



**Review of the potential for
biomanipulation of phytoplankton
abundance by freshwater mussels
(kakahī) in the Te Arawa lakes**

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Review of the potential for biomanipulation of phytoplankton abundance by freshwater mussels (kakahī) in the Te Arawa lakes

Ngaire Phillips

Prepared for

Environment Bay of Plenty

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by:



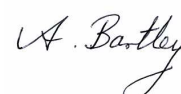
S. Parkyn

Approved for release by:



D. Roper

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Executive Summary

This review has highlighted the range of issues which need to be addressed when considering the potential use of freshwater mussels for biomanipulation of algal biomass in the Te Arawa lakes. The report is necessarily generic in its assessment, given the diversity of physical and chemical characteristics of the Te Arawa lakes. Based on the five focus questions posed at the beginning of this report, the major conclusions that arise are:

1. Can freshwater mussels be increased to levels in the Te Arawa lakes where they would significantly reduce algal biomass?

- Successful establishment of self-sustaining mussel beds requires consideration of physical and biological needs, in particular substrate suitability and presence of a fish host for glochidial development.
- There are large gaps in specific knowledge on the factors influencing available mussel habitat in the Te Arawa lakes, although clearly they are present in large numbers in some lakes. NIWA research is currently focusing efforts on improving our understanding of post-settlement behaviour of glochidia and on gathering basic information on distribution, abundance and population structure of adults.
- At present, it is not possible to culture freshwater mussels, so any lake introduction would require seeding from existing mussel beds. Alternatively, caged mussels could be utilised, but further research is required to establish the efficacy of this method for large-scale biomanipulation.
- Existing information suggests that mussels in sufficient densities could indeed cause a decline in phytoplankton abundance and modify nutrient levels. It is questionable, however, as to whether such densities could be achieved in some lakes, in particular those lakes where kakahi are currently absent.
- Effective biomanipulation couldn't be achieved within a short time frame, simply because the numbers required to be effective would be considerable and significant areas of suitable habitat would also be needed. Not all areas within a given lake are likely to be suitable as habitat, due to physico-

chemical limitations (e.g., poor substrate, low dissolved oxygen below the hypolimnion).

2. Would this be effective for blue-green algal biomass?

- Mussels are known to accumulate blue-green algal cells, so could feasibly remove them from the water column. However, there is some evidence to suggest that freshwater mussel populations may also enhance conditions for growth of blue-green algae, by altering nutrient regimes.

3. Would this affect other species?

- Enhancement of mussel populations can potentially affect other species through impacts on consumers (e.g., through accumulation of blue-green algal toxins (microcystins), as well as heavy metals in various tissues within the mussel). There is renewed interest in the use of mussels as a traditional food source. In addition, bioaccumulation of contaminants at multiple trophic levels (e.g., koura consuming kakahi) may represent a risk to consumers.
- Ecological impacts may also occur, specifically on phytoplankton populations, either as the result of direct consumption through their filtering activity or indirectly by altering nutrient cycling. Any alteration to phytoplankton community composition is likely to manifest at higher trophic levels, with potentially dramatic ecosystem effects. A detailed knowledge of the food-web structure of the waterbody is desirable to be able to predict likely effects.

4. Would this affect nutrient levels in the lakes?

- There is considerable evidence indicating that freshwater mussel species alter nutrient ratios in lakes.

5. Are there other freshwater mussels (native or exotic) or other species that could be effective?

- Introduction of exotic species of freshwater mussels is not recommended, considering overseas experiences and New Zealand's already burgeoning list of exotic species.

While there are considerable limitations to the practical application of using mussels for biomanipulation of algal biomass in the Te Arawa lakes, their use in at least some of the shallower lakes with existing mussel populations is considered worthy of further investigation. We therefore make the following recommendations:

- Initiate a focused biomanipulation experiment on a small, shallow lake, preferably with an existing mussel population and a moderate algal problem, so that changes can be detected. Potentially suitable candidate lakes include lakes Rotoehu, Rerewhakaaitu and Ngahewa.
- Provide support for investigations into culturing of mussels, building on research efforts already underway within NIWA.

