NIWA
Taihoro Nukurangi

Flora and fauna survey for the Hydrilla eradication response 2016

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Executive summary

MPI (Ministry for Primary Industries) is undertaking a biosecurity response to manage and eradicate the submerged weed hydrilla (*Hydrilla verticillata* (L.f.) Royle) from the Hawke's Bay, and hence from New Zealand. The tools for the hydrilla eradication response included an initial application of the aquatic herbicide endothall (Aquathol® K), and introduction of the herbivorous fish grass carp (*Ctenopharyngodon idella*) into the affected lakes in December 2008. A second release of grass carp was made in December 2014.

In autumn 2016, NIWA was contracted by MPI to carry out a vegetation survey at the baseline sites in the hydrilla affected lakes Tutira, Waikōpiro and Opouahi, and a macroinvertebrate survey in Lake Tutira to determine the status of the hydrilla and document any changes in the flora and fauna.

Plants and macroinvertebrates were surveyed at the 13 of the 15 sites established in Lake Tutira in 2008. Two sites at the northern end of the lake were not surveyed as permission from the owners was not granted. Plants were surveyed at five baseline sites in each of the smaller lakes, Waikōpiro and Opouahi.

For the first time since the MPI response commenced, no hydrilla plants were recorded in any of the three lakes (Tutira, Waikōpiro and Opouahi).

In all three lakes, shallow water turf plants and/or marginal emergent plants were present. In Lake Waikōpiro, two species (*Glossostigma elatinoides* and *Nitella hyalina*) were recorded in shallow water. In Lake Opouahi, *Ranunculus trichophyllus* was the only submerged species recorded outside of grass carp exclosure cages. In Lake Tutira, the native aquatic plant *Myriophyllum triphyllum* (milfoil), that had previously expanded its distribution and cover following removal of the hydrilla, remains the most abundant aquatic plant however its cover has reduced over the last year. While the number of macroinvertebrate taxa recorded from Lake Tutira was the same as that obtained before the hydrilla weed beds were removed, chironomids and mites now dominate. Eels, mussels and abundant bullies were also observed by the SCUBA divers in Lake Tutira.

In Lake Opouahi, vegetation in the grass carp exclusion cages was assessed. Only one of the 30 (small and large) cages had established charophytes. Factors described as potentially contributing to the lack of charophyte establishment within the cages (i.e., demise of young charophytes), include localised sediment movement resulting in oospore (seed) burial, and sediment disturbance by native fish. The use of a hessian benthic barrier (like a weed mat) in new cages is proposed as a method to stabilise sediments in cages to support charophyte regeneration in this lake. This method has previously been shown to provide a substrate through which oospores can germinate and grow.

Based on the autumn 2016 monitoring results and the MPI goal to eradicate hydrilla from New Zealand, it is recommended that a reduced flora and fauna survey takes place in autumn 2017. The survey should include an assessment of aquatic vegetation at the baseline sites in Lake Tutira only. Additional activities in Lake Tutira should include, a search for hydrilla on the shallow water plateau, and sampling for mussels in the shallow water of the baseline sites. In Lake Opouahi assessment of vegetation in exclosure cages and the installation of a new type of exclosure cage with a hessian benthic barrier is recommended to continue to foster the regeneration of charophytes, with the goal of providing protected spaces in which native species can establish and serve as seed sources during the hydrilla eradication response.

It is recommended that vegetation assessments along the baseline survey sites in Lakes Waikōpiro and Opouahi are next undertaken in two or three years (in 2018 or 2019, timed to align with Tutira surveys). Monitoring information will be used to inform the timing and frequency of future surveys.

1 Introduction

Hydrilla (*Hydrilla verticillata* (L.f.) Royle) is a submerged aquatic weed classified as a notifiable organism[1] that is only found in the Hawke's Bay, and has been identified as a pest for eradication as a National Interest Pest Response (NIPR).

MPI (Ministry for Primary Industries) developed a plan to manage and eliminate hydrilla in Lakes Tutira, Waikōpiro and Opouahi and to achieve the goal of eradication from New Zealand (MAF 2008). The tools to achieve eradication include stocking the herbivorous fish grass carp (*Ctenopharyngodon idella*) for sustained grazing pressure on the hydrilla, in conjunction with the aquatic herbicide endothall (Aquathol K). Endothall was applied at select sites in Lakes Tutira and Waikōpiro that posed a high risk of plant transfer. In May 2008, before the introduction of grass carp and the use of endothall (December 2008), a comprehensive baseline survey of the flora and fauna in the hydrilla affected lakes was undertaken (Hofstra et al. 2008), with an additional fish survey in spring 2008 (Hofstra and Smith 2008).

To document changes in the lakes, monitoring of flora and fauna within all three lakes at the established baseline sites has been undertaken annually, in autumn, since the grass carp were released. To date, the most significant change has been the removal of the hydrilla weed beds (by autumn 2010) and subsequent to the reduction in hydrilla weed beds, a further fish survey was undertaken in spring 2011 (Smith and Rowe 2011). Additional operations to the hydrilla eradication response have included the installation and monitoring of grass carp exclusion cages in Lake Opouahi. Cages have been installed at seven littoral zone sites, which historically contained native charophytes as opposed to hydrilla, to enable regeneration of charophytes in the absence of grass carp browsing and provide native biodiversity refugia during the hydrilla eradication response (Hofstra 2015). A feasibility assessment for similar exclosure cages in Lake Tutira was also carried out along with an assessment of obstructions to grass carp grazing in Lake Tutira and marking of hydrilla plants on the shallow water plateau in Lake Tutira (Hofstra 2013a).

Based on the findings from the flora and fauna survey in April 2014 (Hofstra 2014) 500 juvenile grass carp were stocked in Lake Tutira (December 2014) and a reduced survey, including macrophytes (plants) in all three lakes and macroinvertebrate in Lake Tutira only, was undertaken in autumn 2015 (Hofstra 2015). Following the continued presence of individual hydrilla plants in Lake Tutira in 2015, MPI contracted NIWA to undertake a further reduced survey in autumn 2016.

This report records and describes the findings from the three lakes:

- Lake Tutira - Aquatic vegetation and macroinvertebrate survey, including monitoring the marked sites and searching for hydrilla on the plateau.
- Lake Waikōpiro – Aquatic vegetation survey.
- Lake Opouahi - Aquatic vegetation survey and exclosure cage assessment.

[1] Biosecurity Notifiable Organisms Order 2006

2 Methods

2.1 Lake Tutira

2.1.1 Aquatic Plant Survey

Photographed landmarks and GPS co-ordinates were used to locate the survey sites in Lake Tutira (Figure 1) (Hofstra et al. 2008). The sites were the same as those surveyed in autumn each year since 2008 with the exception of sites T15 and T18 at the north end of the lake (Figure 1). These sites were omitted from survey in 2016 because access permission was not forthcoming from the lake owners.

At each site, vegetation was recorded by a SCUBA diver along the profile (ca. 2 m wide) down the gradient to the maximum depth of historic plant growth (ca 8 m). Observations were recorded while diving through the profile. Data recorded included plant species present, their depth range, height (maximum and average) and cover (maximum and average). The scale used for plant cover was a modified Braun-Blanquet scale where 1 represents 1–5% cover, 2 was 6–25%, 3 was 26–50%, 4 was 51–75%, 5 was 76–95% and 6 was 96–100% cover (Clayton 1983). The presence of aquatic fauna including koura, mussels, fish and eels and a general description of the site, such as visibility, length and maximum depth of the profile were also recorded (Clayton 1983).

2.1.2 Plateau Plants in Lake Tutira

SCUBA divers assessed hydrilla plants on the shallow water plateau (Figure 1, bathymetric map) that had previously been marked (February and April 2013, Hofstra 2013 a, b). The plant markers were located, presence/absence of hydrilla was recorded and photographs were taken. Underwater scooters were also used to search the plateau for hydrilla.

