Informing a Lake Weed Harvesting Strategy at Lake Horowhenua

January 2015

Horizons Report 2015/EXT/1416

Prepared for:

Dr Jon Roygard
Science Manager
Horizons Regional Council
Palmerston North

January 2015
Report No. 2015/EXT/1416
ISBN 978-1-927259-08-5

Prepared by:

National Institute of Water & Atmospheric Research Ltd
P O Box 11115
Hamilton 3251

Project: HRZ15201
Report No. HAM2015-001

Authors: Mary de Winton, Fleur Matheson, Aleki Taumoepeau

Phone no: +64 7 856 7026
Email: mary.dewinton@niwa.co.nz

CONTACT	**24 hr Freephone 0508 800 800**		**help@horizons.govt.nz**		**www.horizons.govt.nz**
SERVICE CENTRES	**Kairanga** Cnr Rongotea and Kairanga-Bunnythorpe Roads Palmerston North **Marton** Hammond Street **Taumarunui** 34 Maata Street	**REGIONAL HOUSES**	**Palmerston** North 11-15 Victoria Avenue **Wanganui** 181 Guyton Street	**DEPOTS**	**Levin** 11 Bruce Road **Taihape** Torere Road Ohotu **Woodville** 116 Vogel Street
POSTAL ADDRESS	Horizons Regional Council, Private Bag 11025, Manawatu Mail Centre, Palmerston North 4442				F 06 9522 929

Informing a weed harvesting strategy at Lake Horowhenua

Prepared for Horizons Regional Council

January 2015

Authors/Contributors:
Mary de Winton
Fleur Matheson
Aleki Taumoepeau

For any information regarding this report please contact:

Mary de Winton
Group Manager
Aquatic Plants
+64-7-856 1797
mary.dewinton@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 11115
Hamilton 3251

Phone +64 7 856 7026

NIWA Client Report No:	HAM2015-001
Report date:	January 2015
NIWA Project:	HRZ15201

Photo: Panorama of Lake Horowhenua and resident waterfowl (Tracey Burton, NIWA)

Contents

Tables

Figures

Reviewed by

Max Gibbs

Approved for release by

David Roper

Formatting checked by

A. Bartley

Executive summary

Horizons Regional Council commissioned NIWA to carry out comprehensive weed surveys of Lake Horowhenua to inform decisions on the use of weed harvesting as a management tool for restoration of the lake. Surveys were to determine the extent of weed beds on each occasion, estimate the biomass in the main weed beds and measure the nutrient content of the dominant weed species. Hydroacoustics/sonar surveys of the lake were made on three occasions in 2014: in summer (January); in winter (September); and in spring (November). Weed biomass was measured at 16 sites in spring and nutrient content measured in 20 samples from winter and spring collections.

This report presents calculated areas for dense weed beds, maps their distribution and briefly describes weed bed features. Harvestable biomass of weeds and potential nutrient removal by harvesting was calculated from estimated areas of dense weed bed and typical biomass, together with growth rates and harvesting efficiencies reported in the available literature.

Weed bed development measured by hydroacoustics was highest in spring with 118.09 ha of lake having a biovolume of ≥65%, followed by summer (48.87 ha ≥65% biovolume), with the lowest development in winter (0.69 ha ≥65% biovolume). Elodea (*Elodea canadensis*) was the dominant weed in summer and formed fringing weed beds around a clear central basin. Curled pondweed (*Potamogeton crispus*) expanded in winter to be the dominant weed in spring, when it formed large weed beds within the formerly clear central basin.

The spring biomass sampled at sites with ≥65% biovolume averaged 340 g wet weight m^{-2}. Using the area estimates above and this average biomass value we calculated a harvestable standing crop at the time of the surveys of 166.2 tonne wet weight in summer, 2.4 tonne in winter, and 401.5 tonne in spring. Based on average standing crop and weed nutrient content, 0.7 g N m^{-2} and 0.1 g P m^{-2} are incorporated in the weed biomass.

To factor in harvestable macrophyte biomass with growth over time, we reviewed the literature for plant growth rates of elodea, curled pondweed or similar species. Harvesting efficiency (% standing crop removed) was also reviewed. Assuming an 80% biomass reduction by harvesting and intermediate growth rates of 6.3% per day, post-harvest recovery to the pre-harvest biomass level was calculated to take 27 days. Further assuming that harvests are initiated at the seasonal standing crop calculated from each survey, and that 50 tonne of wet weed can be removed per day, a potential 600 tonne wet weight could be removed in summer and 1350 tonne wet weight removed in spring. This equates to a required 3 days harvesting in every 26 to 28 days in summer, and 9 days harvesting in every 29 to 33 days in spring. Based on these scenarios, up to 1.6 tonne of N and 0.25 tonne of P could be removed over summer, and 3.60 tonne of N and 0.55 tonne of P in spring.

We recommend harvesting begin in late October, and continue into summer to target the removal of curled pondweed biomass before seasonal senescence. Harvesting of fringing elodea beds should be more conservative, target shallower zones, and harvesting should cease in the event of any large unexplained reduction in vegetation development. Reserves of curled pondweed should be retained for propagule production. For instance, the retention of a central swath of weed bed across the exposed center of the lake would also provide a wave baffle in spring. A harvested corridor in front of the Arawhata Stream inflow and Hokio Stream outflow may also help entrain nutrient rich waters to the outflow. Another factor to be considered is amenity for rowing and yachting. As a precaution, we recommend harvesting and recovery potential by the weed beds be investigated experimentally before large scale harvesting is undertaken.

1 Introduction

Lake Horowhenua has experienced boom-bust cycles of nuisance submerged weed growth in the past that have interfered with lake utility and that may have deleterious impacts on lake condition and ecology (Gibbs 2011). To manage this problem, Horizons Regional Council (HRC) is investigating requirements for a weed harvester to strategically reduce nuisance weed growth and improve the condition of the lake.

HRC require information on the seasonal development of weed beds, their composition and distribution, as well as measurements of weed biomass and nutrient content, to better inform the assumptions for harvesting requirements and to optimise a harvesting strategy for Lake Horowhenua.

HRC commissioned NIWA to:

- Carry out a hydroacoustics/sonar survey and mapping of weed beds in Lake Horowhenua during winter and in spring 2014 to compare with a previous summer survey (Taumoepeau and de Winton 2014).
- Identify the area of dense weed (as high % biovolume calculated from hydroacoustics).
- Identify seasonal changes in weed bed development and composition.
- Sample and analyse standing crop (biomass, nutrient content) at a range of % biovolume levels in spring.
- Estimate standing crop of weed that is available for harvesting at different times of the year.
- Calculate potential nutrient removal by harvesting.

This report provides maps showing the distribution of dense weed beds as high % biovolume. A description of weed bed composition, features and seasonal development is given. Standing crop, potential growth and harvesting efficiency are considered to develop some harvesting scenarios and estimate the biomass available for harvesting over time. Finally some recommendations for harvesting operations are outlined.

2 Methodology

Hydroacoustic survey

Surveys were undertaken during three seasons (Table 1) to identify annual patterns of weed development. Global positioning system (GPS) referenced, hydroacoustic surveys of weed bed presence and development used a Lowrance™ HDS9 depth sounder/GPS/chart plotter. GPS referenced run lines were navigated at appropriate intervals (<50 m) to guide the boat and ensure as full a coverage of the lake as possible, within navigation and weather constraints. Stage height at the water level gauge is given for each survey to provide a height datum for weed depths and bathymetry (Table 1).

Table 1: Dates of seasonal surveys and average water level for the survey dates.

Season	Survey dates	Average water level
Summer	15th to 17th January 2014	1064.8 mm (range 1006 – 1083 mm)
Winter	2nd to 5th September 2014	1103.8 mm (range 1097-1113 mm)
Spring	17th to 21st November 2014	1063.4 mm (range 1013-1082 mm)

Digital data as position and sonar signal return (detecting vegetation and depth) were simultaneously logged along each run line using a transducer (LSS-2 HD) with a dual frequency of 200 and 455 kHz. Position was logged using the point 1 antenna.

Sonar settings (offset, sensitivity and greyline) were calibrated for each survey to optimise bed and vegetation detection. A ground truth of water depth was undertaken at >five sites by plumbing with a weighted disc on a measuring line, and sonar outputs were also checked against plant cover at >10 sites with contrasting plant presence via rake samples. General notes were made on the composition of the submerged vegetation at each ground truth site.

Raw data was processed using ciBioBase.com, an automated GIS processing engine for Lowrance™ HDS acoustic data which stores site data relative to GPS coordinates for mapping. ciBioBase is the property of Navico marine electronics company, USA. Collected data remains the property of Horizons Regional Council, but is stored and managed on the ciBioBase system and accessed by NIWA as a service subscriber. Raw sonar data files (.sl2) are stored on NIWA's project management system and will be provided upon request.

ciBioBase was used to generate spatial maps of vegetation % biovolume for each survey (Appendix A). % biovolume is defined as plant height divided by water depth multiplied by 100 for the collection of pings bound to each GPS location along a travelled path (https://www.cibiobase.com) and is indicative of the water column occupied by plant matter. The % biovolume maps were interpolated from merged sonar run lines at the resolution of a 5 m grid.

We delineated the main weed bed areas by using ciBioBase to create polygons (a closed shape defined by connected GPS coordinates) of areas of ≥65% vegetation biovolume. Polygons were corrected by ground truth observations where sources of 'noise' in sonar signal were noted during the surveys, which included:

- Unreliable signal return for vegetation presence in shallow depths <0.73 m depth.
- Algal cover in some shallow areas returning a signal that could be confused with weed presence.
- Interference noted in the surface water layer (shallow areas in winter and spring survey especially).
- Dense vegetation obscuring detection of the lake bed and resulting in ‘gaps’ in vegetation mapping (spring survey, Appendix A).

