Northland Lakes Strategy Part II

update and implementation strategy

Prepared for Northland Regional Council

April 2014

Authors/Contributors:
Paul Champion

For any information regarding this report please contact:

Paul Champion
Principal Scientist
Freshwater Biosecurity
+64-7-856 1796
paul.champion@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road
Hillcrest, Hamilton 3216
PO Box 11115, Hillcrest
Hamilton 3251
New Zealand

Phone +64-7-856 7026
Fax +64-7-856 0151

NIWA Client Report No:	HAM2014-038
Report date:	April 2014
NIWA Project:	ELF14202

Contents

Figures

Reviewed by	Approved for release by
Mary de Winton	David Roper

Formatting checked by

Executive summary

Northland Regional Council (NRC) sought technical advice from NIWA, via a medium Envirolink advice grant, to assist it to develop and implement a comprehensive regional strategy for the management of Northland's unique lakes resource. A previous Envirolink advice grant resulted in a Northland Lake Strategy 2012 which provided a system to classify, rank and prioritise Northland's lakes. This report is Part II of the Northland Lake Strategy providing an update of the 2012 report with discussion of issues identified by various NRC staff and additional reports; more detailed information on water and plant nutrient dynamics in lake systems and implications for land-use management; and an implementation strategy for high-value lakes using the Kai-Iwi lakes as an example.

Since the 2012 report, 12 lakes have been approved as 'Outstanding waterbodies' by the Northland Regional Council.

Suggested changes to the Northland Lake Strategy 2012 include:

- changes to classification of lakes, with some lakes previously classed as Type 3 'window lakes' now considered to be either Type 1 'perched lakes' (e.g., Lake Ngatu) or Class 4 'dune contact lakes' (e.g., Lake Te Kahika)
- incorporate re-evaluation of the threat status of endangered species into Lake Ecological Value score
- use trophic level index (TLI) and five year trends in this metric as a measure of eutrophication as opposed to chlorophyll *a* measures (chlorophyll *a* is included in TLI calculation). All relevant parameters required to calculate TLI are currently sampled by NRC.

Plantation pine forestry undoubtedly has a detrimental impact on the health of adjoining Northland dune lakes, but level of impacts depend on a wide range of factors. Impacts include reduced water tables, reduced wind mixing and stronger lake stratification, increased sediment deposition in some lakes and potentially major nutrient enrichment during harvesting. Deterioration of the Parengarenga lakes (e.g., Lake Morehurehu) was reported in 2013 following pine harvest. However, recovery to a state approaching pre-harvest is anticipated.

Invasive nitrogen-fixing plants, especially Sydney golden wattle (*Acacia longifolia*) pose a threat to lakes within low nutrient catchments by nitrogen enrichment of surrounding soils and groundwater. Evaluation of the extent of enrichment to the lake and also removal of wattles and associated leaf litter is advocated.

Fundamental to the management of lake water quality is an understanding of the water balance of the lake with estimation of inputs and outputs. From this an estimation of nutrient budget, including nutrients entering the lake through the catchment and through regeneration of plant-available nutrients from within the lake, and loss of nutrients from the lake. A key factor in estimating water and nutrient budgets is an accurate assessment of the groundwater catchment, which may be much greater than topographic boundaries (e.g., Lake Mokeno and other west coast Pouto lakes). It is imperative that the real catchment of the lake is understood to permit effective management. GNS Science have recently produced guidelines on 'Capture Zone Delineation' that should provide assistance in this endeavour. The oxygen content of groundwater also is an important factor when attempting to identify nutrient sources, especially mobilisation of phosphorus which occurs in deoxygenated conditions.

In addition to management of nutrient sources from the catchment, the limnology of each lake is important when considering the internally regenerated nutrients. Factors for consideration include deoxygenation of bottom waters being important for deep lakes and potential changes from plant dominated to planktonic algal dominated systems being important for shallow lakes, along with the influence of algae on marginal waters. The growth of planktonic algae in many lakes is limited by the availability of nitrogen or phosphorus. Therefore management of the limited nutrient is very important. NIWA has recently (April 2014) been contracted by NRC to determine whether either nutrient is limiting algal growth for 26 Northland lakes.

A range of catchment management options are proposed including farm management plans (farm water quality improvement plans), nutrient interception by riparian management and stock exclusion from lakes. Where ongoing land use is deemed incompatible with the management aims for outstanding regional water bodies, then strategic purchase of land where no other mitigation can prevent continuing lake decline is suggested.

In addition to current NRC TLI monitoring, installation staff gauges to enable monitoring of lake height and installation of thermistor chains and dissolved oxygen probes through the depth profile at the deepest part of each lake (or automated water quality monitoring stations) would detect bottom water deoxygenation signalling release of nutrients from bottom sediments.

A Kai-Iwi lakes implementation strategy should build on existing plans and activities such as the Taharoa Domain Reserve Management Plan which includes an environmental management section, NRC funded lake ecological status and water quality assessments and the Kai-Iwi lakes biosecurity action plan. A preliminary report on groundwater flows affecting Lake Kai-Iwi has been completed.

Catchment management recommendations are to evaluate the use of ground-penetrating radar to chart the depth to water tables and groundwater movement, investigate ground water nutrient and dissolved oxygen content, determine the role and importance of wattles in supplying nitrogen to the lakes using isotopic methods and sensitive land management practices on land contributing nutrients to the lakes.

In-lake monitoring should include establishment of lake height monitoring, dissolved oxygen monitoring and accurate bathymetry and submerged vegetation mapping using side-scan sonar.

A census of populations of all nationally threatened species is advocated for each lake. These should be undertaken every five years, with conservation measures included in individual lake management plans.

1. Introduction

Northland Regional Council (NRC) sought technical advice from NIWA, via a medium Envirolink advice grant, to assist it to implement a comprehensive regional strategy for the management of Northland's unique lakes resource. Part I of the Northland Lake Strategy was developed by Champion and de Winton (2012) and provided a system to classify, rank and prioritise Northland's lakes. The report also identified and ranked threats and pressures to individual Northland lakes. Part I was the basis for a comprehensive strategy for regional management of Northland's lakes. It also included the scoping and development for Part II for the implementation of management actions which will complete the strategy. This report is Part II of the Northland Lake Strategy providing the following:

- an update of the information provided in Champion and de Winton (2012) with discussion of issues identified by various NRC staff, and new and previous reports relating to Northland lakes not referred to in Champion and de Winton (2012)
- more detailed information on water and plant nutrient dynamics in lake systems and implications for land-use management, and
- an implementation strategy for high-value lakes using the three Kai-Iwi lakes (Waikare, Taharoa and Kai-Iwi) as an example.

This report builds on the information provided by Champion and de Winton (2012) and an updated Northland Lake Strategy incorporating Sections 2 and 3 of this report is recommended provided these findings are approved by NRC. Additionally, the Kai-Iwi lakes implementation strategy can be drafted based on identification of management issues as presented in Section 4 of this report.

2. Update of information

2.1 Council approval of twelve 'Outstanding' lakes

Following Phase I of the Northland Lakes Strategy Northland Regional Councillors approved the addition of a nine lakes to Northland's list of Regionally Outstanding Water Bodies making a total of 12 'Outstanding' lakes. These lakes are (from furthest north to south):

- Lake Morehurehu
- Lake Wahakari
- Lake Waihopo
- Lake Waiporohita
- Lake Ngatu
- Lake Waikare (referred to as Waikere until recently)
- Lake Taharoa
- Lake Kai-Iwi
- Lake Humuhumu
- Lake Mokeno
- Lake Rotokawau
- Lake Kanono

This list varies slightly from that proposed in Champion and de Winton (2012) and was based on re-assessment of Ecological Value Scores of Lakes Waiparera and Waiporohita.