2.1.3 Invertebrate Sampling

Sample sites corresponded with the aquatic plant profile sites used in the 2008 baseline survey (Hofstra et al. 2008) as these represented a variety of the habitat types known to be present in the lake (Figure 1).

Along each profile, macroinvertebrate communities were sampled by a SCUBA diver from three zones defined by existing or historic vegetation characteristics (i.e., turf community, macrophyte community where the dense hydrilla beds had previously occurred (ca. 4 m water depth), and bare sediment at a water depth below which plants had occurred (Figure 2)).

Zone 1. Shallow water/Turf community

The shallow water zone at the lake margin is comprised of a turf plant community, willow trees either standing or felled extending into the lake, tall emergent vegetation and/or bare sediment. This zone was sampled at less than ca 1.5 m water depth. The area for sampling was defined by a quadrat (25 x 25 cm), any plants present were aggressively raked with hands to dislodge organisms and these were scooped into the Wisconsin nets (500 µm mesh). This included organisms in the top 1cm of sediment and those that had fallen from plants. This was done three times (in 3 different quadrats) and the samples were pooled into the net and removed to the water surface for sieving and sorting. A description of plant cover in each quadrat was also recorded along with mussel presence or absence.

Zone 2. Macrophyte Community

Dense hydrilla weed beds previously occupied this area. During this survey, plants were absent or sparse at most sites. The quadrat procedure (as described for zone 1) was used to sample from the range of habitats present (i.e., plants or bare sediment), and a core (8.5 cm diameter by 10 cm depth) was used to sample benthic macroinvertebrates in order to enable comparison with previous sampling events from this zone.

Zone 3. Benthic Community

Benthic macroinvertebrates were sampled beyond the deeper margins of the weed bed (where there were no plants) at greater than 6 m water depth in all lakes. The area for sampling was defined by a quadrat (25 x 25 cm), where the top 1 cm of sediment was scooped into a Wisconsin net (500 µm mesh). This was repeated three times (in 3 different quadrats), and the samples were pooled into the bottom of the Wisconsin net which was then secured off before surfacing.

Invertebrate Identification

Onshore, the macroinvertebrate samples were washed out of the Wisconsin net (or core), sieved (500 µm) and placed in sorting trays marked with grids (ca. 6 cm x 6 cm). Water from a wash bottle was used to evenly spread the sample across the tray. Using the fixed count method (Stark et al. 2001), and systematically working from one grid in the tray to another, macroinvertebrates were picked out using forceps, counted and placed in glass Petri dishes. After 200 macroinvertebrates were counted the grid count was completed, the number of grids counted was noted, and then the sample was scanned for rare taxa. When fewer than 200 macroinvertebrates were present in a grid, successive grids were also counted. Where fewer than 200 macroinvertebrates were present in the tray, the entire sample was counted. Macroinvertebrates were identified using Winterbourn et al. (2006) and numbers recorded. The lengths of any mussels present in the sample were recorded. Following identification and counting, samples were released back into the lake.

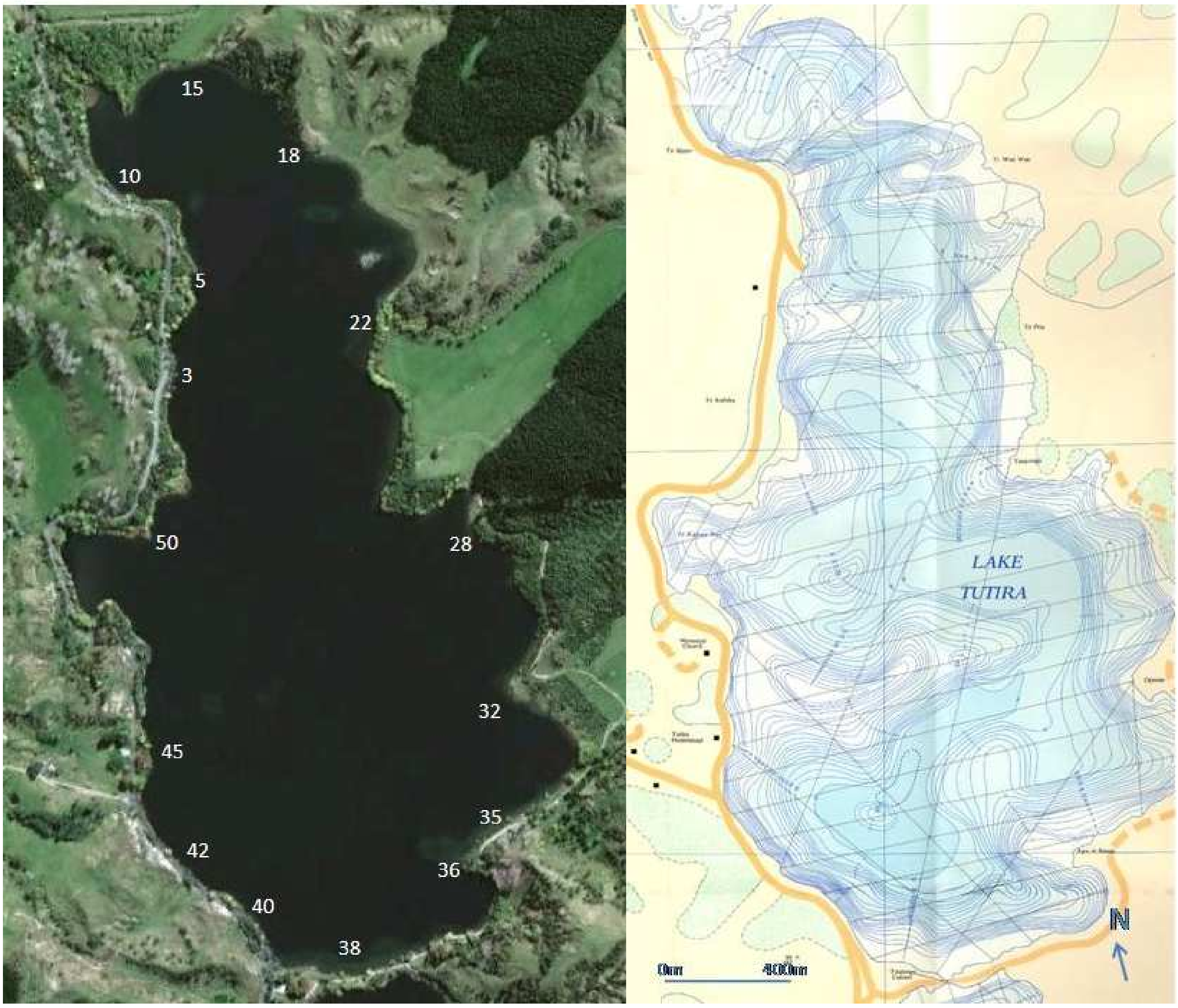

Figure 1: Lake Tutira showing macrophyte and invertebrate sample sites (left) and a bathymetric map (Irwin 1978) showing the shallow water plateau in the southern part of the lake (right).

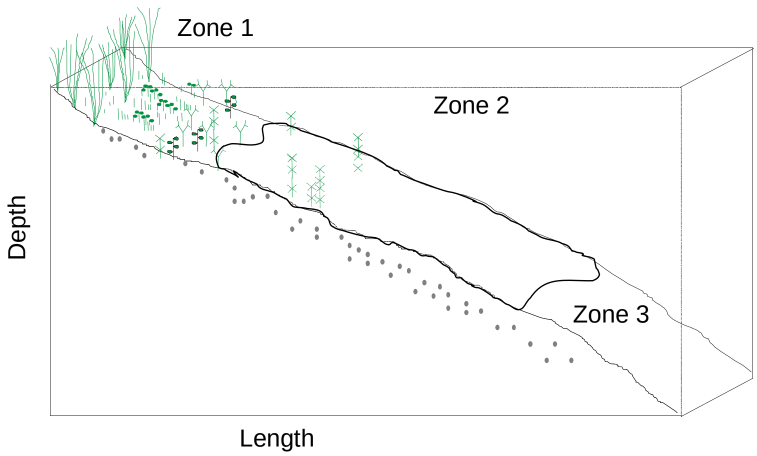

Figure 2: Diagrammatic plant profile showing the zones from which invertebrates were sampled within the lakes. (Source M. de Winton).

