Weed harvesting in the Rotorua Te Arawa Lakes 2006-Present

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Executive summary

The lakes of Rotorua are a taonga (treasure) to the Te Arawa people that are steeped in Māori history and nationally significant to New Zealanders. The Rotorua Te Arawa Lakes Programme, a partnership between the Bay of Plenty Regional Council (BOPRC), the Rotorua Lakes Council and Te Arawa Lakes Trust, is responsible for restoring and protecting water quality in 12 of the Rotorua Lakes.

Rotorua lake weeds became an issue of public and political importance in the 1960s. In New Zealand we have both native and invasive (non-native) species of lakeweed, aquatic plants that grow in lakes. Commonly found species in the Te Arawa Rotorua Lakes include Hornwort, Lagarosiphon, Egeria and Elodea. Invasive weeds such as these degrade New Zealand's wetlands and waterways and can be quick to establish, particularly in lakes. The spread of these weeds within catchments is normally by water movement. New catchments are infested by fragments of the weeds being spread by boats and trailers, diggers, eel nets and people liberating fish.

Lakeweed management is undertaken by BOPRC. The main drivers of aquatic weed management are amenity, biosecurity and nutrient management. Control methods can be categorised into three main groups; physical, chemical and biological. Chemical methods often include herbicide use such as diquat, while examples of physical control methods include harvesting, suction dredging and benthic barriers.

Mechanical weed harvesting is an aquatic weed control method where weed is cut and removed from the waterway. Harvester machines can typically remove the top 2 m-3 m of weed below the water surface. In areas where harvesters can operate effectively, large quantities of weed can be removed which may benefit lake water quality or offset nutrient inputs from the catchment through removal of nutrients that have been assimilated into plants as they grow.

Bay of Plenty Regional Council's weed harvesting programme first began with trial work carried out in 2006 to establish costs for the removal of hornwort as a mechanism to remove nitrogen and phosphorus from the Rotoehu Catchment. Following this trial weed harvesting in Lake Rotoehu occurred yearly from 2008 to 2016 for nutrient removal as part of the Lake Rotoehu Action Plan. Weed harvesting has not been done in Lake Rotoehu for the past three years (2017-2019), predominantly due to lack of weed caused by algae blooms. Weed harvesting in Lake Rotoiti was carried out in 2009, 2010 and 2014 to 2016, the main purpose was to pre-empt lakeweed strandings and remove standing lakeweed from the bay as surface reaching weed has caused amenity issues. It also gave some nutrient reduction benefits as well. A total of 22,300 tonnes of weed have been harvested from the two lakes to date, removing 27,324 kg of Nitrogen and 3,886 kg of Phosphorus from the lakes and costing a total $1.018 million.

From 2008 to 2012 harvesting was carried out using a lakeweed harvester leased from Mighty River Power (MRP). In 2013 harvesting was done using an excavator and an extended digger. The BOPRC purchased a harvesting machine in 2014 which has been used for all weed harvesting to date. Dump sites, composting and vermicomposting have all been used as disposal methods for the weed harvesting. Weed has been disposed of both within and out of the Lake catchment area.

Ideal conditions for weed harvesting are when the weed is very dense, surface reaching and close to the harvesters take out point. The optimal time of year for weed harvesting are during the peak growing season of the weed, February to April in New Zealand. The BOPRC harvester can hold 11 m^3 of weed per load and when operating at peak efficiency it can collect a load approximately every six minutes.

In early 2020 the feasibility of undertaking a weed harvest in Lake Rotorua was investigated. As part of the Lake Rotorua Action Plan there is a target to remove 50 tonnes of Nitrogen from the lake via engineering methods. Weed harvesting was identified as a potential contribution to this target.

The main objective was to investigate the feasibility of starting a weed harvesting programme in Lake Rotorua and make a recommendation on the viability of such a programme as an option to contribute towards achieving the 50 t nitrogen reduction target for Lake Rotorua.

A visual survey of the lake was undertaken by boat and found that the weed was low density, mainly single strands with very little surface reaching, spread out over a 20 m zone located on the drop off from shallow to deep water about 1 km from shore with the majority of the weed being Lagarosiphon major. Based on the visual observations from the boat survey and Howard Emeny's knowledge and experience he recommended that it would not be cost effective to carry out a harvesting operation in Lake Rotorua this year if the justification was for nutrient reduction purposes only.

Samples of this weed were collected from the lake and tested which found that harvesting lagarosiphon would remove more nutrients per tonne of weed than if harvesting hornwort. The testing also showed that the levels of arsenic in the weed were between two to three times the recommended guideline values which may be an issue for weed disposal via vermicomposting.

With the current weed growth in Lake Rotorua it would take up to two hours for the harvester to collect a load of weed, plus 40 minutes travel time per load. The area of weed surveyed only holds approximately five to six loads of weed. Based on this and the lagarosiphon testing results, if the weed harvesting in Lake Rotorua were to proceed, approximately 73 kg-98 kg of nitrogen and 7.2 kg-10.2 kg of phosphorus would be removed.

Based on the visual observations, Howard Emeny's recommendation and the estimated nutrient reduction benefits, the decision was made that a harvesting operation in Lake Rotorua this year should not proceed. Based on the results of the investigation, several recommendations were also made should a weed harvesting operation be carried out on Lake Rotorua in the future.

Introduction

The lakes of Rotorua are a taonga (treasure) to the Te Arawa people that are steeped in Māori history and nationally significant to New Zealanders. Sometimes called the Lakes district of the North Island, lakes of varying sizes were formed by the volcanic activity of the Central Plateau. The Rotorua Te Arawa Lakes are a hot spot for recreational activities in the Rotorua region with great spots for swimming, picnics, fishing, water cruises and water sports (Rotorua Lakes , 2020).

The Rotorua Te Arawa Lakes Programme, a partnership between Bay of Plenty Regional Council, Rotorua Lakes Council and Te Arawa Lakes Trust, is responsible for restoring and protecting water quality in 12 of the Rotorua Lakes (Rotorua Te Arawa Lakes Trust, 2017).

The strategy developed for the programme provides an overall management plan outlining the vision for the future with steps to achieve that vision. The vision is that “The lakes of the Rotorua District and their catchments are preserved and protected for the use and enjoyment of present and future generations, while recognising and providing for the traditional relationship of Te Arawa with their ancestral lakes.”

The Bay of Plenty Regional Council implement the strategy for the Lakes of the Rotorua District, administer the relevant sections of the Resource Management Act 1991, implement the Rotorua Te Arawa Lakes Programme through operational objectives, implement Rotorua Lakes Recreation Strategy and Regional Pest Management Plan, and contribute to funding to help improve the health of Rotorua lakes in association with the Crown and District council.

1 Lakeweeds in New Zealand

1.1 What are lakeweeds?

Lakeweeds are aquatic plants (plants that grow in water) that grow in lakes. Aquatic plants provide food and shelter, improve water quality and clarity, protect shorelines, improve aesthetics and provide economic value (NIWA, 2017).

1.1.1 Native vs invasive

In New Zealand we have both native and invasive (non-native) species of lakeweed. Common species of native lakeweeds include turf communities, isoetes, native pondweeds and milfoils and charophyte species.

Invasive submerged weeds are defined as plants that interfere with, or have the potential to interfere with the uses or values of a water body. Commonly found species in the Te Arawa Rotorua Lakes include Hornwort, Lagarosiphon, Egeria and Elodea.

1.2 Why are invasive lakeweeds an issue?

Invasive submerged weeds can replace our native plants. When this happens there are significant environmental consequences as well as an adverse effect on economic value (presented in Table 1).

Table 1 Environmental and economic consequences of invasive weeds replace native plants.

Environmental consequences	Economic consequences
Loss of biodiversity	Clog hydroelectric dams
Native fish and wildlife habitats modified or destroyed	Block navigational pathways
Recreational activities (swimming, boating, fishing etc.) can be restricted	Restrict drinking water intakes and irrigation
Can ruin the aesthetic appeal of the lake	Reduce tourism and property values
	Restrict water movement

Invasive weeds degrade New Zealand's wetlands and waterways and can be quick to establish, particularly in lakes. Once established the invasive weeds can form solid bands of dense weed around the margins of the lake.