2.2 Classification of dune lakes

The following changes to classification of lakes tentatively assigned as window lakes (Class 3 of Timms 1982) in Section 3 of Champion and de Winton (2012) have been made based on a request from Susie Osbaldiston (Groundwater Management Specialist, NRC) to reassess this classification, with additional information from Moreau et al. (2013) and Collier (1996). Lake heights 15 to 20 m above groundwater in the Sweetwater area and also Lake Wahakari, suggest that all those lakes are better assigned to Class 1 (perched lakes in leached dunes). Additionally, defined inflows for several other lakes indicate they should be assigned to Class 4 (dune contact lakes).

The following changes are proposed:

Class 1, Upper Quaternary soils, Aupouri

- Lake Wahakari
- Lake Waiparera
- Lake Ngakapua

- Lake Ngatu
- Lake Rotoroa

Class 4, Lower Quaternary soils, Aupouri

- Lake Te Kahika
- Lake Morehurehu

Class 4, Upper Quaternary soils, Pouto

- Lake Wainui

Class 4, Holocene soils, Pouto

- Lake Kapoai
- Lake Parawanui

Remaining lakes in Northland classified as window lakes include:

Class 3, Lower Quaternary soils, Dargaville

- Lake Shag
- Lake Waikare
- Lake Taharoa
- Lake Kai-Iwi

Class 3, Upper Quaternary soils, Pouto

- Lake Rototuna
- Lake Phoebe
- Lake Rotopouua
- Lake Roto-otuauru
- Lake Rotokawau
- Lake Waingata

2.3 Lake ecological values

2.3.1 Endangered species

A re-assessment of the threat status of indigenous New Zealand plants was undertaken in 2012 (de Lange et al. 2013) replacing de Lange et al. (2009). The following changes in classification of endangered plants associated with Northland lakes and used to assess Lake Ecological Value scores are as follows (from highest to lowest threat status):

Nationally Critically Endangered

- *Centrolepis strigosa* previously Naturally Uncommon
- *Hibiscus diversifolius* previously Nationally Endangered
- *Utricularia australis* previously Nationally Endangered

Nationally Endangered

- *Centipeda minima* previously Nationally Critically Endangered
- *Trithuria inconspicua* previously Nationally Vulnerable

At-Risk - Naturally Uncommon

- *Thelypteris confluens* previously At-Risk - Declining

At-Risk - Coloniser

- *Juncus polyanthemus* not previously assessed

Least concern

- *Myriophyllum votschii* previously Naturally Uncommon

Endangered Species scores assigned to each class of threatened species by Champion and de Winton (2102) were:

- Nationally Threatened taxa were each given a score of 5
- declining species, a score of 2
- other At-Risk and new to New Zealand species, a score of 1 and
- least concern species, no score

Thus lakes supporting populations of *Centrolepis strigosa* (+5) and *Juncus polyanthemus* (+1) would increase in score, whereas those with *Thelypteris confluens* (-1) and *Myriophyllum votschii* (-1) would decrease, although these would not necessarily change Lake Ecological Value scores (see Section 4.6 in Champion and de Winton 2102).

Potentially additional species that are regionally threatened could be included in future assessments. This would require updated assessments of regional threat lists and their significance to enable their inclusion in the lake ecological value score.

The threat status of New Zealand birds was also undertaken in 2012 by Robertson et al. (2013). There were no changes to the threat status of species associated with Northland lakes.

2.3.2 Lakes ecological survey 2013

The 2013 NIWA-led survey (Wells and Champion 2013a) reported the ecological value rating of Lakes Te Paki Dune, Wahakari, Waihopo and Kanono had remained unchanged. Lakes Morehurehu, Morehurehu South 2, Te Kahika (all adjacent to Parengarenga Harbour) and Te

Werahi Lagoon had lower ecological value ratings than previous assessments. Changes reported were:

- Lake Morehurehu — High (Outstanding in 2009)
- Lake Morehurehu South 2 — Moderate (High in 2009)
- Lake Te Kahika — High-Moderate (High in 2009)
- Te Werahi Lagoon — Moderate (High in 2004)

The ecological value declines in the Parengarenga lakes were probably due to pine harvesting in the lakes catchments (see Section 2.4.2). NRC monitoring subsequent to the April 2013 survey have indicated that water quality parameters in these lakes may be improving (Lisa Forester, Biodiversity Specialist, NRC unpublished internal communication, July 2013 REQ 570507). Te Werahi Lagoon decline was due to increased abundance of aquatic weeds.

2.4 Lake Pressure/threats

2.4.1 Pest fish

Champion and de Winton (2012) gave a lake pressure/threat score related to pest fish based on the Rowe & Wilding (2012) Fish Risk Assessment model (FRAM) to quantify the potential impact of invasive freshwater fish.

The biosecurity status of non-native freshwater fish species in Northland has recently been reviewed by Rowe (2014). He identified seven warm-water pest fish, describing potential impacts on lake systems including reduced water clarity, increased eutrophication, reduced biodiversity and ecosystem services and increased risk of disease or parasite spread to indigenous or other valuable fish species.

Another pest fish not recorded by Rowe (2014) is the orfe (*Leusiscus idus*) which was apparently stocked into Lake Parawanui, but not known to have established there (Kokich 1991). Rowe (2014) records gambusia (*Gambusia affinis*) as the most widespread species occurring in more than 50% of sites sampled in Northland, but apart from Lake Rototuna, unknown from the Pouto lakes. Goldfish (*Carassius auratus*) were next most abundant, occurring in 13% of sampled Northland habitats, but the remaining five species, including perch (*Perca fluviatilis*) the species ranked highest by FRAM occurred in much lower than 10% of sampled sites (with perch only recorded at 0.5% of sites). Rowe (2014) also maps these occurrences and provides sampling protocols to detect those species. This information is invaluable to enable targeted surveillance of nearby high value lakes.

Rowe (2014) also identifies potential vectors of pest fish spread, with contaminated eel fishing nets and bilge water of recreational boats identified as the most important accidental means of transfer. He also identifies deliberate transfer of some species (including perch) to establish coarse fisheries as a potentially important vector. The fish parasite *Ligula intestinalis* has been recorded in a few west coast Northland lakes and he postulates the deliberate spread of pest fish could result in further distribution of this tapeworm, with unknown consequences for native fish.

The current assessment of lake pressure/threat score related to pest fish appears to adequately represent these impacts.

2.4.2 Water quality trends

Champion and de Winton (2012) gave a lake pressure/threat score related to in-lake nutrient enrichment (eutrophication) based estimated concentration of planktonic alga (Chlorophyll a concentration). This is only one of several parameters measured by NRC, including other measurements taken in order to calculate a Trophic Level Index (TLI).

Trends in water quality were calculated over the past five years for Northland 28 lakes (Emma Simpson, Water Quality Specialist, NRC unpublished data). These data potentially provide a much better measure of direct change in nutrient status and consequent impacts (e.g., water transparency, Secchi depth, Chlorophyll a concentration, pH, Dissolved oxygen, suspended sediments) and integrated into a TLI score. Her approach allows detection of change in contributing elements of water quality (e.g., ammonia (ium) concentration, dissolved reactive phosphorus) which may guide possible identification of sources and mitigation measures.

Thus pressures/threats relating to eutrophication would be better approximated by assessment of trends over the past five years and the following lake pressure/threat scores are proposed:

- Lake oligotrophic or mesotrophic; all water quality trends improving or stable – 3.
- Lake oligotrophic or mesotrophic; water quality trends deteriorating -2.
- Lake eutrophic; water quality trends improving -2.
- Lake eutrophic; water quality trends stable -1.
- Lake eutrophic or worse (i.e., supertrophic, hypertrophic); water quality trends deteriorating – 0.