2.2 Lakes Waikōpiro and Opouahi aquatic plant survey

2.2.1 Aquatic plant survey

Five sites in Lakes Waikōpiro and Opouahi were surveyed for aquatic vegetation (Figure 3). These were the same sites as those surveyed in autumn each year since 2008. The sites were located by GPS co-ordinates and photographed landmarks (Hofstra et al. 2008).

The aquatic plant survey method is described above (see Section 2.1.1).

Figure 3: Lakes Waikōpiro (left) and Opouahi (right) showing survey and exclosure cages sites. Numbers refer to the survey sites for both lakes. On Lake Opouahi the large and small asterisks represent the large and small exclosure cages respectively and the star represents the tunnel cage.

2.2.2 Exclosure cage assessment

In Lake Opouahi SCUBA divers assessed the presence/absence of vegetation in 15 large and 15 small submerged exclosure cages (at a total of six sites with five cages at each) that were installed in February 2012 and a single tunnel cage that was installed in April 2015 (Figure 3). Photographs were taken of each cage to compare with previous images to assess charophyte emergence and growth, and to provide an estimate of localised changes in sediment level (if any), and hence the potential for burial of charophyte oospores. Temperature and light loggers that had been installed on the tunnel cage were removed and downloaded.

3 Results and Discussion

No hydrilla plants or propagules were found in any of the three lakes.

Vegetation and macroinvertebrates trends are in-line with those described in the assessment of environmental effects (AEE) prior to the stocking of grass carp (Hofstra and Rowe 2008). However, it is also noted that the lakes are subject to changes that are not attributed to the MPI response, such as unprecedented surface water temperatures in Lake Tutira during the summer of 2015-2016 with an associated algal bloom (see section 3.1). Although the lakes have been subject to severe algal blooms historically (e.g., TTC 1977, Tierney 1980, 2008), and elevated surface water temperature is not an isolated occurrence (O'Reilly et al. 2015), such high temperatures and periods of calm weather drive limnological processes (e.g., Green et al. 1987) and algal blooms that can in turn compromise submerged macrophyte growth (e.g., through shading) and habitat for faunal diversity.

3.1 Lake Tutira

Information gathered by the SCUBA divers from Lake Tutira is presented in Appendix A. The divers reported poor water clarity with visibility of only ca. 1.5 m. The low visibility was associated with a severe algal bloom that was monitored by HBRC (Hawkes Bay Regional Council) throughout the summer, and included high surface water temperatures (< 30°C) and fish kill events (e.g., HBRC website January 29th 2016; http://www.hbrc.govt.nz/our-council/news/latest-news/media-releases/article/14). Neither mussels nor eels were observed as frequently by divers compared with the previous year, bullies however were abundant (as were their eggs, Figure 4) and present at all survey sites. No koura were located. The boat crew reported dabchicks, herons, shags (black, little and pied), black swans, coot, scaup, shoveler and mallard ducks during the survey period.

3.1.1 Aquatic plant survey

No hydrilla was found in Lake Tutira. In addition to surveying the baseline sites, extensive searches were made by SCUBA divers at those sites where hydrilla was found in 2015 (i.e., sites on the eastern shore and causeway). No plants were detected (Table 1, Appendix A1).

Lake Tutira continues to support a range of low growing turf, and marginal emergent plants (e.g., *Typha orientalis*) (Table 1 and Appendix A1). The turf plant species occurred in water less than ca. 1 m deep at generally very low cover values, while the *T. orientalis* was in water less than 0.4 m deep (Table 1) and remains dense only where it is inaccessible to grass carp. Aquatic plants found in deeper water (ca. 2.5 m) were charophyte germlings, or milfoil (*Myriophyllum triphyllum*) which occurred down to 3.2 m. As in previous years since the removal of the hydrilla weed beds, milfoil was the dominant submerged plant. However the abundance of milfoil has declined since 2015, with plants now generally smaller and less dense than they were in April 2015 (Figure 5). Whilst browsed shoot tips were evident amongst the milfoil plants, extensive algal growth was also noted on submerged plants (Figure 6) and along with the sustained summer algal bloom and low water clarity is also likely to have had an impact on the growth of all submerged plants (Clayton and Edwards 2006).

As this was the first survey that no hydrilla was located in Lake Tutira, a further vegetation survey is recommended for April 2017.

Figure 4: **Bully eggs cover the surface of a small rock.**

Table 1: **Lake Tutira vegetation summary.**

Plant species	No. of sites where found	Depth range (m)	Height (m)		Cover	
			max	ave	max	median
Bolboschoenus fluviatilis	1	0.2				
Chara australis	6	0.9-2.5	0.1	0.07	2	1
Glossostigma diandrum	5	0-0.6			3	2
Glossostigma elatinoides	4	0-0.8			5	1
Lilaeopsis ruthiana	7	0-0.8			3	1
Myriophyllum triphyllum	13	0-3.2	0.2	0.1	6	1
Nitella hyalina	2	0.1-1	0.1	0.07	1	1
Ranunculus limosella	2	0-0.6			3	1
Ruppia polycarpa	3	1.4			1	1
Typha orientalis	5	0-0.2	3	2.5	5	4

NB: Cover data 1=1–5%, 2=6–25%, 3=26–50%, 4=51–75%, 5=76–95%, 6=96–100%. Marginal plants include *Bidens frondosa, Carex maorica, Cyperus eragrostis, Eleocharis acuta, Lotus pedunculatus, Lycopus europaeus, Persicaria decipiens* and *Symphyotrichum subulatum.* Two of the 15 survey sites were not assessed as access was not granted by the owners.

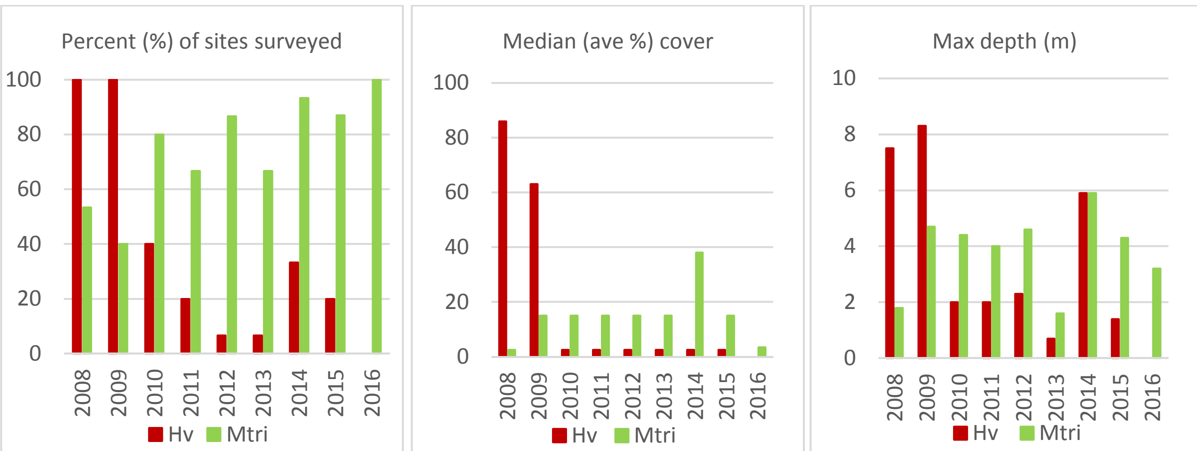

Figure 5: **Hydrilla and milfoil abundance from 2008 to 2016.** Hydrilla and milfoil are represented by the abbreviations Hv and Mtri respectively.