Both Hornwort and Lagarosiphon impede irrigation, drainage, other water uses as well as being a major weed in hydroelectric dams.

The main causes of increased aquatic weed growth are generally accepted to be:

- Increased levels of available nutrients such as nitrogen and phosphorus.
- Removal of other less invasive species.
- Intensive hydraulic engineering changes to waterways.

1.3 Invasive species found in Te Arawa Lakes

Rotorua lake weeds became an issue of public and political importance in the 1960s with early research carried out by Professor Val Chapman, University of Auckland and his students (NIWA, 2015). Submerged weed species, particularly hornwort (Ceratophyllum demersum) and the three oxygen species (Lagarosiphon major, Egeria densa and Elodea Canadensis), are a management challenge in the Rotorua Lakes. Figure 1 shows the introduction of these four lakeweed species into the Rotorua Lakes. The spread of these weeds within catchments is normally by water movement. New catchments are infested by fragments of the weeds being spread by boats and trailers, diggers, eel nets and people liberating fish.

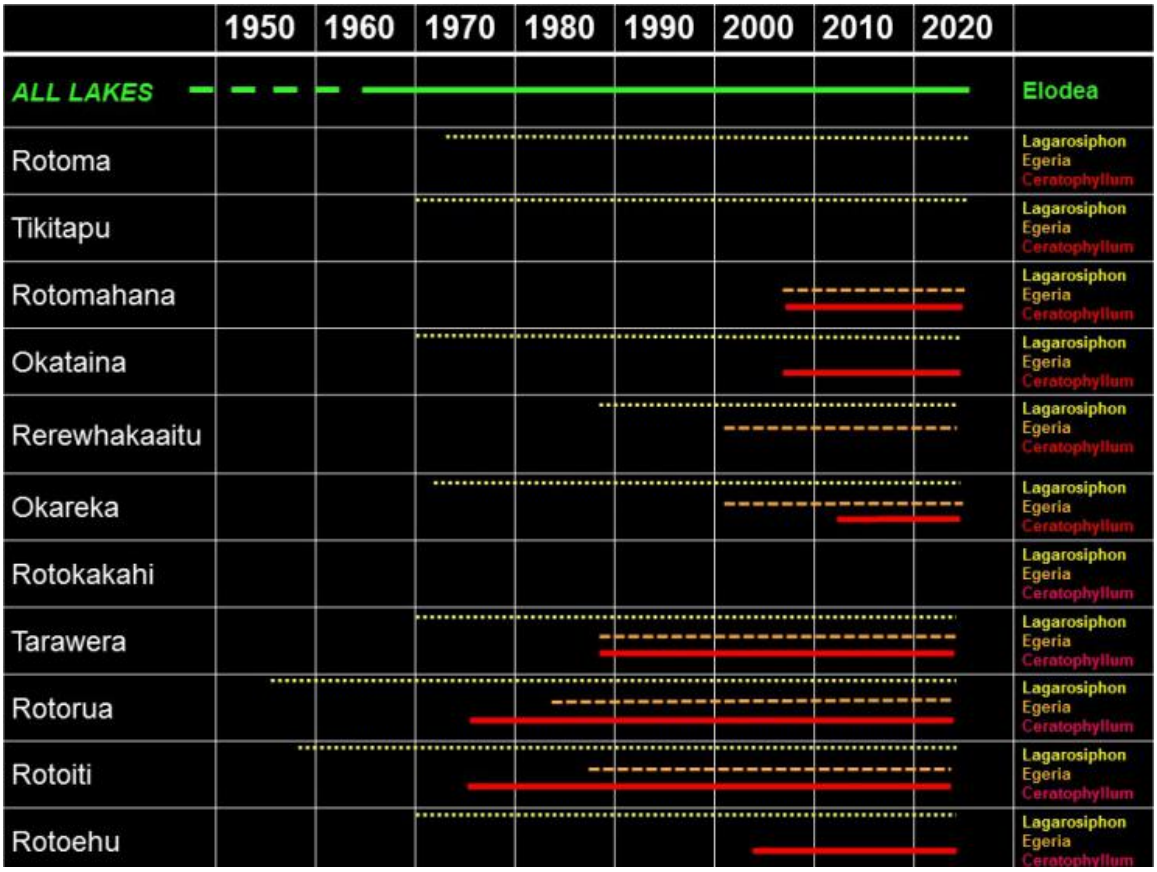

Figure 1 *Invasion sequence of four submerged invasive alien aquatic plants in the Rotorua Lakes (NIWA, 2015).*

1.3.1 Hornwort

Hornwort (*Ceratophyllum demersum*) also known as Coontail is a submerged, free-floating or anchored perennial freshwater weed that is found in still and flowing waters of rivers, lakes, streams and ponds (Weedbusters, 2020).

It is found growing to depths of up to 16 m and lacks roots but has modified leaves that anchor the plant in bottom sediments. Stems are brittle and easily broken by wave action which can lead to large floating rafts of the weed on water surfaces. It has thin dark green leaves in whorls, which are densely crowded at the stem tip and increasingly spaced down the stem.

Figure 2 *A Hornwort weed bed seen from the surface (top) and underwater (bottom left), with a close-up of the plat, forked leaves and minute flower (NIWA, 2020).*

Hornwort's dense growth habitat crowds out native species, rapidly invading water of varying clarity, light, temperature and nutrient level. It threatens most submerged plant communities. New plants can grow from pieces of the stems which are easily broken. When the plant starts to die off during the winter months the rotting vegetation stagnates

the water, killing fauna and flora. Under the Biosecurity Act 1993, Hornwort is an unwanted organism and is banned from sale, propagation and distribution under the National Plant Pest Accord (Ministry for Primary Industries, 2020).

1.3.2 Lagarosiphon

Lagarosiphon (*Lagarosiphon major*) also known as oxygen weed is a submerged, bottom-rooting perennial freshwater weed that is found in rivers, lakes, dune lakes and other still or slow-moving waters with moderate to high levels of light (Department of Conservation, n.d.). It is widespread throughout New Zealand and still spreading.

It grows quickly, up to 5 m tall and forms dense mats which block waterways and displace native plants. Leaves of the plant are arranged spirally around the stem, have tiny serrations along the edges and are curved backwards or downwards. This distinctive downward curl differentiates it from other oxygen weeds.

Figure 3 A submerged Lagarosiphon weedbed view from above and a close-up of the plant stem showing re-curved leaves (Biosecurity New Zealand, 2013).

Lagarosiphon forms deep underwater meadows which shade out smaller native species and prevent native seedlings from establishing. Large clumps can dislodge from the underwater meadows creating floating weed rafts that can be blown and washed ashore in windy storms. Rotting vegetation also turns the water stagnant which can kill both fauna and flora.

Under the Biosecurity Act 1993, Lagarosiphon is an unwanted organism and is banned from sale, propagation and distribution under the National Plant Pest Accord.

1.4 Management, removal and treatment methods

The main drivers of aquatic weed management are amenity, biosecurity and nutrient management. There are many control tools available to manage invasive weeds and the selection of the most suitable tool is usually based on the following:

1 The weed management goal or desired outcome.

2 The weed species to be targeted.

3 The scale of the infestation and type of waterbody.

4 The tools or methods available.

Control methods can be categorised into three main groups; physical, chemical and biological. Physical control methods include removing vegetation or biomass (mechanical and manual harvesting) and habitat manipulation (barriers to plant growth). Chemical control refers to the use of herbicides such as diquat and glyphosate. Biological control is when organisms are used to graze on and control, or suppress the growth of target weeds. A summary of control methods by type is presented in Table 2.

Table 2 Control methods for the management of invasive freshwater weeds.

Physical	Chemical	Biological
Manual – hand-weeding, raking and netting	Diquat	Classical biocontrol
Mechanical – suction dredge, excavators, mowing, cutting and harvesting	Endothall	Grass Carp
Habitat manipulation – benthic barriers and draw down	Glyphosate	

Figure 4 is a weed management diagram which illustrates key factors to be considered when selecting a weed control tool appropriate to the situation.