Additional checks were made by comparing run lines viewed in ciBioBase for the results of mapping (200 kHz frequency) with the signal return from the 455 kHz frequency which has less surface interference.

Metrics (area, depth range and average biovolume) for each polygon were exported from ciBioBase. Mapping graphics generated from ciBioBase also included spatial mapping of bathymetry (see summer example (Appendix C).

Biomass and nutrient sampling

Weed biomass was sampled to explore relationships between the biovolume measures and the amount of harvestable plant material. Biomass sampling was undertaken immediately after sonar survey in spring 2014.

Locations of contrasting biovolume measurement were selected from run line areas where biovolume (recorded approximately every second) appeared to be reasonably uniform. At each selected site, above-bed weed biomass was collected by scuba divers from within a circular quadrat of 0.355 m diameter, with three quadrats collected at each site. Water depth was recorded at the site. For each quadrat, total plant cover and maximum height were estimated by the diver, together with the species composition in the collected sample (% total). Biomass samples were labelled in sealed plastic bags and processed within 2 days of collection.

Each quadrat sample was drained and lightly blotted before weighing for wet weight. Samples were then dried to constant weight at 80˚C and re-weighed. If a species contributed more than an estimated 20% of the biomass, it was processed separately.

Results were calculated as g dry weight and g wet weight per m^2 lake bed, and also g per m^3 water column volume. Diver observations were also used to estimate Percent Volume Infested (PVI) as plant cover multiplied by plant height divided by depth. These parameters were explored for their relationship to biovolume %.

Biomass results were extrapolated to the survey results, to estimate standing crop of weed that is available for harvesting at different times of the year.

The nutrient content of 20 dried samples of weed was analysed for particulate nitrogen (N) and phosphorus (P) using an NH_4-N and DRP auto analysis method following grinding and acid digest. Results are expressed as % dry weight. Five samples comprised elodea (*Elodea canadensis*), collected in winter. The remaining 15 samples comprised mixed samples of curled pondweed (*Potamogeton crispus*) and elodea taken as quadrat biomass samples (15 quadrats from five sites) during spring. Calculations of harvestable nutrients in weed material were made on the same basis as weed biomass.

3 Results

3.1 Hydroacoustics survey

Lake conditions at the time of the three surveys allowed navigation coverage of between 77.6% and 84.47% of the known lake area (ciBioBase metric), with areas inaccessible by boat including the shallow margins and the inner part of the north-eastern bay (Appendix B).

Overall weed bed development was highest in spring with 118.09 ha of lake having a biovolume of ≥65%, followed by summer (48.87 ha), with the lowest development in winter (0.69 ha).

In summer (Figure 1) the greatest weed bed development was in the west of the lake (weed bed 2a and b). There was also an extensive bed in the northeast (weed bed 1 a-c) and fringing beds along the southern shore (weed bed 3 a-d). However, the deeper (over 1.2 m) central area of the lake was clear of major weed growth.

The dominant plant in all summer weed beds was elodea with curled pondweed as occasional plants only. Average bed covers of elodea were estimated at between 26 to 75%, and it was surface reaching within the southern edge of weed bed 3 (Figure 1). At several sites the canopy of the weed beds had been grazed by waterfowl.

By winter (Figure 2), only remnants of the summer weed bed 3 were detected with a biovolume ≥65%. However, development of small scattered weed colonies were detected in the central and northern part of the lake (see sites marked x, Figure 2), which had not had significant weed development in summer.

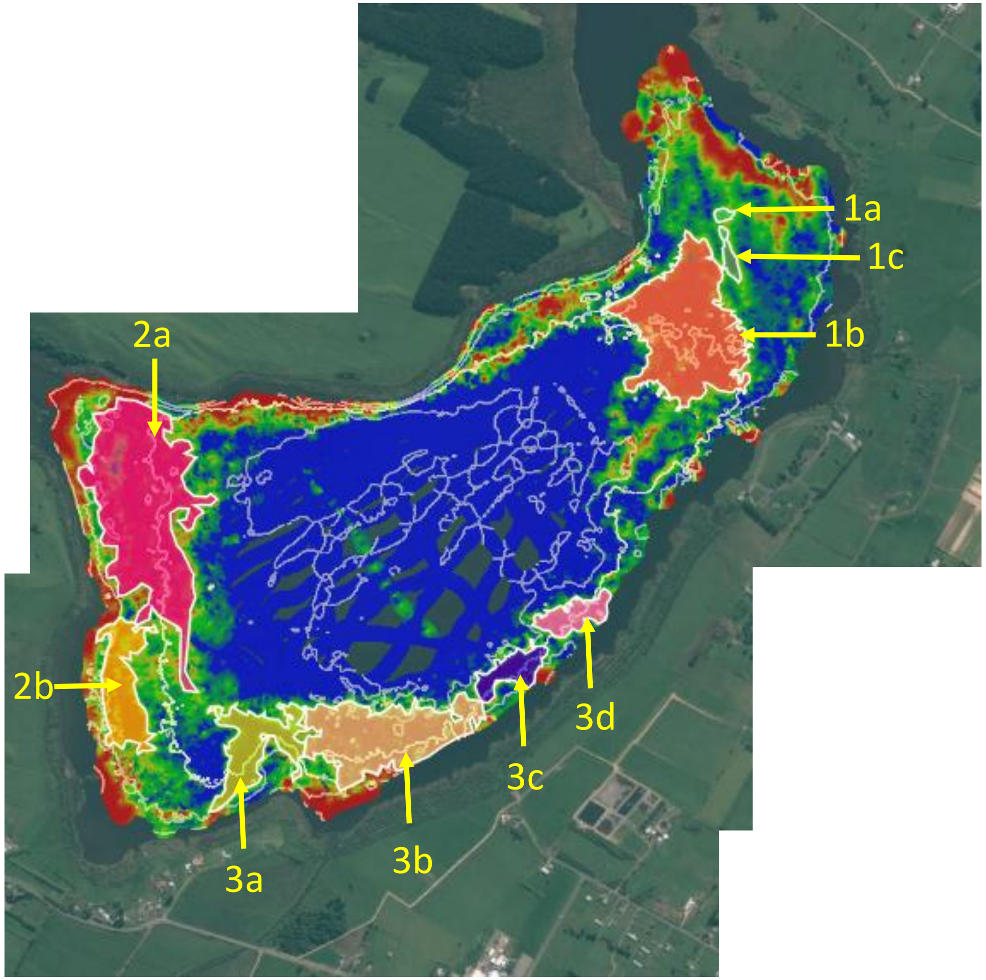
Curled pondweed was the dominant winter species and was widespread, especially in the central part of the lake where it grew up to 0.8 m tall (Figure 5). Elodea was also widely distributed and dominant in the northeast and along the southern shoreline, but was usually low growing at 0.1 to 0.15 m tall (Figure 5). No surface reaching weed beds were present.

In spring it was evident there had been a substantial increase in the height of vegetation, which contributed to high % biovolume measures over a substantial area of the lake (Figure 3). Of note is a continued development of a central weed bed (weed bed 4 a, b and c), which was not recorded in summer. High vegetation density in some areas of the lake meant that the top of the weed bed was interpreted as the lake bed by the ciBioBase processing algorithm, leading to gaps in the vegetation mapping (Appendix A) and erroneous bathymetry recorded at this time (not shown). These gaps are incorporated into the polygons of significant weed beds (Figure 3).

In spring curled pondweed was the dominant species in the central area (spring weed bed 4a and b, and 3c), but graduated to elodea dominance in the northwest (weed bed 2a). The pondweed was the taller of the species, growing up to 0.8 to 1 m tall within weed beds 4a and b, and 3c. Elodea was more dominant in the northeast (weed bed 1), but was low growing (<0.3 m tall). Elsewhere the species were often equally dominant or in mixed patches (Figure 6). Waterfowl grazing had widely reduced the height of the weed canopy to 0.8 m below the surface and approximately 100 black swan were present during the survey.