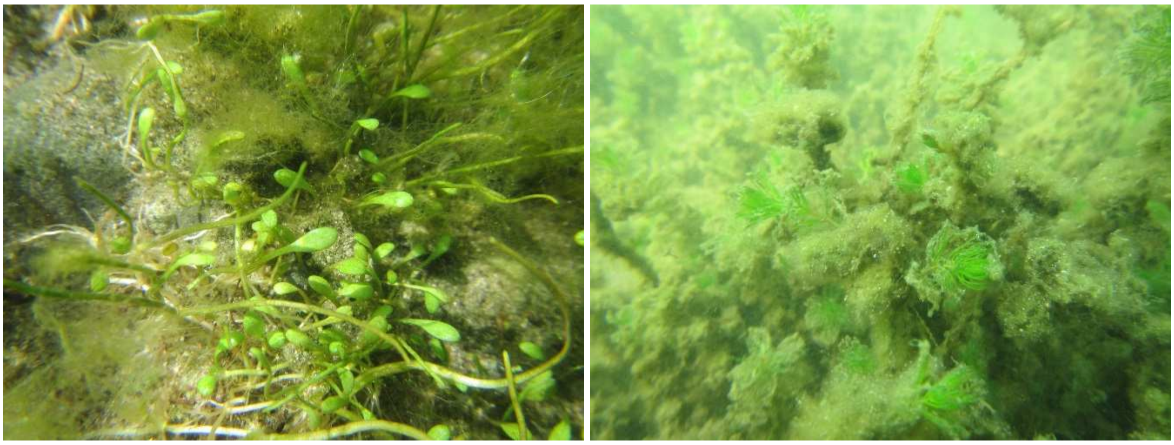

Figure 6: Aquatic plants from site 32 in Lake Tutira. The plants shown here are covered with filamentous algae both on turf forming plants (*Glossostigma diandrum* and *Lilaeopsis ruthiana*) in shallow water (left) and the milfoil (right) where only a small portion of the plant shoots are green and clean (Photo by A Taumoepeau).

3.1.2 The plateau

The markers (stakes) that were placed adjacent to hydrilla plants on the shallow water plateau in February and April 2013 were located and assessed. No hydrilla was found on the plateau.

In April 2014 and 2015, half of the stakes had adjacent hydrilla plants, which although browsed the plants were observed with new growth (Hofstra 2015). In 2016, not only were there no hydrilla plants adjacent to the stakes, but there was also less milfoil on the plateau, and the milfoil plants consistently showed signs of having been browsed (Figure 7). In addition to assessing the stakes, SCUBA divers used underwater scooters to enable a survey of a wider area of the plateau for hydrilla. No hydrilla was found during that search.

As this is the first year that no hydrilla plants have been recorded on the plateau, the next vegetation survey is recommended to occur in April 2017.

Figure 7: Native milfoil on the plateau. The images show plants of short stature with browsed shoot tips, and low abundance (Photos by M de Winton).

Figure 8: Stakes on the plateau. In these images stakes are seen in 2015 (top) with arrows indicating the hydrilla, compared with 2016 (lower images) where there is no hydrilla and more open, low stature native milfoil vegetation is present (Photos by M de Winton).

3.1.2 Invertebrates

The total number of taxa recorded from Lake Tutira was within the range of values obtained before the hydrilla weed beds were removed by the grass carp (i.e., 2008 and 2009, Table 2), and the taxa recorded in this current survey were also present in previous surveys (Figure 9, Appendix A2).

Samples from the shallow water (zone 1) in general had higher macro-invertebrate diversity than the deeper water samples (zone 3), a trend that was also apparent in 2008 and 2009, prior to the removal of the hydrilla weed beds (Table 2). The most abundant macroinvertebrates were chironomids and mites. In particular, chironomids dominated the samples from zones one and two, compared with zones 3 samples that were dominated by mites (Appendix A2).

Table 2: **Number of taxa per zone in Lake Tutira.**

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total	19	14	18	20	16	16	19	19	18
Zone 1	16	14	15	18	16	16	18	19	15
Zone 2	16	14	15	14	15	14	17	18	13
Zone 3	6	3	10	8	11	9	15	15	5

Mussels were recorded in the macro-invertebrate samples from nine of the thirteen sites. However, diver's observations confirm mussels were present at the four sites where mussels were not amongst the invertebrate samples. There were fewer mussels amongst the invertebrate samples in 2016 compared with counts from 2014 and 2015 (Figure 10). The largest number of mussels recorded from any one site was on the western shore site (T45, zone 1), a site characterised by fine sediment over a firm base (diver's notes). Although mussels are recognised for their patchy distribution and variable abundance (Roper and Hickey 1994), the potential for fluctuations in numbers as a consequence of rat predation (Hofstra 2013b), and/or poor water quality and low DO (dissolved oxygen) events have been described (e.g., Champion and Burns 2001, McDowall 2002, Nalepa et al. 2007 (for other taxa). Continued monitoring of mussels in Lake Tutira, including observations by the divers provides a valuable opportunity to develop a better understanding of mussel population structure.

In general, the trends in macroinvertebrate data are consistent with those outlined in the assessment of environmental effects prior to the stocking of grass carp (Hofstra and Rowe 2008). It was recognised that there would be a reduced number of caddis, dragon and damselfly larvae and snails, and an increase in the number of chironomid larvae in the benthos that would support an increase in the abundance of common bullies (Hofstra and Rowe 2008 and references therein), in turn providing food for predatory fish (trout and eels). Given that the trends are in-line with predicted outcomes, it is recommended that frequency of macroinvertebrate monitoring is reduced, with the next macroinvertebrate survey timed to coincide with the first flora survey after April 2017 (potentially in two to three years, April 2018 or 2019). However, given the variable nature of mussel data in general, the recent severe algal bloom in the lake and the apparent drop in numbers this year, the next mussel survey is recommended for April 2017. It is envisaged that the mussel survey takes place in conjunction with the flora survey for Lake Tutira, and only targets zone 1 (shallow water below ca. 1.5 m, using the method in 2.1.3) as this is where the majority of mussels have been located in the past. Divers should continue to record observations of mussel presence or absence along the full length of the profile.

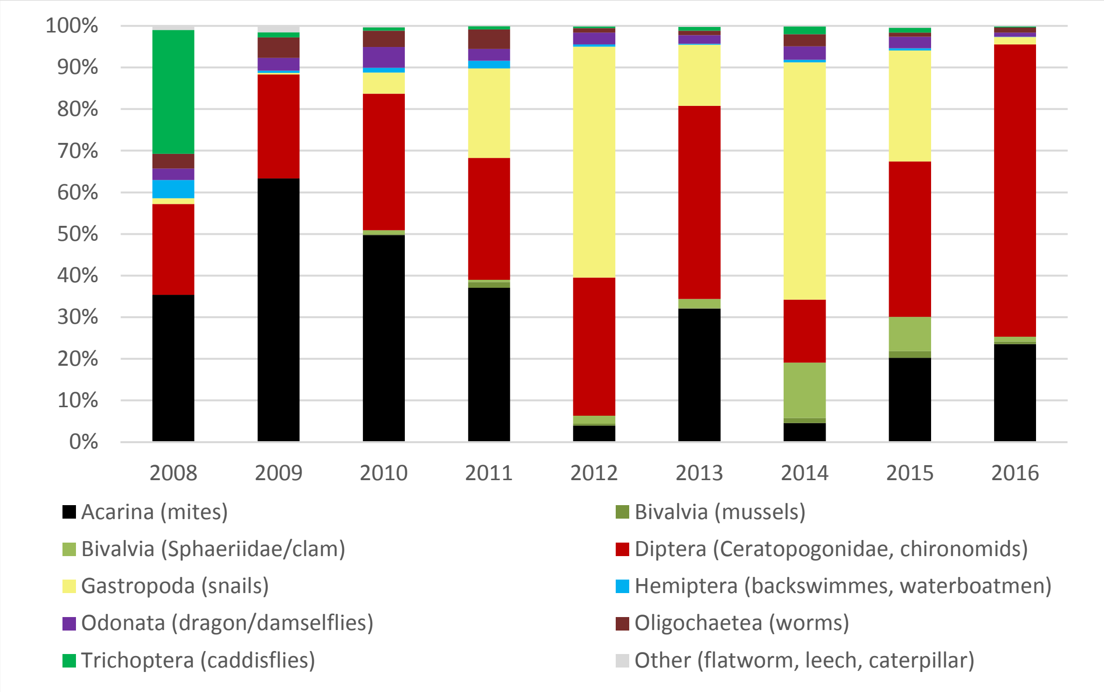

Figure 9: The relative abundance of macroinvertebrate taxa from 2008 to 2016 autumn surveys.