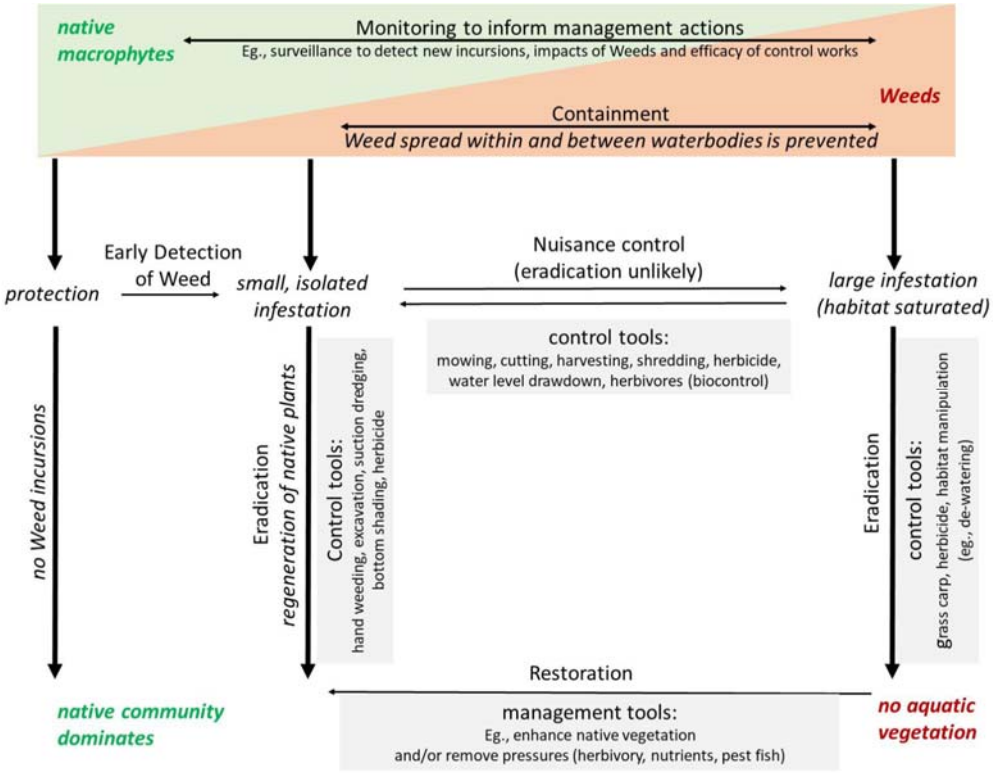

Figure 4 Weed control management tool selection guide (NIWA, 2019).

2 Weed harvesting

Mechanical weed harvesting is an aquatic weed control method where weed is cut and removed from the waterway. Suction dredging is where a venturi suction pump uproots the aquatic weed and then discharges it into a collection bag. Hand harvesting is carried out by divers physically removing the aquatic plant. This is an ideal method for removing targeted invasive weeds growing within areas of native species. A variety of machinery is also used for weed harvesting including harvesters, trucks, diggers and boats. Harvester machines can typically remove the top 2 m-3 m of weed below the water surface. Limiting the use of this method for weed management when compared to other methods are the energy, labour and machine capital costs.

Disposal of the harvested weed can sometimes be problematic. Harvested material may need to be trucked off site or out of the catchment area which can add to the total cost. Also related is that stockpiling the weed may cause leaching of nitrate and nitrite into the storage land area, and if heavy metals such as arsenic are high that can also cause issues. Weed can be disposed into the lake itself, either by being pulverized or deep water

discharge of negatively buoyant material. These are much cheaper disposal options but not suitable for operations where the removal of nutrient from the lake held in the weed is required.

Many New Zealand aquatic weeds can regrow from very small fragments which can remain viable for long periods of time. As such, much care and stringent biosecurity controls must be put in place and used when storing and transporting lakeweed, especially out of catchment areas. Harvester units must also be thoroughly cleaned and decontaminated before moving to another location to minimise the biosecurity risk of potentially introducing fragments of weed.

Weed harvesting is a useful tool to reduce weed in sensitive areas such as boat ramps and beaches, or from areas where weeds detach and form drifting rafts that interfere with recreational or commercial activities.

In areas where harvesters can operate effectively, large quantities of weed can be removed which may benefit lake water quality or offset nutrient inputs from the catchment through removal of nutrients that have been assimilated into plants as they grow. Unlike with herbicide spraying, the nutrients associated with the vegetation are removed with the weed when harvested. With spraying as the weeds die and decay the nutrients they held are released back into the lake. As this process occurs the dissolved oxygen content in the water decreases, with harvesting this does not occur.

Unlike herbicides, weed harvesting is not restricted by dilution effects or toxicity and restrictions over chemical applications to water do not apply.

Herbicides address the effects but not the cause of weed proliferation; that is they do not reduce the nutrient load from the waterways. However, harvesting addresses both the cause and the effects, it removes the plant biomass from the waterway. Harvesting over large areas may not be much more expensive than herbicide controls. Harvesting has proven to be a valuable option where the removal of biomass and nutrients from the waterway is required or there are concerns over high levels of herbicide.

3 Overview of BOPRC's weed harvesting programme

Bay of Plenty Regional Council's weed harvesting programme first began with trial work carried out in 2006 to establish costs for the removal of hornwort as a mechanism to remove nitrogen and phosphorus from the Rotoehu Catchment. Following this trial weed harvesting in Lake Rotoehu occurred yearly from 2008 to 2016 for nutrient removal as part of the Lake Rotoehu Action Plan.

Weed harvesting in Lake Rotoiti was carried out in 2009, 2010 and 2014 to 2016, the main purpose was to pre-empt lakeweed strandings and remove standing lakeweed from the bay as surface reaching weed has caused amenity issues. It also gives some nutrient reduction benefits as well.

The amounts of weed and nutrients removed, as well as the costs for the entire operation to date are shown in Table 3. For year by year breakdowns please refer to sections 6 and 7. A total of 22,300 tonnes of weed have been harvested from the two lakes to date, removing 27,324 kg of Nitrogen and 3,886 kg of Phosphorus from the lakes and costing a total $1.018 million.

Table 3 Key details of BOPRC's weed harvesting programme 2006–Present.

	Weight harvested (tonnes)	Total cost	Kg N removed	Kg P removed
Lake Rotoiti	2182.1	$ 150,647.86	3181.65	666.70
Lake Rotoehu	20118.5	$ 867,974.00	24142.00	3218.88
Total	22300.6	$ 1,018,621.86	27323.65	3885.58

From 2008 to 2012 harvesting was carried out using a lakeweed harvester leased from Mighty River Power (MRP). In 2013 harvesting was done using an excavator and an extended digger. The BOPRC purchased a harvesting machine in 2014 which has been used for all weed harvesting to date.

Dump sites, composting and vermicomposting have all been used as disposal methods for the weed harvesting. Weed has been disposed of both within and out of the Lake catchment area.

4 Method of harvesting

From 2008 to 2012 the Bay of Plenty Regional Council leased a lake weed harvester from Mighty River Power (MRP) each year (shown in Figure 5) and used Lakeweed Harvesters & Contractors to remove lakeweed from Lake Rotoehu. The MRP machine was also used to carry out harvesting in Okawa Bay at Lake Rotoiti in 2009 and 2010.

Figure 5 Mighty River Power weed harvesting machine used for weed harvesting operations on the Rotorua Lakes 2008–2012.

In 2013 Mighty River Power advised BOPRC that they would need the harvester for their own use and that it would no longer be available for lease. The harvesting contract was put out for expressions of interest and the contract was let out to Rob Burrell Earthmoving Limited. Weed removal was performed with two excavators, one on a barge and an extended digger operating on the shoreline relaying the weed collected from the barge onto a truck for removal. Figure 6 shows images of the harvesting operation in 2013.