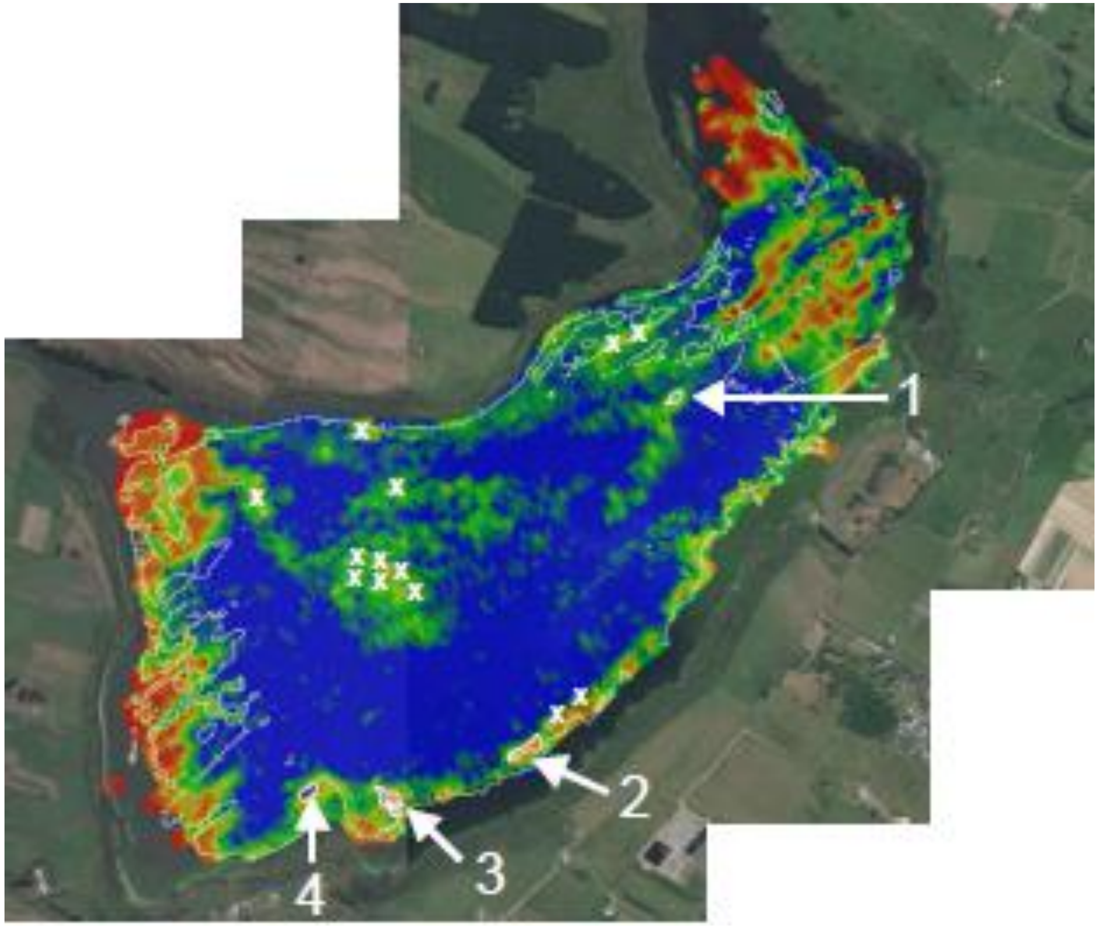
Although the weed egeria (*Egeria densa*) has been reported from the lake as an anecdotal but not confirmed sighting (Champion et al. 2002), it was not seen during any survey. Other, native, submerged plant species were local or rare and included *Nitella* sp. aff. *cristata*, *Ruppia polycarpa*, *Zannichellia palustris*, and *Stuckenia pectinata*.

Figure 1: Summary survey results and mapped weed bed polygons for areas ≥65% biovolume, with metrics for each area in a table. Weed bed polygons are outlined in white and filled with different colours for clarity.



Weed bed	Surface area (ha)	Average biovolume (%)	Minimum depth (m)	Maximum depth (m)
1a	0.18	67.32	0.90	1.04
1b	12.19	89.23	0.84	1.10
1c	0.46	71.85	0.90	1.04
2a	16.24	86.32	0.69	1.39
2b	4.07	81.99	0.76	1.07
3a	3.95	85.7	0.78	1.42
3b	8.47	89.72	0.71	1.52
3c	1.66	86.89	0.78	1.47
3d	1.65	85.68	0.74	1.37

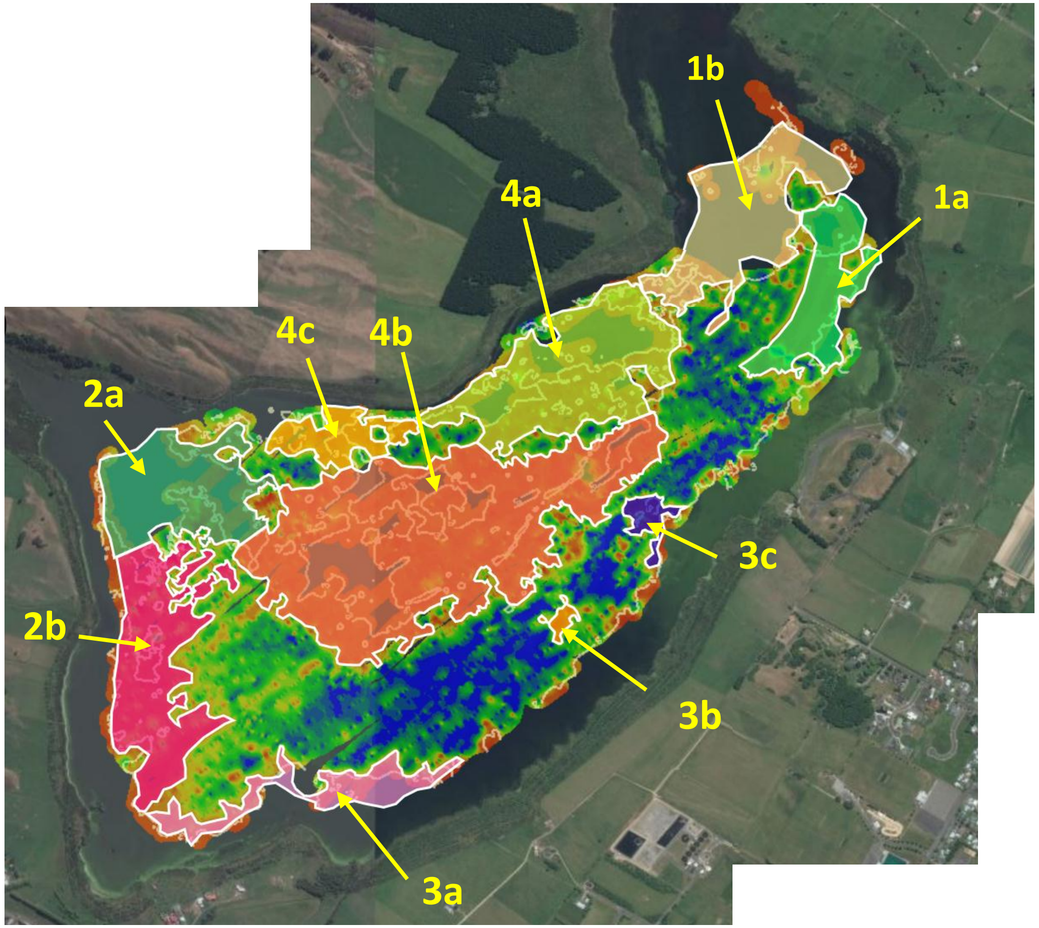
Figure 2: Winter survey results and mapped weed bed polygons for areas ≥65% biovolume, with metrics for each area in a table. Weed bed polygons are outlined in white and filled with different colours for clarity.



Weed bed	Surface area (ha)	Average biovolume (%)	Minimum depth (m)	Maximum depth (m)
1	0.08	76.79	0.99	1.03
2	0.2	75.26	0.99	1.25
3	0.13	73.73	0.90	1.18
4	0.28	70.3	0.96	1.20

White “x” indicate small isolated vegetation clumps ≥65 % biovolume.

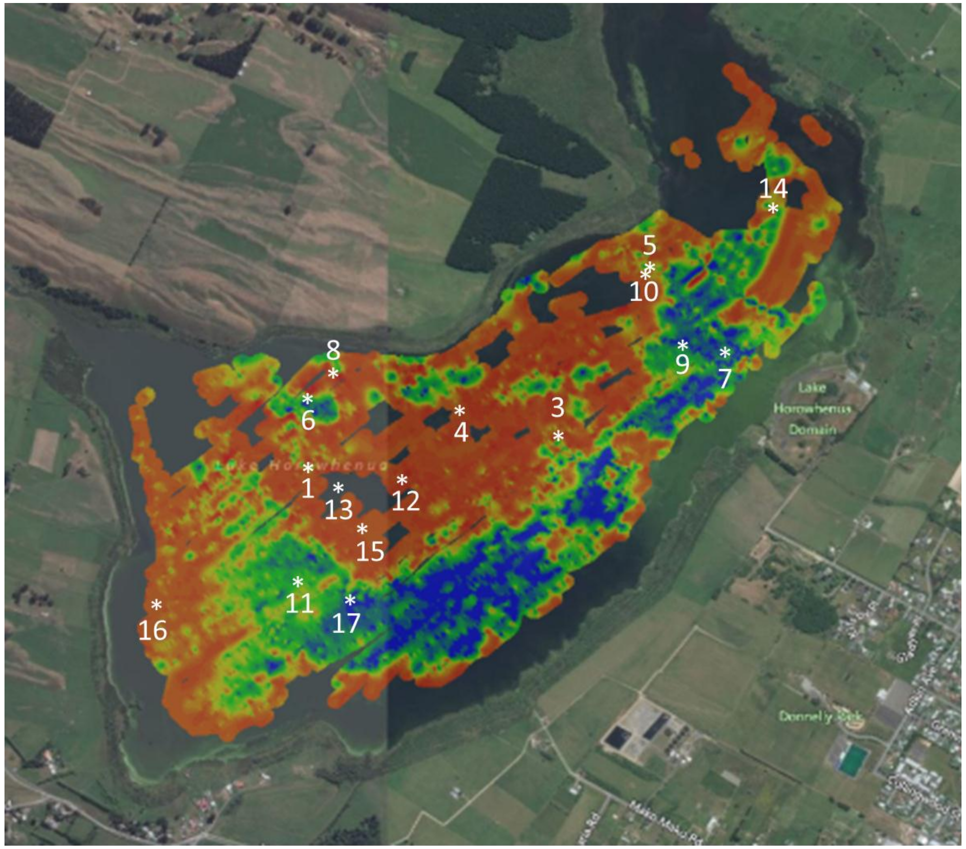
Figure 3: Spring survey results and mapped weed bed polygons for areas ≥65% biovolume, with metrics for each area in a table. Weed bed polygons are outlined in white and filled with different colours for clarity.