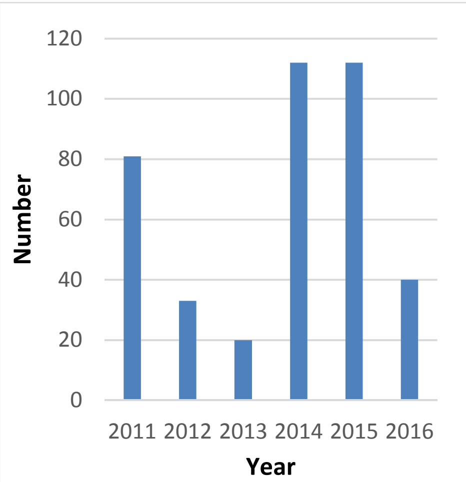

Figure 10: Mussel summary. The number of mussels recorded from 2011 to 2016 amongst macroinvertebrate samples (left), and a mussel in shallow water amongst short growing native plants at site T32, zone 1 (right) (Photo by A Taumoepeau).

3.2 Lake Waikōpiro

Information gathered by the SCUBA divers from Lake Waikōpiro is presented in Appendix B. In summary, the divers reported better water clarity (visibility ca. 1.8 m) than in the adjacent Lake Tutira. The divers observed numerous bullies and four eels in the lake and the boat crew reported a white-faced heron, four dabchicks and twelve mallard ducks on the lake.

The marginal emergent flora included 16 species (Table 3), of all which have previously been recorded from Lake Waikōpiro. *Nitella hyalina* was restricted to the shallow water, all other taxa extended from the water to the lake margins. All species had low cover values within the lake.

No hydrilla was found in Lake Waikōpiro. Hydrilla plants were last reported in this lake in 2008, and a propagule (turion) was last seen in 2012. However, it is recognised that the high rainfall events (as occurred in April 2012, Hofstra 2012) that resulted in flooding of the causeway between Lakes Waikōpiro and Tutira may have enabled the migration of grass carp (Hofstra et al. 2014) and reduced the browsing pressure in Lake Waikōpiro. Whilst monitoring of Lake Waikōpiro is still recommend, the consistent result of zero hydrilla in Lake Waikōpiro since 2012 indicate that it is now timely to reduce the frequency of vegetation monitoring (Hofstra and Rowe 2008).

It is recommended that Lake Waikōpiro vegetation is next monitored in conjunction with the first vegetation survey of Lake Tutira that takes place after 2017 (i.e., in two to three years).

Table 3: List of marginal aquatic plants from Lake Waikōpiro.

Plant species recorded from multiple sites (max 5)		Plant species recorded from one site
Alnus glutinosa	3	*Agrostis stolonifera*
Carex maorica	3	*Bidens frondosa*
Carex virgata	5	*Carex dipsacea*
Cyperus eragrostis	2	*Centella uniflora*
Cyperus ustulatus	2	*Coprosma propinquum*
Eleocharis acuta	4	*Euchiton japonicus*
Glossostigma diandrum	2	*Galium palustre*
Glossostigma elatinoides	5	*Hydrocotyle pterocarpa*
Lilaeopsis ruthiana	2	*Juncus edgariae*
Ludwigia palustris	4	*Lythrum hyssopifolia*
Lycopus europaeus	5	*Myriophyllum propinquum*
Myosotis laxa	3	*Persicaria hydropiper*
Nitella hyalina	2	*Salix alba* var. *vitellina*
Paspalum disctichum	5	*Schedonorus arundinaceus*
Persicaria decipiens	2	*Schoenoplectus tabernaemontani*
Symphotrichum subulatum	5	*Triglochin striata*

3.3 Lake Opouahi

Information gathered by the SCUBA divers from Lake Opouahi is presented in Appendix C. In summary the divers reported reasonable water clarity with visibility of ca. 2m. Eel holes in the lake sediment were evident and one eel was observed. This year a single dense patch of mussels was found in Lake Opouahi at site 5 at ca. 2.6 m water depth. The patch had ca. 30 mussels with a further 10 mussels located nearby (Figure 11). The boat crew reported two dabchicks on the lake.

3.3.1 Aquatic plants

No hydrilla was observed in Lake Opouahi.

In contrast to Lakes Tutira and Waikōpiro, Lake Opouahi did not have an extensive shallow water turf plant community prior to the release of grass carp, rather significant areas of charophytes were present amongst the hydrilla (Hofstra et al. 2008). As anticipated, the charophytes beds along with the hydrilla have been removed by the grass carp (Hofstra and Rowe 2008), and charophytes were only recorded in the exclosure cages in April 2016 (section 3.3.2). The only submerged macrophyte recorded at the survey sites was *Ranunculus trichophyllus*, which appears to be increasing in its distribution with plants recorded from three sites and down to ca. 6 m (Appendix C). *Ranunculus trichophyllus* is considered a less palatable or non-desirable species for grass carp (Rowe and Schipper 1985) and plants show little evidence of having been browsed although a few floating plants near site 1 were indicative of some disturbance and having been uprooted (Figure 12). *Ranunculus trichophyllus* was noted to be heavily encrusted with calcium deposits (Figure 12).

Figure 11: Mussels in Lake Opouahi. (Photo by A Taumoepeau).

