoration targets.
- There was a desire for a holistic approach to lake management rather than the present often fragmented approach that comes from multiple agencies having different roles and inadequate accountabilities.
- An interest in understanding lake processes and linkages between different biotic and abiotic components of a lake ecosystem. They would like to see the concept behind the index clearly explained in simple terms so that local people can understand what is important and why.
- Iwi agencies would like to educate their own members about lake natural processes, indigenous biota and the impacts of human activities on lakes. This would help them improve their lake management and decision-making.
- A keenness to be involved in the implementation of LakeSPI. This could include testing how LakeSPI could contribute to Maori traditional methods of assessing lake quality.
- A desire to obtain hard information on lake changes to assist them in discussions and negotiations with other agencies.

Chapter 6

6. LakeSPI method

6.1 Method concepts

Any waterbody can be assessed for macrophyte content and status quite quickly and with minimal effort. Using a viewing tube, grapnel, snorkel, or SCUBA, a brief initial assessment of the ecological state can be obtained within a few minutes. For example:

- *Are there any submerged plants present*?

  Macrophytes can range from being absent (e.g., devegetated turbid lakes like Waikare, Rotomanuka) to being present at 50 metres depth or more (e.g., clear water glacial lakes like Wakatipu, Wanaka, Coleridge).

- *Do native or invasive macrophytes dominate*?

  Few lakes still retain exclusively native vegetation (e.g., Lochnagar – Southern Alps, Wahakari - Northland, Serpentine North - Waikato). Some lakes are still predominately native (e.g., Wakatipu, Rotomahana), while most have a substantial presence or even total domination by invasive species (e.g., Hayes – South Island, Rotoiti – Rotorua Lakes).

- *How diverse are the plant species and community types*?

  Apart from the more familiar emergent or marginal vegetation found around water bodies, there can be distinctive submerged plant communities such as shallow turf, tall vascular, and charophyte meadows. Each of these community types may be comprised of one or more species.

Despite the wide range of lake types and sizes found throughout New Zealand, the presence and nature of submerged aquatic plants reflect many common environmental influences.

Historically there have been two major influences affecting the ecology and condition of water bodies, and these continue to change ecological condition (relative to pristine state):

- The water quality and clarity of many lakes have been reduced by increases in suspended sediment and nutrients from catchment based activities. A reduction in water clarity reduces the habitat for available aquatic plant growth and in severe cases can result in the decline and loss of all submerged plants.
- There has been a significant invasion of native plant communities by alien plant species in many lakes. This often leads to the loss of virtually all native plant species from a lake.

These influences provided the key concepts for development of the LakeSPI method (Edwards & Clayton 2002; Clayton & Edwards 2006). The first concept is based on the universal principle that a plant requires light to photosynthesise and grow. The maximum depth to which submerged plants can grow in a lake often shows a close relationship to the depth to which sufficient light for photosynthesis penetrates (in other words, water clarity) (Schwarz *et al*. 2000). In general (in the absence of other determining factors), the deeper the record for submerged vegetation the better the water clarity. This generality means that the deeper the submerged plants, the better the ecological condition, therefore a higher value can be placed on an index used to represent this information.

Submerged plants can tolerate short periods of reduced water clarity, and because net growth is an integration of average water clarity over ecologically meaningful time-scales, the maximum depth to which they grow tends to be relatively stable throughout any one-year and often over much longer time frames. This contrasts with physical light or water clarity readings, which can be highly variable over short time frames. Even on any one-day Secchi readings can vary between observers and can be affected by cloud cover and time of day.

The second concept is based on the principle that native species are preferable to invasive species (e.g., the freshwater section of The New Zealand Biodiversity Strategy, DoC & MfE 2000 states "Prevent, control and manage plants and animal pests that pose a threat to indigenous biodiversity.") and that high native biodiversity is preferable to low native biodiversity. This concept is really comprised of two elements that need to be independently measured; native biodiversity, and invasive status and impact. Biodiversity of native species within a lake is related to many factors but two important aspects are habitat diversity and ecological condition of a waterbody. The presence of an invasive species does not necessarily detrimentally affect native biodiversity, but all too often an invasive species can displace most native species. Developing a method that adequately characterised 'native condition' (inclusive of biodiversity) and 'invasive condition' (status and impact), as well as macrophyte response to water clarity (reflected in depth limits) therefore became the key components in the development LakeSPI method.

6.2 Scoring parameters

The LakeSPI method seeks to characterise both the native condition and the invasive condition in any lake containing submerged plants. Both of these conditions are individually assessed and measured by considering structural and compositional features of the lake vegetation. These features are represented by a numerical score, which is then used to construct a **Native Condition Index** and an **Invasive Condition Index** (Figure 2). Selected components from each of these indices is then used to develop a **LakeSPI Index**, which represents the overall biological or ecological status of a lake based on submerged plant vegetation information. Native macrophytes and high diversity are taken to represent healthier lakes or better lake condition, while invasive macrophytes are ranked for undesirability based on their displacement potential and degree of measured ecological impact. Key assumptions for the LakeSPI Index are that the *presence* of certain native values will increase the LakeSPI score directly, while the *absence* of certain invasive features will similarly increase the LakeSPI score. Therefore, a high Native Condition Index describes good native conditions, while a high Invasive Condition Index describes well-developed invasive conditions. The latter has the effect of reducing the overall condition or index used to characterise a lake.

The following sub-sections describe the concepts and scoring criteria behind each of the features that contribute to the LakeSPI index. The features are illustrated in Figure 2 and are discussed as three distinct groupings.

1. Independent LakeSPI features
2. Native condition features
3. Invasive condition features

The scoring boxes for each feature use data captured on field sheets during the field assessment (described in the User Manual).

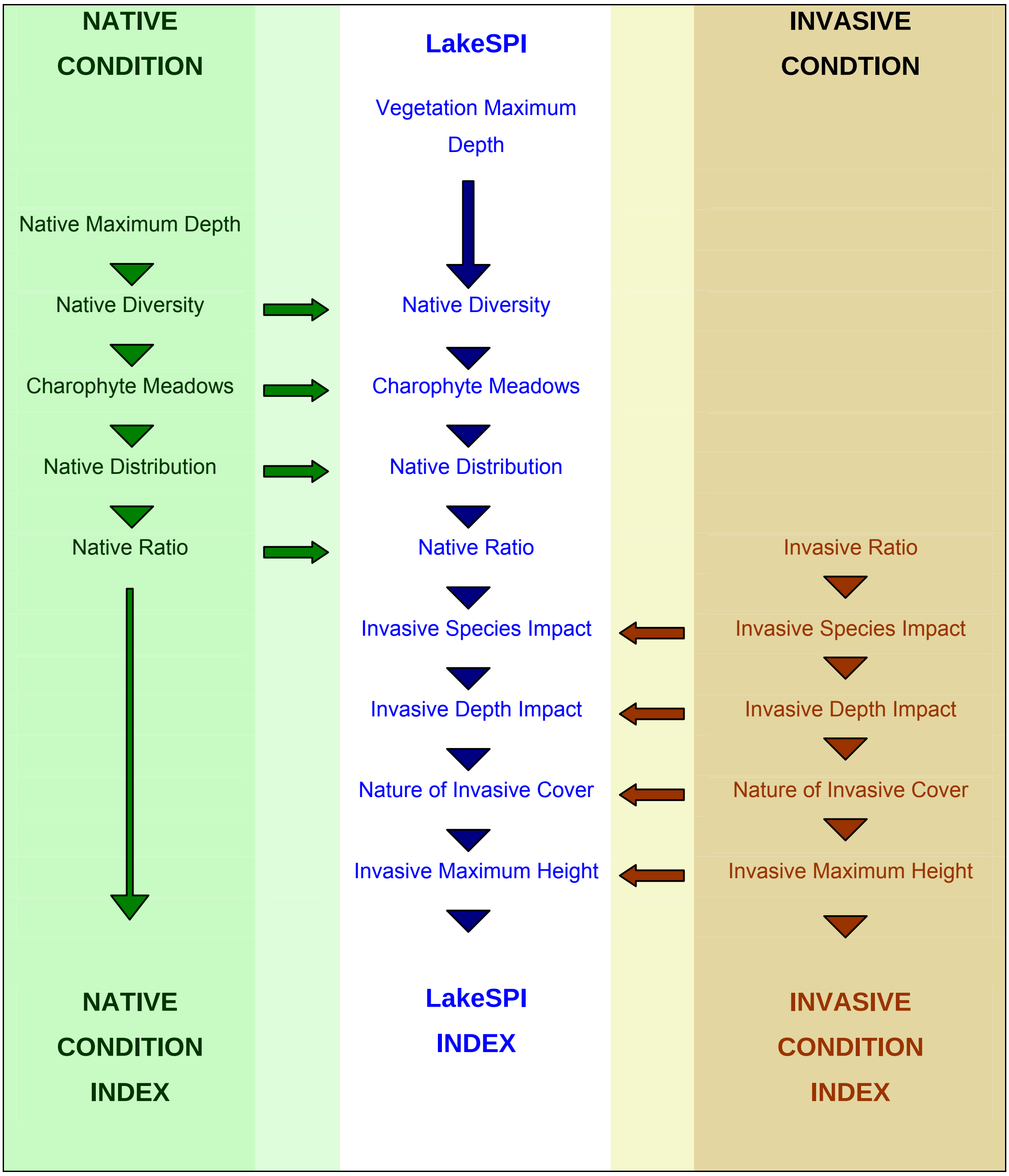


Figure 2. **Conceptual flow of submerged plant measures used to produce a Native Condition Index, an Invasive Condition Index and a LakeSPI Index.**

6.2.1 Independent LakeSPI features

There is only one feature of lake vegetation that fits into the independent LakeSPI feature category - the 'vegetation maximum depth' score. This is a stand-alone feature, as it does not contribute to the generation of the Native Condition Index or the Invasive Condition Index, however it does contribute to the LakeSPI Index (Figure 2).