Remote sensing shows some promise for future water quality monitoring and NRC will are considering its use in the future (Lisa Forester, NRC pers. comm.). Deployment of permanent water quality monitoring stations are advocated for representative ‘outstanding ‘ lakes and other oligotrophic or mesotrophic lakes where water quality trends show deterioration.

2.4.3 Forestry impacts

Champion and de Winton (2012) gave a lake pressure/threat score related to pine plantation forestry impacts in Sections 5.6 (area of catchment covered by pines), 5.8 (water level change), also including shading and impacts of harvesting as unquantified threats (Section 5.10).

Collier (1996) identified a range of potential impacts of pine forestry on Northland dune lakes, also providing interim guidelines for riparian management. He identified physiographic features that could potentially influence forestry impacts such as topography influencing erosion and wind-exposure of lakes, soil type and nutrient status. Hydrological features included presence of inlet streams to import forestry effects to the lake and forest growth impacts on groundwater. Major effects identified were:

- Transpiration and water interception by pines affecting lake levels.
- Increased shelter reducing wind induced mixing and increased stratification of lakes.
- Sediment accretion (deposition) in lakes with inflows or steep-sided catchments.
- Nutrient enrichment during harvesting through sediment run-off and re-mobilisation in anoxic bottom waters.
- Exposure shock after harvesting, with rapid removal of shading and increase in wind exposure.

Some of these effects are discussed below.

Transpiration

Collier (1996) reported the loss of more than 50% of lakes on the South Kaipara Heads (Auckland Region) and nearly all temporary pan wetlands on Aupouri Peninsula, both attributed to pine transpiration losses and rainfall/groundwater interception. He reports New Zealand studies showing reduction of groundwater recharge of up to 70% under pines and increased run-off of 60 to 80% in high rainfall areas for up to three years post-harvest, with a slow decline as vegetation re-establishes after this time. Rolon et al. (2011) examined pine influences on ponds in Southern Brazil and report a reduction of water yield from 20 to 80% with conversion of pasture to pine plantation. Observations of lakes, particularly in the Aupouri Peninsula, by Wells and Champion (2013b) also indicate loss of some lakes and apparent reduction of lake height associated with pine plantation forestry. Further investigation into lake and wetland loss in pine-forested parts of Northland (Aupouri and Pouto) are advocated.

Shelter

Collier (1996) reported the stabilising effect of pines on previously mobile dunes on the western side of Northland, with more stable marginal vegetation and increased infilling. This compounds the effects of transpiration discussed above. Lake stratification combined with benthic anoxia as a result of shelter can impact on nutrient release from bottom sediments (discussed more fully in Section 3).

Accretion and nutrient enrichment

Harvesting of pines leading to increase in sediment accretion is noted by Collier (1996) to be greatest where there are logging tracks (especially at stream crossings), landslips on steep slopes and bank collapses. Nutrient, especially phosphorus but also organic nitrogen enrichment associate with accretion has been reported in Collier (1996). Additional to nutrient release resulting from harvesting, common top-dressing rates of up to 125 kg P ha^{-1} yr^{-1} and 500 kg P ha^{-1} yr^{-1} are reported usually as one-off applications during the life span of each forest rotation, but Collier (1996) did not report any studies showing serious enrichment of stream water unless fertilisers were directly applied to water, advocating a 20 m buffer of vegetation that would be likely to remove much of the nutrient passing through groundwater accessible to their roots. Crowther et al. (2014) analysed changes in soil microbial composition as a result of deforestation and found the greatest changes occurred in coarse sandy soils, whereas silt and clay based soils did not change significantly. The dominant drivers of changes in microbial community changes were loss of organic matter (indicated by the reductions in soil %C and %N). Presumably these losses would be transported through groundwater or surface losses to sink areas (i.e., lower-lying lakes and wetlands).

Wells and Champion (2013a) reported plantation pine forest in the Parengarenga area had recently been logged and re-planted. The lakes had become heavily stained brown/red allowing little light penetration and consequently had very little submerged vegetation. Similar concerns were raised over the harvesting of pines in the vicinity of Lake Humuhumu (Bruce Griffin, Land Management Advisor, Lisa Forester, NRC - August 2013).

The decline in the Parengarenga lakes was initially thought to be due to high concentrations of resin acids derived from pine trees entering the ground water, released following harvesting of pines when later subject to saturated conditions due to high winter rainfall. Analysis of resin acids (Hill Laboratories 1156153) showed elevated concentrations of isopimaric acid, lignoceric acid and 7-oxodehydroabietic acid in Lake Te Kahika from samples taken in July 2013 (Lisa Forester, NRC). NRC analysis of water quality data showed a significant drop in pH in Lake Morehurehu (old range 5.9 to 6.8 now 4.9 to 6.1), with increasing total nitrogen (TN) has in particular nitrate and dissolved organic nitrate levels. Water clarity dropped in Lake Te Kahika since harvesting and an increase in volatile suspended solids (organic matter) was observed (Emma Simpson, NRC unpublished data).

Based on the above results, it appears that increased staining of Lakes Te Kahika, Morehurehu and Morehurehu South 2 were the result of mobilised organic matter as result of harvesting. Interestingly, Lake Morehurehu South 2 is situated outside of the pine harvesting area, but obviously linked by groundwater. It is anticipated that the impacts from this accretion will reduce over time as this organic material is reduced through breakdown and flushing through the lake systems, hopefully with restoration of high ecological value ratings.

Conclusion

Pine forestry undoubtedly has a detrimental impact on the health of adjoining dune lakes, but level of impacts depend on a wide range of factors. The current assessment of lake pressure/threat score related to pines appears to adequately represent these impacts. Communication with forestry companies over their management practices around dune lakes is advocated, which may include running a workshop on lake management for key forestry companies.

2.5 Other threats/pressures

Section 5.10 of Champion and de Winton (2012) identified additional threats that were not included in the threat/pressure ranking. Some of these have been addressed in Sections 2.4.1, and 2.4.4 and the other unquantified threats basically relate to:

- Impacts of other land use practices on nutrient enrichment, water clarity and other physicochemical effects:
  - e.g., drought mobilisation of nutrients through erosion, harvesting buried kauri logs, nitrogen-fixing plants, relative impacts of different farm practices.
- Biosecurity impacts:
  - e.g., nitrogen-fixing weed species, additional vectors of pest spread.

Removal of kauri logs from a wetland that is hydrologically linked to Lake Ngatu was identified in 2012 and water samples were collected from the outlet drain of the wetland and compared with Lake Ngatu water (Lisa Forester, NRC, pers. comm.). Analysis by Watercare Laboratory Services (# 130831-053) showed greater concentration of tannins (4.4 mg L^{-1} cf. 0.34 mg L^{-1}) and total phosphorus (40 µg L^{-1} cf. 8 µg L^{-1}) in the drain compared with Lake Ngatu. Impacts on Lake Ngatu would depend on the volume of drainage water entering it, but localised impacts in clarity and potential sufficient P-enrichment to permit additional algal growth may occur. Excavation of kauri logs has also occurred in wetlands in the vicinity of the Kai-Iwi lakes and Lakes Rotoroa and Rotokawau (Lisa Forester, NRC, pers. comm.).