1. Introduction

This report has been prepared in response to a request from Environment Bay of Plenty regarding the possible use of kakahi (freshwater mussels - *Hyridella menziesi*) as a method for reducing algal blooms in the Te Arawa lakes. The report presents background information on the mussel, then addresses each of the following questions as part of the potential of mussels in biomanipulation, and finally draws conclusions. The specific questions we have addressed in this report are:

1. Can freshwater mussels be increased to levels in the Te Arawa lakes where they would significantly reduce algal biomass?
2. Would this be effective for blue-green algal biomass?
3. Would this affect other species?
4. Would this affect nutrient levels in the lakes?
5. Are there other freshwater mussels (native or exotic) or other species that could be effective?

The report generally does not provide any lake-specific guidance as to the amenability of a particular lake to biomanipulation of algal populations by resident mussels. Such a task is beyond the scope of the present study and should only be undertaken after consideration of the more generic issues identified within this report.

2. Background information

2.1 General biology

Freshwater mussels are under threat and are declining, both in New Zealand and worldwide (Byrne, 1998; Walker et al. 2001; Brainwood et al. 2006). This decline has been attributed to the loss of habitat associated with river regulation, eutrophication and other types of pollution and possibly through loss of the host fish, on which completion of the life cycle depends (Walker et al. 2001; McDowall, 2002) (also see discussion of life cycle later).

The freshwater mussel Family Hyriidae is represented in New Zealand by two genera and three species/sub-species - *Hyridella menziesi*, *Hyridella aucklandica*, *Cucumerunio websteri* / *Cucumerunio websteri delli* (Figure 1). Recent evidence indicates that other species may also be present (Fenwick and Marshall, 2006). *H. menziesi* is common and widespread throughout New Zealand, in habitats ranging from small, fast-flowing streams to lakes. In contrast, *H. aucklandica* and *C. websteri* are restricted to the northern North Island, near Auckland and are little known (Walker et al. 2001).

Conventional studies of benthic macroinvertebrates in the Te Arawa lakes have generated limited information about mussels (Forsyth, 1978). On the basis of these studies, they were found to be present in Lakes Rotokakahi and Ngapouri, but not in Lake Okataina, Rotoma, Tikitapu, Okareka, or Okaro (Forsyth 1978). Subsequent surveys have recorded mussels from L. Rerewhakaaitu, Rotoehu, Rotoiti, Rotoma, Rotorua, Tarawera and Tutaeinanga (J. Clayton, unpublished data), although these surveys were not specifically targeted at recording mussels and it is possible that they are found in other lakes. Mussels (kakahi) were important as a food source and utensils for Maori (Hiroa, 1921).



Figure 1: The freshwater mussel *Hyridella menziesi* (Photo: Erica Williams).

Adults are long-lived (over 50+ years in Lake Waipori (South Island), with a mean age of 20-25 years) (Grimmond, 1968) and reasonably hardy, so that residual adult populations may be present but do not necessarily indicate viable, self-sustaining populations. Mussels of more than 100mm length have been recorded in New Zealand (Ogilvie, 1993) and ages reported for large individuals range from 13 years (61mm) in Lake Taupo (James, 1985) to 33 years (84mm) in lakes on the Waikato River (Roper and Hickey, 1994). This species lacks a byssal thread commonly found in other mussel species as a mechanism of attachment to the substrate; instead it partially buries itself into soft sediment. There are many factors that influence their distribution and abundance and are discussed in section 3.1.

2.2 Life cycle

The life cycle of mussels is complicated and involves a parasitic larval stage on a host fish. There is little or no published information on mussels in the Te Arawa lakes, on larval and juvenile life history stages, or on potentially major controlling factors. Figure 2 summarises the status of current knowledge of the biology of mussels.