6.2.1.1 Vegetation maximum depth

Indicator Concept

The maximum depth of plant growth has long been recognised as a direct indicator of water clarity in lakes (Sculthorpe 1967). Although native species growing within a lake are considered to be of higher ecological value, invasive species growing in a lake are recognised as better than no plants at all and their maximum depth of growth still provides an indicator of water clarity. The maximum depth of plant growth (with a cover of greater than ten percent) is the only measurement that is recorded independently of whether the vegetation is comprised of native or invasive species since the objective of this measurement is to reflect the clarity of the water irrespective of species composition.

Scoring Concept

If the deepest recorded vegetation is comprised of native species then this maximum depth is given a score from 0 to 10 based on the scoring box (Scoring Box 1) below. (N.B. cover must be greater than ten percent to help avoid the risk of spurious low cover estimates). If the maximum depth of plants is comprised of invasive species then this depth is given a score between 0 and 5. Invasive plants that exceed depths of 11 metres are restricted in their scoring potential by imposing a maximum score of 5 as shown by the dotted red line on the scoring box below (Scoring Box 1). The reason for ignoring any invasive species depth record of 11 metres or deeper is that one invasive species (i.e., *Ceratophyllum*) can occupy deeper water, however it is a non-rooted and highly productive invasive species that can slump into deeper water and appear to be 'growing' when in fact it is only occupying deeper habitats in a depositional form (i.e., *Ceratophyllum* may appear alive but at times is likely to be at depths beyond its photosynthetic compensation point). All other invasive species have rooted stems and for physiological reasons, they will only ever be found growing in water of less than 10 metres depth.

Any native species found deeper than 10 metres will invariably be a charophyte (or bryophyte). These non-vascular species have no aerenchyma and only limited 'root' systems so they appear not to be affected by water pressure. They also have a much lower light requirement for growth (photosynthetic compensation point) and in New Zealand lakes their maximum depth of growth is often a direct measure of water clarity.

If native vegetation (charophytes) exceeds a depth of 19 metres, then a maximum native score of 10 is awarded. There are only a few lakes in New Zealand where charophytes will exceed this depth, so in such cases it is not necessary to determine the exact depth both for diver safety reasons (maximum depth can exceed 50 metres!) and because any lake with vegetation deeper than 19 metres is already quite exceptional and deserving of the highest score.

Scoring Box 1

LakeSPI criteria for assessing the 'vegetation maximum depth' score.

NATIVE SCORE	DEPTH (m)	INVASIVE SCORE
0	No plants *or* <10% plant cover	0
1	0 – 2.9	1
2	3 – 4.9	2
3	5 – 6.9	3
4	7 – 8.9	4
5	9 – 10.9	5
6	11 – 12.9	
7	13 – 14.9	
8	15 – 16.9	
9	17 – 18.9	
10	19 m +	

The score for 'vegetation maximum depth' adds directly to the LakeSPI Index (Figure 2).

6.2.2 Native condition features

Native condition features are grouped together as they all contribute to the generation of the Native Condition Index. All but one native vegetation feature (i.e., native maximum depth) then contributes directly to the generation of a LakeSPI Index (Figure 2).

6.2.2.1 Native maximum depth

Indicator Concept

Native vegetation when present at the greatest depth in a lake is an indicator of water clarity. If however, native plants are not the deepest vegetation then their maximum depth of growth no longer represents water clarity, but rather reflects the degree of displacement of native plants by invasive species as well as the ability for native plants to persist in an environment that is impacted by invasive species.

If native species are the deepest vegetation recorded at a site with a greater than 10% cover then this native depth score will be the same as for the score recorded for the 'vegetation maximum depth' score (section 6.2.1.1). If charophytes comprise the deepest vegetation then it is quite common to find high vegetation cover with an abrupt lower depth boundary with few or no plants below. If the boundary is not distinctive but rather forms a transition from high to low cover, then a subjective estimate is made of when a cover of approximately 10% has been reached. This cover criterion is used to help avoid the difficulty of defining an acceptable end point in depth limit arising from spurious low cover estimates.

If invasive species are the deepest vegetation recorded, then it is still important to record the maximum depth of native species.

Scoring Concept

The native depth scoring box (Scoring Box 2) ranges from 0 to 10 and has the same score and depth intervals as those used for 'vegetation maximum depth' scores (Scoring Box 1).

Scoring Box 2

LakeSPI criteria for assessing the 'native maximum depth' score.

DEPTH (m)	NATIVE SCORE
No plants *or* < 10% plant cover	0
0 – 2.9	1
3 – 4.9	2
5 – 6.9	3
7 – 8.9	4
9 – 10.9	5
11 – 12.9	6
13 – 14.9	7
15 – 16.9	8
17 – 18.9	9
19 m +	10

This score for 'native maximum depth' adds to the Native Condition Index but it does not contribute to the LakeSPI Index (refer Figure 2) since the LakeSPI depth indicator was recorded separately by using 'vegetation maximum depth'.

6.2.2.2 Native diversity

Indicator Concept

Native plant species and high native diversity are recognised in the LakeSPI method as representing healthier lakes that are in better ecological condition.

Native diversity is assessed at a community, generic and species level depending on plant type in order to simplify the identification skills necessary for the LakeSPI method and to minimise the effect of potential species sensitivity to the trophic status of water bodies. The following descriptions will give an overview of the native vegetation types used for LakeSPI.

Charophytes, turf species and emergent species are only identified at the **Community** Level. Charophytes are grouped at a community level and include species of both *Chara* and *Nitella*. Further differentiation is not required because of the skills required to identify plants even to a genera level (e.g., some *Chara* species are often mistaken for *Nitella* species) and because some species of charophytes have morphologically different shallow and deep-water growth forms (e.g., *Nitella pseudoflabellata*).

Turf plants (also known as 'low mound community') are also considered on a community level because of difficulties in species identification and the large number of species present. Like charophytes they typically form a mosaic of species but are readily recognised at the community level and it is simply the presence of this community that is important in the LakeSPI method.

Emergents are only scored if present at a site where there are NO turf species and providing other native submerged vegetation is present. Emergent species occupy sheltered habitats only and are therefore commonly associated with small water bodies and sheltered backwater areas in large water bodies. As the level of shelter increases it is common for emergents to displace turf species, since they are able to occupy the same depth range from the waterline to around 2 metres depth. Where the density of the emergent community is low (i.e., as exposure increases) it is common to find turf species and emergent species mixed together. Since these two community types have overlapping habitat requirements and their relative proportion is directly related to wind and wave exposure, no distinction is made between them (i.e., for the purpose of scoring) when they occur together.

Milfoils (*Myriophyllum* species) and pondweeds (*Potamogeton* species) are only identified at the **generic** level. Both *Myriophyllum* and *Potamogeton* genera have two or more species that are widespread throughout New Zealand water bodies, irrespective of their trophic status. They also occupy similar overlapping depth ranges and habitats. It is relatively easy for someone with basic training to distinguish between a pondweed and milfoil, however it is much more difficult to distinguish between the species in each genus. Apart from *Potomageton crispus*, all of the species of *Myriophyllum* and *Potamogeton* currently found in New Zealand lakes are native. *Potomageton crispus* must be recognised as 'invasive' and it is not to be included in the native diversity score. Normally *P. crispus* can be distinguished from the native pondweed species, however it can be quite variable in appearance and it is not always possible to differentiate. Fortunately this rarely poses a problem since it tends to be either uncommon (in which case other native pondweeds are typically present in greater abundance) or it dominates (in which case it tends to be the only pondweed present and will not contribute to a native diversity score). *P. crispus* typically only dominates in highly eutrophic water bodies (e.g., Lake Horowhenua).

Isoetes kirkii is the only native plant that is identified to a **species** level. This species appears to be the only distinctive species of *Isoetes* found in New Zealand lakes (Johnson & Brooke, 1989) and it is easy to recognise. *Isoetes* is particularly abundant in several South Island lakes, however its presence within North Island lakes has continued to decline over recent years. Its most northern record was Lake Omapere in Northland, but this population has since disappeared. *Isoetes* has also disappeared from the Waikato lakes. Several of the Rotorua lakes currently represent the northern most occurrence of this species, but it is now quite rare in these lakes. *Isoetes* can have a prominent influence on vegetation structure and composition due to its densely packed growth form. It can also occupy a much greater depth range than turf communities and is considerably more tolerant to a wider range of exposure conditions.

Bryophytes (mosses and liverworts) are excluded from the native diversity score because of their highly patchy distribution. For example, as a deep-water community they are geographically restricted with their absence from clear water North Island lakes (e.g., Lake Taupo) being primarily attributable to biotic disturbance from koura (freshwater crayfish), which are not recorded in most South Island lakes (Coffey & Clayton 1988). This difference alone would affect national comparisons between lakes. Furthermore, bryophyte communities frequently exist at great depth (e.g., bryophytes may occupy depths of 45 to 70 metres in Lake Coleridge), which are beyond the limits of safe diving practice (20 m for LakeSPI). Even in shallow waters bryophytes are not a good indicator since they tend to be associated with hard surface substrates in exposed habitats, and often in locations not suited to any other macrophytes.