Invasive nitrogen (N)-fixing plants, especially Sydney golden wattle (*Acacia longifolia*) and coastal wattle (*A. sophorae*) pose a threat to lakes within low nutrient catchments, such as the Kai-Iwi lakes, where the species has invaded areas after pine harvesting. Impacts include direct nitrogen enrichment of soils and most likely mobilisation via groundwater into the lakes. Rascher et al. (2012) noted that Sydney golden wattle stands impacted an area more than 1000 times that occupied by wattle trees by N enrichment of surrounding sandy soils resulting from N-fixing by those plants. Marchante et al. (2008) found that sandy areas recently invaded Sydney golden wattle showed elevated concentrations of N, but these rapidly declined after removal of this species. However, where this species had been present for >20 years, increased soil carbon (C) and N did not decline for several years. Removal of wattle leaf litter significantly increased the rate of decline of soil C and N compared with control of wattles with no litter removal. Rascher et al. (2012) mapped the influence of N fixed by the wattle using isotopic analysis with an elemental analyser interfaced with a continuous flow stable isotope ratio mass spectrometer. It would be fairly straightforward to undertake a similar isotopic assessment in the Kai-Iwi lakes which would allow estimation of N contribution to the lakes from wattle N-fixation (Max Gibbs, NIWA pers. comm., March 2014).

Pulsed input of nitrogen and potentially other nutrients to lakes may result from the mobilisation of livestock urine patches in the catchment that are mobilised during heavy rainfall events especially following drought conditions.

A recent forest fire on the Pouto Peninsula resulted in the filling of monsoon buckets from Lake Phoebe. Lisa Forester (NRC, pers. comm.) observed the lake had been severely disturbed, with submerged vegetation die-off. Bottom resuspension of phosphorus may have caused the deterioration. Additionally, fire fighters apparently source water from a number of different lakes, in order to reduce impact on a single lake, but this may lead to inter-lake spread of pest species. NRC need to work closely with fire authorities to ensure high value lakes are not substantially impacted by similar activities in the future.

The current assessment of lake pressure/threat score related to nutrient enrichment and changes in water clarity (eutrophication – in-lake enrichment) appears to adequately represent these impacts.

3. Lake and catchment water and nutrient dynamics

Ben Tait and Susie Osbaldiston (NRC internal memo to Waiora Northland Water Steering Group, 6th March 2014) identified a series of information gaps relating to land use and resultant impacts on Northland lakes. Their memo states:

"Understanding the water and nutrient inputs i.e., both surface and groundwater, is key to identifying appropriate management actions for a lake. This is particularly important when attempting to understand and manage land-use impacts. Understanding the hydrogeology of Northland's lakes is currently a critical information gap that requires addressing. Such work will enable accurate classification of Northland's lakes and subsequent efficient and effective management.

The top four actions identified as information gaps were (in priority order):

1. Ground-truthing the initial estimated classifications of Northland's dune lakes.
2. Understanding areas of surface and ground water influence as guided by lake classification (what is the major influence(s) on lake condition for each lake type – surface water/land use inputs or groundwater quality).
3. Understanding the relationship between in-lake water quality and nutrient loading.
4. Understanding N, P, and co-limitation in the lakes (i.e., what are the key management variables?)

They stated that this information is "critical to designing an efficient and effective regional planning framework for managing the lakes, including the scale at which the lakes can be managed (e.g., regionally, local zone, lake classification, or individually). It will also inform other regulatory and non-regulatory functions of the council (biodiversity, biosecurity, and land management)".

Additional gaps identified were:

1. "The extent to which enriched lakes can be restored and the most effective interventions.
2. Understanding likely and predicted land use changes (e.g., forestry) and their contribution to nutrient loads. This could also extend to looking at the impacts of forestry on lake water quantity and quality (in terms of non-conventional contaminants)".

In this memo Tait and Osbaldiston state "The proposed Regional Policy Statement for Northland and the National Policy Statement for Freshwater Management (with proposed 2013 amendments) require the regional council to manage nutrient levels in dune lakes in order to achieve specific trophic level targets". To assign such targets require an understanding of catchment and in-lake nutrient processes as discussed below.

The following section discusses aspects of water and nutrient balance of the Northland lakes and catchment boundaries based on discussion with Max Gibbs (Water Quality Scientist, NIWA) and Sandy Elliott (Principal Scientist – Catchment Processes, NIWA), their assessment of recent pieces of work commissioned in the Northland region (Moreau et al. 2013; Golder Associates 2013) and various enquiries from NRC staff (e.g., John Ballinger, Environmental Monitoring Programme Manager, September 2013), also the report MfE SMF (2005) outlining best management in pastoral catchments, based on a study of Lake Kapoai and an Envirolink funded study of remediation opportunities and recommendations for management of dune Lakes Pauri and Wiritoa in Whanganui-Manawatu Region (Gibbs and Champion 2013).

Fundamental to the management of lake water quality is an understanding of the water balance of the lake with estimation of inputs (variously through rainfall, ground water and overland flow), outputs (evaporation, outlets and other water losses from the lake) and calculated from this, the residence time of water in the lake (i.e., how long does water take to flush through the lake). Once the water budget is estimated, then a nutrient budget should be considered. This provides a measurement or estimation of plant nutrients (N and P) entering the lake through the catchment (associated with water inputs, wind dispersed or N-fixation within the lake), regeneration of plant-available nutrients from within the lake, and loss of nutrients from the lake (associated with water outputs or denitrification in the case of N).

3.1 Assessment of catchment boundaries

Both water and nutrient budgets would benefit from an accurate assessment of the catchment supplying the lake as outlined in point 2 above. In the case of Lake Ngatu, the catchment appears to be limited to the area defined by surrounding dunes, with the lake situated on a perched water table, rather than being linked to the Aupouri Aquifer some 15 to 20 m beneath this layer (Moreau et al. 2013). Conversely, the lakes on the western edge of the Pouto Peninsula appear to be linked by a common aquifer. Figures 3.1 and 3.2 show a time series of aerial photographs of Lakes Karaka and Mokeno (Andrew MacDonald, GIS Officer, NRC). The 2010 photos (Figure 3.1) show the lakes with no algal blooms, then a bloom developing in the more northern Lake Karaka, followed by the northern end of Lake Mokeno. Two photos in subsequent years (Figure 3.2) show all of both lakes in bloom, followed by only Lake Mokeno in bloom. In this case, management activities a long way away from the immediate lake surrounds can impact on the lake water quality and may explain why algal bloom have been noted as prevalent in Lake Mokeno, despite its topographical catchment being relatively pristine, vegetated by scrub and mobile dunes, with little farming influence. Thus it is imperative that the real catchment of the lake is understood to permit effective management.

Figure 0-1: Lakes Karaka (blue arrow) and Mokeno (yellow arrow) time series 2010. Left- 9th January 2010 (no algal bloom); centre- 8th February 2010 (algal bloom in Karaka); right 15th May 2010 (algal bloom in Karaka and north end of Mokeno - orange arrow).

Figure 0-2: Lakes Karaka (blue arrow) and Mokeno (yellow arrow) time series 2012-13. Left- 31st December 2012 (algal bloom throughout both lakes); right- 28th June 2013 (algal bloom only in Mokeno).

3.2 Ground water and land-based sources of nutrient

Measurement of groundwater inputs were undertaken for Lake Ngatu (Moreau et al. 2013) and Lake Kai-Iwi (Golder Associates 2013). These studies used observations of seepages, boreholes and piezometers to model ground water flows. GNS Science have recently produced guidelines on 'Capture Zone Delineation' that should provide assistance in the mapping of ground water catchments (Moreau et al. 2014a and b). Potentially ground-penetrating radar can provide a much greater range of continuous, high-resolution records to chart the depth to water tables in coarse-textured soils (Doolittle et al. 2006), such as the sandy soils of western Northland. Suitability of this method to measuring ground water flow should be investigated further.

The Catchment Land Use for Environmental Sustainability (CLUES) model has been developed by NIWA and MPI as a GIS-based system to predict land use and farm practice change scenarios and its suitability/application for prediction of nutrient or other contaminant inputs to Northland lakes was queried. Unfortunately, the model is unlikely to be useful as it has poor resolution (minimum of 0.5 km2) and is based on surface water quality (Sandy Elliott pers. comm.). OVERSEER, an on-farm management and decision-support model developed by AgResearch is more likely to be of use when working with landowners to optimise fertiliser requirements and demonstrate the impact of different use and management of fertilisers on lake water quality. This model was applied to the Lake Kapoai catchment (MfE SMF 2005).