The excavator operation used in 2013 had a number of drawbacks when compared to a specialist harvester operation. The excavators caused some sediment issues and more fragmentation of weed. It was slower than a harvester and resulted in a higher cost per kg of Nitrogen removed ($46.24 per kg/N compared to the average of $34.91 per kg/N with the MRP harvester).

Figure 6 *Weed harvesting on Lake Rotoehu in 2013 carried out by Rob Burrell Earthmoving Limited. Two excavators were used (shown in pictures), one a barge on the lake (left) and a long reach machine operated on the shoreline transferring the weed to a truck for removal.*

Deloitte were contracted to investigate future harvesting options. These looked at four main options; continue to use a barge and digger to remove the weed, to purchase a harvester and perform the contracting work with Council, to purchase a harvester and contract the work externally, and to support a contractor in their goal to purchase a harvester. As a result of their investigation Deloitte recommend the best options were to either purchase a harvester and contracting the work externally or supporting a contractor to purchase a harvester. As a result of these recommendations BOPRC purchased and imported a specialised harvesting machine from the United States manufactured by Aquarius Systems. The operation of the machine was tendered out and awarded to Lakeweed Harvesters & Contractors. The BOPRC's harvester has been used for harvesting operations in Lake Rotoehu and Lake Rotoiti from 2014 to the present day (shown in Figure 7).

Figure 7 *Aquarius HM420 Harvesting machine purchased by the BOPRC in 2014.*

5 Weed disposal

Disposal of the weed from the harvesting operation has used different options over the years of operation. Dump sites, composting and vermicomposting have all been used as disposal methods for the lakeweed. Weed has also been disposed of both within and out of the Lake catchment area.

When the weed is disposed of within the catchment, monitoring needs to be carried out to make sure that nutrient does not leach back into the lake. Removing the weed and disposing of it out of the catchment area ensures that the nutrients do not re-enter the lake.

For the first few years of the harvesting operation on Lake Rotoehu (2008-2010) the weed was transported out of the catchment and disposed of on Don Pammets property at Hamilton Road.

For the harvesting operation in Lake Rotoiti the weed was transferred to a dump site located out of the catchment, off State Highway 33, in 2009, and sent to a composting site located out of the catchment in 2010.

In 2011, 3,436 tonnes of weed was harvested from Lake Rotoehu. Approximately 1,700 tonnes of weed were moved out of the catchment to Paengaroa for composting by Hortworx Limited, and approximately 1,800 tonnes was transferred within the catchment to Taumanu for vermicomposting. Using composting/vermicomposting as the disposal method compared to previous years resulted in lower transport costs for the operation.

The weed harvested in 2012 was also transferred within the catchment to Taumanu for composting. In 2013 the weed was transferred to the Tautara Matawhaura Trust vermicomposting operation within the Rotoehu Catchment.

Since 2014, weed from harvests in both Lake Rotoehu and Lake Rotoiti have been transported to Ecocast at Kawerau, a vermicomposting operation out of the Lake catchments.

The disposal method used can affect the price per kg N removed. Transporting the weed longer distances to dispose of it increases the price. This was seen in 2011 when the price per kg N removed dropped after a change in disposal method, meaning the weed was transported over a shorter distance. The cost per kg N removed also was significantly lower for the 2016 Okawa Bay and Wairau Bay Lake Rotoiti harvesting operation. Instead of the weed from Wairau Bay being transported to Kawerau for composting it was instead stacked on the shoreline. This was due to there being no take out point to remove the weed from the harvester.

6 Lake Rotoehu harvesting

Lake Rotoehu, located between Lake Rotoiti and Lake Rotomā on SH 30, is a secluded lake with great fly fishing of rainbow trout and its shoreline home to several quintessential kiwi batches. The total size of the lake is 800 ha with a catchment size of 4,710 ha. A shallow lake, Rotoehu has an average depth of 8 m and its deepest point 13 m. The lake has no surface outlets, with discharge via northerly flowing groundwater.

Figure 8 Lake Rotoehu. Photo from Lakes Water Quality Society.

Formed around 8,500 years ago, Rotoehu is Māori for 'murky water' which makes it likely that the lake has never been clear. Water quality in the lake remained stable until 1993 when the level of nutrients and algae rose dramatically. There has been much effort in recent years to improve water quality, including land management changes and weed harvesting, but it will take time for the effects to be seen.

Lakeweed harvesting at Lake Rotoehu first started with trial work carried out in 2006. The purpose of the trial was to establish costs for the removal of hornwort as a mechanism to remove nitrogen and phosphorus from the Rotoehu Catchment.

The trial was carried out over six days in mid-August, which is outside the peak growing season of hornwort (February to April). This was due to other commitments the harvester had. However, hornwort was still present and small surface rafts of floating weed were targeted. 135 tonnes of wet weight hornwort was removed and transported during the trial.

To calculate the wet weight of the weed, 50 litres of lightly compressed weed was weighed and repeated measurements were all consistent at 25 kg. This makes newly harvested hornwort 50% of the weight of water by volume.

The maximum harvestable rate achievable was found to be approximately 52.8 tonnes of hornwort per day. That was assuming operating the MRP harvester with a consistent supply of hornwort, a truck with the capacity to transport 6.6 tonnes of wet weight weed per load and 8 truckloads per day.

Costs from both the harvesting and transportation of the weed out of the catchment were used to calculate the overall cost. Total cost per day was found to be $2400.00 and costs per wet tonne (at 52.8 tonne per day) was $45.45.

Following the trial harvesting of hornwort weed for nutrient management has been carried out on Lake Rotoehu as part of the lake's action plan annually between 2008 and 2016. Weed harvesting on Lake Rotoehu has been carried out by commercial operators, Lakeweed Harvesters & Contractors, during 2008-2012 using the MRP harvesting machine and then also from 2014-2016 using the BOPRC harvesting machine. Harvesting in 2013 was carried out by Rob Burrell Earth Moving Ltd. using an excavator on a barge and an extended digger. The species of weed removed from Lake Rotoehu was Hornwort. Further details can be found in tables 4 and 5 which summarise the operations in Lake Rotoehu to date.

Table 4 Summary of the weed harvesting operations in Lake Rotoehu 2006–Present.

Summary of lakeweed harvesting in Lake Rotoehu 2006 - Present									
Year	Time of Harvest	Number of days/hours worked		Weight harvested	Disposal method	Total Cost (excl GST)	Kg N removed	Kg P removed	Cost per kg N
2006	15/08 - 21/08	48	hours	135 tonnes	Weed removed out of the lake catchment to a site on Pongakawa Valley Rd.		162	21.6	
2008	14/04 - 12/05 (4 weeks)	160	hours	600 tonnes	Weed removed out of the lake catchment to Don Pamments property on	$ 36,979.00	720	96	$ 51.36
2009	30/03 - 20/05 (8 weeks)	320	hours	3073.5 tonnes	Weed removed out of the lake catchment to Don Pamments property on	$ 108,978.00	3688.2	491.76	$ 29.55
2010	06/04 - 18/06 (10 weeks)	443	hours	2744 tonnes	Weed removed out of the lake catchment to Don Pamments property on	$ 142,240.00	3292.8	439.04	$ 43.20
2011	17/03 - 30/05 (10 weeks)	400	hours	3436 tonnes	≈1700 tonnes moved to Paengaroa for composting by Hortworx Ltd and ≈ 1800	$ 142,681.00	4123.2	549.76	$ 34.60
2012	16/04 - 21/05 (4 weeks)	160	hours	1472 tonnes	Weed transferred within the catchment to Taumanu for vermicomposting.	$ 57,000.00	1766.4	235.52	$ 32.27
2013	17/04 - 24/05 (4 weeks)	234	hours	1622 tonnes	Weed removed and transported to a vermicomposting operation	$ 90,000.00	1946.4	259.52	$ 46.24
2014	19/05 - 31/06 (6 weeks)	198	hours	2926 tonnes	Composting at Ecocast Kawerau	$ 101,374.00	3511.2	468.08	$ 28.87
2015	06/03 - 16/04 (6 weeks)	208	hours	2882 tonnes	Composting at Ecocast Kawerau	$ 101,739.00	3458.4	461.12	$ 29.42
2016	01/04 - 24/04 (3.5 weeks)	151.4	hours	1228 tonnes	Composting at Ecocast Kawerau	$ 86,983.00	1473.6	196.48	$ 59.03

Table 5 Summary table for Lake Rotoehu weed harvesting - key details.