Weed bed	Surface area (ha)	Average biovolume (%)	Minimum depth (m)	Maximum depth (m)
1a	7.79	75.61	0.63	1.33
1b	13.28	74.18	0.52	1.22
2a	11.92	77.5	0.50	1.49
2b	14.19	74.06	0.65	1.38
3a	0.50	71.41	1.09	1.31
3b	1.39	77.44	0.62	1.70
3c	5.42	77.23	0.51	1.36
4a	4.11	79.11	0.48	1.73
4b	17.42	78.82	0.38	1.92
4c	42.07	79.99	0.62	2.15

NB. Minimum depths may be erroneous for polygons that incorporate data gaps.

Figure 4: **Locations for biomass sampling and categorisation of sites according to % biovolume derived from the spring survey, with table showing metrics derived from sonar (ciBioBase).**



Site	Biovolume (%)	Depth (m)	Plant height (m)
1	30	1.46	0.45
3	79	1.48	1.17
4	81	1.21	0.97
5	78	0.94	0.74
6	72	1.16	0.84
7	49	1.31	0.64
8	21	1.39	0.29
9	18	0.34	0.24
10	52	1.08	0.57
11	41	1.24	0.51
12	78	1.50	1.17
13	*	*	*
14	81.9	1.11	0.91
15	78.4	0.93	0.73
16	79	0.94	0.74
17	22.7	1.47	0.33

*Dense weed bed not differentiated by sonar.

Figure 5: **Typical winter heights for elodea (left) and curled pondweed (right).**

Figure 6: **Curled pondweed expanded in winter (top) and was a dominant component of summer weed beds (bottom).**

3.2 Biomass and nutrient sampling

Figure 4 shows the location of the 16 biomass sampling sites (site 2 was discarded as an erroneous navigation target). Also given are the sonar derived metrics for the sites as extracted from run lines in ciBioBase (Figure 4). Site 13 was targeted as one location where weed beds were so dense as to prevent sonar differentiation of the lake bed. This meant that weed height, depth and therefore biovolume could not be calculated.

There was a strong linear relationship between wet macrophyte weight and dry weight (dry weight = 0.0627 wet weight + 0.0199, n = 33, $R^2 = 0.9945$). Because of this, we preferentially used wet weight (as more relevant to harvested weed volumes). The dominant species (>80% sample) was curled pondweed in 24 samples and elodea in 8 samples, with no discernible differences between species in wet to dry weight ratio.

Biomass sampling was post hoc to the sonar survey, because processing was needed to obtain % biovolume values for sites. Navigation back to the selected sites was possible to within 2-15 m (based on target and actual recorded GPS position). We also acknowledge a 2-5 m accuracy in our current navigation capacity (point 1 antenna).

Four of the selected sites with biovolumes above 0% (range 18 to 49%) did not have weed present that could be sampled, however these sites were retained in subsequent analyses. Relationships between sampled parameters and % biovolume are shown in Figure 7. Overall, there was a weak relationship between % biovolume and average biomass in g m^{-2}, which improved only slightly when biomass was expressed as g m^{-3} (i.e., incorporating depth). A diver estimated PVI was also weakly related to % biovolume (Figure 7).

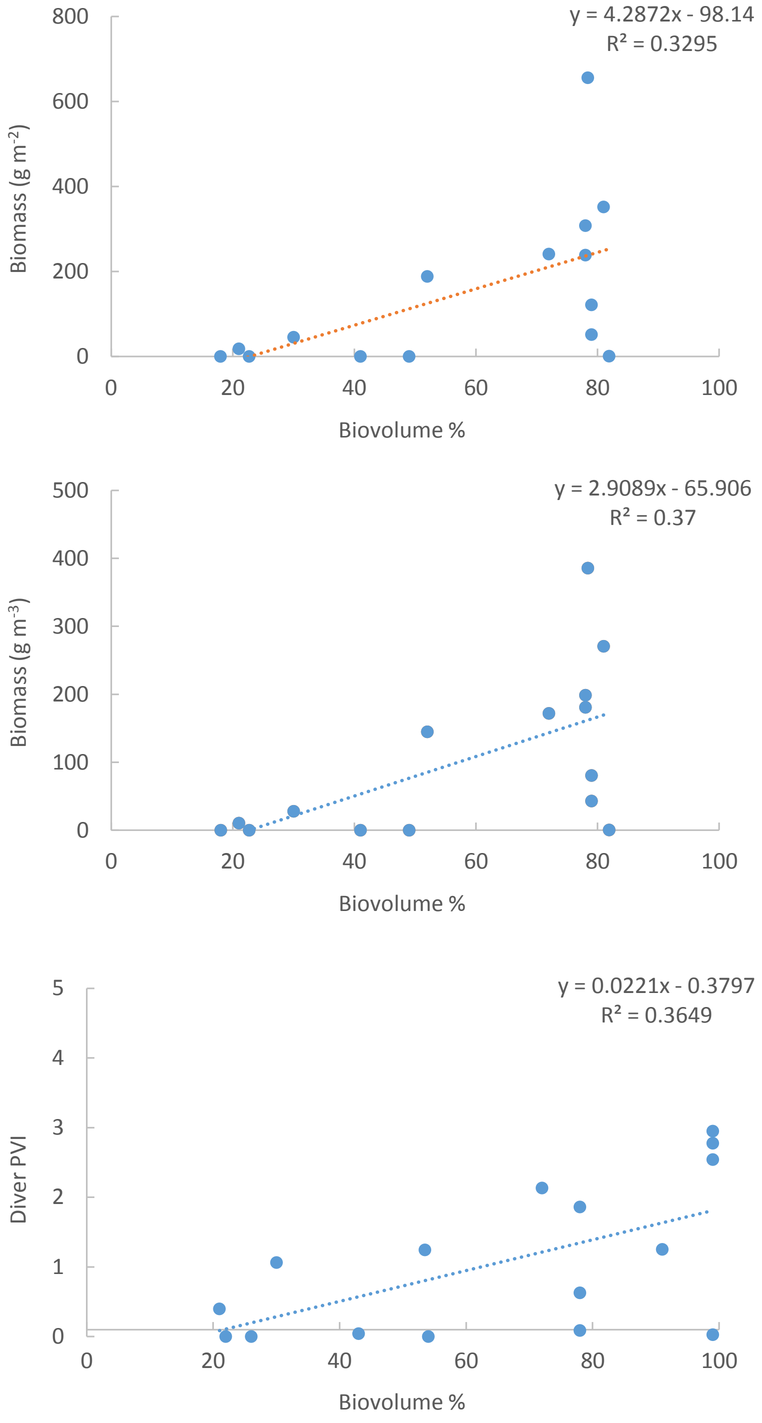


Figure 7: **Relationships between biovolume and biomass as g wet weight m^{-2} (top), g wet weight m^{-3} (middle) and diver PVI (bottom).**

The highest biomass (>300 g m^{-2} wet weight) were recorded in quadrats at sites 4, 5, 6, 10, 12, 13, and 15 (Figure 4). The biomass from quadrats at sites with ≥65% biovolume (excluding zero values) ranged from 44 to 1177 g m^{-2} wet weight, with an average of 340 g wet weight m^{-2}. Using the areas of weed bed ≥65% biovolume from each survey, and the average wet weight above, we estimate the standing crop of weed in Table 2.

Table 2: **Estimated standing crop in Lake Horowhenua on three occasions in 2014.**

Season	Area with ≥65% biovolume (ha)	Estimated standing crop (tonne)
Summer	48.87	166.2
Winter	0.69	2.4
Spring	118.09	401.5

Nutrient content of weed samples was similar for winter-collected elodea and spring-collected material Table 3. The overall range of nutrient content was 2.3-4.8% dry weight for N and 0.3-0.9% for P.

Table 3: **Nutrient content in weed samples collected from Lake Horowhenua (% dry weight ± 1 SE).**

Sample	Average N (% dry weight)	Average P (% dry weight)
Winter elodea in (n= 5)	3.9 (0.12)	0.5 (0.05)
Spring (n = 15)	3.8 (0.19)	0.7 (0.03)
All samples (n = 20)	3.9 (0.14)	0.6 (0.14)

4 Discussion

4.1 Macrophyte dynamics

Seasonal patterns in the development, distribution and composition of macrophytes were evident from the sonar survey results for Lake Horowhenua over 2014. We cannot confirm if the seasonal dynamics captured by our surveys are similar year to year. The only previous mapping of weed beds that we are aware of is in the 1970's (Figure 8), where a different spring and summer weed bed distribution of curled pondweed was evident, and a survey by NIWA in 2002 (Champion et al. 2002). NIWA's survey of 13 sites in winter 2002 (29/08/2002) showed curled pondweed to be the dominant species at all sites, at covers of 1 to 85%, with ≤1% cover by elodea at 4 sites only.