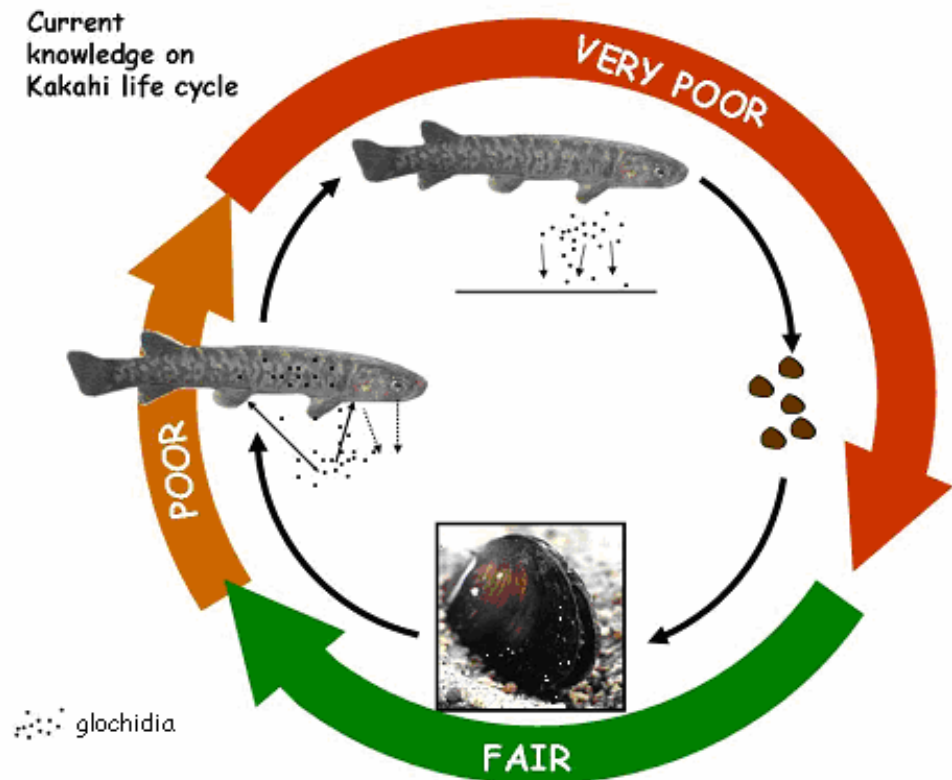


Figure 2: Current status of knowledge on different stages of the mussel life cycle.

The sexes are separate, eggs of the female are laid into the space above her gills and are fertilised by sperm ejected into the open water by the male and then drawn in with the water current generated by the female. Spawning occurs in summer. Larvae are brooded in the mantle cavity of the female, developing into tiny (3mm) larvae known as glochidia. After being released from the females in spring, the glochidia attach themselves to the pectoral fins, head, and mouth of eels (Hine, 1978) and small native fish – Koaro (*Galaxias brevipennis*) and Giant Bully (*Gobiomorphus gobioides*) (Percival 1931) and Common Bully (*G. cotidianus*) or toitoi (DS Roper and CW Hickey, unpublished data), using a tooth on the shell. They drop off later to develop further independently. Large individuals dominate population studies and it is rare to find juvenile mussels (Grimmond, 1968; James, 1985; Roper and Hickey, 1994). It is possible that juvenile mussels occur in a different habitat from the adults and undergo a migration as they develop. For example, Grimmond (1968) found juvenile mussels near the mouths of inflowing rivers.

2.3 Parasites/predators

A chironomid *Xenochironomus canterburyensis*, first recorded in Lake Taupo in 1978, is entirely dependent on mussels for its development (Forsyth 1983). The first instar larvae have a short free-living stage which is spent searching for a mussel host. In late summer, one or two second instar larvae appear inside the mussel, where they feed on sloughed-off cells on the outer surface of the body and on material swept in from the lake water. By early winter the third instar larva moves towards the shell margin and in November, the change to fourth instar coincides with mussel annual growth that causes the membranes at the shell margin to rupture and the chironomid larvae is released to open water. The larva then pupates and rises to the lake surface to emerge as an adult. Roper and Hickey (1994) found that dead individuals of this species can become embedded and result in shell abnormalities.