Lake Rotoehu										
Year	**2006**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Weight harvested (tonnes)	135	600	3073.5	2744	3436	1472	1622	2926	2882	1228
Kg N removed	162	720	3688.2	3292.8	4123.2	1766.4	1946.2	3511.2	3458.4	1473.6
Cost per kg N removed	N.A.	$ 51.36	$ 29.55	$ 43.20	$ 34.60	$ 32.27	$ 46.24	$ 28.87	$ 29.42	$ 59.03

Weed harvesting has not been done in Lake Rotoehu for the past three years (2017-2019) predominantly due to lack of weed caused by algae blooms. Photos of the algae blooms in Lake Rotoehu are shown in Figure 9. When algae blooms occur they restrict the light to the weed beds which limits the weed growth.

Figure 9 *Lake Rotoehu algae blooms. Clockwise from top left; 2017, 2018, 2019 and 2019.*

7 Lake Rotoiti harvesting

Lake Rotoiti, 'the small lake', is a relatively large lake lying to the east of Rotorua and a great spot for fishing and boating (Lakes Water Quaility Society, 2017). The total size of the lake is 3,400 ha with a catchment size of 12,160 ha and an average lake depth of 31 m. The deepest point of the lake is 93.5 m. The lake drains into the Kaituna River, flowing into the ocean at Maketū.

Lake Rotoiti is connected to Lake Rotorua via the Ōhau Channel, as such the water quality in Lake Rotorua has a significant effect on Lake Rotoiti. The Ōhau Diversion Wall was built in 2008. This 1,300 m long wall diverts down the Kaituna River and prevents water with a high nutrient content from flowing directly into Lake Rotoiti. This dramatically improved water quality in the lake, with more that 70 percent reduction in the nutrients that were entering the lake.

Weed harvesting was carried out on Lake Rotoiti in 2009, 2010 and 2014–2017. Key details can be found in tables 6 and 7 which summarise the operations in Lake Rotoiti to date. The harvesting most years was done primarily as a management tool to pre-empt lakeweed strandings and to remove standing lakeweed from the bay as surface reaching weed has caused amenity issues. Removing the weed has also given some nutrient management benefits as the nitrogen and phosphorus present within the weed was removed from the Lake Rotoiti Catchment.

Table 6 Summary of the weed harvesting operations in Lake Rotoiti 2009-Present.

Summary of lakeweed harvesting in Lake Rotoiti 2009 - present										
Year	**Location**	**Time of harvest**	**Number of days/hours**		**Weight harveste**	**Disposal**	**Total cost (excl GST)**	**Kg N removed**	**Kg P removed**	**Cost per kg N**
2009	Okawa Bay	23/03 - 30/03	6 days (50 hrs)		125.5 tonnes	Dump site out of the lake catchment located off SH 33	$ 14,164.00	184.5	39.5	$ 76.77
2010	Okawa Bay	11/03 - 17/03	6	days	145 tonnes	Composting site outside of the lake catchment	$ 12,936.00	223.2	47.76	$ 57.96
2014	Okawa Bay	after Lake Rotoehu harvest	5	days	110 tonnes	Composting at Ecocast Kawerau	$ 8,276.22	124.41	12.44	$ 66.52
2015	Okawa Bay	02/03 - 05/03	4	days	99 tonnes	Composting at Ecocast Kawerau	$ 10,094.00	145.59	31.16	$ 69.33
2016	Okawa Bay	Feb/Mar/Apr (2 harvesting periods)	291.4	hours	1,354.6 tonnes	Composting at Ecocast Kawerau	$ 85,625.94	1992.07	426.37	$ 38.96
	Wairau Bay				140 tonnes	Weed stacked on shoreline (no take out point to remove the weed)		205.88	44.07	
	Te Weta Bay	March	49.3	hours	208 tonnes	Composting at Ecocast Kawerau	$ 19,551.70	306	65.47	$ 63.89
2017	Wairau Bay	1-Feb	1	day	10 tonnes	Weed was pushed to the shore and raked up onto the beach by volunteers.	$ 2,647.00			

Table 7 Summary table for Lake Rotoiti weed harvesting – key details.

Lake Rotoiti						
Year	**2009**	**2010**	**2014**	**2015**	**2016 - OB & WB**	**2016-TWB**
Weight harvested (tonnes)	125.5	145.0	110.0	99.0	1494.6	208.0
Kg N removed	184.50	223.20	124.41	145.59	2197.95	306.00
Cost per kg N removed	$ 76.77	$ 57.96	$ 66.52	$ 69.33	$ 38.96	$ 63.89

Weed harvesting on Lake Rotoiti has been carried out by commercial operators – Lakeweed Harvesters & Contractors. The main species of weed removed from Lake Rotoiti was Hornwort although Lagarosiphon, Egeria and Myriophyllum were also present. Harvesting was carried out in Okawa Bay in 2009, 2010, 2014, 2015 and 2016. Weed harvesting was also done in Te Weta Bay in 2016 and Wairau Bay in 2016 and 2017. The purpose of the harvesting done in Wairau Bay was to clear weed from the beach site which was used for the wooden boat parade (shown in Figure 10).

8 Operational costs and efficiency

8.1 Transport and disposal

For the harvesting operations in Lake Rotoiti, the year with the lowest cost per kg N removed was 2016. Weed was harvested from both Okawa Bay and Wairau Bay. The weed from Okawa Bay was sent to Ecocast for composting but at Wairau Bay the weed was stacked on the shoreline as there was no take out point to remove the weed. The cost per kg N removed was $38.96 which is substantially lower than the average for all other years, $66.29 per kg N removed, due to the weed from Wairau Bay not been transported for disposal.

The weed disposal can also make a difference on the cost. During the first few years of harvesting on Lake Rotoehu the weed was transported for disposal on Don Pammets property on Hamilton Road, out of the catchment. For these years (2008-2010) the average cost per kg N removed was $41.37. When the switch was made to dispose of the weed via composting/vermicomposting instead, the cost was lowered to $33.44 per kg N (2011-2012). This was due to lower transport costs for the operation.

The transport and disposal method for the harvested weed is a significant factor for the overall cost of operations and can have large impact on the cost as detailed previously. The cheapest option is for the weed to be left in the lake, however, when the purpose of the harvesting is primarily for nutrient reduction associated with removing the weed from the lake, this is not a viable option. A significant portion of the cost is related to transporting the weed, the further it has to be transported the higher the cost. If the weed must be transported for disposal the most cost effective solution would be to have a drying site for the weed as close as possible to the take out site and the disposal site also as close as possible. Minimising the distance the weed has to be transported helps to minimise the overall cost of operations.

8.2 Harvesting method

The method of harvesting can also affect the total cost. For the first several years of operating the weed harvesting programme the harvesting machine from Mighty River Power was used. For Lake Rotoehu this gave an average of $33.44 per kg N removed. In 2013 the MRP harvester was unavailable and removal was performed with two excavators, one on a barge and an extended digger operating on the shoreline relaying the weed collected from the barge onto a truck for removal. The cost per kg N removed for 2013 was $46.24 which was higher than those of previous years due to the change in harvesting methodology. In 2014 the BOPRC harvester was purchased and has been used for all subsequent years of weed harvesting. This harvester has proven to be the most cost effective, giving an average $29.15 per kg N removed (2014-2015).

Weed harvesting can be carried out using different methodology, however, the most cost effective and efficient method is to use a purpose built aquatic weed harvesting machine.

8.3 Length of harvest

For any harvesting operation there are fixed costs and as such it is more cost effective when there is a large amount of weed to support a longer working timeframe. This can been seen in the difference in cost between harvesting in Lake Rotoehu, which is carried out over 4-10 weeks and Lake Rotoiti which usually operates for less than a week. Lake Rotoehu has an average of $39.39 per kg N removed and Lake Rotoiti has an average of $62.24 per kg N removed.