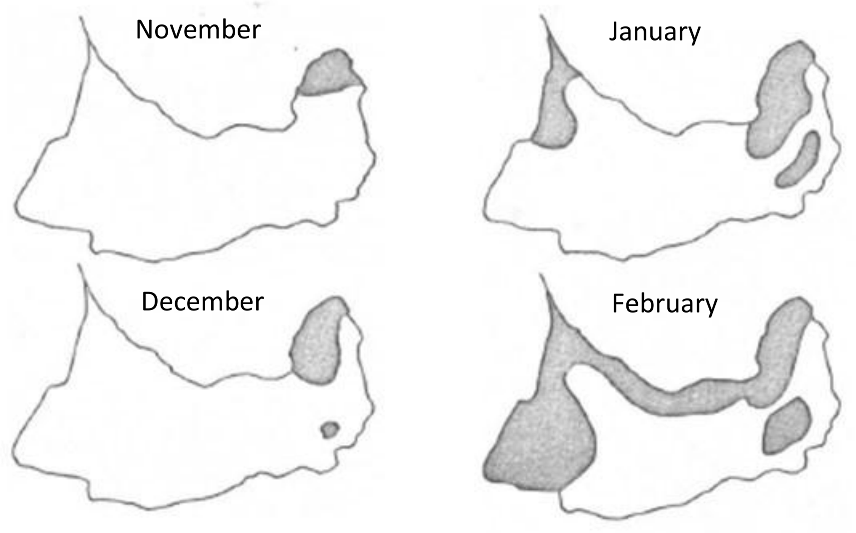


Figure 8: Time series of weed bed development in 1975/76, from Gilliland 1978.

In 2014 the change from only fringing weed beds in summer to the development of additional central vegetated beds in spring was a major change. This initial absence of vegetation in the lake centre was likely to be due to light limitation of plant growth in the deeper lake areas in summer, however, very small changes in water clarity in a uniformly shallow lake can lead to large changes in vegetation distribution. Macrophyte development was minimal in winter, with growths of low stature only.

Overall weed dominance changed from elodea in summer to curled pondweed in winter and spring. Elodea remained present throughout the year, dominating in the fringing beds to the northeast and southwest, although the plant height was much reduced in winter. In contrast, curled pondweed was a minor component earlier in the year but increased substantially in the central lake from winter to spring. Such seasonality is a characteristic of this species. A large number of turions (specialised vegetative propagules) were noted amongst the biomass samples of curled pondweed, and these propagules may be a major source of widespread plant recovery when growth conditions favour curled pondweed.

4.2 Biomass and nutrient calculations

Values for the spring biomass, at an overall average of 18.3 g dry weight m^{-2} (range 0.9 to 76.9 g dry weight m^{-2}), were at the lower end of 15 to 43 g dry weight m^{-2} values from the literature (Rogers and Breen 1980), that were used in previous harvesting calculation for the lake (Gibbs and Quinn 2012).

The nutrient content of weed on dry weight basis of 3.9% N and 0.6% P differed somewhat from suggested 3% N and 1.2% P reported from literature by Gibbs and Quinn (2012). Based on average standing crop values above, 0.7 g N m^{-2} and 0.1 g P m^{-2} was represented in the weed biomass (range 0.035 – 3.0 g N m^{-2} and 0.004 – 0.46 g P m^{-2}).

A relationship between biomass and % biovolume was explored for possible extrapolation of standing crop information to the whole lake, and towards informing a harvesting strategy. Other workers have determined significant relationships between vegetation biomass and hydroacoustic measures of plant height for different plant types (Duarte 1987), a horizontal measure of volume backscattering strength (Hohausová et al. 2008), cover, height and total echo strength (Haga et al. 2007), integrated echo intensity (Sabol et al. 2002) and measures of cover, height and depth (Maceina and Shireman 1980, Maceina et al. 1984). However, we could find no existing information on how the ciBioBase metric of % biovolume was likely to relate to biomass.

Our results (based on limited data) suggest only a weak relationship between biomass and % biovolume. Although accurate biomass values could not be predicted by % biovolume measures, % biovolume is still thought to be a valid measure relevant to weed harvesting as it indicates the occupation of the water column by plant tissue.

Elsewhere, reflectivity of the plant in terms of its hydroacoustic signal is suggested to be related to biomass, but also the gas content of tissues and possibly other structural characteristics that may be species specific (Hohausová et al. 2008). Also recognised is a threshold of higher biomass, beyond which no further increase of hydroacoustic reflection occurs (Hohausová et al. 2008, Haga et al. 2007). Equally, there will be a minimum aquatic plant biomass required for reliable hydroacoustic detection, which was 60 g m^{-2} wet weight for sea grasses (Sabol et al. 2002). Like our spring hydroacoustics survey, other investigators also found that very high weed bed density does not permit differentiation of the lake bed (Maceina and Shireman 1980).

The absence of vegetation at some of our selected sites with a % biovolume above 0% may reflect the patchy presence of weed in some lake areas, or differences in spatial resolution of vegetation between sonar (i.e., 20 degree transducer cone equals c. 0.36 m diameter area at a depth of 1 m), our biomass sampling approach (3 x 0.355 m diameter quadrats), and limits to the accuracy of boat navigation.

4.3 Harvesting scenarios

The standing crop that may be available for harvesting at any one time can be calculated from the areas that had ≥65% biovolume and the average biomass of 340 g wet weight m^{-2} at these sites Table 2. However, to calculate the net potential macrophyte crop available for harvest (i.e., recovery by biomass accrual over time), we also need to factor in plant growth rate. No growth rate information is available for plants growing under the conditions of Lake Horowhenua, however, values from the literature may be used for estimates.

Table 4 lists a range of Relative Growth Rate (RGR) values (g/g/day) for curled pondweed, elodea or similar species that are given in available literature. Poorer growth may be expected when water temperatures are low and/or water clarity is poor. Because of self-shading in dense beds (Pistori et al. 2004), it is also likely that growth rates after harvesting are higher than those in the pre-harvest weed beds. Literature values suggest low RGR is 0.02, high RGR is 0.13, and an intermediate RGR is c. 0.063 (Table 4).

Table 4: Range of Relative Growth Rates reported for weed species in published literature.

Species	RGR (g/g/day)	Reference
Curled pondweed	0.02-0.035	Yonghong Xie et al. 2011
Curled pondweed	0.039	Jingqing Gao et al. 2009
Curled pondweed	0.095	Hui Fu et al. 2012
Elodea canadensis	0.11 – 0.13	Cedergreen Forchhammer 1999
Elodea canadensis	0.066	James and Eaton 2006
Elodea canadensis	0.066-0.086	Riis et al. 2009
Egeria densa	0.063	Pistori et al. 2004

A review of available literature suggests 70 to 80% of standing crop can be removed by harvesting (Table 5). Assuming an 80% reduction in standing crop by harvesting, recovery to pre-harvest biomass in Lake Horowhenua would take 14 days at the highest RGR of 0.13, 27 days at an intermediate RGR of 0.063, and 82 days at the lowest reported RGR of 0.02.

Table 5: Reported harvesting efficiency (% removed relative to pre-harvest standing crop) from literature.

Harvesting efficiency	Reference
75%	Envirovision Corporation 2004.
70%	David and Greenfield 2004.
50 to 70% (30% too shallow or deep for harvester operation)	Engel 1990
76 to 79%	Serafy et al. 1994
77 to 80%	Madsen et al. 1988

We can estimate the potential harvestable biomass over a three month period in spring and summer based on four assumptions:

- 80% removal of standing crop is possible.
- Harvests are initiated at the seasonal standing crop given in Table 2.
- 50 tonne of weed material can be removed per day (EBOP et al. 2011).
- Weed bed recovers at an RGR of 0.063.

Figure 9 illustrates this harvesting scenario. Results suggest a required 3 days harvesting in every 26 to 28 days in summer, 9 days harvesting in every 29 to 33 days in spring. This equates to a potential 600 tonne wet weight removed in summer and 1350 tonne wet weight removed in spring. Note that no seasonal plant senescence in summer has been factored into these calculations, although such events have been noted for Lake Horowhenua.

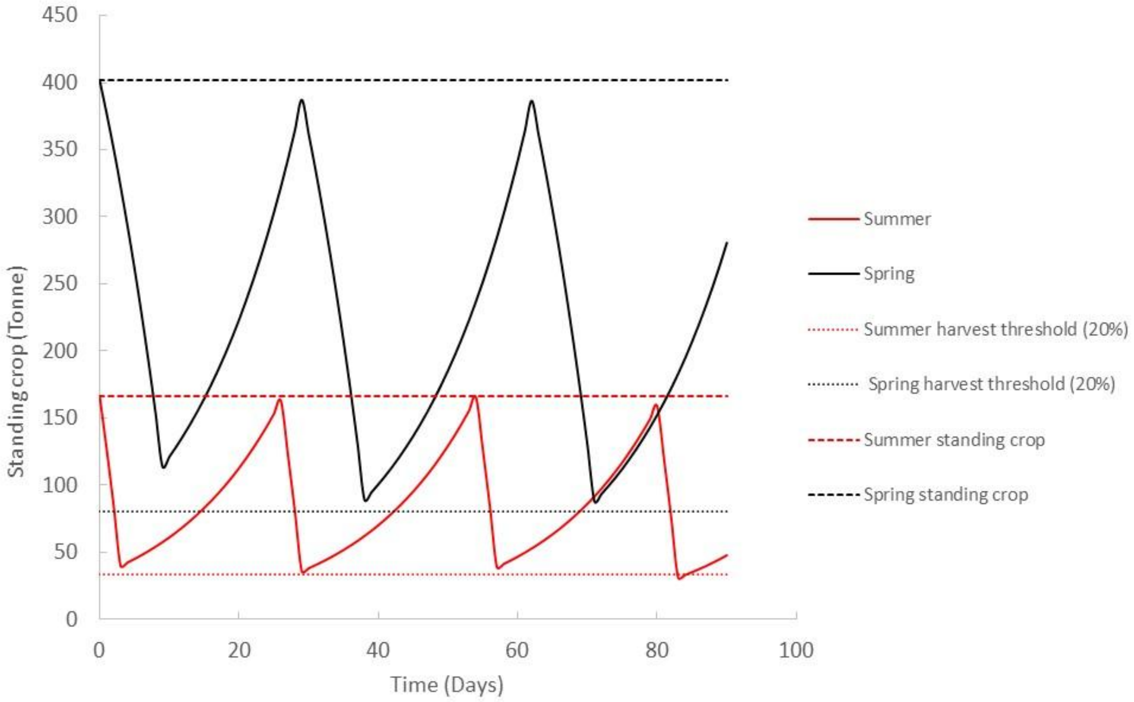


Figure 9: Potential harvesting during three months in spring and summer based on assumptions given in the text.