Scoring Concept

For each of the native plant types used for assessing native diversity, 1 point is allocated for their presence (Scoring Box 3). The points are added, so the maximum score for this factor would be 5 provided all diversity categories were recorded.

Scoring Box 3

LakeSPI criteria for assessing the 'native diversity' score.

DIVERSITY	POINTS
Charophytes	1
Pondweeds	1
Milfoils	1
Isoetes	1
Turf Plants	1
Emergents (if no Turf Plants are present)	
	Total Score ≤ 5

The 'native diversity' score adds directly to the Native Condition Index and the same score contributes to the LakeSPI Index (refer Figure 2).

6.2.2.3 Charophyte meadows

Indicator Concept

The objective of this indicator is to represent the existing condition or value of charophyte dominant communities present in a lake. For the purposes of this score, a charophyte meadow is represented by a greater than 75% cover of charophytes.

Deep-water charophyte meadows are sensitive to two key influences - invasive displacement and reduced water clarity. Where both influences are prominent, charophytes meadows will not be found. If water is sufficiently clear, then even where invasive species have achieved their maximum depth distribution in a lake it is still possible to have intact charophyte beds in deeper water. The contribution of this 'native reserve' to total native representation will become higher as charophyte meadows extend deeper. If water is sufficiently turbid in a lake to prevent charophyte growth beyond a depth of 10 - 11 metres, then charophytes are highly vulnerable to displacement by invasive species. It is clear that the relative risk of total charophyte displacement increases as the maximum potential depth of charophytes decreases.

Even when charophyte meadows aren't the deepest vegetation they still add biological value to a lake system, so their depth record still contributes to the description of native condition.

Scoring Concepts

The objective of this score is to represent the existing value of charophyte meadows present in a lake. Scoring Box 4 allocates up to 5 points for charophyte meadows depending on their depth and this value will increase in direct proportion to their depth of occurrence.

Scoring Box 4

LakeSPI criteria for assessing the 'charophyte meadows' score.

DEPTH (m) OF CHAROPHYTE MEADOW	NATIVE SCORE
None	0
0 – 4.9	1
5 – 9.9	2
10 – 14.9	3
15 – 19.9	4
20+	5

If a charophyte meadow extends deeper than 20 metres then this is recorded as 20+ metres. The reason for this is not only safety for the diver collecting this information, but also there are few lakes where charophytes grow deeper than 20 metres. Any such lake will clearly be distinguished as an exceptional clear-water lake and so will achieve a maximum score.

The 'charophyte meadows' score adds directly to the Native Condition Index and the same score contributes to the LakeSPI Index (refer Figure 2).

6.2.2.4 Native distribution

Indicator Concept

The objective of this indicator is to present more information on native vegetation structure and composition than can be derived from native biodiversity alone. For example, it is proposed that a more diverse and stable community structure exists if native species are above and below 5 m depth. This feature is considered only for pondweeds, milfoils and *Isoetes*, since it is of significance to find these plants below 5 m. The NIWA Aquatic Plant Database shows that of lakes recording these plants (over fifty lakes), approximately 30% and 15% have pondweeds and milfoils respectively extending below 5 m depth.

Milfoils and pondweeds are the only commonly found, tall-growing native vascular plants in New Zealand water bodies and they tend to be somewhat more tolerant than other natives to displacement by invasive species. For example, pondweeds and milfoils can co-exist within moderately dense beds of *Elodea* and *Lagarosiphon*, although they would not normally be found within dense beds of *Ceratophyllum*. Consequently they can often still contribute to native vegetation character even in the presence of invasive species, and the wider their occupation of depth range the greater their contribution.

Scoring Concept

Scoring Box 5 allocates up to 3 extra points for the Native Condition Index whenever milfoils, pondweeds and *Isoetes* are present deeper than 5 metres.

Scoring Box 5

LakeSPI criteria for assessing the 'native distribution' score.

DISTRIBUTION (present >5 m depth)	POINTS
Milfoils	1
Pondweeds	1
Isoetes	1
	Total Score ≤ 3

The 'native distribution' score adds directly to the Native Condition Index and the same score contributes to the LakeSPI Index (refer Figure 2).

6.2.2.5 Native ratio

Indicator Concept

This is an indication of how much of the vegetation at a site is native. The 'native ratio' is a subjective estimate of the percentage of native vegetation over the entire depth profile. For this ratio, the vegetated area (irrespective of height, biomass or density) is assessed along the profile. The 'native ratio' and the 'invasive ratio' must add up to 100% (see later).

'Ratio' is used as opposed to 'proportion' for this indicator since ratio helps to emphasise that only those areas occupied by vegetation are assessed (i.e., all bare patches of sediment are ignored).

The value of this assessment comes from the fact that gradient or littoral slope can have a large effect on the actual area occupied by native or invasive species. For example, charophytes can grow as extensive flat meadows with little change in depth, so that they can still present a high native ratio. This information would be lost if natives were measured as a proportion of the depth range of total vegetation.

Scoring Concept

The scores used for this feature range from zero when no natives are recorded to 7 when all vegetation is native (Scoring Box 6).

Percent categories have been left sufficiently broad to help minimise confusion over exact percentages, but are still sensitive enough to detect significant changes. This is a subjective estimate of the percentage of native vegetation and percentage does not have to be exact.

Scoring Box 6

LakeSPI criteria for assessing the 'native ratio' score.

NATIVE RATIO %	NATIVE SCORE
No Natives	0
1 – 5	1
6 – 25	2
26 – 50	3
51 – 75	4
76 – 95	5
> 95	6
100 % Native	7

The native ratio score adds directly to the Native Condition Index and the same score contributes to the LakeSPI Index (Figure 2).

6.2.3 Invasive condition features

Invasive condition features are grouped together as they all contribute to the generation of the Invasive Condition Index. All but one invasive vegetation feature (invasive ratio) then contributes to the generation of a LakeSPI Index (Figure 2). For addition to the LakeSPI Index, scores must be inverted as demonstrated in the scoring boxes of this section.

6.2.3.1 Invasive ratio

Indicator Concept

This is an indication of how much of the vegetation at a site is invasive. Although it is recognised that this is the complement of 'native ratio' (section 6.2.2.1), it is important that the invasive ratio is still given an individual score as this will be used in the generation of an Invasive Condition Index.

The 'invasive ratio' is a subjective estimate of the percentage of invasive vegetation over an entire depth profile.

Scoring Concept

The scores used for this feature range from zero when no invasives are recorded to 7 when all the vegetation at a site is invasive (Scoring Box 7).

Scoring Box 7

LakeSPI criteria for assessing the 'invasive ratio' score.

INVASIVE RATIO %	INVASIVE SCORE
No Invasives	0
1 – 5	1
6 – 25	2
26 – 50	3
51 – 75	4
76 – 95	5
> 95	6
100 % Invasive	7

The score for 'invasive ratio' adds to the Invasive Condition Index only, since the LakeSPI Index is already determined using the score based on 'native ratio' (see Figure 2).

6.2.3.2 Invasive species impact

Indicator Concept

The presence of different invasive species has widely different implications for the ecological condition of a lake. Invasive species can be ranked on the known *severity* of their impact on lake condition as well as the range of habitat types they can occupy. The severity of impact is not just limited to their ability to displace native vegetation, but also the extent to which they can alter sediment properties, affect water quality (e.g., tall dense weed beds have widely fluctuating pH and dissolved oxygen profiles) and provide suitable habitat for fauna such as insects and fish. The *tolerance* or range of habitats that each invasive species can occupy is quite variable with respect to trophic status, depth (light and pressure tolerance) and sensitivity to exposure (lake size).

Scoring Concept

Key invasive species are considered in terms of their severity of impact and known habitat tolerance range to create an 'invasive species impact' score (Table 1).

Table 1. The factors used to establish an overall impact score for each invasive species.

Species	Severity	Tolerance	Total Invasive species impact score
Juncus bulbosus	0	1	1
Ranunculus trichophyllus	0	1	1
Potamogeton crispus	1	1	2
Utricularia gibba	1	1	2
Elodea canadensis	1	2	3
Vallisneria spp.	2	2	4
Lagarosiphon major	2	2	4
Egeria densa	3	2	5
Hydrilla verticillata	3	3	6
Ceratophyllum demersum	4	3	7

For example, *Elodea* is ranked quite lowly on a total impact score compared to many of the other common invasive species despite a tolerance rating of 2. This is because *Elodea* tends to form less dense and shorter beds than the higher ranked invasive species and consequently it often co-exists with native vegetation. In contrast, more invasive species (e.g., *Ceratophyllum)* tend to completely displace native vegetation and often most other invasive species.

All the nominated invasive species noted at a site are recorded on the LakeSPI field sheet, but only the highest scoring species actually contribute to the Invasive Condition Index and LakeSPI Index. The reasoning for this is that the worst weed has greatest overall impact. It should be noted that the presence of any other invasive species is still recorded and their percentage contribution to overall invasive presence is estimated.

The full invasive potential or ecological impact of an invasive species may not be fully expressed for any given site (or waterbody) at the time of survey. Nevertheless, the 'invasive species impact' score is an estimate of predicted impact and the significance of its presence. If the impact of an invasive species has not reached its full potential, then other LakeSPI parameters (especially invasive ratio and cover) will show the progression of invasive impact during subsequent surveys.