Soil type also need to be considered when identifying risk of nutrient leaching, especially close to the lake margins. In the case of Lake Kapoai, recent Pinaki soils have very low phosphate retention and thus P-rich fertiliser is readily lost from this soil. Upper Quaternary Redhill soils are naturally rich in P (the mineral allophane) but have minimal P-leaching (MfE SMF 2005). However, overland movement of Redhill soils into the lake will be a major source of P, but this remains biologically unavailable in well oxygenated water. Oxygen concentration of ground water is another important variable, with increased concentrations of plant-available nutrients in deoxygenated waters. The following ions are mobilised at the following O_2 concentrations:

- 5-3 mg/L - manganese (Mn) and associated P.
- 3-1.5 mg/L - iron (Fe) and Mn with greater release of associated P.
- <1 mg/L - more P release.
- <0 – release of ammonia (NH_3).

Measurement of DO by optodes or other O_2 probes is advocated.

Fencing off the lakes to exclude livestock from the water will immediately prevent the direct addition of nutrients through urine and faeces to the lake, reduce faecal coliform input, but also help to reduce shoreline erosion and permit establishment of marginal and emergent plants. This vegetation effectively slows water flow permitting deposition of sediments and utilising those nutrients for plant growth, attenuating groundwater and overland flow of nutrients to the lake. Emergent vegetation also provides ideal conditions (microaerophilic) for denitrification bacteria to convert plant-available forms of N to atmospheric nitrogen. These emergent species and many marginal plants have delicate roots, adapted to survival in waterlogged conditions and are highly susceptible to damage by stock trampling. MfE SMF (2005) recommended the use of kikuyu (*Cenchrus clandestinus*) as a highly effective nutrient 'stripper'. Whilst this species is highly effective at removing nutrients, it is also invasive, especially in periodically dry areas, whereas a wide range of native plants would perform a similar nutrient removal function (Tanner 1996). A range of nutrient mitigation techniques are currently being researched by NIWA and AgResearch.

3.3 In-lake nutrient dynamics

The fate of nutrients once they enter the lake is complex, depending on a wide range of lake factors including the size, depth, degree of exposure, presence of vegetation, current lake condition etc. Basically, nutrients are either taken up by plants (either macrophytes or planktonic algae) or deposited in sediment. When aquatic plants/algae die organic material containing nutrients is also deposited into bottom sediments. Once deposited in sediments, these nutrients are usually of limited availability to plants, especially planktonic algae.

In deeper lakes, thermal partitioning of upper (epilimnion) and lower waters (hypolimnion) commonly occur during summer (and winter) effectively separating these bodies of water until temperatures equalise during autumn (and spring). Nutrient enrichment of such lakes may result in build-up of organic material in bottom waters causing deoxygenation through microbial respiration. Such benthic anoxia can lead to release of P and N as forms readily available to plants and once mixing of epi- and hypolimnion occur, then nuisance algal blooms may result.

Shallow lakes are likely to be well mixed by wind-induced wave action and therefore less likely to experience benthic anoxia. In shallow lakes, two different stable states can exist under the same nutrient inputs. These are a clear-water state dominated by submerged vegetation or a turbid-water state dominated by planktonic algae. The more nutrient enrichment the lake receives the more likely the lake will 'flip' to a turbid state. Switches between these states have been well documented in Lake Omapere, and a number of shallow Northland lakes are currently devegetated.

The ratio of total N to total P (TN:TP) provides information on the utilisation of the dissolved nutrients in the lake by algae. Ratios >17:1 are indicative of phosphorus concentrations that are potentially growth limiting nutrient to algae. Conversely ratios <10:1 indicate that nitrogen is a potential growth limiting nutrient to algae. It is not uncommon for lakes to switch between phosphorus and nitrogen as the potential growth limiting nutrient during the course of a year. It is important to determine if the lake is either N- or P- limited, or even co-limited by both nutrients and this would guide lake nutrient management. The best way to determine whether a lake is nutrient limited is by undertaking N and P enrichment experiments and observing the greatest phytoplankton response to identify the limiting nutrient. (Pridmore 1987). NIWA has been contracted in April 2014 by NRC to carry out these enrichment experiments for 26 Northland lakes (Max Gibbs, NIWA pers. comm.).

pH is also an important factor in the shallow margins of lakes. Inshore effects can stimulate the growth of different cyanobacteria species, with several encrusting species such as *Scytonema coactile, S. mirabile* and *Schizothrix friesii* present in the marginal shallows of the Kai-Iwi lakes (Champion et al. 1993). As algae grow, they consume CO_2 from the water causing the pH to rise from around mid-7s to a maximum of around 10.5. Above a threshold of pH 9.2, dissolved reactive P may be desorbed from iron oxides in the sediment. The DRP is released into the water column where it can sustain further growth of the cyanobacteria bloom. Another effect of the increase in pH is the conversion of ammonium nitrogen (NH_4-N) to ammonia (NH_3), which is highly toxic and is probably the cause of fish kills around the edge of a lake during a cyanobacteria bloom.

3.4 Management options

Gibbs and Champion (2013) provided recommendations for the management of Lakes Wiritoa and Pauri near Whanganui (see Appendix A). The topics could provide a basis for management strategies to improve water quality, with the recommendation that they were investigated further for adoption in full or in part.

While these actions are specific to those lakes, and some are not relevant to some Northland lakes, it is envisaged that a similar overview of water quality issues and management be made for the twelve ‘Outstanding’ lakes of Northland, or other Northland lakes where management is desired.

4. Kai-Iwi lakes implementation strategy

Champion and de Winton (2012) recommend that individual management plans should be developed for each high value lake outlining:

- Tenure of lake and catchment.
- International/national/regional significance of the lake.
- Lake classification.
- Ecological Value Score and important components of this.
- Current threats and pressures.
- Agencies and individuals involved in management.

Additionally, a communications strategy highlighting the significance, values and threats of these lakes, whilst raising their political and public profile is strongly recommended.

The three lakes situated within the Taharoa Domain, namely Lakes Waikare, Taharoa and Kai-Iwi have been managed under the Taharoa Domain Reserve Management Plan prepared in accordance with the requirements of the Reserves Act 1977 by DJ Scott Associates Ltd. (2002). This plan was prepared for Kaipara District Council (TDC) and is overseen by the Domain Governance Committee (Kaipara District Council, Te Kuihi and Te Roroa). The plan is currently under review, however in the interim this is still operational.

The plan covers five aims, the one most pertinent to this lakes management strategy is Aim 3 – Environmental *"To protect and enhance the natural environment of the Domain for the benefit of all people".*

Key principles of this aim are to:

- Balance between protection and utilisation.
- Managing the environmental quality of the catchment and, in particular, water quality.
- Pine forestry and vegetation management / enhancement.
- Management of the Domain within catchment context.
- Integrated management of habitat and species.
- Use of monitoring as a key environmental management tool.

Objectives are:

- To recognise through appropriate land use strategies the sensitivity, natural values and functions of the Domain and the lake systems in order to ensure the sustainable use of the reserve.
- To promote and monitor investigations into the ecology, hydrology and wildlife values of the lakes.

- To integrate the management of the Domain with adjacent land.