Based on the scenario above and nutrient content of 3.9% dry weight as N and 0.6% dry weight as P, up to 1.6 tonne of N and 0.25 tonne of P could be removed by harvesting over summer, with 3.60 tonne of N and 0.55 tonne of P removable in spring.

5 Recommendations

Weed harvesting can be used as a management tool in a number of ways including maintenance of amenity access for recreational activities on the lake and removing nutrients for lake restoration. We make the following recommendations in the context of removing nutrients for lake restoration without destroying the weed beds. A nutrient budget for Lake Horowhenua would be required to clarify the degree of benefit from harvesting nutrients in this way. The timing and recommendations for other management options may be different to these.

- Harvesting should begin in late October when maximal spring biomass is developing and accruing the excess nitrate nitrogen available in the lake waters late in the year (Gibbs and Quinn 2012).
- Harvesting should continue into summer to remove curled pond weed biomass before it senesces. Curled pond weed mats on the lake bed are likely to cause sediment anoxia and release DRP from the sediments (Gibbs and Quinn 2012).
- Harvesting of elodea should be more conservative and focus on the shallower edges of the main weed beds, where recovery is likely to be faster.
- Harvesting should cease if there is an unexplained reduction in plant biomass that signifies unfavourable growth conditions.
- Consideration should be given to leaving a swath of weed along the southern edge of the central weed bed (weed bed 4b) and the northwest bed (1a) in spring to act as a wave baffle. We suggest this weed bed should be 100 to 150 m in width.
- Keeping such a reserve of curled pondweed in spring will also help ensure turion production continues in the lake, which is likely to be the major mechanism for regeneration of this species. As turions form within the plant canopy they may be removed by harvesting before they can mature and separate from the plant.
- A harvested corridor in front of the Arawhata Stream and Hokio Stream in spring may assist entrainment of high nutrient water towards the outflow.
- Harvesting may also need to consider accommodating the 2000 m rowing course (http://www.rowit.co.nz/venues/hor#vm) or a similar course, and identify high use area for yachting also.
- Harvesting in extremely shallow areas should be avoided due to likely disturbance of the bottom sediments.
- We also recommend harvesting and recovery potential by weed beds be investigated experimentally before large scale harvesting is undertaken.

6 Acknowledgements

Many thanks to Jon Roygard, Logan Brown (Horizons Regional Council), Rob Warrington and Marakopa Wiremu-Matakatea (Lake Horowhenua Trust) for assistance during the lake surveys. NIWA divers Rohan Wells and Tracey Burton contributed to biomass sampling.

7 References

Cedergreen Forchhammer, N. (1999) Production potential of aquatic plants in systems mixing floating and submerged macrophytes. *Freshwater Biology,* 41: 183-191. http://www.ib.usp.br/limnologia/textos/Production%20potential%20of%20aquatic%20plants%20in%20systems%20mixing%20floating%20and%20submerged%20macrophytes.pdf

Champion, P., Dugdale, T., Matheson, F. (2002) Lake Horowhenua – assessment of the status of *Egeria densa* and implications for lake stability. *NIWA Client Report* HAM2002-058, prepared for Horizons Regional Council: 25.

David N., Greenfield B.K. (2004) Aquatic pesticide monitoring program: Field evaluations of alternative pest control methods in California waters. Chapter 1. *Environmental effects of mechanical harvesting in freshwater lakes and ponds.* San Francisco Estuary Institute: 38. http://www.waterboards.ca.gov/water_issues/programs/npdes/pesticides/docs/sfei_reports/pestalt_field.pdf

Duarte, C.M. (1987) Use of echosounder tracings to estimate the aboveground biomass of submerged plants in lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 44: 732-735.

Engel, S. (1990) Ecological impacts of harvesting macrophytes in Halverson Lake, Wisconsin. *Journal of Aquatic Plant Management, 28*(1): 41-45.

Environment Bay of Plenty, Rotorua District Council, Te Arawa Lakes Trust (2011) Lake Rotoehu Action Plan. *Environmental Publication 2007/19*, November 2007 (as amended April 2011). http://www.boprc.govt.nz/media/88456/finallakerotoehuactionplanlraphearingpanelchangesv7.pdf

Envirovision Corporation (2004) *Technical memorandum: harvesting and phosphorus control in Long Lake Thurston County:* 12. http://www.co.thurston.wa.us/waterresources/lakes/long/Long%20Lake%20Integrated%20Plan/LongLkTechMemoFinal.pdf

Gibbs, M. (2011) Lake Horowhenua Review: Assessment of Opportunities to Address Water Quality Issues in Lake Horowhenua. *NIWA Client Report* HAM2011-046, prepared for Horizons Regional Council: 117. http://www.horizons.govt.nz/assets/publications/managing-our-environment/water-quality/new-publicationholder/Lake-Horowhenua-reviewAssessment-of-opportunities-to-address-water-quality-issues-in-Lake-Horowhenua.pdf

Gibbs, M., Quinn, J. (2012) Restoration Plan for Lake Horowhenua. *NIWA Client Report* HAM2012-004, prepared for Horizons Regional Council: 52. http://www.horizons.govt.nz/assets/Lake-Horowhenua/WQual2012Restoration-Plan-for-Lake-HorowhenuaNIWA.pdf

Gilliland, B.W. (1978) Development of weed beds over summer 1976 and brief description. In: *Lake Horowhenua current condition, nutrient budget and future management.*

Haga, H., Ohtsuka, T., Matsuda, M., Ashiya, M. (2007) Echosounding observations of coverage, height, PVI, and biomass of submerged macrophytes in the southern basin of Lake Biwa, Japan. *Limnology*, 8: 95-102.

Hohausová, E., Kubecka, J., Frouzová, J., Husák, S., Balk, H. (2008) Experimental Biomass Assessment of Three Species of Freshwater Aquatic Plants by Horizontal Acoustics. *J. Aquat. Plant Manage*. 46: 82-88. http://www.apms.org/japm/vol46/v46p082_2008.pdf

Fu, H., Yuan, G., Cao, T., Ni, L., Li, W., Zhu, G. (2012) Relationships between relative growth rate and its components across 11 submersed macrophytes. *Journal of Freshwater Ecology*, 27: 4: 471-480 http://wetland.ihb.cas.cn/zgsdyj/yggyhp/201409/P020140926721419842873.pdf

James, C.S., Eaton, J.W. (2006) Responses of three invasive aquatic macrophytes to nutrient enrichment do not explain their observed field displacements. *Aquatic Botany*, 84(4): 347-353. http://www.sciencedirect.com/science/journal/03043770

Gao, J., Xiong, Z., Zhang, J., Zhang, W., Obono Mba, F. (2009) Phosphorus removal from water of eutrophic Lake Donghu by five submerged macrophytes. *Desalination*, 242 (2009): 193-204. http://www.academia.edu/1208977/Phosphorus_removal_from_water_of_eutrophic_Lake_Donghu_by_five_submerged_macrophytes

Maceina, M., Shireman, J. (1980) The use of a recording fathometer for determination of distribution and biomass of Hydrilla. *Journal of Aquatic Plant Management*, 18: 34-39. http://apms.org/wp/wp-content/uploads/2012/10/v18p34.pdf

Maceina, M.J., Shireman, J.V., Langland, K.A., Canfield, D.E. Jr. (1984) Prediction of submerged plant biomass by use of a recording fathometer. *Journal of Aquatic Plant Management*, 22: 35-38. http://apms.org/wp/wp-content/uploads/2012/10/v22p35.pdf

Madsen, J.D., Adams, M.S., Ruffier, P. (1988) Harvest as a control for sago pondweed (*Potamogeton pectinatus* L.) in Badfish Creek, Wisconsin; frequency efficiency and its impact on the stream community oxygen metabolism. *Journal of Aquatic Plant Management, 26*: 20-25.

Matheson, F., Clayton, J. (2002) Aquatic Plant Harvesting in Lakes for Nutrient Renovation. *NIWA Client Report* HAM2002-010, prepared for Environment BOP: 29.

Pistori, R.E.T, Camargo A.F.M., Henry-Silva, G.G. (2004) Relative growth rate and doubling time of the submerged aquatic macrophyte Egeria densa Planch. *Acta Limnol . Bras*., 16 (1): 77-84. http://www.ablimno.org.br/acta/pdf/acta_limnologica_contents1601E_files/art7_16(1).pdf

Riis, T., Madsen, T.V., Sennels, R. (2009) Regeneration, colonisation and growth rates of allofragments in four common stream plants. *Aquatic Botany,* 90(2): 209-212. doi:http://dx.doi.org/10.1016/j.aquabot.2008.08.005

Sabol, B.M., Melton, R.E., Chamberlain, R., Doering, P., Haunert, K. (2002) Evaluation of digital echosounder system for detection of submerged aquatic vegetation. *Estuaries and Coasts,* 25: 133-141.