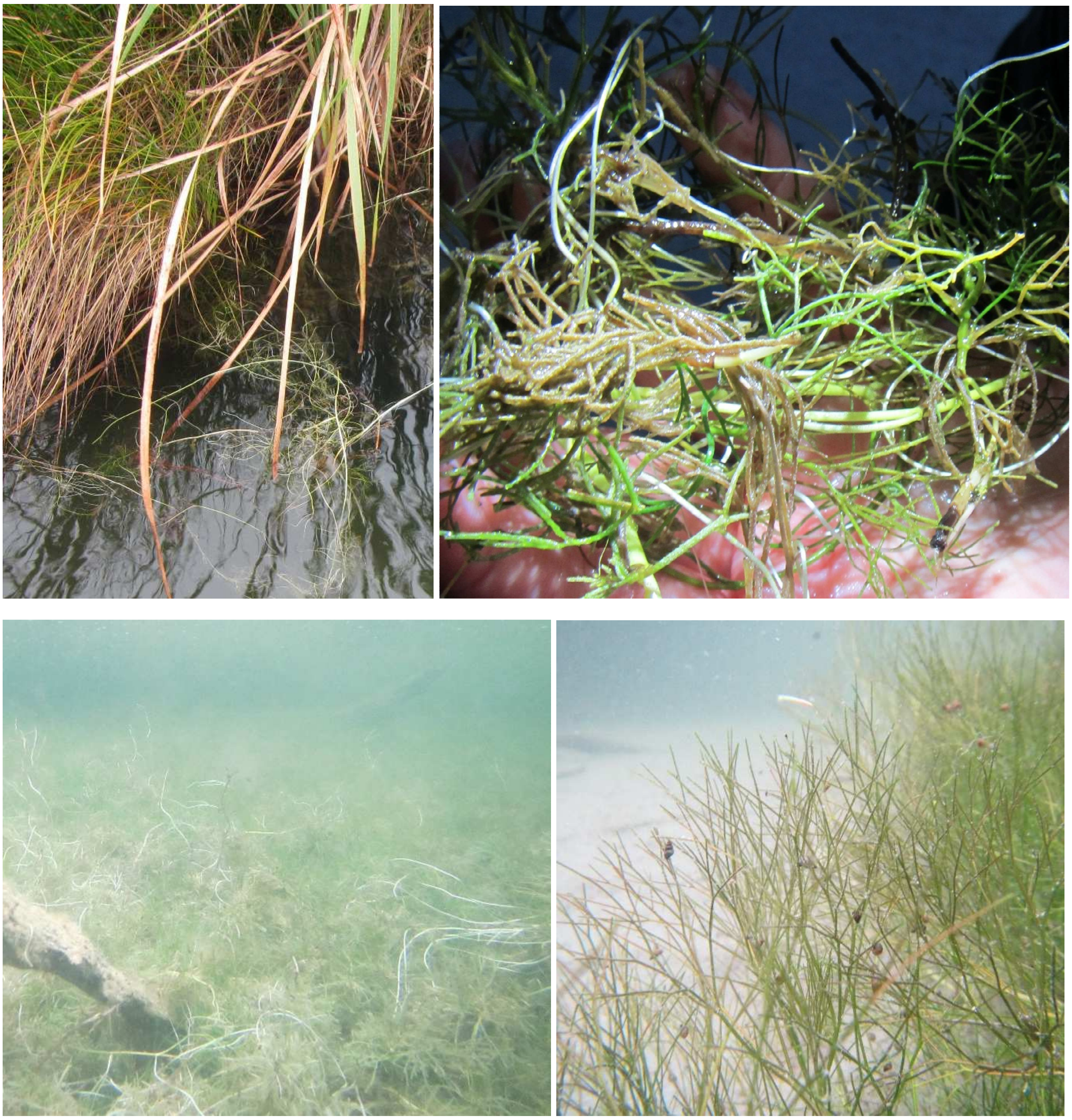

Figure 12: ***Ranunculus trichophyllus*****.** Emergent aquatic plants with uprooted *R. trichophyllus* floating in the foreground (top left); a sample of *R. trichophyllus* showing new green shoots and brown/grey shoots covered in calcium deposits (top right); a bed of *R. trichophyllus* at site 7 (lower left) and on closer inspection plants covered in snails (lower right) (Photos by A Taumoepeau).

3.3.2 Exclosure cages

Amongst the 15 small grass carp exclosure cages, all five cages from one site (site 7, see Figure 2) had germling charophytes. Similarly amongst the large cages, the majority were empty, but three cages at two sites (1 and 4 (northern shore)) had plants in them. The cages at site 1 contained *Potamogeton crispus* that had nearly grown to the top of the cage, and a second cage had a small *Nitella* sp. aff. *cristata* plant. The charophytes in one large cage (site 4) have continued to grow since 2015, and now cover the surface area of the cage (Figure 13). The continued growth of these plants supports the hypothesis that once a threshold density or size is reached the plants will persist, as opposed to small plants or germlings that appear to be highly susceptible to disturbance and a large portion have not survived longer than a year (Hofstra 2014, 2015).

To investigate the potential factors contributing to the demise of small plants, indicators of localised sediment movement or disturbance that could result in oospore (seed) burial, along with oospore presence and germination response (from extracted cores) were reported (Hofstra 2014, 2015). In summary, germling presence at different monitoring events, and photographic records indicate that localised sediment movement occurs, but was not the primary cause of the empty exclosure cages. Localised sediment disturbance by bullies, as a consequence of their preference for hard surfaces for spawning in lakes (Rowe et al. 2001), was also considered as a potential contributor to the limited establishment of charophytes. There was no direct evidence to support interference by bullies, however it was considered that any potential impacts on young plants in the cages could be mitigated by reducing the edge effect of the cage and a larger tunnel cage was installed at one site in April 2015. Although oospores counts from sediment cores from that site (Hofstra 2015), were consistent with published numbers from 1996 (de Winton and Clayton 1996), and data logger records for a calendar year indicate that light conditions were suitable, no plants were observed in the tunnel cage during the April 2016 survey. Over the same time period, cores that were removed from the lake in 2015 and placed in a cultivation tank, produced five young charophytes up to 10 cm tall.

Divers' observations of localised sediment movement in and around the cages, whilst not conclusive, do indicate that efforts to mitigate the sediment disturbance may improve charophyte germling survival. It is proposed that hessian is used as a benthic barrier to stabilise the sediment surface in a new set of five large exclosure cages or a tunnel cage (based on divers observations of appropriate sites at installation). For example if there is sufficient space (depending on the initial hydrilla mapping and presence of submerged trees) adjacent to the existing tunnel cage then a second tunnel cage with a hessian benthic barrier could be installed at the south end of the lake. Similarly, space adjacent to one existing set of large cages, if favourable relative to mapping and debris, is proposed for a new set of five large cages with a hessian benthic barrier. The benefits of using hessian as a benthic barrier for weed control have been established (Caffrey et al. 2010), and experimental studies in New Zealand have demonstrated that charophyte oospores are able to germinate and grow through hessian (Hofstra and Clayton 2012) which also provides a supportive matrix. The hessian will naturally biodegrade over time (ca. 2 years) (Caffrey et al. 2010). As with the existing cages, the new cages with the hessian will require monitoring for charophyte response, and to ensure that any regenerating hydrilla is removed.

To mitigate risk to the MPI hydrilla eradication response, placement of the new cages will be informed by the initial mapping of hydrilla in the lake. This means selecting sites for cage placement that were previously dominated by charophytes and free of hydrilla.

It is recommended that the existing cages in Lake Opouahi are monitored in April 2017, and a set of five new cages or a tunnel cage is installed with a hessian benthic barrier.

Figure 13: A view through the mesh of a large exclosure cage with Chara australis in Lake Opouahi.(Photo by A Taumoepeau).

4 Recommendations

MPI is conducting an eradication response for hydrilla in Lakes Tutira, Waikōpiro and Opouahi. This report documents the changes that are occurring in these lakes, following the initial use of endothall and release of grass carp in December 2008. The hydrilla weed beds were removed by the grass carp by April 2010. The effects of hydrilla removal on lake ecology are in line with predictions in the assessment of environmental effects (Hofstra and Rowe 2008), and increased browsing pressure has been noted in Lake Tutira following the second release of grass carp in December 2014.

Based on the autumn 2016 monitoring results the following recommendations are made:

A reduced survey is recommended for autumn 2017.

1. In Lake Tutira this should include:

   (a) An assessment of aquatic vegetation at the baseline survey sites in Lake Tutira only.

   (b) A focussed investigation on the shallow water plateau in Lake Tutira, assessing the markers for evidence of hydrilla regeneration. Any hydrilla plants (if present) should be assessed for browsing damage and excavated to assess tuber production.

   (c) Mussel data are collected from zone 1 of all sites (using the same methods as in previous years) to enable continued monitoring of the mussel population.

2. In Lake Opouahi this should include:

   (a) The existing submerged grass carp exclosure cages are assessed for charophyte regeneration. Any hydrilla or elodea (*Elodea canadensis*) plants (if present) are documented, excavated and removed.

   (b) A set of five new cages or a tunnel cage is installed with a hessian benthic barrier to provide a supportive matrix to aid young charophyte plant survival.

   (c) Charophyte regeneration should be used to inform decisions to improve the utility of the cages as refugia for native biodiversity, during the hydrilla eradication response.

3. Monitoring information is used to inform the timing and frequency of subsequent monitoring events, recognising MPIs intent to move toward biennially and then triennial monitoring as the hydrilla eradication response progresses.

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Appendix A Lake Tutira Data

Table A1: Lake Tutira Aquatic Vegetation.