While LakeSPI is not a method designed to pick up early stages of any new invasive species establishment (a site targeted surveillance method is required for this purpose), it will pick up new species if they are already well established and are having an impact on lake condition.

In Scoring Box 8 below, if no invasive species are recorded, the Invasive Condition Index scores zero, which is then inverted to 7 to provide a maximum score towards the LakeSPI Index; whereas the converse applies if *Ceratophyllum* is present. Inversion of each invasive score is necessary before adding it to the LakeSPI index since the latter decreases proportionally to any increase in Invasive Condition Index score.

Scoring Box 8

LakeSPI criteria for assessing the 'invasive species impact' score.

INVASIVE SPECIES	INVASIVE SCORE	*INVERTED*	LakeSPI SCORE
'No Invasives'	0	▶	7
Juncus bulbosus	1	▶	6
Ranunculus trichophyllus	1	▶	6
Potamogeton crispus	2	▶	5
Utricularia gibba	2	▶	5
Elodea canadensis	3	▶	4
Vallisneria spp.	4	▶	3
Lagarosiphon major	4	▶	3
Egeria densa	5	▶	2
Hydrilla verticillata	6	▶	1
Ceratophyllum demersum	7	▶	0

6.2.3.3 Invasive depth impact

Indicator Concept

This indicator is a measure of both invasive displacement and water clarity and is based on the extent of native vegetation extending beyond the maximum depth of invasive species. In most cases this would be charophytes, since these are the main plants found deeper than any invasive species. The greater the depth that native vegetation extends to, the lower the potential for invasive species to occupy or dominate the entire vegetated depth range of a site or lake. The 'invasive depth impact' is therefore a measure of just how far invasive species have managed to displace any deepwater native vegetation. It is measured as the extent that native vegetation (with a cover >10%) extends into deeper water beyond the invasive vegetation.

Scoring Concept

A maximum invasive depth impact score will result at a site dominated by invasive species to the maximum depth of plant growth. If native vegetation is present beyond invasive vegetation then the latter maximum depth is subtracted from the native maximum depth to measure the depth range (in metres) of the non-impacted native reserve zone.

The invasive scores range from zero when no invasive species are present or do not exceed a ten percent cover, to 5 when no native vegetation is present below the deepest growth of invasive species (Scoring Box 9). An invasive score of 1 means that there are more than 8 metres of vertical depth colonised by native vegetation beyond the maximum depth of invasive species.

Scoring Box 9

LakeSPI criteria for assessing the 'invasive depth impact' score.

DEPTH (m)	INVASIVE SCORE	*INVERTED*	LakeSPI SCORE
No Invasives	0	▶	5
> 8	1	▶	4
4 – 7.9	2	▶	3
2 – 3.9	3	▶	2
0 – 1.9	4	▶	1
No Natives	5	▶	0

The 'invasive depth impact' score adds directly to the Invasive Condition Index to reflect maximum invasive impact (refer Figure 2). Each score is inverted before contributing to the LakeSPI Index.

6.2.3.4 Nature of invasive cover

Indicator Concept

High cover weed beds can have a profound impact on lake condition by interfering with water circulation and altering physico-chemical properties within, particularly where the littoral zone represents a high proportion of total lake area. Tall dense weed beds also displace native vegetation and can interfere with recreational lake usage. Hence high cover invasive weed beds are given a high score in the scoring system to reflect their deleterious impact on lake and ecological condition.

Scoring Concept

The 'nature of invasive cover' is a subjective estimate of the highest percent cover value for any discrete patch or band of invasive vegetation present as illustrated in Figure 3. Emphasis is placed on the 'nature of invasive cover' to help avoid confusion between cover and proportion.

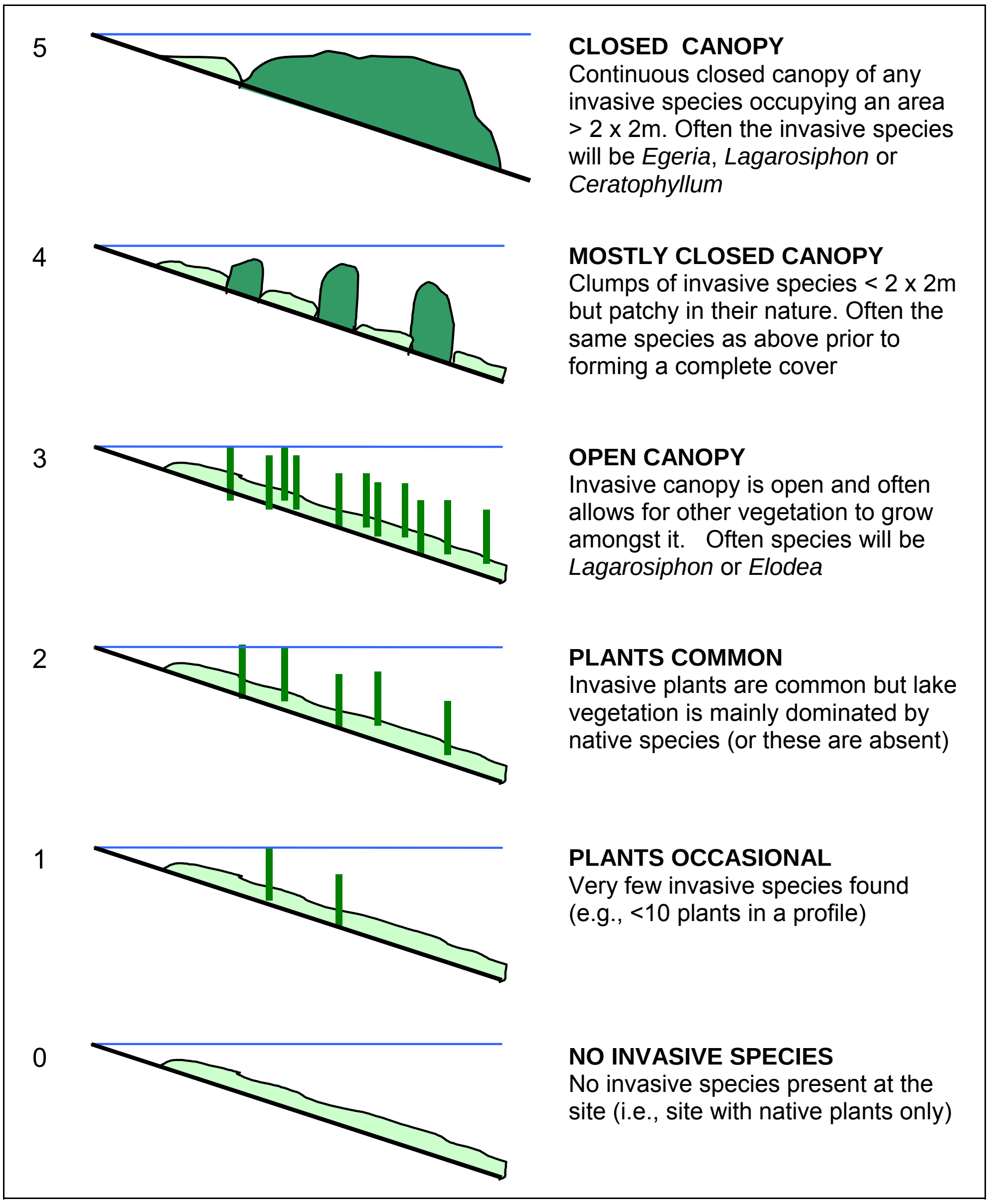


Figure 3. Cover categories and their associated scores used for the 'nature of invasive cover' score. Invasive species are shown by the dark filled in areas.

The discrete area of highest cover of invasive vegetation must be greater than 2 x 2m^2 at any point on the depth profile. The objective of noting only the highest cover of any invasive species is to characterise the degree of impact that an invasive weed species can have in the selected waterbody. Any patch 2 x 2m^2 in size would be sufficiently large to assume that other patches of this size or even larger would occur elsewhere in the lake.

A closed cover with a high score of 5 adds directly to the Invasive Condition Index to account for maximum invasive impact (Scoring Box 10), but scores are inverted before contributing to the LakeSPI Index.

Scoring Box 10

LakeSPI criteria for assessing the 'nature of invasive cover' score.

INVASIVE COVER	INVASIVE SCORE	*INVERTED*	LakeSPI SCORE
No Invasives	0	▶	5
Plants Occasional	1	▶	4
Plants Common	2	▶	3
Open Canopy	3	▶	2
Partly Closed Canopy	4	▶	1
Closed Canopy	5	▶	0

6.2.3.5 Invasive maximum height

Indicator Concept

Invasive weed beds tend to grow more densely and much taller than many native species and can reach 6 m or more in height and be visible from the surface. Apart from interfering with water-based activities (e.g., swimming, boating, fishing) tall weeds can also have detrimental impacts on water quality within the weed beds and create unfavourable habitats for other biota resulting in reduced biodiversity and degraded ecological conditions (Howard-Williams *et al*. 1987, de Winton & Clayton 1996).

The objective here is to note the tallest overall height achieved for any area of invasive weed found within the profile. The minimum area of invasive species to be measured is 2 x 2m to avoid measuring isolated tall shoots. In most cases the tallest plants occur on the deeper outer margins of an invasive weed bed.

As height can be seasonally affected, it is recommended that most lake assessments would be carried out when weed beds and overall vegetation are expected to be in good condition (i.e., not mid-winter or early spring), since the objective is to use vegetation as a measure of lake condition. Surface reaching plants have been excluded from the scoring categories, as this feature is too variable and can be affected by water fluctuations, grazing and time of year.