Stated policies are:

- To establish environmental buffers between sensitive areas and those subject to human activity.
- To establish a long term vegetation management programme.
- To identify and remedy non-sustainable activities.
- To implement monitoring programmes.
- To promote changes to regulatory systems to ensure integrated management of the catchment.
- To develop infrastructure which is aesthetically pleasing.
- To restore, over time, the indigenous ecology of Lake Kai Iwi.

and finally

Outcomes sought are:

- Selective removal of exotic vegetation from identified areas including lakes.
- Revegetation of identified areas with appropriate native species.
- Removal of stock and feral faunal species from the Domain.
- Monitoring programmes established.
- State of the Environment report produced annually.

Other affected agencies and individuals involved with management of the Kai-Iwi lakes are:

- NRC who monitor ecological status, surveillance for pest species and water quality – also lead agency of Waiora Northland.
- The independent Taharoa Domain Lakes Group (supervised by KDC and NRC) to develop a planned programme of projects.
- Northland Fish and Game who manage the trout fishery in these lakes.
- Taharoa Domain Kai Iwi Lakes Water Ski Club who oversee ski activities in the lakes.
- Adjacent landowners who farm land that potentially impact the water quality of the lakes.

The annual Northland Lakes Ecological Status report (most recently Wells and Champion 2013b) build on a baseline report (Champion et al. 2005) that is updated annually. The former report presents a summary of information gathered on Northland lakes including vegetation descriptions (submerged and wetland), the LakeSPI method of assessing submerged plant indicators for lake ecological condition, records of water birds, fish and macroinvertebrates and surveillance for plant pests. Ecological and lake condition changes were identified by comparison with previous surveys and major threats to the current lake condition are identified. Finally, management recommendations are presented for each lake. This information is key for the NRC Lakes Strategy as it is essential for managers to rapidly respond to new incursions or other identified threats and monitor responses to past management initiatives.

Wells and Champion (2013) report all three Kai-Iwi lakes are ranked as 'Outstanding', with very good current water quality (Oligotrophic in Lakes Waikare and Taharoa and Mesotrophic in Lake Kai-Iwi), primarily indigenous aquatic plants including several nationally endangered plants, with the deepest growing submerged vegetation in any North Island lake occurring in Lake Taharoa and a range of endangered fauna. Pest species include gambusia and humped bladderwort (Utricularia gibba), with other threats identified as potential nutrient enrichment from farming activities in the catchment, impacts from pine harvesting and nitrogen addition resulting from the invasion of Sydney golden wattle. Surveillance for new aquatic weeds is undertaken annually.

Other reports on the Kai-Iwi lakes commissioned or produced over the past decade include Kai-Iwi aquatic weed strategy (Wells and Bodmin 2008), Kai-Iwi Lakes Catchment Description - Draft (Grey 2013), Kai-Iwi hydrogeology: summary of field investigation, drilling and hydraulic testing (Golder Associates 2013) and Kai-Iwi Lakes: Pest Management Action Plan - Draft (NRC 2014).

4.1 Threatened species

The Kai-Iwi lakes support a number of nationally threatened or 'At-Risk' species (de Lange et al. 2013; Robertson et al. 2013; Allibone et al. 2010; Hitchmough et al. 2007). These include:

Nationally threatened

- Critical – *Centrolepis strigosa.*
- Endangered – *Trithuria inconspicua*, Australasian bittern.
- Vulnerable – *Drosera pygmaea*, dabchick.

At-Risk

- Declining – North Island fernbird, longfin eel, *Echyridella menziesii*, koura.
- Relictural – marsh crake, spotless crake.
- Naturally uncommon – black shag, little shag, little black shag, dune lakes galaxias, freshwater crab.

The presence of these species is reported during annual field trips but no lake-wide census of threatened biota populations is made to enable meaningful assessment of their status. It appears that some of the biggest populations of some species occur in one or more of the Kai-Iwi lakes (e.g., *T. inconspicua* – Champion et al. 1993, *C. strigosa* – authors pers. obs.) whereas the dune lakes galaxias is restricted to these lakes. A number of conservation activities, such as establishment of populations in pest fish-free lakes and including this species in Kai-Iwi lakes management plans have been recommended for dune lake galaxias in the New Zealand non-migratory galaxiid fishes recovery plan 2003-13 (Allibone and

Barrier 2004). Translocation of dune lake galaxias from Lake Waikare to Lake Riu (Waipoua) has occurred, along with community engagement in conservation of these fish by DOC. Further genetic analysis of dune lakes galaxias, dwarf inanga and other lake-locked populations of inanga (e.g., fish from Lake Ngatu) is planned (Michael Pingram, DOC, pers. comm.).

A census of all Nationally Endangered species and At-Risk species primarily restricted to Northland (sensu Townsend et al. 2004) is advocated for each lake. These should be undertaken every five years, with conservation measures included in individual lake management plans.

4.2 Biosecurity

The biosecurity component of this lakes implementation strategy is well advanced. Wells and Bodmin (2008) outline public awareness and surveillance activities currently in operation, but also provide information of weed exclusion cordons and a prescriptive range of incursion response tools and response readiness actions. NRC (2014) also include an immediate action plan involving inspection of adjacent properties for pest species, terrestrial plant and animal pests, especially those that may directly or indirectly affect the lakes (e.g., Sydney golden wattle). A long-term study on the regeneration of wattles at the Kai-Iwi lakes is underway that will include evaluation of leaf litter removal (Ashlee Lawrence, Biosecurity Officer, NRC, pers. comm.). Awareness of biosecurity issues is currently targeting landowners but could be expanded to groups such as duck hunters, eel fishermen and recreational lake users.

4.3 Water quality

A number of previous investigations have relevance to the identification of water and nutrient budgets, potential threats to water quality and mitigation of these. Grey (2013) summarises previous work on the lakes including water quality data observing a deterioration in water quality in Lake Kai-Iwi moving from an oligotrophic to mesotrophic state, with a deteriorating trend for algal biomass also detected for Lake Taharoa over the last 10 years. This report also describes potential groundwater flows in the lakes and measurement of lake height. Golder Associates (2013) provide a conceptual model for the movement of groundwater into and away from Lake Kai-Iwi, providing evidence of groundwater flow from pasture catchments to the south west of the lake.

The following recommendations are made for future management consideration:

Catchment

- Investigate the use of ground-penetrating radar or other methods to provide a much greater range of continuous, high-resolution records to chart the depth to water tables in sandy soils in the lakes catchments.
- Investigate ground water nutrient and dissolved oxygen content.
- Identify the role of wattles in fixing N using isotopic methods and compare this with other N sources to the lakes.
- Ensure wattle control undertaken as part of the biosecurity plan involves removal of wattle leaf litter.

- Evaluate the catchment management recommendations of Gibbs and Champion (2013) and apply where relevant to the Kai-Iwi lakes.

In-lake

- Regularly monitor lake height in all three lakes and attempt to estimate a water budget.
- Undertake an accurate bathymetry map for each lake, also assessing sediment hardness, macrophyte distribution and biovolume using side-scan sonar (ciBioBase 2014). There are limitations for assessment of low-growing vegetation in deep lakes, where plant beds need to be >5% the height of the water column (which may be an issue in Lake Taharoa).
- Evaluate the in-lake management recommendations of Gibbs and Champion (2013) and apply where relevant to the Kai-Iwi lakes.

Where ongoing land use is deemed incompatible with the management aims for these outstanding regional water bodies, then intensive remediation, such as planting of nutrient-stripping wetlands or even strategic purchase of land where no other mitigation can prevent continuing lake decline is suggested.

5. Acknowledgements

I would like to thank Envirolink (administered by Ministry of Business, Innovation and Employment - Science and Innovation) for funding this work.

Many thanks to NRC staff who attended various meetings scoping this work and especially Lisa Forester, Gail Townsend, Emma Simpson, Susie Osbaldiston, John Ballinger, Bruce Griffin, Ben Tait and Andrew MacDonald for providing a wide range of information relating to the lakes and useful discussions throughout the project. Lisa, Susie, Don McKenzie and Ashlee Lawrence reviewed draft versions of the report and helped improve various parts of this.