8.4 Optimal operating conditions

Ideal conditions for weed harvesting are when the weed is very dense, surface reaching and close to the harvesters take out point. In order for any weed harvesting to be cost effective it is recommended that the operations need to be within a maximum of 1 km from an offload ramp. The optimal time of year for weed harvesting are during the peak growing season of the weed. In New Zealand this means that the best time for harvesting is February to April.

The BOPRC harvester can hold 11 m^3 of weed per load and operates at peak efficiency in dense weed (see Figure 11 for an example of dense weed) where it can collect a load approximately every six minutes.

Figure 10 Photo showing dense, surface reaching weed growing in a dam at the Taharoa iron sands mine. Photo credit Howard Emeny.

9 Lake Rotorua harvesting

In early 2020 the feasibility of undertaking a weed harvest in Lake Rotorua was investigated. The main purpose of any weed harvesting done in Lake Rotorua would be the nutrient removal contributing to the 50 T per year Nitrogen removal target for Lake Rotorua by engineering methods.

9.1 Background

As part of the Lake Rotorua Action Plan there is a target to remove 50 tonnes of Nitrogen from the lake via engineering methods. Weed harvesting has been identified as a potential contribution to this target. The quantity of nitrogen that could be removed by weed harvesting is uncertain and also subject to seasonal changes.

Weed harvesting has been carried out in the Te Arawa Lakes previously. Harvesting in Lake Rotoehu has been carried out for nutrient removal purposes as part of the Lake's Action Management Plan, while harvesting in Lake Rotoiti has mainly been done for amenity and clearance of navigational waterways. Harvesting operations in Lake Rotoehu have achieved significant nitrogen reductions. In 2014 BOPRC purchased and imported a

specialised weed harvesting machine from Aquarius systems in the United States for use in its weed harvesting operations.

An investigation into the viability of using the BOPRC harvester to conduct a weed harvesting programme in Lake Rotorua was initiated. The purpose of harvesting would be nutrient removal contributing to the 50 tonnes of Nitrogen target.

Figure 11 Lake Rotorua, looking out to Mokoia Island.

9.2 Objectives

The main objective was to investigate the feasibility of starting a weed harvesting programme in Lake Rotorua and make a recommendation on the viability of such a programme as an option to contribute towards achieving the 50 t nitrogen reduction target for Lake Rotorua.

The main points of consideration for the investigation included:

- The size, location and species of weed for any weed rafts in Lake Rotorua.
- An estimation of the potential nutrient removal benefits that the programme would have.
- Any consents or permissions that may be required.
- Disposal methods.
- Logistics such as a suitable boat ramp, weed dump site and transport of the weed.

9.3 Current situation

In response to amenity weed issues some minor weed removal is carried out in Lake Rotorua every so often. A number of organisations can be involved including LINZ and BOPRC whose interest in weed management of the lake is for biosecurity purposes. Previously areas of invasive weeds have been sprayed with herbicides to contribute to

weed management control, including areas of a large weed raft around Kawaha Point. Weed can also become unattached from areas and blown into specific bays around the lake side during storm events. This mainly causes amenity issues and is normally responded to by removing the weed from shallow areas of the lake and off beaches.

9.4 Outcomes

9.4.1 Boat survey of weed

A visual survey of the lake was undertaken by boat to identify areas of weed, what types of weed were present, the density of weed present and how much if any was surface reaching.

The weed was low density, mainly single strands with very little surface reaching, spread out over a 20 m zone located on the drop off from shallow to deep water about 1 km from shore. The majority of the weed was Lagarosiphon major with some native weed also present. The closest boat ramp area was North West of Ngongotaha. Howard Emeny, BOPRC Harvester contractor, estimated that it would take up to two hours for the harvester to collect one load, plus 20 minutes travel time to the boat ramp each way, and that the whole area contained about five to six loads of weed.

A recent diving survey undertaken by the BOPRC's biosecurity team found that the weed bed located around Kawaha Point contained Lagarosiphon, Elodea and Egeria.

Figure 12 shows the locations where weed was observed during the boat survey and the location of the Kawaha Point raft identified by the biosecurity team.

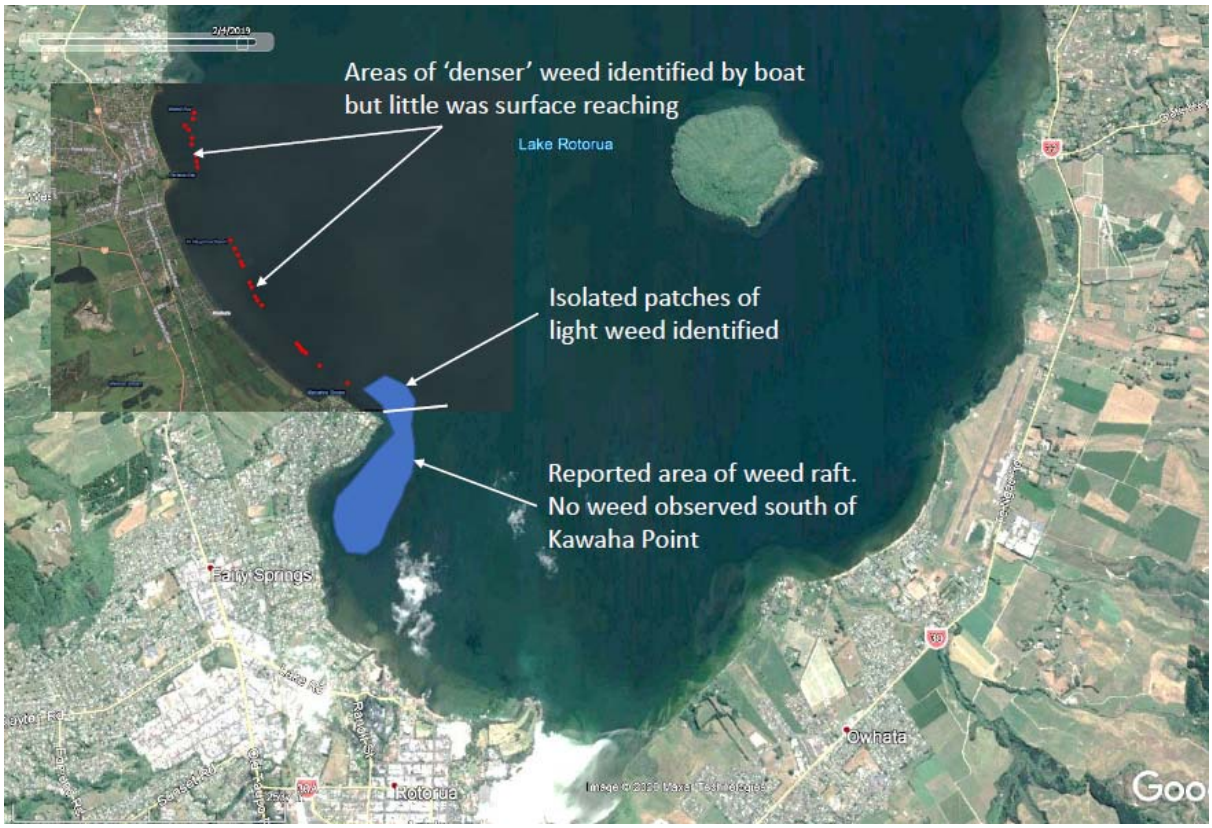

Figure 12 Map showing observations of weed growth from visual survey undertaken on 20/02/2020.

9.4.2 Nutrient contents of Lagarosiphon

For previous weed harvesting operations Hornwort has been the dominant weed species present and harvested. As such all nutrient and testing data has been done for hornwort. From the boat survey it was found that the majority of weed that was observed and present in Lake Rotorua was Lagarosiphon major. Research of academic literature was done to try and find data about the nutrient properties of Lagarosiphon. A research paper published in Hydrobiologia in 2018 tested lagarosiphon from the Kaituna River near Te Puke and found that the percent dry matter (%DM) was 14% with 2.66% Nitrogen and 0.25% Phosphorus (on a dried matter basis). These results indicate a significantly higher percentage dry matter for Lagarosiphon compared to Hornwort (2.9%-6.2% DM). With comparable nitrogen and phosphorus amounts, but higher dry matter, this would indicate that for the same weight of weed there would be larger nutrient reduction for lagarosiphon.