Site No & Comments	Plant Species	Depth Range (m)*	Height (m) max (ave)	Cover max (ave)
3. Raupo, woody debris and branches. Max dive depth 7m; Total vegetation cover was 1%; Mussels and bullies present; Visibility ca 1.5m.	*Typha orientalis* *Myriophyllum triphyllum*	0-0.2 0.8	2.5(2.5) 0.05(0.05)	5(4) 1(1)
5. South of the old boat ramp. Overhanging willows; Max depth of dive 7.2m; Visibility 1.5m; Mussels and bullies present. Soft sediment.	*Lilaeopsis ruthiana* *Myriophyllum triphyllum*	0 0		1(1) 1(1)
10. Steep site, raupo overhanging. Max depth of dive 7.5 m; Total vegetation cover 1%; Visibility 1.2m. Mussels and bullies present.	*Typha orientalis* *Myriophyllum triphyllum*	0 1.7	 0.05(0.05)	 1(1)
15. North end beach. Not surveyed				
18. North-eastern shore. Not surveyed.				
22. Next to the fenceline near the island. Max depth of dive 7.2m; Total vegetation cover 10%; Visibility 1.5m; Mussels and bullies present.	*Glossostigma diandrum* *Lilaeopsis ruthiana* *Myriophyllum triphyllum*	0 0 0.8-2.5	 0.2-0.1	3(2) 2(1) 4(2)
28. By four warratahs in the lake. Max depth of dive 7.1 m; Visibility 1.1 m; Total vegetation cover 5%; Eel holes at 2m. Mussels and bullies present.	*Glossostigma elatinoides* *Lilaeopsis ruthiana* *Myriophyllum triphyllum* *Chara australis* *Nitella hyalina*	0-0.1 0-0.1 0.8-1.5 1 1	 0.15(0.15) 0.1(0.1) 0.1(0.1)	5(3) 2(2) 4(1) 1(1) 1(1)
32. Pa site, seat and lookout. Max depth of dive 7.1 m; Total vegetation cover 25%; Visibility 0.8 m; Mussels and bullies present. Eel holes present from 2.5 to 7m; No koura located, despite targeted searching.	*Lilaeopsis ruthiana* *Glossostigma diandrum* *Ranunculus limosella* *Myriophyllum triphyllum* *Chara australis* *Glossostigma elatinoides* *Ruppia polycarpa* (observed, but not on the profile)	0-0.8 0-0.6 0-0.6 0.4-1.6 0.9-2.5 0-0.6		3(1) 3(2) 3(1) 6(2) 2(1) 2(1)

Site No & Comments	Plant Species	Depth Range (m)*	Height (m) max (ave)	Cover max (ave)
35. At camp ground by the picnic table and large willows. Max depth of dive 7.1 m; Total vegetation cover 20%; Visibility 1.5m; Mussels and bullies present, and one eel was observed.	*Myriophyllum triphyllum* *Ruppia polycarpa*	0.8-2.4 1.4	0.15	5(2) 1(1)
36. Rat point. Steep profile. Max depth of dive 7.1 m; Total vegetation cover 1%; Visibility 1.4m; Mussels and bullies present. Low mound-forming plant community was above the water line.	*Glossostigma elatinoides* *Glossostigma diandrum* *Lilaeopsis ruthiana* *Myriophyllum triphyllum* (floating in shallow water)	0-0.1 0-0.1 0-0.1		2(1) 2(1) 1(1)
38. Causeway Max depth of dive 7.3 m; Total vegetation cover 25%; Visibility 1.5m; Mussels and bullies present, and one eel observed.	*Lilaeopsis ruthiana* *Glossostigma diandrum* *Myriophyllum triphyllum* *Chara australis* *Ruppia polycarpa*	0-0.1 0-0.1 0.6-2.4 1.4-1.8 1.4	 0.15(0.1)	2(1) 3(2) 6(2) 1(1) 1(1)
40. Southwest shore. Max depth of dive 7.9 m; Total vegetation cover <5%; Visibility 1.8m; Mussels and bullies present.	*Myriophyllum triphyllum* *Chara australis*	0.9-3.2 1.8	0.15-0.1 <0.1	5(1) 1(1)
42. Max depth of dive 7.6 m; Total vegetation cover <3%.; Visibility 1.5m. Mussels and bullies present.	*Typha orientalis* *Myriophyllum triphyllum* *Chara australis*	0 0.8-1.6 1.7	 0.1(0.1) <0.05	 2(1) 1(1)
45. Willows, shed over road. Max depth 7 m; Total vegetation cover 3%; Visibility 1.5m; Wood, branches and logs in the shallow. Mussels and bullies present.	*Typha orientalis* *Myriophyllum triphyllum*	0 0.8-1.3	2.5 0.2(0.1)	5(5) 3(1)

Site No & Comments	Plant Species	Depth Range (m)*	Height (m) max (ave)	Cover max (ave)
50. Typha point.	*Typha orientalis*	0.2	3(2)	5(3)
Max depth 7.4 m;	*Bolboschoenus fluviatilis*	0.2		
Vegetation cover 1-5%; Visibility	*Glossostigma elatinoides*	0.1-0.8		2(1)
1.5m; Mussels and bullies present.	*Chara australis*	1.9	germling	1(1)
T. orientalis and *Bolboschoenus* on	*Myriophyllum triphyllum*	0.8-1.3	0.1(0.1)	2(1)
a shallow bank.	*Nitella hyalina*	0.1	0.05	1(1)
	Lilaeopsis ruthiana	0.1		1(1)
	Glossostigma diandrum	0-0.1		2(1)
	Ranunculus limosella	0-0.1		1(1)
NB: For % Cover data 1=1–5%, 2=6–25%, 3=26–50%, 4=51–75%, 5=76–95%, 6=96–100%.				

Table A2: Lake Tutira Invertebrate Data (Fixed 200 count).

Site	Invertebrates	Zone 1	Zone 2 (core)	Zone 3
3	Description	1.5m, bare sediment and woody debris	Ca 3 to 6m	Sampled at 8m.
	Mites (Acarina)	25	31	
	Mussels (Bivalvia)	1		
	Midge (Chironomidae)	34	176(7)	22
	Worm (Oligochaeta)		3(1)	
	Snail (*Glyptophysa*)	1		
	Snail (*Potamopyrgus*)	3		
	Clam (Sphaeriidae)	6	1	
	Dragonfly (*Hemicordulia*)	3		
5	Description	1.4 to 1.5m bare sediment and woody debris		
	Mites (Acarina)	27	8(4)	51
	Leech (Hurdinea)		1	
	Mussels (Bivalvia)	1	1	
	Midge (Chironomidae)	159	48	17
	Worm (Oligochaeta)	3		
	Snail (*Potamopyrgus*)	2		
	Clam (Sphaeriidae)	9		
	Dragonfly (*Hemicordulia*)	1	3	
	Stick caddis (*Triplectides*)	2		
10	Description	1.5m, bare sediment and raupo debris.		
	Mites (Acarina)	47	65(40)	
	Midge (Chironomidae)	85	50(5)	16
	Snail (*Potamopyrgus*)	4		3
	Clam (Sphaeriidae)	12	(1)	
	Dragonfly (*Hemicordulia*)	3	(1)	
	Stick caddis (*Triplectides*)	1		
15	Description			
	Not sampled			
18	Description			
	Not sampled			
22	Description	1.4 to 1.5m, bare sediment and 5 to 30% milfoil		
	Mites (Acarina)		37	
	Midge (Chironomidae)	141	185(3)	13
	Ceratopogonidae		6	
	Waterboatmen (*Sigara*)		1	
	Clam (Sphaeriidae)	9	2	
	Dragonfly (*Hemicordulia*)	6		
	Stick caddis (*Triplectides*)	1		
28	Description	1.5m bare sediment and 10 to 70% milfoil, mussels		
	Mites (Acarina)	24	58(16)	20
	Midge (Chironomidae)	148	142(3)	
	Ceratopogonidae		(1)	
	Snail (*Glyptophysa*)	2		
	Snail (*Gyraulus*)	2		
	Snail (*Potamopyrgus*)	6		
	Clam (Sphaeriidae)	2	8	
	Dragonfly (*Hemicordulia*)	12	2	
	Damselfly (*Xanthocnemis*)	4		
	Stone caddis (*Oecetis*)	2		
	Stick caddis (*Triplectides*)	6		