The freshwater crayfish (*Paranephros planifrons*) has been reported to prey on mussels (CW Hickey, unpubl.). It is also possible that birds and fish may take this species, as anecdotal evidence from overseas reports this for other species (e.g., Vestjens, 1973; Van Tets, 1994).

2.4 Shell morphology

The adult has a very variable growth form and this causes confusion in separating the three New Zealand species. *H. menziesi* is known to show strong variation in shell form (Walker et al. 2001). Figure 3 illustrates some examples of changes in shell morphology. Variation in other characteristics e.g., physiology and behaviour have also been reported. For example, *H. menziesi* varies in glycogen levels, oxygen consumption, heart rate and patterns of valve movements (Hiscock, 1950; Walker 1981, Hickey et al. 1995; C.W. Hickey, unpublished data). The causal mechanisms for such variability may be simple (e.g., riverine versus lake forms, McMichael and Hiscock, 1958) or may involve complex interactions between physical, chemical and biological factors (Roper and Hickey, 1994).

Effects on shell shape & form

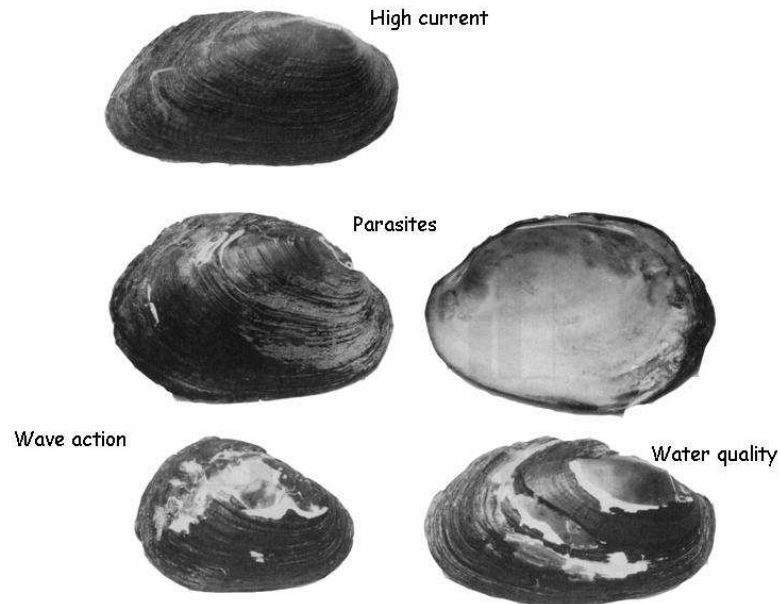


Figure 3: Examples of changes in shell morphology in mussels.

2.5 Biomonitoring

There have been numerous studies into the potential use of mussels as biomonitors. Burggraaf (1996) investigated the use of mussels as bioindicators of metals and resin acids, a common component of kraft pulp and paper mill effluent. Mussels tested from Lake Taupo in winter, spring, summer, and autumn recorded low levels of mercury, copper, lead, cadmium, and chromium but relatively high levels of arsenic (33 – 50 mg kg⁻¹). Significant seasonal changes in metals only occurred for potassium, zinc and cadmium. Mussel lipid values varied seasonally, being lowest after spawning in early autumn. Mussels incubated in kraft pulp and paper mill effluent accumulated resin acids in their tissues rapidly.

Mercury speciation in water, mussels and sediment was investigated at lakes Taupo, Aratiatia, Ohakuri, Whakamaru in the Waikato River system (Hickey et al. 1995). Mercury burden increased with mussel size. *H. menziesi* can therefore be considered as a useful biomonitor for trace levels of mercury.

A study on the toxicity of arsenic to the Dipteran *Chironomus zealandicus* and mussel was undertaken by McKinney (1995). There was no significant difference in survival, growth or condition between mussels suspended in test chambers containing sediments that were contaminated with arsenic (Lake Rotoroa) and sediments without known arsenic (Lake Ngaroto). Mussels did not show avoidance behaviour to sediments with arsenic from Lake Rotoroa. Levels of arsenite in solution at 1200 mg/l decreased the time *H. menziesi* spent respiring and filtering and complete closure of valves occurred at 2400 mg/l. Mussels appear quite hardy to arsenic.