Scoring Concept

Only 3 points are allocated for 'invasive maximum height', with a 3 scored for invasive plants exceeding 3 metres in height (Scoring Box 11). This score adds directly to the Invasive Condition Index, whereas the score is inverted before contributing to the LakeSPI Index.

Scoring Box 11

LakeSPI criteria for assessing the 'invasive maximum height' score.

INVASIVE HEIGHT (m)	INVASIVE SCORE	*INVERTED*	LakeSPI SCORE
No Invasives	0	▶	3
< 1 m	1	▶	2
1 – 3	2	▶	1
> 3 m	3	▶	0

Chapter 7

7. Practical application

7.1 Skills required

The LakeSPI method does require suitably qualified divers and for many lakes the support of a suitably qualified boat operator (see Section 7.2). In many instances it is unlikely that managing authorities will have salaried staff with the appropriate diving and boating skills to implement the LakeSPI method, however these skills are readily available and can often be contracted locally if preferred within most regions.

Apart from the diving and boating requirements, the LakeSPI method itself has been developed with simplicity in mind. A basic level of plant identification is essential for accurate use of the LakeSPI method and the User Manual provides specimen and community photographs as well as line drawings of all the key species that each field operator must know. It is expected that most people will quickly develop the required proficiency for identification since difficult taxa such as charophytes do not require identification below community level. . Training workshops can be carried out on the practical side of the LakeSPI method to ensure competence in method application and consistency between users.Training could also focus on the broader issues of designing a lake monitoring programme, converting data from the field sheets, interpreting scores, and presentation and reporting of data.

7.2 Equipment required

SCUBA equipment - In addition to the use of standard SCUBA gear it is important that an accurate depth gauge is used with 0.1 metre depth intervals displayed. It is always helpful to carry out a calibration check against a graduated line to confirm gauge accuracy. A compass is an essential underwater navigation aid, particularly if a survey site has any flat or level sections.

Boat equipment - In addition to standard safety equipment carried in boats it can be helpful to carry an underwater viewing box and depth sounder. Sonar equipment with a digital display that is able to record lakebed profiles and display the presence of bottom-rooted vegetation is very useful, particularly during initial site selection. Laser distance finders can be used to estimate the length of any vegetation profiles, while a handheld GPS recorder and a camera are highly desirable for accurate site relocation subsequent surveys.

Field equipment – The required field equipment is minimal. A clipboard (preferably rigid plastic), a standard pencil (2B recommended) and pre-printed waterproof paper for recording field data are essential. It can be helpful to have a small graduated line with a lead weight attached at one end, so that height of weed beds can be determined. Plastic zip-lock bags and jars should be carried for collecting any plant samples that may require further identification.

7.3 Boating and diving requirements

In accordance with Occupational Safety and Health (OSH) requirements, any SCUBA divers employed to apply the LakeSPI method should be registered as Occupational Divers with the Labour Department and have a current Certificate of Competency issued by the Department. They should also hold a current Diving Medical Certificate issued by the Naval Health Service.

No diver needs to exceed a depth of 20 metres when applying this method and all divers should follow appropriate dive safety guidelines with respect to dive procedures. Many lakes in New Zealand are at considerable altitude and standard precautions must be followed in terms of flying after diving and driving over high altitude road passes when exiting from a lake. It is the responsibility of the diver and the employer to ensure that only divers with suitable qualifications and experience are used. A useful guideline to follow is the "Diving Safety and Standards Manual" (NIWA 1999). It is also recommended that guidance from the OSH Diving Officer in the Labour Department be sought if there is uncertainly in any of these matters. All divers should have also received appropriate training to apply the LakeSPI method.

Many lakes will require the use of a boat to assist divers while carrying out the LakeSPI method. The Maritime Safety Authority (MSA) should certify any boat used by divers since they administer the Safe Ship Management System for any boats used in occupational activities. Boat operators should also have appropriate MSA boat handling qualifications and hold a MSA certificate of competency.

7.4 Lake selection

The LakeSPI method is designed for use in all lakes with submerged plants except where salinity, alkalinity, acidity, altitude (mountain tarns) or their small size prevent the development of normal submerged vegetation composition (see Section 9.2). It is not suitable for lakes where submerged plants are rare (i.e., plant cover within vegetated areas never exceeds 10%) or non-existent. Since the LakeSPI method involves use of SCUBA it should not be used in lakes where water contact has been identified as a significant human health hazard.

If it is not possible to monitor all lakes in a region, then the lakes should be prioritised based on factors such as known ecological values, management and public goals or interests and risk of change. Lakes could also be grouped into categories with representative lakes surveyed from each category. If a management agency intends to use a sample of lakes to report on trends throughout its region, then the monitoring programme must include unmanaged as well as managed lakes. If monitoring only addresses managed lakes this could give an inaccurate picture of the trends for all lakes.

Lakes at high risk of change include all lakes where boats can be launched or that are fished for eels (risk of introducing weed species); lakes where there is a risk of accidental or deliberate introduction of coarse fish species; and any lakes with catchment areas impacted by agricultural, exotic forestry or urban land uses. Such land use activities tend to accelerate changes relative to the natural condition, largely due to sediment, nutrient and contaminant inputs through ground water and stream flows, especially where riparian margins are removed (e.g., where lake edges are accessible to cattle). Selection of lakes for LakeSPI assessment will often focus on lowland and mid altitude lakes where there is greatest risk of change. Remote upland lakes with no road access and with undisturbed catchments in protected areas dominated by indigenous vegetation have low risk of human induced change. However, it is still important to select examples of such lakes as representative of undisturbed catchment areas.

7.5 Site selection

To obtain a meaningful LakeSPI score it is important that information is collected from sites within the lake that support common vegetation features and community composition. Initial assessments of a lake will always take longer than any subsequent re-surveys, since during the first visit care has to be taken to locate suitable sites.

A bathymetric map for any lake to be surveyed can be particularly helpful in selection of sites. If no bathymetric map is available a topographic map should be used to provide an indication of likely bathymetry and other features that can help in the selection of sites. These maps will also help determine whether a boat is required or whether sufficient representative information can be gathered from accessible shoreline areas. Preliminary site selection based on lake bathymetry and other criteria may still prove unsuitable at the time of survey, therefore requiring some sites to be abandoned and alternative sites selected.

Previous reports, herbarium records and the NIWA Aquatic Plant Database can be helpful in anticipating likely plant species to be encountered and in understanding the nature of the lake to be surveyed. This information can also be useful in identifying potentially suitable areas for LakeSPI site selection.

Discussions with agencies responsible for managing the lake, local botanical groups or knowledgeable residents can also be helpful in identifying important features about the lake, such as lake level stability, access sites, past or present weed problems, and any areas regularly controlled for weed growth.

Criteria for selection of suitable sites includes:

- Avoidance of unfavourable influences including stream inflows, steep gradients, shallow bottom limits less than the typical depth for plant growth in that particular lake, and exposed shorelines with a wave fetch exceeding 10 km. Also avoid boat ramps where disturbance from boating activities can occur, or areas where regular weed control is undertaken.
- Selection of sites with favourable conditions supporting plant growth including moderate gradients, stable substrate and moderate to high (< 5 km wave fetch) exposure.

The gradient of prospective sites is a particularly important selection criterion. Moderate gradients are preferable to shallow shelving gradients since the latter tends to contain the same information, but extended over a much longer profile. Simplicity of vegetation pattern and speed of survey favour selection of profiles with moderate gradients. However very short steep profiles are not favoured as these often lack vegetation and are more prone to periodic slumping.

The influence of aspect may be worth considering for some lakes, since north-facing slopes can display the deepest vegetation growth. This would be most relevant for clear lakes with deepwater charophyte vegetation where it is useful to have at least one site that contains the deepest likely record for submerged plant growth. Such a site can act as a particularly sensitive marker for vegetation response to small declines in water clarity.

Sheltered sites likely to support emergent vegetation are also more likely to have shallow gradients or insufficient depth to establish a bottom vegetation depth boundary. Furthermore, the presence of emergent vegetation provides no extra points in the LakeSPI scoring method. For these reasons it is recommended that in large lakes, sites with moderate exposure to wave action are preferable, provided submerged vegetation is present. If wave fetch exceeds 10 km then there may be no submerged plants present, so it is recommended that sites with a lesser wave fetch be selected. As noted under 'equipment required' it can be very helpful to have a depth sounder on a boat that can generate images of the lake bed and present an overall image of vegetation density and height to help confirm suitability of a proposed area within which to establish a survey site.

Initial site selection is very important but could be quite difficult for some lakes. Where practicable it is preferable to select sites from around the lake rather than have all sites clustered in an area. If there is uncertainty over selecting suitable sites it is recommended that experienced operators be used to help establish baseline sites. Once representative sites have been established any future assessment using LakeSPI should be based on these original sites. However if for any reason an original site subsequently indicates disturbance (e.g., slumping), then an alternative site should be substituted.

7.6 Number of sites

For most lakes it is anticipated that five sites will be sufficient to obtain meaningful scores.

For large or complex lakes five sites may not be sufficient. An initial analysis of the data as it is collected will indicate whether there is large variation between sites and therefore how many sites may be required to get stable or representative data.