Serafy, J.E., Harrell, R.M., Hurley, L. M. (1994) Mechanical removal of hydrilla in the Potomac River, Maryland: Local impacts on vegetation and associated fishes. *Journal of Freshwater Ecology,* 9(2): 135-143.

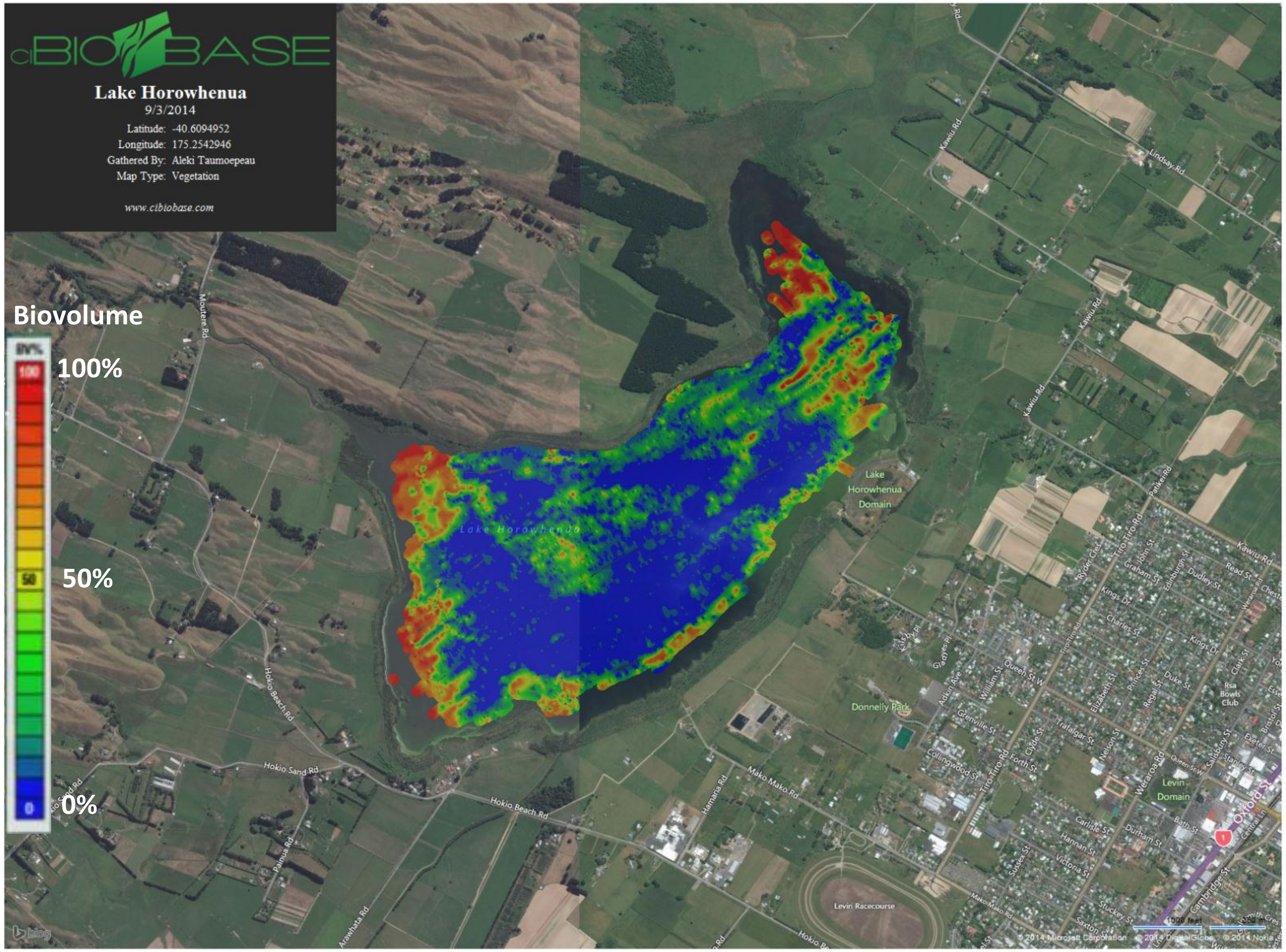
Taumoepeau, A., de Winton, M. (2014) *Delimitation of submerged weed bed areas in Lake Horowhenua.* NIWA report prepared for Horizons Regional Council: 17.

Yonghong, X., Dan, Y., Xianhua, G., Yongqing, Y., Yongming, H. (2004) Phenotypic Plasticity in the Submersed Macrophyte Potamogeton crispus as a Response to Elevated [CO2]. *Journal of Freshwater Ecology,* 19: 4, 701-708. DOI:10.1080/02705060.2004.9664752 http://www.tandfonline.com/doi/pdf/10.1080/02705060.2004.9664752

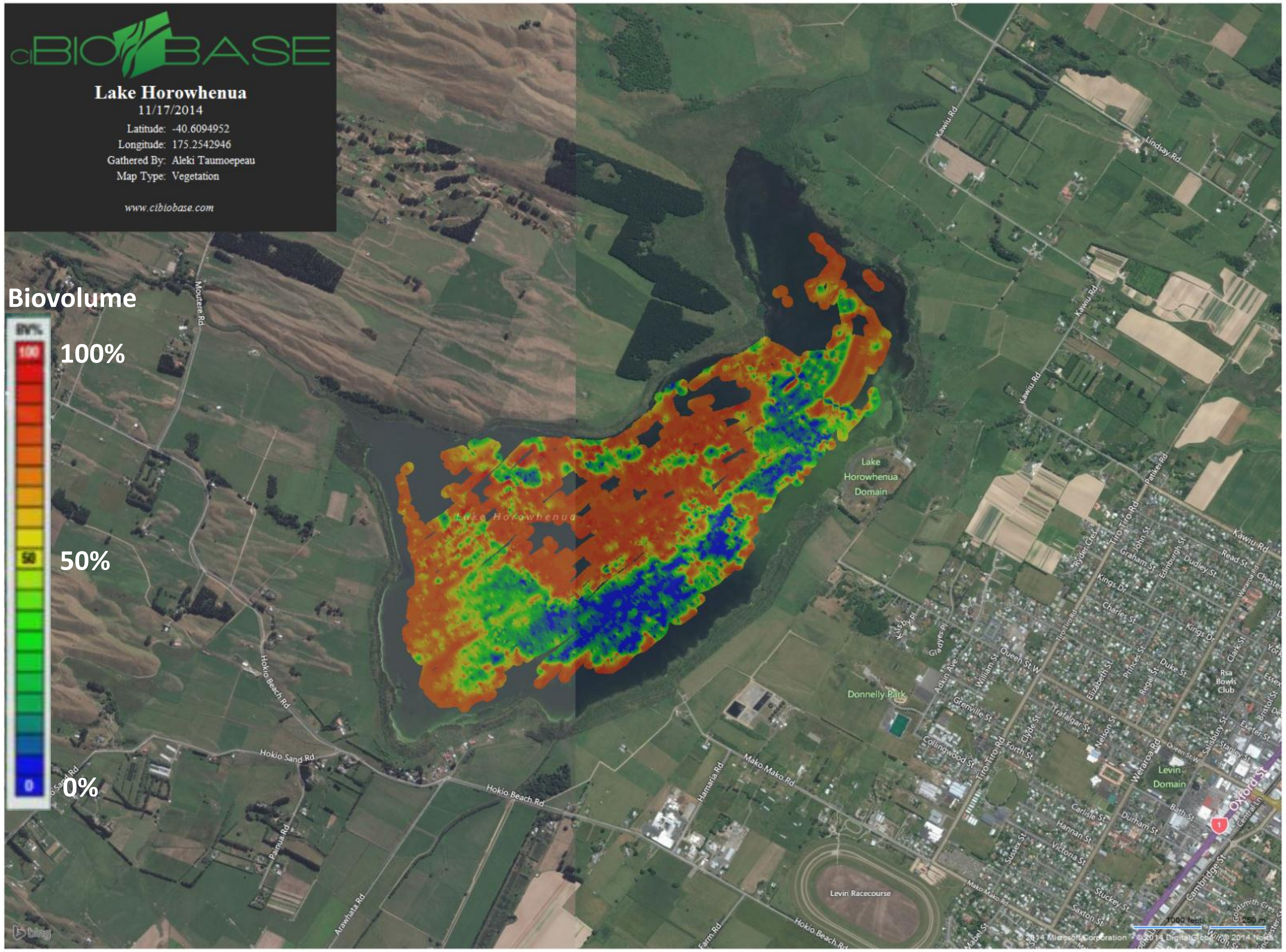
Appendix A Spatial maps of vegetation development