3. Biomanipulation

3.1 Can freshwater mussels be increased to levels in the Te Arawa lakes where they would significantly reduce algal biomass.

The primary food source for mussels is material suspended in the water column (Walker et al. 2001). A variety of suspended particulates, including bacteria, phytoplankton, detritus and micro-zooplankton, as well as dissolved organic material, can be utilised as food for bivalves (Hawkins and Bayne, 1992). *H. menziesi* has been shown to derive more than 95% of its carbon requirements from allochthonous organic material (James 1987). Various studies indicate that the filter feeding behaviour of mussel species can markedly reduce phytoplankton biomass (Stephenson et al. 1984; Madenjian, 1995; Ogilvie and Mitchell, 1995; White, 2000), although there is also evidence to indicate that they can promote phytoplankton primary production (Asmus and Asmus, 1991).

Increasing mussel numbers to a point where algal biomass is reduced requires consideration of the factors influencing their abundance (i.e., is it possible to establish populations and/or increase and maintain abundance?), as well as an assessment of their filtering capacity and subsequent effect on phytoplankton abundance.

3.1.1 Factors influencing abundance

Physical factors

A number of physical factors influence the density of mussels (James, 1985; James et al. 1998). Sediment type and stability has been suggested as a dominant factor, but bed slope, wave action, temperature (associated with depth), oxygen availability and presence of toxins are also important (James et al. 1998). Presence of macrophyte beds is also known to limit available habitat (James, 1985).

Mussels require soft sediment for burial, generally sand or mud, although fine silt has been found to be unsuitable due to potential for clogging of filtering mechanisms (James, 1985; 1987).

Water level variability results in areas that periodically dry out. Lakes with large water level variations are likely to support mussels only in the deeper regions (Ogilvie,

1993). Similarly, areas of regular wave action are unlikely to support settlement of juveniles and even adults are likely to be adversely affected (James, 1985).

In Australian species, viability and development of glochidia are temperature-dependent (Walker, 1981), as is glochidia release from the fish host (Atkins 1979). In addition, clutch size is strongly influenced by habitat trophic status (Byrne, 1998). These influences have not been investigated in New Zealand species, however.

James et al. (1998) suggested that oxygen levels above 5mg/L are likely to be a threshold concentration for long term viability of mussel beds. Available habitat for mussels will therefore be restricted in lakes that stratify and record DO levels below 5mg/L.

The presence of toxins in lake sediments may also be a consideration (James et al. 1998) and limit the areal extent of mussel beds in some lakes, particularly where geothermal activity is found.

Reproduction in *Hyridella* species appears to be sensitive to eutrophication (Roper and Hickey, 1994; Byrne, 1998). Byrne (1998) found that reproductive output was higher in eutrophic than in oligotrophic lakes.

Biological factors

Availability of a suitable fish host is of paramount importance for successful development of the glochidia (see discussion above on life cycle). Therefore an understanding of the factors influencing distribution and abundance of the fish host is also required for the establishment of a self-sustaining mussel population.

The long term viability of populations will also be affected by the condition of the mussels (Roper and Hickey, 1994)

3.1.2 Filtration rates for effective reduction of algal blooms

Factors influencing the filtration rate of mussels include:

1. Density - Limited information is currently available on population densities in the Te Arawa lakes (Table 1).

Table 1: Population densities and biomass of *H. menziesi* recorded from the Te Arawa lakes.