Site	Invertebrates	Zone 1	Zone 2 (core)	Zone 3
32	Description	1.3 to 1.6m, 90% milfoil to bare sediment, mussels		
	Mites (Acarina)	11	30(12)	154
	Mussels (Bivalvia)	5		
	Leech (Hurdinea)		1	
	Midge (Chironomidae)	168	185(11)	2
	Worm (Oligochaeta)			1
	Waterboatmen (*Sigara*)	1		
	Snail (*Gyraulus*)		1	
	Snail (*Potamopyrgus*)	31	1(1)	2
	Clam (Sphaeriidae)		2	
	Damselfly (*Xanthocnemis*)	1		
35	Description	1.5m, 50 to 70% milfoil, mussels, algae		
	Mites (Acarina)	30	39	16
	Mussels (Bivalvia)	7		
	Midge (Chironomidae)	208	231(3)	8
	Worm (Oligochaeta)	8		
	Snail (*Gyraulus*)	1		
	Snail (*Physa*)			2
	Snail (*Potamopyrgus*)	10	(3)	
	Clam (Sphaeriidae)	2	1(1)	1
	Dragonfly (*Hemicordulia*)	1		
36	Description	1.5m bare sediment and wood debris		
	Mites (Acarina)	37	46(1)	2
	Mussels (Bivalvia)	2	1	
	Midge (Chironomidae)	147	28(31)	26
	Worm (Oligochaeta)	19	(1)	
	Snail (*Potamopyrgus*)	7	2	2
	Clam (Sphaeriidae)		1	
	Dragonfly (*Hemicordulia*)		1	
	Case caddis (*Paroxyethira*)	1		
38	Description	1.5m, bare sediment and 10 to 50% milfoil, mussels		
	Mites (Acarina)	37	11(48)	56
	Flatworm		2	
	Midge (Chironomidae)	126	191(1)	2
	Ceratopogonidae	1		
	Worm (Oligochaeta)	23		1
	Waterboatmen (*Sigara*)	1		
	Snail (*Gyraulus*)	1		
	Snail (*Potamopyrgus*)	1	8	
	Clam (Sphaeriidae)	4	3	
	Stone caddis (*Oecetis*)	1		
40	Description	1.3 to 1.6m, bare sediment, milfoil, wood debris, mussels		
	Mites (Acarina)	48	48	68
	Mussels (Bivalvia)	1		
	Midge (Chironomidae)	144	81(7)	
	Worm (Oligochaeta)		(3)	
	Snail (*Potamopyrgus*)	2		
	Clam (Sphaeriidae)	2		
	Dragonfly (*Hemicordulia*)	9	4	
	Damselfly (*Xanthocnemis*)	1		
	Stick caddis (*Triplectides*)		1	
	Snail (*Gyraulus*)	Seen on milfoil in a photo from this site and zone		

Site	Invertebrates	Zone 1	Zone 2 (core)	Zone 3
42	Description	1.2 to 1.6m bare sediment, mussels, wood debris		
	Mites (Acarina)	14		6
	Flatworms			
	Mussels (Bivalvia)	4		
	Midge (Chironomidae)	199	229(2)	
	Ceratopogonidae		1	
	Worm (Oligochaeta)		5	
	Clam (Sphaeriidae)		1	
	Dragonfly (*Hemicordulia*)	1	1	
	Damselfly (*Xanthocnemis*)			
	Stone caddis (*Oecetis*)			
45	Description	1.5m bare sediment, mussels, wood debris		
	Mites (Acarina)	8	42(3)	16
	Mussels (Bivalvia)	14		
	Midge (Chironomidae)	198	184	2
	Clam (Sphaeriidae)	1	2	
	Dragonfly (*Hemicordulia*)	1	1	
	Damselfly (*Xanthocnemis*)			
	Stone caddis (*Oecetis*)			
	Stick caddis (*Triplectides*)			
50	Description	1.3m, bare sediment; 5 to 30% milfoil		
	Mites (Acarina)	60	51(11)	
	Flatworm			4
	Mussels (Bivalvia)	3		
	Midge (Chironomidae)	156	194(2)	22
	Worm (Oligochaeta)		3	
	Snail (*Potamopyrgus*)		5	
	Clam (Sphaeriidae)	1		
	Dragonfly (*Hemicordulia*)	1		

Appendix B Lake Waikōpiro Data

Table B1: Lake Waikōpiro Aquatic Vegetation

Site No & Comments	Plant Species	Depth Range (m)	Cover, max (ave)
1. Causeway, by silver birch. Tall submerged macrophytes absent, marginal emergent species present.	*Glossostigma elatinoides* *Ludwigia palustris* *Carex virgata* *Paspalum distichum* *Symphotrichum subulatum* *Lycopus europaeus* *Bidens frondosa* *Cyperus eragrostis* *Coprosma propinquum*	0-0.05	
3. Causeway Tall submerged macrophytes absent.	*Nitella hyalina* *Eleocharis acuta* *Glossostigma elatinoides* *Triglochin striata* *Lilaeopsis ruthiana* *Glossostigma diandrum* *Myriophyllum propinquum* *Ludwigia palustris* *Juncus edgariae* *Carex moarica* *Carex dipsacea* *Carex virgata* *Centella uniflora* *Lycopus europaeus* *Galium palustre* *Lythrum hyssopifolia* *Paspalum distichum* *Myosotis laxa* *Symphotrichum subulatum* *Euchiton japonicus*	0-0.06	
4. South east. Tall submerged macrophytes absent.	*Glossostigma diandrum* *Lycopus europaeus* *Eleocharis acuta* *Symphotrichum subulatum* *Persicaria decipiens* *Carex virgata* *Alnus glutinosa* *Glossostigma elatinoides* *Ludwigia palustris* *Myosotis laxa* *Salix alba* var. *vitellina* *Paspalum distichum* *Cyperus eragrostis* *Schoenoplectus tabernaemontani* *Carex maorica*	0-0.15	

Site No & Comments	Plant Species	Depth Range (m)	Cover, max (ave)
5. South side. Tall submerged macrophytes absent.	*Glossostigma elatinoides* *Eleocharis acuta* *Symphotrichum subulatum* *Paspalum distichum* *Cyperus ustulatus* *Nitella hyalina* *Agrostis stolonifera* *Lycopus europeaus* *Alnus glutinosa* *Carex virgata* *Hydrocotyle pterocarpa* *Schedonorus arundinaceus*	0-0.15	
7. South end Roadside. No tall submerged macrophytes.	*Glossostigma elatinoides* *Eleocharis acuta* *Ludwigia palustris* *Lilaeopsis ruthiana* *Paspalum disctichum* *Symphotrichum subulatum* *Lycopus europeaus* *Cyperus ustulatus* *Alnus glutinosa* *Persicaria decipiens* *Persicaria hydropiper* *Carex maorica* *Carex virgata* *Myosotis laxa*	0-0.06	

Appendix C Lake Opouahi Data

Table C1: Lake Opouahi Aquatic Vegetation.

Site No & Comments	Plant Species	Depth Range (m)	Height (m) max (ave)	Cover max (ave)
1. Left side of the jetty. Max depth 6 m; *Potamogeton crispus* was present in a cage adjacent to this profile.	*Ranunculus trichophyllus*	1-2.3	0.4(0.3)	6(5)
3. North west side.	No submerged plants			
5. North east side. Mussels at 2.6m depth, a dense patch of ca 30 with more (ca 10) nearby.	No submerged plants			
7. South end. Max depth of dive 7.6 m. *High cover only in very shallow water	*Ranunculus trichophyllus* Drift fragments down to 5.3m	0.3-4.2	0.3(0.2)	6*(1)
9. South end. Steep site, with submerged trees and rocks.	*Ranunculus trichophyllus*	0.5-6.7	0.4(0.3)	4(3)
NB: For % Cover data 1=1–5%, 2=6–25%, 3=26–50%, 4=51–75%, 5=76–95%, 6=96–100%.				