Where it is apparent that large site variations exist it may be necessary to partition the lake into sections. If the factors responsible for large differences in the aquatic vegetation are known (excluding factors such as weed invasion) then it may be possible to score selected regions based on these determinants. For example, diverse catchment activities may surround different arms of a large lake, which in turn may have significant localised influences on water quality. Alternatively, the criteria for partitioning should be based on readily distinguishable features such as geomorphologically distinctive arms or separate basins of a lake (e.g., the Frankton Arm of Lake Wakatipu). Each section of a lake can then be scored and monitored separately to give a more meaningful measure of lake condition.

7.7 Timing

LakeSPI is largely independent of seasonal influences, but it is recommended that summer or autumn assessments are made as this is when submerged plant growth is usually at its healthiest. Summer and autumn sampling is also preferable from a practical perspective since water temperatures are warmest. The timing of any survey may need to be varied in some lakes, particularly where they have algal blooms and poor water quality conditions (i.e., low visibility). In such cases it may be easier to carry out fieldwork during winter. Where possible it is recommended that any repeat surveys on a lake be carried out at the same time of the year.

Most lake surveys should be easily completed with one day or less of fieldwork. Shallow shelving lakes with extended vegetation across the bottom will naturally be time consuming to survey, but generally it is possible to survey two or three small to medium sized lakes in one day. Large lakes would usually require a full day to survey on account of the travel distance between sites and possible need for additional survey sites. Survey plans need to be flexible enough to respond to weather conditions so that boating and diver safety are never compromised.

7.8 Frequency of survey

The frequency of survey for any lake will depend primarily upon: the lake's current condition and vulnerability to change; and its management objectives and use. Many lakes may only require reassessment every ten years or so. This would apply to large stable lakes and those isolated from disturbance factors. Some degraded lakes may also be of low priority or interest to managing authorities, with the result that they are of low priority for reassessment relative to other lakes. It is recommended that ecologically valuable lakes and those lakes vulnerable to change (from catchment/riparian activities or pest plant or fish species) be assessed every one to three years.

Chapter 8

8. Data analysis and interpretation

8.1 Generation of LakeSPI indices

LakeSPI indices are generated by using information from field sheets and converting this into scores using the scoring boxes for each parameter as presented in section 6. Individual scores for each parameter are then added and LakeSPI scores generated by taking a mean of the final scores for the surveyed sites around a lake. Once LakeSPI scores have been assessed, LakeSPI indices are calculated and expressed as a percentage of a lakes maximum potential – that is how close a lake is to its best possible condition. To proceed with this final step, lake maximum depth must be known and final scores adjusted using the 'Depth Calibration Table' (section 8.3) Calculation can then be made to produce the three indices representing the Native Condition Index, the Invasive Condition Index and the LakeSPI Index. Reference should be made to the User Manual (section 5.3) for a more detailed account of the score generation process.

LakeSPI indices can also be generated directly using the LakeSPI database. This database was created in 2004 to house the growing amount of LakeSPI survey information and automatically generates the LakeSPI indices for a lake after entering the field data requirements. Although not yet accessible to outside parties, it is proposed that assistance can be provided to management agencies to ensure accurate processing and assessment of LakeSPI data.

8.2 Interpretation of LakeSPI indices

A key assumption of the LakeSPI method is that native values indicate better lake condition and they will proportionally increase the value of the LakeSPI index. In contrast, any invasive species will decrease the LakeSPI value. The LakeSPI Index alone provides a useful assessment of the condition of any lake. The 'Native Condition Index' and 'Invasive Condition Index' used to create the LakeSPI Index still play a valuable part in allowing managers to better understand the LakeSPI result. For instance a lake that undergoes a decline in LakeSPI Index will be better understood by looking at the contributing effects of the Native and Invasive Condition Indices. This may then help to establish appropriate management needs to better protect or manage lake condition.

LakeSPI indices are calculated as a percentage of a lakes maximum potential. This maximum score is based on what a lake could achieve if there had been no invasion by alien plant species and no decline in water quality due to human induced changes. By expressing the indices in this way, lake managers are able to use LakeSPI to determine three key conditions:

1. Pristine Condition (lake plant communities in pre-impacted times)
2. Historical Condition (described by historical data)
3. Present Day Condition (using most recent data)

These conditions can then provide the benchmark for which all future lake assessments can be measured and lake condition assessed.

8.3 Development of LakeSPI Indices

The physical characteristics and chemical nature of a lake have a large influence on the type and extent of submerged vegetation and in order to interpret any LakeSPI score it is necessary to place that score into some meaningful context. To do this one must consider the nature of the waterbody from which the score has been derived.

Water bodies can be grouped into categories based on their similarity of key features. Various lake classification schemes have been proposed for a variety of purposes and were each considered in the development of the LakeSPI method and found unsuitable for providing a suitable indicator from which to measure lake condition. For example, a classification framework developed by Ward & Lambie (2000) for New Zealand wetlands was considered but this does not provide a suitable basis for recognising different LakeSPI scoring potentials for various lake types.

An alternative approach was adopted by considering the key components within the LakeSPI method that affected the maximum scoring potential. These components are:

- The maximum LakeSPI score for any lake assumes a complete absence of alien species.
- Naturally reduced water clarity (e.g., dystrophic lakes) reduces the potential submerged plant score.
- Lakes less than 20 m deep and not impacted by naturally reduced water clarity have reduced potential LakeSPI scores.

The maximum potential LakeSPI score is 50 but this score is only possible for lakes 20 m or deeper and NOT impacted by naturally reduced clarity or invasive weeds. In New Zealand this maximum potential score applies to many North Island lakes (e.g., Waikaremoana, Taupo, Tarawera, Pupuke) and South Island lakes (e.g., Wanaka, Hawea, Hayes). In the absence of invasive species in these lakes, any LakeSPI score less than 50 indicates less than optimal lake ecological condition, which in turn could be explained by factors such as eutrophication (e.g., Lakes Pupuke and Hayes), artificial water level fluctuations (Lake Hawea) or biotic disturbance (Lake Taupo).

Many lakes could never achieve the maximum LakeSPI score of 50. For shallow lakes less than 2 m deep, the maximum LakeSPI score is 34. This score is only possible if they are NOT impacted by naturally reduced clarity or invasive weeds. Under optimal conditions for submerged plant growth, vegetation would be expected across the bottom of shallow lakes. This applies to many lakes around New Zealand, including Waikato shallow lakes (e.g., Waahi, Serpentine), many Northland sand dune lakes, and most lagoons (e.g., Pukepuke). In the absence of invasive species, any LakeSPI score less than 34 would indicate less than optimal lake ecological condition, which in turn could be explained by factors such as eutrophication, accelerated or unnatural turbidity (e.g., Lake Waahi) or other disturbance factors.

Figure 4 demonstrates how lake depth affects the maximum LakeSPI scoring potential. It shows that both the LakeSPI and Native Condition Indices change in proportion to the depth of a lake. This is expected, since apart from the ‘maximum depth of vegetation’ the only other scoring parameter to be affected by lake depth is ‘charophyte meadows’. The invasive Condition Index is not affected by changes in lake depth.

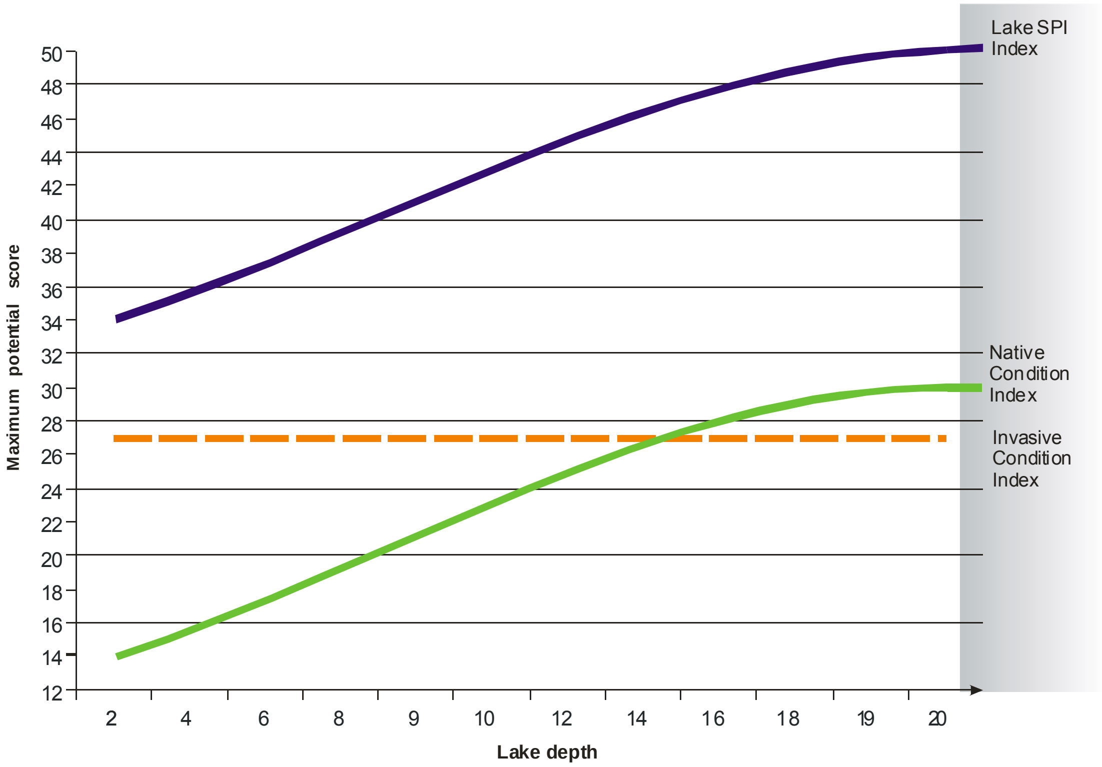


Figure 4. **Maximum potential scores for each of the LakeSPI Indices based on the depth of a lake.**

8.4 Depth Calibration Table

The 'Depth Calibration Table' was developed to allow quick calculation of the LakeSPI indices. It shows the adjusted maximum potential scores that can be achieved for overall LakeSPI Condition, Native Condition and Invasive Condition based on a lakes maximum physical depth.