Lake	Mean density (m ⁻²)	Mean DW (g)	Reference
Rotokawau	160	0.9	James (1987)
Rotokakahi	13	-	Forsyth (1978)
Ngapouri	5	-	Forsyth (1978)
Taupo	5.6	2.8	James (1985)
Rotoiti	73.8	-	Happy (2006)
Rotoma	17.2	-	Happy (2006)
Rotorua	62.1	-	Happy (2006)
Tarawera	18.3	-	Happy (2006)

2. Biomass - Larger individuals are likely to be more effective than smaller individuals at removing phytoplankton (Arnott and Vanni, 1996).
3. % time spent filtering - Ogilvie (1993) found that individual mussels in Lake Tuakitoti (South Island) filtered on average for 93% of the time.
4. Lake depth - Filtration appears to be a more effective option in shallow lakes (Ogilvie, 1993; White, 2000).
5. Mixing regime - Effective filtration by mussels requires sufficient vertical mixing to ensure phytoplankton is available for filtering.
6. Phytoplankton community composition - Many bivalves showing a preference for particles > 2µm in size (Reeders and Bij de Vaate, 1990).
7. Phytoplankton growth rate and associated food concentration – experimental evidence suggests filtering activity increases to a food concentration where the maximum ingestion rate is reached, with filtering rate decreasing with increasing concentrations while the amount of food ingested remains constant (Winter, 1978). Therefore the nature of the filtration rate depends on the food

concentration. Roper and Hickey (1995) found that mussel condition was optimal at intermediate food concentrations and that filtering rates decreased with increasing food levels.

8. Season – mussels filter less in winter than in summer as a consequence of lower temperatures (White, 2000).

James et al. (1998) developed a simple model to predict the influence of mussels on phytoplankton in Lake Rotorua. Their model uses a mean filtration rate of 1.6 l/hr/g DW, a mean density of 6 mussels/m², mean biomass of 1.6g dry weight per individual and mean filtering time per individual of 93% (based on Ogilvie, 1993). Their values are based on averages of published data. On this basis they calculated that, for a mean depth of 2.4m (for Lake Rotorua) and assuming 100% vertical mixing of the water column, that it would take 168 hours for this density of mussels to filter the lake. Ogilvie and Mitchell (1995) suggested that 32 hours turnover time of water by mussels in Lake Tuakitoto would be sufficient to cause a continuous decline in phytoplankton abundance, although their estimate was based on an average filtration rate of 1.81 L/h/g and a mean lake depth of 0.70m. In Lake Rotorua, James et al. (1998) suggested a mussel density of 32/m² would be required to achieve a similar result. Table 3 presents the results of a similar analysis of the Te Arawa lakes, using the same values as James et al. (1998). The density of mussels required to achieve Ogilvie and Mitchell's (1995) estimate for continuous decline of phytoplankton abundance ranges between 42 and 720. Clearly even the lower numbers are likely to be higher than naturally recorded densities (e.g., Forsyth (1983) recorded a mean density of 5 mussels/m² from Lake Ngapouri), but for the first 5 lakes in the table, are within the range of densities recorded from other lakes (e.g., James (1987) recorded a density of 160 mussels/m² in Lake Rotokawau concentrated in a narrow band. Also, Happy (2006) recorded a maximum of 440 mussels/m² at one location in Lake Rotorua at a depth of 2m). For those lakes where kakahi have not been recorded, establishment of populations is likely to be challenging.

Table 2: Estimate of mussel numbers required for effective reduction in phytoplankton abundance (mean filtration rate = 14.28 for 1 m² of mussels), along with known mean mussel densities for Te Arawa lakes.

Lake	Mean depth (m)	Lake area (km ²)	Volume of water above 1 square metre of substrate (l)	Time to filter lake (hours) based on a mean density of 6 mussels/m ²	# of mussels (per m ²) required to filter lake in 32 hours ¹	Known mean mussel density (# per m ²) (from Table 1 and from Phillips et al, 2007)	Maximum densities recorded (depth, m)
Ngahewa	3.5	0.1	3500	245.02	46	? ²	?
Rerewhakaaitu	7	5.17	7000	490.03	92	?	?
Rotoehu	8.16	7.9	8160	571.24	107	?	?
Rotorua	11	80.47	11000	770.05	144	62.1	440.0 (2)
Opouri/Ngapouri	11.8	0.22	11800	826.05	155	5	?
Okaro	12.5	0.3	12500	875.06	164	-	-
Rotokakahi	17.5	4.33	17500	1225.08	230	13	100 ³
Tikitapu	18	1.44	18000	1260.08	236	-	-
Okareka	20	3.34	20000	1400.09	263	-	-
Rotoiti	31.5	33.7	31500	2205.14	413	73.8	615.0 (7)
Rotoma	36.9	11.12	36900	2583.17	484	17.2	90.0 (11)
Okataina	39.4	11.73	39400	2758.18	517	-	-
Tarawera	50	41.15	50000	3500.22	656	18.3	?
Rotomahana	60	9.02	60000	4200.27	788	-	-