Samples of Lagarosiphon weed were collected from three locations around Kawaha Point in Lake Rotorua and from Hamurana Stream, which feeds into the Lake. These samples were sent for testing at Hill Laboratories for confirmation about the properties Lagarosiphon, particularly the dry matter and nutrient contents. The weed samples were also tested for heavy metal concentrations as there was concern raised over the arsenic levels due to geothermal activity in Lake Rotorua and how this might affect the weed disposal options.

Lab testing results found that the dry matter content for lagarosiphon was higher than hornwort as the literature suggested, although not as high as (Redekop et al., 2018). The percentages of dry matter, nitrogen and phosphorus as well as the total arsenic concentrations for the tested weed are shown in Table 8. For the weed samples taken from Lake Rotorua the arsenic levels were higher than the recommended guidelines for both NZS 4454:2005 and Biogro Std 2009 Appendix A. These guidelines recommend that arsenic concentrations should not exceed 20 mg/kg and the samples from Kawaha Point, Kawaha Point East and Kawaha Point West were 63 mg/kg, 68 mg/kg and 43 mg/kg respectively.

Table 8 Results of weed testing of Lagarosiphon from Lake Rotorua and Hamurana Stream.

Sample	Dry Matter (%)	Total Nitrogen (%)	Total Phosphorus (%)	Total Arsenic (mg/kg)
Hamurana Stream	8.2	3.61	0.66	4.0
Kawaha Point	6.4	4.23	0.41	63
Kawaha Point East	6.2	4.28	0.50	68
Kawaha Point West	7.7	3.86	0.34	43

9.4.3 MPI permissions

The current MPI permission that the BOPRC has for its weed harvesting operations is to collect and communicate hornwort for nutrient management purposes. The permission holder is the Bay of Plenty Regional Council and it expires on 30 April 2024. The permission allows the unwanted organism (hornwort) to be transported from any collection site within the Bay of Plenty Region to the dump site at 154 Pongakawa Valley Road for drying or directly to Ecocast, Tamarangi Drive Kawerau, for composting.

Under the Biosecurity Act 1993 Lagarosiphon is also classified as an unwanted organism. For any weed harvesting operation on Lake Rotorua an amendment/variation of the permission to transport Lagarosiphon instead of hornwort would be required. Also if a

different dump site for drying the weed or a different disposal method are to be used then this would also need to be put in the consent amendment.

9.4.4 Logistics

The main logistics to be considered were the availability of a suitable boat ramp and dump site as well as transportation of the weed. In order for any weed harvesting to be cost effective it is suggested that the operations need to be within a maximum distance of 1 km from an offload ramp. This creates limited possibilities. Possible boat ramps and launch sites were investigated and are shown in Figure 13 below.

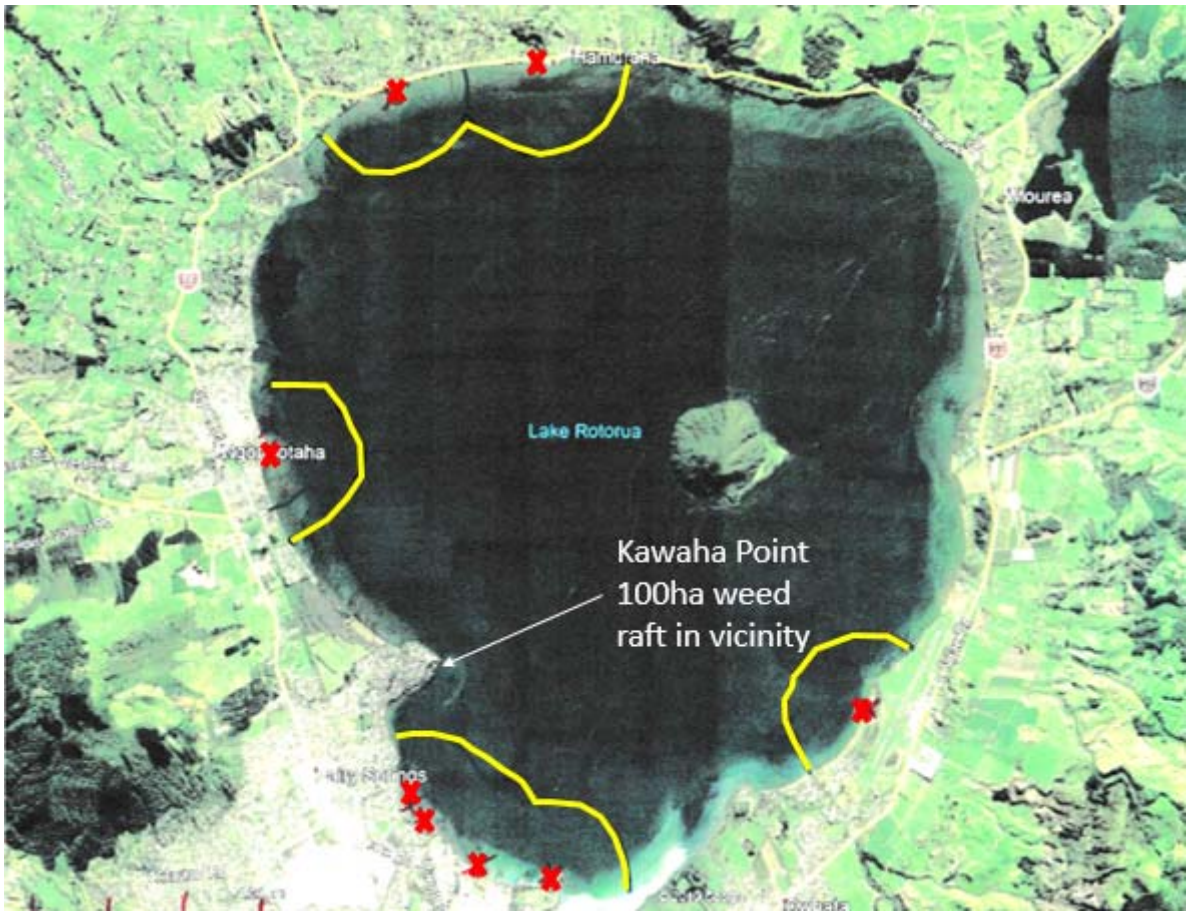

Figure 13 Lake Rotorua boat ramp locations (red crosses) with 1 km radius marked in yellow.

9.4.5 Disposal options

For the most recent harvesting operations undertaken in Lake Rotoehu and Lake Rotoiti the disposal method used was vermicomposting. For this investigation there were two main options suggested.

The first option suggested was a composting facility next to the Puarenga Wastewater treatment plant. This option is within the Lake Rotorua Catchment but as it is close to the lake the cost of transporting weed there would be lower. However, the plant is no longer in use and therefore not a viable option for weed disposal.

The second option considered was vermicomposting at Ecocast Kawerau. Bay of Plenty Regional Council has disposed of lakeweed here previously and they are still in operation. Kawerau is out of the catchment and transport costs would be higher. There was also some concern about the levels of heavy metals, particularly arsenic, in the weed due to the geothermal activity in Lake Rotorua. After testing samples of weed taken from different

locations in Lake Rotorua the concentration of arsenic in all three samples exceeded the recommended guidelines for both NZS 4454:2005 and Biogro Std 2009 Appendix A. The arsenic concentrations were between 43 mg/kg to 68 mg/kg which are between double and triple the recommended guideline value of 20 mg/kg. These high arsenic concentrations may pose an issue for weed disposal via vermicomposting at Ecocast Kawerau.