Summer 2014

Winter 2014

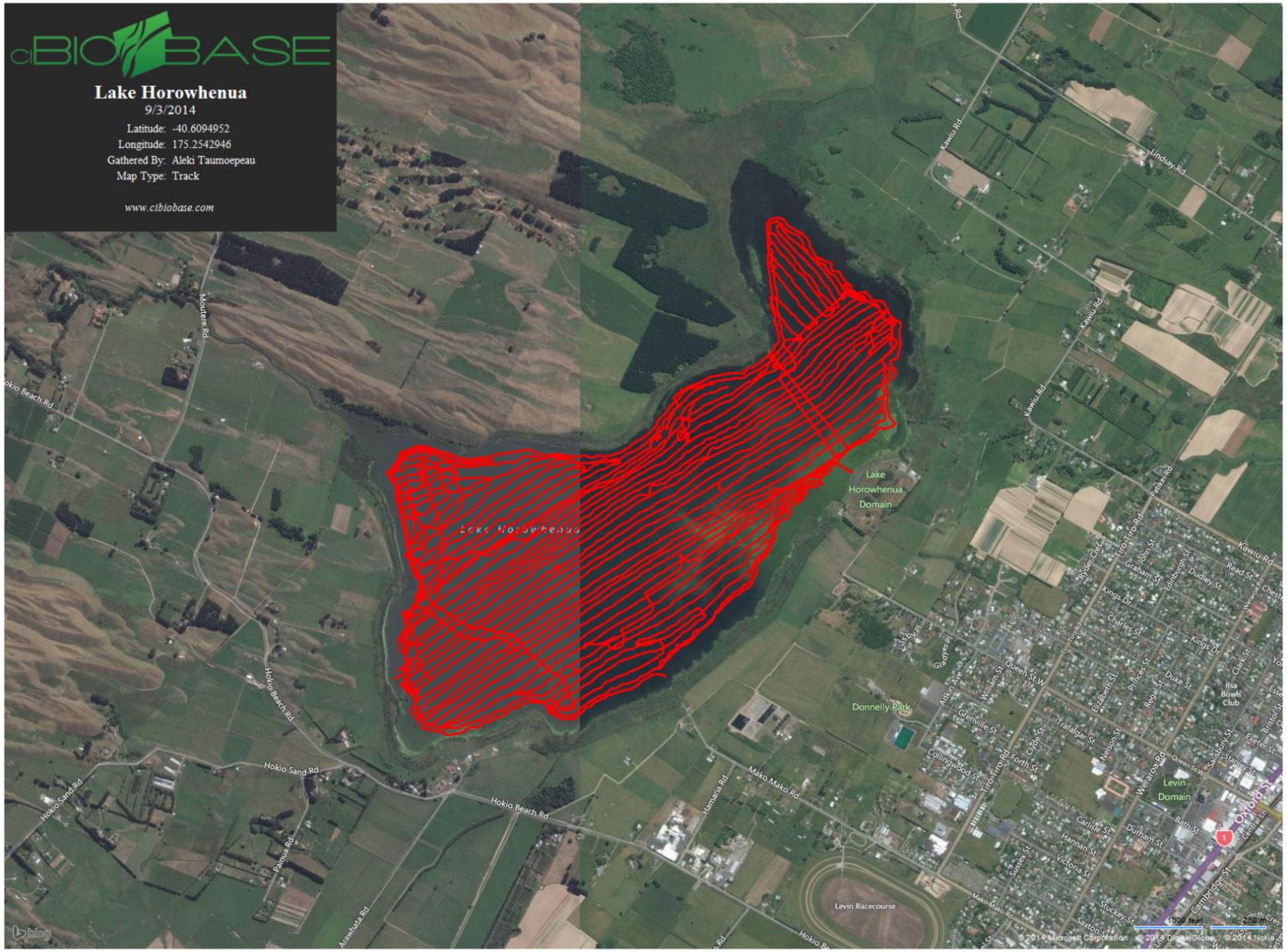

ciBIOBASE
Lake Horowhenua
9/3/2014
Latitude: -40.6094952
Longitude: 175.2542946
Gathered By: Aleki Taumoepeau
Map Type: Vegetation
www.cibiobase.com
Biovolume
BV%
100
100%
50
50%
0
0%
Lake Horowhenua
Lake Horowhenua Domain
Donnelly Park
Levin Domain
Levin Racecourse
Hokio Sand Rd
Hokio Beach Rd
Kawiu Rd
Lindsay Rd
Mako Mako Rd
Oxford St

Spring 2014


ciBIOBASE
Lake Horowhenua
11/17/2014
Latitude: -40.6094952
Longitude: 175.2542946
Gathered By: Aleki Taumoepeau
Map Type: Vegetation
www.cibiobase.com
Biovolume
BV%
100
100%
50
50%
0
0%
Lake Horowhenua
Lake Horowhenua Domain
Donnelly Park
Levin Domain
Levin Racecourse
Hokio Sand Rd
Hokio Beach Rd
Mako Mako Rd
Kawiu Rd
Lindsay Rd
Oxford St
Mouterere Rd
Arawhata Rd

Appendix B Trace of run lines over the navigable lake area of Lake Horowhenua

Summer 2014

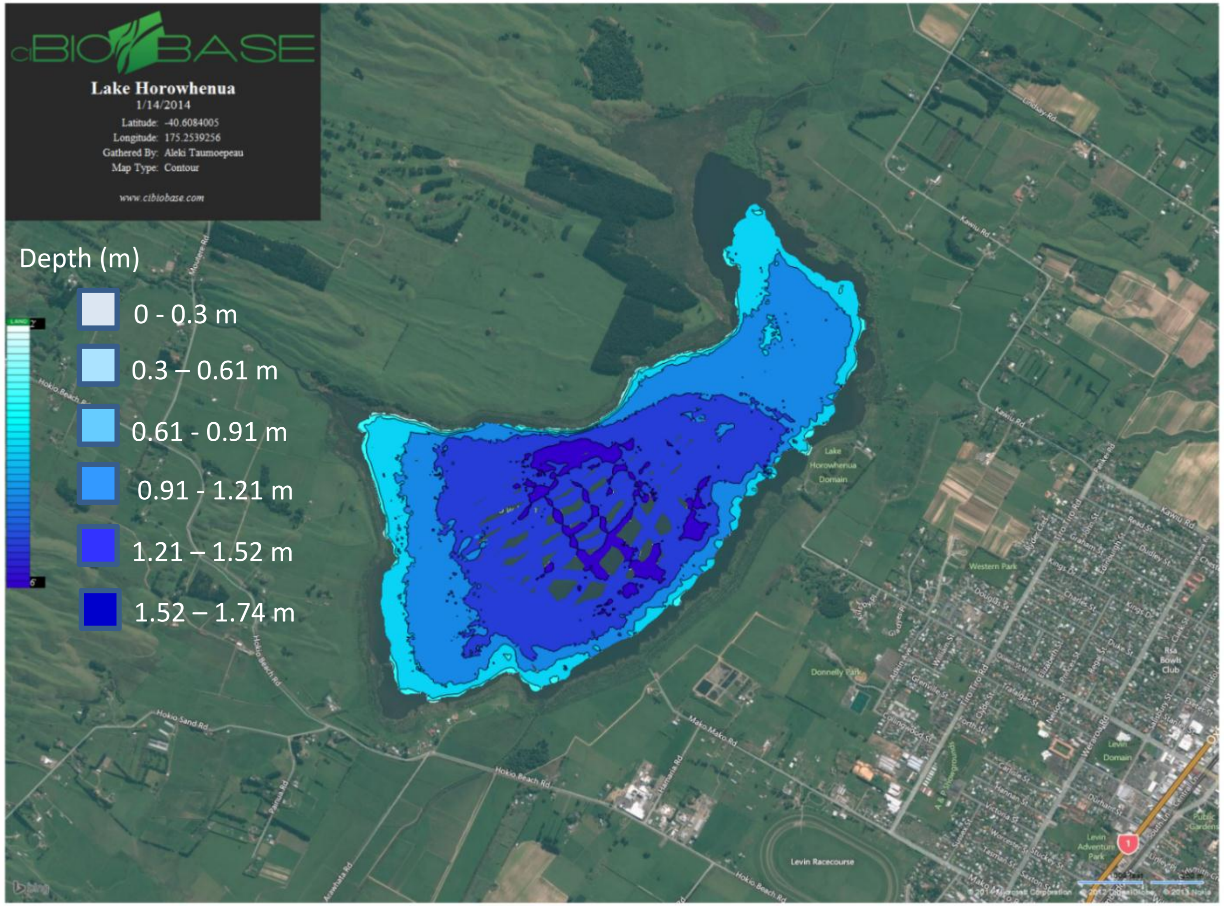

ciBIOBASE
Lake Horowhenua
9/3/2014
Latitude: -40.6094952
Longitude: 175.2542946
Gathered By: Aleki Taumoepeau
Map Type: Track
www.cibiobase.com
Lake Horowhenua
Lake Horowhenua Domain
Donnelly Park
Levin Domain
Levin Racecourse
Hokio Beach Rd
Hokio Sand Rd
Moutere Rd
Kawiu Rd
Lindsay Rd
Mako Mako Rd
Queen St W
Oxford St
© 2014 Microsoft Corporation © 2014 DigitalGlobe © 2014 Nokia

Winter 2014


ciBIOBASE
Lake Horowhenua
11/17/2014
Latitude: -40.6094952
Longitude: 175.2542946
Gathered By: Aleki Taumoepeau
Map Type: Track
www.cibiobase.com
Lake Horowhenua
Lake Horowhenua Domain
Donnelly Park
Levin Domain
Levin Racecourse
Hokio Beach Rd
Hokio Sand Rd
Moutere Rd
Kawiu Rd
Lindsay Rd
Mako Mako Rd
Oxford St

Spring 2014

Appendix C Bathymetry



Depth contours equivalent to c. 0.3 m (ciBioBase.com output is in imperial measurements as feet), surveyed in summer 2014.

horizons
regional council

11-15 Victoria Avenue
Private Bag 11 025
Manawatu Mail Centre
Palmerston North 4442

T 0508 800 800
F 06 952 2929
help@horizons.govt.nz
www.horizons.govt.nz