¹Ogilvie and Mitchell (1995) suggested a turnover time of 32 hours would be sufficient to cause a continuous decline in phytoplankton abundance. Turnover times will vary depending on the turnover of algal cells.

² Known to be present but no information currently available on densities

³ J Butterworth, pers obs, 2006

- none recorded

3.2 Would this be effective for blue-green algal biomass?

Mussels are known to accumulate blue-green algal cells, so could feasibly remove them from the water column (Wood et al. 2006). However, there is some evidence to suggest that freshwater mussel populations may enhance conditions for growth of blue-green algae, by altering nutrient regimes (Arnott and Vanni, 1996). It has been found that many algal species growing at maximal rates maintain a molar N:P ratio close to 16:1 in their cells (Redfield, 1958; Goldman et al. 1979). Blue-green algae grow optimally at low N:P ratios because some species can fix atmospheric nitrogen.

Blue-green algae may therefore dominate the phytoplankton assemblages when N becomes the limiting nutrient (Smith, 1983).

3.3 Would this affect other species?

There are several ways in which the enhancement of mussel populations for the purpose of reducing algal biomass can affect other species.

Consumer impacts

Mussels have been shown to accumulate blue-green algal toxins (microcystins) in various tissues within the mussel (Prepas et al. 1997; Vasconcelos, 1999; Wood et al. 2006) and therefore potentially pose a problem to consumers. Wood et al. (2006) concluded that, because this species is seldom consumed in New Zealand, the health risk from its consumption is considered minimal. However, mussels were important as a food source and utensils for Maori (Hiroa, 1921) and there is renewed interest in their use as a traditional food source (I. Kusabs, pers. comm., August 2006). Freshwater mussels have been shown to accumulate other contaminants (e.g., heavy metals, pesticides) (Hickey et al. 1995; Burggraaf et al. 1996). The extent of such contamination in the Te Arawa lakes is currently unknown. In addition, the freshwater crayfish (*Paranephros planifrons*) has been reported to prey on mussels (CW Hickey, unpubl.). Koura are a valued mahinga kai species and considered a delicacy by Te Arawa iwi (I. Kusabs, pers. comm., August 2006). Bioaccumulation of contaminants at multiple trophic levels may represent a risk to consumers.

Ecological impacts

Freshwater mussels can affect phytoplankton populations in two ways – by direct consumption through their filtering activity or indirectly by altering nutrient cycling (Arnott and Vanni, 1996). As a consequence of these effects phytoplankton community composition may change. Any alteration in phytoplankton community composition is likely to manifest at higher trophic levels (Lowe and Pillsbury, 1995). As discussed above, alterations to nutrient ratios may favour undesirable algal species (e.g., blue-greens) (Arnott and Vanni, 1996; White, 2000).

Biomanipulation is likely to have dramatic ecosystem effects and a detailed knowledge of the food-web structure of the waterbody is desirable to be able to predict

likely effects (Perrow et al. 1997). A recent study of food web structure in Rotorua (McBride, 2005) did not include the mussel in its investigation.