9.4.6 Nutrient removal benefits of Lagarosiphon and Hornwort

A way to estimate how much nitrogen or phosphorus could potentially be removed by a weed harvesting operation is to use an approximation of the amount of nutrient removed per tonne of weed. This has been calculated for major nutrients of concern; nitrogen and phosphorus, as well as lagarosiphon and hornwort.

The total nitrogen removed per tonne of weed (kg-N/tonne) and total phosphorus per tonne of weed (kg-P/tonne) for lagarosiphon and hornwort are shown in tables 9 and 10 respectively. These show the potential Nitrogen and Phosphorus removal rates per tonne of weed and give a range of values based on available nutrient testing data.

With these values nitrogen and phosphorus removal for 1 tonne of lagarosiphon can be compared to 1 tonne of hornwort. Harvesting hornwort removes 1.1-1.7 kg-N per tonne of weed and 0.1-0.026 kg-P per tonne of weed. Harvesting lagarosiphon yield significantly higher nutrient removal per tonne of weed with 2.7-3.0 kg-N removed per tonne of weed and 0.26-0.31 kg-P removed per tonne of weed.

Table 9 Lagarosiphon properties including nutrient removal per tonne of weed. Weed samples from Lake Rotorua.

Sample	Dry Matter (%)	Total Nitrogen (%)	Total Phosphorus (%)	Total Arsenic (mg/kg)	Dry Matter (kg/tonne)	Total Nitrogen (kg-N/tonne)	Total Phosphorus (kg-P/tonne)
Hamurana Stream	8.2	3.61	0.66	4.0	82	2.96	0.541
Kawaha Point	6.4	4.23	0.41	63	64	2.71	0.262
Kawaha Point East	6.2	4.28	0.50	68	62	2.65	0.310
Kawaha Point West	7.7	3.86	0.34	43	77	2.97	0.262

Table 10 Hornwort properties including nutrient removal per tonne of weed. Weed samples from Lake Rotoiti and Lake Rotoehu.

Sample	Dry Matter (%)	Total Nitrogen (%)	Total Phosphorus (%)	Dry Matter (kg/tonne)	Total Nitrogen (kg-N/tonne)	Total Phosphorus (kg-P/tonne)
Lake Rotoiti - Okawa Bay Apr 2014	2.9	3.9	0.39	29	1.13	0.113
Lake Rotoiti 2009	4.3	3.42	0.732	43	1.47	0.315
Lake Rotoehu 2006	4.0	3.0	0.4	40	1.2	0.16
Lake Rotoehu 2009	6.2	2.55	0.275	62	1.58	0.171
Lake Rotoehu 2013	4.6	3.68	0.57	46	1.69	0.262
Lake Rotoehu 2014	5.8	2.22	0.18	58	1.29	0.104

These values can also be used to estimate the nutrient removal if a weed harvest were to be undertaken in Lake Rotorua this year. Based on visual observations of weed growth, it was estimated that currently the area of harvestable weed growth is about five to six

loads. The harvesters can hold 11 m^3 of weed per load so this would equate to 55 m^3-66 m^3 of weed. Assuming that 1 m^3 of wet weed weighs 500 kg (this was what was established for hornwort from the 2006 Lake Rotoehu trial, and using this as a rough estimate for lagarosiphon), then the harvestable weight of wet weed would be 27.5–33 tonnes. Using the data from Table 9 a weed harvest could remove approximately 73 kg-98 kg nitrogen and 7.2 kg-10.2 kg phosphorus.

9.5 Conclusions and recommendations

Based on the visual observations from the boat survey and Howard Emeny's knowledge and experience he recommended that it would not be cost effective to carry out a harvesting operation in Lake Rotorua this year if the justification was for nutrient reduction purposes only.

The BOPRC harvester can hold 11 m^3 of weed per load and operates at peak efficiency in dense weed (see Figure 10 for an example of dense weed) where it can collect a load approximately every six minutes. With the current weed growth in Lake Rotorua it would take up to two hours for the harvester to collect a load of weed, plus 40 minutes travel time per load. The area of weed surveyed only holds approximately five to six loads of weed. Based on this and the lagarosiphon testing results, if the weed harvesting in Lake Rotorua were to proceed approximately 73 kg-98 kg of nitrogen and 7.2 kg-10.2 kg of phosphorus would be removed.

Based on the visual observations, Howard's recommendation and the estimated nutrient reduction benefits the decision was made that a harvesting operation in Lake Rotorua this year should not proceed.

9.5.1 Recommendations for any future weed harvesting in Lake Rotorua

In the future, should the weed growth in Lake Rotorua increase in area (becoming predominantly surface reaching and denser) a harvesting operation may become viable. In such a case the following recommendations are made:

- Elodea and Egeria may need further investigation. The diving survey of the weed raft at Kawaha Point done in March found that these species of weed were also present and dominated in some areas. If these are what has the potential to be harvested, more information and testing may be required to establish their properties and potential nutrient removal rates.
- For the logistics of future operations the following would need to be investigate/organised; the availability of a suitable boat ramp for the harvester and trailer, a weed dump site area for the weed collected to dry out and the transport and disposal of the weed from the dump site.
- The current MPI permission is to collect and communicate hornwort for nutrient management purposes. For future weed harvesting operations in Lake Rotorua, BOPRC would need to make a request for an amendment/variation of the permission to transport Lagarosiphon (and potentially Elodea and Egeria as well) instead of hornwort. Also if a different dump site for drying the weed or a different disposal method are to be used then these would also need to be put in the consent amendment.
- If, in the future, there are sufficient amounts of weed to harvest then estimating how potentially effective weed removal would be, the rates and method described in Section 9.4.6 can be used to calculate the nutrient removal of a weed harvest.

10 References

Department of Conservation. (n.d.). *Freshwater weeds: Common weeds*. Retrieved from Department of Conservation: https://www.doc.govt.nz/nature/pests-and-threats/weeds/common-weeds/freshwater-weeds/

Lakes Water Quaility Society. (2017). *Lake Rotoiti*. Retrieved from Lakes Water Quailty Society: https://lakeswaterquality.co.nz/lake-rotoiti/

Ministry for Primary Industries. (2020). *Pest and disease search*. Retrieved from Biosecurity New Zealand: https://www.biosecurity.govt.nz/protection-and-response/finding-and-reporting-pests-and-diseases/pest-and-disease-search/

NIWA. (2015). *Invasion sequence of four submerged invasive alien aquatic plants (Elodea canadesis, Egeria densa, Lagarosiphon major and Ceratophyllum demersum) in the Rotorua Lakes.* Retrieved from https://niwa.co.nz/freshwater-and-estuaries/freshwater-and-estuaries-update/freshwater-update-6-may-2015/weeds-and-the-rotorua-lakes

NIWA. (2015, May 12). *Weeds and the Rotorua Lakes*. Retrieved from NIWA Climate, Freshwater & Ocean Science: https://niwa.co.nz/freshwater-and-estuaries/freshwater-and-estuaries-update/freshwater-update-6-may-2015/weeds-and-the-rotorua-lakes

NIWA. (2017). *Freshwater Aquatic Plants*. Retrieved from NIWA Climate, Freshwater & Ocean Science: https://niwa.co.nz/freshwater-and-estuaries/our-services/aquaticplants/outreach/education#benefits

NIWA. (2019). *Best management practice for aquatic weed control. Part one: the Framework.* NIWA Client Report 2019047HN.

Redekop, P., Nultens, A., Gross, E. M., Hofstra, D. E., Clayton, J. S., & Hussner, A. (2018). Hygraula nitens, the only native aquatic caterpillar in New Zealand, prefers feeding on an alien submerged plant. *Hydrobiologia, 812*, pp. 13-25. doi:10.1007/s10750-016-2709-7

Rotorua Lakes . (2020). Retrieved from New Zealand on the Web: http://www.rotorua.nz.com/lakes.aspx

Rotorua Te Arawa Lakes Trust. (2017). *Love our Lakes*. Retrieved from Rotorua Te Arawa Lakes Programme: https://www.rotorualakes.co.nz/

Weedbusters. (2020). *Hornwort weed information sheet*. Retrieved from Weedbusters: https://www.weedbusters.org.nz/weed-information/weed-list/hornwort/