Michael Pingram of DOC Hamilton provided useful discussion on the management of dune lake galaxias.

Thanks also to NIWA staff especially Max Gibbs, whose wealth of knowledge relating to ground water and nutrient dynamics in lakes provided much of the information presented in section 3 and 4, also Sandy Elliott for useful discussion on catchment nutrient modelling, Rohan Wells for continued discussions on lake management requirements and Mary de Winton who kindly reviewed this report and co-authored the Part I of the Northland lake strategy.

6. References

Allibone, R., Barrier, R. (2004) New Zealand non-migratory galaxiid fishes recovery plan, 2003-13. *DOC Threatened Species Recovery Plan 53.* http://www.doc.govt.nz/Documents/science-and-technical/TSRP53.pdf 45.

Allibone, R., David, B., Hitchmough, R., Jellyman, D., Ling, N., Ravenscroft, P., Waters, J. (2010) Conservation status of New Zealand freshwater fish, 2009. *New Zealand Journal of Marine and Freshwater Research,* 44: 271-287.

Champion, P.D., Clayton, J.S., de Winton, M.D. (1993) Study on *Hydatella inconspicua* seed production, germination and maintenance of habitat in the Northland dune Lakes. *NIWA Consultancy Report* DOC001, Hamilton: 41.

Champion, P.D., Wells, R.D.S., Matheson, F.E., de Winton, M.D. (2005) Northland Lakes Assessment. *NIWA Client Report* HAM2005-113: 267.

Champion, P.D., de Winton, M.D. (2012) Northland Lake Strategy. *NIWA Consultancy Report* HAM2012-121: 42.

ciBioBase (2014) Lake Contour and Vegetation Mapping Made Easy with CI BioBase http://www.cibiobase.com/downloads/docs/ciBioBaseInformation.pdf

Collier, K.J. (1996) Potential impacts of plantation forestry on dune lakes in Northland, with interim guidelines for riparian management. *NIWA Client Report to Department of Conservation* DOC60204, Hamilton: 36.

Crowther, T.W., Maynard, D.S., Leff, J.W., Oldfield, E.E., McCulley, R.L., Fierer, N., Bradford, M.A. (2014) Predicting the responsiveness of soil biodiversity to deforestation: a cross-biome study. *Global Change Biology*. doi: 10.1111/gcb.12565. 12 p.

de Lange, P.J., Norton, D.A., Courtney, S.P., Heenan, P.B., Barkla, J.W., Cameron, E.K., Hitchmough, R., Townsend, A.J. (2009) Threatened and uncommon plants of New Zealand (2008 revision). *New Zealand Journal of Botany,* 47: 61-96.

de Lange, P.J., Rolfe, J.R., Champion, P.D., Courtney, S.P., Heenan, P.B., Barkla, J.W., Cameron, E.K., Norton, D.A., Hitchmough, R.A. (2013) Conservation status of New Zealand vascular plants, 2012. *New Zealand Threat Classification Series* 3. Department of Conservation, Wellington: 70.

Doolittle, J.A., Jenkinson, B., Hopkins, D., Ulmer, M., Tu, W. (2006) Hydropedological investigations with ground-penetrating radar (GPR): Estimating water-table depths and local ground-water flow pattern in areas of coarse-textured soils. *Geoderma,* 131: 317-329.

D.J. Scott Associates Limited (2002) *Reserve Management Plan: Taharoa Domain.* http://www.kaipara.govt.nz/site/kaiparadistrictcouncil/files/pdf/A-Z%20Documents/675%20-%20TD%20Reserve%20Management%20Plan%20Final%2009-02-2002.pdf:27.

Gibbs, M.M., Champion, P.D. (2013) Opportunities to address water quality issues in Lakes Wiritoa and Pauri. *NIWA Envirolink Report* 1196. http://www.envirolink.govt.nz/PageFiles/1196/1283-HZLC96%20Opportunities%20to%20address%20water%20quality%20issues%20in%20Lakes%20Wiritoa%20and%20Pauri.pdf 64.

Golder Associates (2013) Kai Iwi hydrogeology: summary of field investigation, drilling and hydraulic testing. *Client Report* No. 1278610982-003-R.

Gray, T. (2013) Kai iwi lakes catchment description. *Unpublished internal report prepared for Northland Regional Council by TEC Services*, Northland: 59.

Hitchmough, R., Bull, L., Cromarty, P. (compilers) (2007) New Zealand Threat Classification System lists 2005. Wellington, Department of Conservation: 194.

Marchante, E., Kjøller, A., Struwe, S., Freitas, H. (2008) Soil recovery after removal of the N_2-fixing invasive *Acacia longifolia*: consequences for ecosystem restoration. *Biological Invasions* doi: 10.1007/s10530-008-9295-1: 11.

Ministry for the Environment Sustainable Management Fund (MfE SMF) (2005) *Guidelines for pastoral management in the catchment of dune lakes in Northland.* MfE: 37.

Moreau, M., White, P.A., Lovett, A., Rawlinson, Z. (2013) State of hydrogeological knowledge and identification of information gaps for water management plan, Lake Ngatu, Northland. *GNS Science Consultancy Report,* 2013/188: 62.

Moreau, M., Nokes, C., Cameron, S., Hadfield, J., Gusyev, M., Tschritter, C., Daughney, C. (2014a) Capture zone guidelines for New Zealand*, GNS Science Report* 2013/56. http://www.envirolink.govt.nz/PageFiles/31/R6-2%20Capture%20zone%20guidelines%20for%20New%20Zealand.pdf 52.

Moreau, M., Cameron, S., Daughney, C., Gusyev, M., Tschritter, C. (2014b) Envirolink Tools Project – Capture Zone Delineation – Technical Report, *GNS Science Report* 2013/57.http://www.envirolink.govt.nz/PageFiles/31/R6-2%20Capture%20Zone%20Delineation%20-%20Technical%20Report.pdf:98.

Northland Regional Council (NRC) (2014) *Kai iwi Lakes Draft Pest Management Action Plan.* NRC, Whangarei: 17.

Pridmore, R.D. (1987) Phytoplankton response to changed nutrient concentrations. Chapter 18. In: W.N. Vant (Ed). Lake Manager's Handbook. *Water & Soil Miscellaneous Publication,* No. 103, NWSCO, Wellington: 183-194.

Rascher, K.G., Hellmann, C., Máguas, C., Werner, C. (2012) Community scale 15^N isoscapes: tracing the spatial impact of an exotic N_2-fixing invader*. Ecological Letters* doi: 10.1111/j.1461-0248.2012.01761.x: 8.

Robertson, H.A., Dowding, J.E., Elliott, G.P., Hitchmough, R.A., Miskelly, C.M., O'Donnell, C.F.J., Powlesland, R.G., Sagar, P.M., Scofield, R.P., Taylor, G.A. (2013) Conservation status of New Zealand birds, 2012. *New Zealand Threat Classification Series* 4*.* Department of Conservation, Wellington: 22.

Rolon, A.S., Rocha, O., Maltchik, L. (2011) Does pine occurrence influence the macrophyte assemblage in Southern Brazil ponds? *Hydrobiologia,* 675: 157-165.

Rowe, D.K. (2014) Biosecurity status of non-native fish species in Northland. *NIWA Consultancy Report* HAM2014-008: 26.

Rowe, D.K., Wilding, T. (2012) Risk assessment model for the introduction of non-native freshwater fish into New Zealand. *Journal of Applied Ichthyology,* 28: 582-589.

Tanner, C.C. (1996) Plants for constructed wetland treatment systems – a comparison of the growth and nutrient uptake of eight emergent species. *Ecological Engineering,* 7: 59-83.