There are three key factors in the LakeSPI scoring system that are influenced by lake depth. These three factors are shown in the 'Depth Calibration Table' (Table 2) below accompanied by the resulting penalties they have on the LakeSPI scores. A 'Depth penalty', 'Meadows penalty' and 'Distribution penalty' are assigned to a lake according to its maximum water depth. Table 2 shows that as the depth of a lake decreases, so too does the potential score attributed to 'maximum depth of vegetation', depth of 'charophyte meadows' and 'native distribution' (see Scoring Box 1, 4 & 5 in Section 6). The combined effect is additive. The maximum scoring potential that can be achieved for the full range of possible lake depths is presented in the right hand columns of Table 2.

Table 2. ‘Depth Calibration Table’ showing the penalty adjustments and maximum potential scores that can be achieved for lakes with different maximum depths.

Max lake depth (m)	Penalty adjustments			Total Penalty	Maximum Potential LakeSPI Score	Maximum Potential Native Condition Score	Maximum Potential Invasive Condition Score
	Depth penalty	Meadows penalty	Distribution penalty				
1- 2.9	-9	-4	-3	-16	34	14	27
3- 4.9	-8	-4	-3	-15	35	15	27
5- 6.9	-7	-3	0	-10	40	20	27
7- 8.9	-6	-3	0	-9	41	21	27
9- 9.9	-5	-3	0	-8	42	22	27
10- 10.9	-5	-2	0	-7	43	23	27
11- 12.9	-4	-2	0	-6	44	24	27
13- 14.9	-3	-2	0	-5	45	25	27
15- 16.9	-2	-1	0	-3	47	27	27
17- 18.9	-1	-1	0	-2	48	28	27
19- 19.9	0	-1	0	-1	49	29	27
20+	0	0	0	0	50	30	27

The ‘Depth Calibration Table’ uses physical depth limitation of a lake as the key ‘natural’ factor limiting maximum LakeSPI score potential. Less common factors that are still ‘natural’ can also reduce water clarity (e.g., dystrophic lakes, glacial flour) and thereby impose a ‘natural’ limit on the maximum LakeSPI score potential. These other natural factors are more difficult to assess than physical depth constraints, particularly since they can change more quickly over time than lake depths. Also water clarity is more difficult to characterise on account of seasonal changes associated with glacial snowmelt (glacial impacted lakes) and rainfall (dystrophic lakes).

As a guideline it is suggested that any lake with natural discoloured or turbid water should be checked for any historical water clarity data to establish an approximate value for photic depth. Unfortunately it may not always be possible to separate ‘natural’ clarity from other human-related factors responsible for clarity reduction. For example, naturally dystrophic lakes in the Waikato region have also been impacted by catchment development and associated eutrophication, which has led to turbidity arising from phytoplankton algal growth and suspended sediments. Nevertheless, in this case most of these lakes are less than 3 to 5 metres in depth, so their depth already constrains the maximum potential LakeSPI score.

8.5 Repeatability and reproducibility

For the method to be a useful long term monitoring tool results should be 'repeatable' and 'reproducible'.

The definitions used in the evaluation of the LakeSPI method were as follows:

Repeatability: The characteristic that makes it possible for surveyors to use the LakeSPI method at the *same site* to produce an index that is not significantly different.

Reproducibility: The characteristic that makes it possible for different surveyors to use the LakeSPI method at *different sites* around a lake to produce a mean LakeSPI index that is not significantly different.

Repeatability was determined by having two surveyors independently survey the same 10 sites in Lake Rotoma. The between observer coefficient of variation was 2.1% for Native Condition, Invasive Condition and LakeSPI Indices, indicating that good repeatability can be achieved between surveyors on the same survey sites.

To assess reproducibility two independent teams were each given a bathymetric map of the same lake and clear instructions on site selection criteria. Each team then chose their own five survey sites and completed their field sheets and score sheets independently. The scores generated by the two teams in Lake Okataina (Table 3) had a coefficient of variation between teams of less than 6%, indicating good reproducibility of the method when the guidelines are followed.

Table 3. LakeSPI scores generated by two independent teams of divers on Lake Okataina demonstrating reproducibility of results.

	Native Index	Invasive Index	LakeSPI Index
Team 1	12.8	18	19
Team 2	13.8	17.2	20.6

Reproducibility was also tested in a large lake with diverse vegetation (Lake Tarawera). This lake was chosen for this test as it posed a challenge to the LakeSPI method due to the high site variation within the lake, as it is undergoing a substantial change in vegetation from native to invasive species domination. The lake was surveyed by two teams with a total of 16 sites sampled from around the lake. There were large differences in scores between some sites and consequently there was noticeable variation (coefficient of variation of 25%) in the mean scores of combinations of 5 randomly chosen sites (out of the total of 16 sites surveyed). Any lake undergoing vegetation changes will inevitably have an unstable score, but this variation would reduce as the invasion process tends towards completion.

One of the reasons for careful initial site selection and subsequent sampling using the same sites is to largely avoid the variation that would otherwise occur if different or random sites were selected during subsequent surveys on a lake. On the other hand it is also suggested that such variability in a diverse or complex lake could be addressed by selecting more than 5 sites during lake survey.

In summary, testing and data analysis has shown that different surveyors applying the LakeSPI method can achieve repeatable and reproducible results for any given lake provided that the method guidelines are followed. Initial site selection is important since this will help ensure representative sites are used to generate LakeSPI indices and future survey of these same sites will minimise repeatability and reproducibility errors.

Chapter 9

9. LakeSPI management application

9.1 Questions that LakeSPI can answer

LakeSPI will help managers answer many questions. A selection of these questions include:

Lake condition generally

1. Is the overall condition of this lake improving or declining?
2. How can I prioritise lakes in my region?
3. Are lakes in this region or area improving or declining?
4. Is the water clarity improving or deteriorating for this lake/lakes in this region?
5. What is the rate of this improvement or decline?
6. Is the lake condition typical for a lake of this type (in this region)?

Invasive alien plants

1. How pervasive has alien plant invasion been in this lake? How many invasive species are there? Which species are present?
2. What is the current regional or national distribution and relative abundance of alien plant species in lakes?
3. How vulnerable is this lake to (further) impact from invasive plant species? What sorts of impacts are possible?

Native plant communities

1. What is the quality of the native plant communities in this lake? Is there a good diversity of native plant communities or have they been largely or entirely replaced by invasive alien species?

2. Are there lake attributes (e.g., native plant communities) that require special management? What type of management would be needed?

3. How do the existing plant communities in a lake/group of lakes compare to pre-European/ pre-human times?

Restoration goals

1. What would be the appropriate restoration goals for water clarity and plant communities given the lake type and its current state?

9.2 Limitations of LakeSPI

Not all lakes can be assessed using the LakeSPI method. Naturally the lake must have submerged plants and cover of vegetated areas must exceed ten percent before the scoring system will work. Any lake with emergent species around the lake margins must also have submerged vegetation present for scoring purposes. Many quite small lakes (such as farm ponds and reservoirs) are surrounded by emergent vegetation (e.g., raupo (*Typha*)) with their surface waters often covered by free-floating plants (e.g., duckweed (*Lemna*), water fern (*Azolla*)), or bottom rooted plants with large surface floating leaves (e.g., water lilies (*Nymphaea* species)). Dense mats of floating plants will often exclude light and prevent submerged species from growing, so these types of lakes would be unsuitable.

The LakeSPI method is not suitable for brackish or estuarine waterbodies, since quite different plant species are found which are tolerant to saline conditions. The LakeSPI method will also not work effectively in any lake where the pH affects the presence of a normal complement of submerged plant types. For example, the Kai-Iwi lakes in Northland have low alkalinity that only supports charophyte vegetation. Whenever water chemistry prevents the presence of vascular species, then scoring criteria for both native and invasive condition will be affected.

The LakeSPI method has not been evaluated for its applicability to high altitude tarns. Some high altitude lakes have very impoverished submerged vegetation and may only contain submerged bryophytes, which have been deliberately excluded from LakeSPI scoring concepts. If mountain tarns support the usual range of plant community types discussed in this report, then the LakeSPI method will work, however further evaluation will be required to better define any limitations for this type of lake.

LakeSPI will pick up new invasive species if they are already well established and having an impact on lake condition, but it is not a method designed to pick up early stages of any new invasive species establishment. A site targeted surveillance method (see Section 9.4.1) is required for this purpose.

The LakeSPI method has been developed for New Zealand lakes. Many of the principles behind the methodology would be directly relevant to lakes in other countries, but some of the specific indicators would either be inappropriate (e.g., various invasive species are native plants elsewhere) or have limited application.

9.3 Reporting

An essential part of monitoring is the reporting of the analysed and interpreted results. This allows for the information gained from monitoring programmes to contribute directly to management decision-making.

For this reason the LakeSPI indices are designed to be relatively easy for non-experts to understand and interpret. Once a LakeSPI score is adjusted against the maximum potential score for that lake it can be reported either individually or as part of a wider study of a suite of lakes.

The methodology is sufficiently simple that it should be possible to measure and report on all readily accessible lakes. Less accessible lakes are generally less vulnerable to adverse water quality effects caused by human activities and by invasive plants. However, it would be appropriate to measure and report on a representative selection of less accessible lakes of different types.

A new step in reporting on lake condition has been through the development of the NIWA LakeSPI reporting web pages – www.lakespi.niwa.co.nz. This web site includes a map of New Zealand highlighting those lakes that have been assessed by LakeSPI. Lakes can also be searched by name and report cards for these lakes and are set out in a user friendly format showing LakeSPI information through a variety of graphs, tables and photos. Historical survey information can also be viewed from the website. It is expected that with time all LakeSPI survey results from throughout New Zealand will be made available on this site.

9.4 The relationship between LakeSPI and other methods

LakeSPI has not been designed to replace other methods of assessing aspects of lake condition and the threats to their ecology. Rather, LakeSPI will provide a new tool that is able to complement the range of tools already available to lake managers and which provide meaningful results that stand on their own for assessing lake ecological condition.

9.4.1 Comparison with other vegetation survey methods used in New Zealand

It is important to distinguish between three quite different aquatic vegetation survey methods, each with different objectives:

LakeSPI monitoring requires a modest level of skill, but it is designed to be a simple, cost effective way of converting carefully selected and representative lake vegetation information into a score that reflects overall lake condition. Care must be taken to select representative sites. LakeSPI is not a substitute for lake vegetation surveys or for surveillance monitoring (see below).

Surveillance monitoring generally requires minimal skill depending on the range of species being searched for. It specifically focuses on sites vulnerable to change, such as public access points and their immediate surrounds where the risk of new weed species incursions is greatest. This form of monitoring is different from LakeSPI and the lake vegetation survey method in that the sites selected will not normally be representative of the overall lake vegetation, the frequency of application is likely to be higher than any other method, and it can not be used to characterize lake vegetation as a whole.

The Lake Vegetation Survey method (Clayton 1983) provides a full description of the vegetation within a lake. Typically a full lake survey will involve twenty-five sites systematically located around a lake, although a lower number of sites may be used where water bodies are small or access is difficult. It requires a high skill level with a wide knowledge of aquatic plant species. It is more time consuming and intensive than either of the other two methods, but its purpose is to generate a detailed description of the vegetation composition and community structure in a lake. This method results in a comprehensive species list, as well as detailed information on species frequency and distribution, species cover and height in relation to depth and various other analyses.

LakeSPI can be used in conjunction with, or as a precursor to, other survey and monitoring methods. For example, it could be used to establish a priority order of lakes for full vegetation surveys or for surveillance monitoring. If a full vegetation survey is required, this same data can be converted into a LakeSPI index. If LakeSPI information were the primary purpose for monitoring, then high risk or valued lakes may also benefit from surveillance monitoring at targeted sites.

9.4.2 Comparison between LakeSPI and vegetation survey methods overseas

Aquatic macrophytes have been widely surveyed, described and monitored, but their use to measure or assess lake water quality and/or condition has been limited. In the United Kingdom and Europe, macrophytes have been used to characterise the trophic status of a range of waterbodies. Palmer *et* *al.* (1992) reports on the TRS (Trophic Ranking Score) based on species in standing water bodies, while Holmes *et al.* (1990) reports on the MTR (Macrophyte Trophic Rank) using species in streams and river habitats. Melzer (1999) developed a 'macrophyte index' using aquatic macrophytes as indicators of water pollution in European lakes. These scoring systems are based on the frequency and cover of species present and how each species characterises the trophic state of a waterbody based on their individual tolerance to eutrophic water condition. In these countries there is a wide range of species, each with a narrower ecological tolerance (e.g., nutrients) compared to New Zealand where there is fewer species (e.g., milfoils and pondweeds only have two common species each) with wide ecological tolerance.

In the USA, Nicols *et al.* (2000) also used aquatic macrophytes to develop an AMCI (Aquatic Macrophyte Community Index) for Wisconsin lakes, which was based on maximum depth of plant growth, percentage of littoral area vegetated, Simpson's diversity index, frequency of submerged species, taxa number and frequency of exotic species to characterise aquatic plant community quality.

It is clear from the few studies where aquatic macrophytes have been used for assessing water quality or lake condition that there are differences in the way sensitive and invasive species respond to environmental conditions (e.g., lake trophic status). Also, there are differences in the monitoring objectives of management agencies between countries. For these reasons the development of the LakeSPI method was based on New Zealand environmental conditions with particular relevance for lake managers at the local, regional and national levels.

9.4.3 Relationship to other lake monitoring methods in New Zealand

There are several established methods that address different aspects of lake monitoring. This section identifies these methods and their relationships to LakeSPI.

The "Lake Managers Handbook" (Vant *et al.* 1987) describes a range of resource survey and assessment methods available to lake managers. Traditional approaches have often been based on quite simple methods such as Secchi disc to measure water clarity. More comprehensive measurements have focused on a variety of physico-chemical parameters, such as pH, conductivity, vertical temperature profiles through the water column, chlorophyll *a*, and measurement of dissolved and total nitrogen and phosphorus.

Burns *et al*. (1999, 2000) recently revised methods for the collection and analysis of data to develop a means for detecting early change in waterbody condition using a range of these same water quality parameters. This methodology (Trophic Level Index) is relatively expensive to implement and while a wider suite of lakes was measured during the methodology development phase only a few lakes are now regularly monitored. Much of the cost relates to the need to regularly collect water samples from the centre of the lake so requiring multiple boat trips each year. LakeSPI is a method that can monitor a much larger number of lakes for the same cost as plants integrate long-term trends in water quality and so fewer lake visits are required.

Alternative approaches for assessing water quality have been developed in stream and river habitats. Most notable in New Zealand was the work by Stark (1985) who used macroinvertebrates to develop a biotic index to classify the water quality of streams in New Zealand. This approach was extended recently with the development of the SHMAK model (Stream Health Monitoring and Assessment Kit), which provides a simplified approach to the description and monitoring of the health of streams (Biggs *et al.* 1998). However, both methods are restricted to rivers and streams. LakeSPI provides a complementary method for lakes.

9.5 Future developments

Additional indicators for potential incorporation into LakeSPI are under investigation. These include selected benthic macro-invertebrates such as the abundance of koura (native freshwater crayfish) and kakahi (native freshwater mussels), as well as benthic cyanobacteria films immediately below the maximum submerged macrophyte deoth limit.

Further testing of LakeSPI methodology is also required on a range of lakes that presently have limitations using this method (e.g., alpine, dystrophic, and brackish).

Chapter 10

10. Conclusions

The use of submerged plants as indicators of lake ecological condition has been developed into a cost effective tool referred to as LakeSPI or Lake Submerged Plant Indicators. Managers can use the LakeSPI methodology for almost any lake within their region, provided that submerged plants are present at greater than ten percent cover. The method is not suitable for assessing brackish waterbodies or any lake (e.g., alpine tarn) devoid of the usual complement of submerged plant community and species types.

LakeSPI is sensitive to two key factors that influence all water bodies throughout New Zealand, and that managers generally aim to regulate or minimise. These factors are: (1) the effect of catchment developments that result in increased sediment and nutrient influx to receiving water bodies; and (2) the impacts arising from invasive water plants. The LakeSPI method is based on direct field measurement of key vegetation features that reflect these influences on lake condition. This information is converted into numerical scores that express both Native Condition and Invasive Condition of a waterbody. Both of these scores in turn are used to generate a LakeSPI score reflecting the overall ecological condition of any waterbody that contains submerged plants. Final LakeSPI indices are calculated based on a maximum potential score for each lake and by expressing the indices in this way, dissimilar lakes can be more directly compared. The LakeSPI method is a useful complement to open water physico-chemical methods in that it focuses on the littoral margins of water bodies where biological productivity and public interaction are greatest.

LakeSPI has many notable benefits. Any lake can be readily assessed within a day, and only one assessment or less per year is required to describe and monitor a lake's ecological condition. The frequency of application is dependent upon stability of lake condition, risk of change, the lake's ecological values and priorities with respect to management goals. LakeSPI can also be used to help establish management priorities for a lake by comparing indices between lakes and interpreting LakeSPI scores as to how they reflect lake ecological condition. LakeSPI has also been designed as a management tool to contribute to local, regional and national state of environment reporting. In view of its simplicity, speed of implementation and cost effectiveness it will also enable managers to assess and monitor lakes in their regions that have previously been ignored on account of budget constraints.

The selection of initial survey sites within each waterbody is an important step to securing meaningful results that will accurately reflect a lake's vegetation structure and composition. As future monitoring should be based on resurvey of the same sites it is important to ensure that long-term monitoring data is not compromised by poor site selection at the outset.

It is strongly recommended that LakeSPI be applied following appropriate training in the method. This should include field survey skills, particularly identifying the minimal level of plant species and community types likely to be encountered and the necessary skills to ensure repeatability and reproducibility of results.

The LakeSPI Technical Report and LakeSPI User Manual have been written to complement each other for overall use of the method. Both reports are available as PDF files from the NIWA LakeSPI website – www.lakespi.niwa.co.nz. The LakeSPI User Manual will require some initial training to ensure appropriate implementation and interpretation during the initial adoption phase.

Because LakeSPI is a relatively new method, we (the authors) would appreciate any suggestions and feedback that will help to ensure that beneficial refinements can be made to the method. For further information please contact the authors.

Chapter 11

11. References

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