Timms, B.V. (1982) Coastal dune waterbodies of north-eastern New South Wales. *Australian Journal of Marine and Freshwater Research,* 33: 203-222.

Townsend, A.J., de Lange, P.J., Norton, D.A., Molloy, J., Miskelly, C., Duffy, C. (2008) The New Zealand Threat Classification System Manual. Wellington, Department of Conservation: 30.

Wells, R.D.S., Bodmin, K.A. (2008) Kai iwi lakes Aquatic Weed Strategy. *NIWA Consultancy Report* HAM2008-180: 30.

Wells, R.D.S., Champion, P.D. (2013a) Northland Lakes - Annual Report 2013. *NIWA Consultancy Report* HAM2013-077: 61.

Wells, R.D.S., Champion, P.D. (2013b) Northland Lakes Ecological Status. *NIWA Consultancy Report* HAM2013-088: 294.

Appendix A Recommendations for the management of Lakes Wiritoa and Pauri

The following recommendations were made by Gibbs and Champion (2013):

Catchment

1. *Farm management plans (FMP) should be developed to reduce nutrient discharge to land. They should also cover land disposal by irrigation or infiltration near the lakes and especially between the two lakes. Whey should not be used on the land near or between the lakes.*

2. *While there are presently no dairy farms in the catchments of these lakes, any new conversions should be subject to rules and FMPs.*

3. *These FMPs should include plans to minimise the use of fertiliser near the lakes or the stream channels draining into these lakes.*

4. *The FMPs should include plans for sediment reduction through best farming practices, including using non-tillage versus tillage options where appropriate.*

5. *The small embayments or expansions of the stream channel width at the mouths of stream inflows (both permanent and ephemeral) could be used as sediment traps to reduce or prevent sediment entering the lakes during rainfall events.*

6. *Stock exclusion fences should be maintained.*

7. *Riparian buffer zone plantings should be maintained and enhanced.*

8. *The connecting stream running between the two lakes and the outlet stream from Lake Wiritoa should be managed to have one-way flow only from Lake Pauri into Lake Wiritoa.*

9. *The connecting stream running between the two lakes needs to be shaded with evergreen native trees which will reduce weed and grass growth in the water and on the stream banks. This will also reduce the incidence of frosts cooling the stream water so that it plunges as a density current to the bottom of Lake Wiritoa.*

10. *The stormwater from the prison complex should not be discharged into the connecting stream where the nutrients will have an effect on these lakes. The stormwater pipes should be re-aligned along the side of the road to the outlet stream to discharge downstream from Lake Wiritoa.*

11. *Domestic septic tanks and disposal fields (including the camp sites) should be inspected to determine whether they are a problem, or not. As a general rule domestic septic tanks should be inspected at least once every three years and regularly maintained. Replacement or new septic tank disposal systems should be multiple chamber systems with a denitrification stage before discharge to subsurface dripper irrigation fields.*

12. *The direction of flow of infiltrating effluent water from the prison wastewater treatment plant should be determined and action taken to divert the direction of flow away from the lakes should it be found to be moving towards the lakes.*

13. *Where practical, deciduous trees e.g., willows and other broad leaf, should be removed close to the lake to reduce leaf drop into the lake as a carbon source for oxygen depletion.*

14. *A windbreak of Casuarina trees should be planted across the western end of Lake Pauri. This will reduce exposure to prevailing winds that are thought to play a role in its poorer water quality. However, as the lake is used by sailing schools and others for yachting, an investigation of internal lake currents is needed first and consultation is recommended.*

15. *The outflow from Lake Pauri could be diverted directly to the outflow stream from Lake Wiritoa to reduce the nutrient load on that lake.*

In lake management strategies

In lake management strategies require more data (preferably a years' worth) to enable informed decisions about what could improve water quality and what would not. Based on the available data, potential strategies that could be tested include:

- *Aeration for preventing thermal stratification and thus bottom water anoxia with coupled nutrient release in summer in both lakes.*
- *Engineered structures could be placed on the bed of Lake Pauri to disrupt any lake currents or internal waves that resuspend sediment and release nutrients into the water column.*
- *The use of phosphorus-inactivation agents to prevent dissolved reactive phosphorus release from the lake beds in summer.*
- *The use of a flocculent to precipitate cyanobacteria from the water column in spring before they bloom in summer or as a "knock-down" action to allow the bathing beaches to re-open sooner after a bloom has occurred.*

Macrophyte weed beds and marginal plants

Although they can be a nuisance obstructing lake access for boats and bathers, the submerged macrophytes play an important role in maintaining the relatively high level of water quality in Lake Wiritoa. Their collapse would result in poorer water quality.

- *It is recommended that grass carp are not released in either lake. While they may be capable of reducing the macrophyte biomass, they are indiscriminate feeders and will eventually destroy all macrophytes (native and exotic) turning the lakes from macrophyte dominated, clear-water lakes to algal dominated, turbid lakes.*

The data available indicates that both lakes are at or near "tipping points" between these two states.

- *The lake access points should be managed, by clearing by using a harvester or selective herbicides to clear only enough of the macrophyte beds to provide that boat access or a clear length of bathing beach.*
- *The riparian buffer zone plants block the seepage of nutrients in the ground water and prevent bank erosion by wind-waves and boat wakes. They should be protected and not sprayed to provide better lake views or new beach areas.*

Monitoring

Water quality monitoring programmes should be designed to assess the efficacy of restoration measures for adaptive management and to provide long-term SOE data to assess trends.

1. *A water quality monitoring programme should be established to provide the data required for informed management decisions. The sampling site for each lake should be the deepest water and should be marked with a permanent marker buoy. This monitoring is independent of the bathing beach monitoring programme although samples can be collected for both on the same day.*
2. *The water quality monitoring programmes should be in two parts:*
   - *<u>The first</u> as a long-term SOE monitoring programme collecting data at 2-monthly intervals over several years. Measurements should include total nitrogen, total phosphorus, water clarity (Secchi depth) and chlorophyll a as required for estimating Trophic Level Index (TLI).*
   - *<u>The second</u> is an investigative monitoring programme that is designed to provide short-term information to assess the efficacy of the remediation actions implemented and to identify when the management goal(s) have been met or exceeded. The data from this investigative monitoring programme should be sufficient to allow adaptive management of the remedial action. It should augment the SOE monitoring and should use the same sampling sites and methods plus additional measurements such as dissolved reactive phosphorus and dissolved inorganic nitrogen species. Samples can be collected at the same time as the SOE monitoring but should include more frequent sampling to allow more detailed assessment of changes in lake processes affected by the remediation measures.*
3. *Lake levels should be measured on every sampling visit. Staff gauges may need to be installed.*
4. *To obtain better data on thermal stratification (timing, response to wind stress events), thermistor chains could be installed in each lake at the deepest site with temperature loggers staring 1 m above the lake bed and then at 2 m intervals up to the near surface. These thermistor chains would be attached to the marker buoys used to locate the monitoring programme sampling sites. Dissolved oxygen probes could also be included on each thermistor chain at 1 m below the surface and 1 m above the lake bed and timed for synchronous*

logging with the thermistors, to establish the rate of sediment oxygen demand and the period of low oxygen which may result in nutrient release from the sediments.

The thermistor chains and dissolved oxygen loggers would be set to record data at 15-minute intervals and would be left in these lakes for a period of at least 12 months. The temperature and dissolved oxygen loggers would be down loaded at 6-monthly intervals and the data compiled in a data base with wind and rainfall records from the Whanganui Airport met station.

If possible, a water quality profiler measuring depth-referenced temperature, dissolved oxygen, conductivity and chlorophyll fluorescence should be used in each lake at one or more sites along the length of the main axis on every sampling visit.