3.4 Would this affect nutrient levels in the lakes?

There is considerable evidence indicating that freshwater mussel species alter nutrient ratios in lakes (Arnott and Vanni, 1996). Nutrients processed by mussels may be deposited as faeces or pseudofaeces, utilised for growth and reproduction, or excreted in dissolved form. There is therefore the potential for enhancement of certain phytoplankton species by the recycling of dissolved nutrients back into the ecosystem. As phytoplankton growth in most freshwater environments is under the control of nitrogen and phosphorus, the rate and ratio at which these nutrients are supplied will affect algal growth rates and community structure. As stated above, alterations to nutrient ratios may also favour undesirable algal species, such as blue-greens. This effect has been shown for the zebra mussel *Dreissena polymorpha* in Lake Erie (Arnott and Vanni, 1996), although factors other than nutrients (e.g., light intensity) mitigate this effect in some lakes. However, in an enclosure experiment, Ogilvie (1989) did not find any effect by *H. menziesi* on phytoplankton growth rates (as measured by production/chlorophyll a) associated with an increase in nutrients.

3.5 Are there other freshwater mussels (native or exotic) or other species that could be effective?

Perhaps the most well-known example of a freshwater mussel species that has proven effective in reducing algal bloom impacts on water quality is the zebra mussel (*Dreissena polymorpha*) (Griffiths et al. 1991). The presence of substantial *Dreissena* populations has been associated with increased water clarity in European studies where they have been introduced into eutrophic lakes to reduce phytoplankton densities and mediate “oligotrophication” of plankton-dense habitats (Reeders et al. 1993; Stanczykowska et al. 1976). However, they are also found in extremely high numbers and are generally considered a major ecological threat outside their country of origin, despite their positive effects on water clarity. For example, densities ranging from 21,000 m⁻² to 340,000 m⁻² have been recorded from Lake Erie proper and up to 700,000m⁻² from the western basin of Lake Erie (Cooley, 1991; MacIssac et al. 1992; Dermott et al. 1993). The introduction of a highly invasive exotic species such as the zebra mussel into New Zealand lakes is likely to accelerate the decline of the slower growing and reproducing native species. Zebra mussels are known to colonise other bivalves and slower-moving invertebrates, impeding movement and potentially

affecting filtering and other activities. Native species of birds and fish in countries experiencing zebra mussel invasions have been shown to feed on zebra mussels, but not to an extent where they have any major controlling effect on the mussel populations. They are also known to affect recreational activities such as boating (through attachment to hulls) and fishing (through alterations to food webs leading to declines in some native species). Once zebra mussels become established in a water body, they are impossible to eradicate with the technology currently available.

4. Conclusions

This review has highlighted the range of issues which need to be addressed when considering the potential use of freshwater mussels for biomanipulation of algal biomass in the Te Arawa lakes. The report is necessarily generic in its assessment, given the diversity of physical and chemical characteristics of the Te Arawa lakes. Based on the five focus questions posed at the beginning of this report, the major conclusions that arise are:

6. Can freshwater mussels be increased to levels in the Te Arawa lakes where they would significantly reduce algal biomass?

- Successful establishment of self-sustaining mussel beds requires consideration of physical and biological needs, in particular substrate suitability and presence of a fish host for glochidial development.
- There are large gaps in specific knowledge on the factors influencing available mussel habitat in the Te Arawa lakes, although clearly they are present in large numbers in some lakes. NIWA research is currently focusing efforts on improving our understanding of post-settlement behaviour of glochidia and on gathering basic information on distribution, abundance and population structure of adults.
- At present, it is not possible to culture freshwater mussels, so any lake introduction would require seeding from existing mussel beds. Alternatively, caged mussels could be utilised, but further research is required to establish the efficacy of this method for large-scale biomanipulation.
- Existing information suggests that mussels in sufficient densities could indeed cause a decline in phytoplankton abundance and modify nutrient levels. It is questionable, however, as to whether such densities could be achieved in some lakes, in particular those lakes where kakahi are currently absent.
- Effective biomanipulation couldn't be achieved within a short time frame, simply because the numbers required to be effective would be considerable and significant areas of suitable habitat would also be needed. Not all areas within a given lake are likely to be suitable as habitat, due to physico-

chemical limitations (e.g., poor substrate, low dissolved oxygen below the hypolimnion).

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- Mussels are known to accumulate blue-green algal cells, so could feasibly remove them from the water column. However, there is some evidence to suggest that freshwater mussel populations may also enhance conditions for growth of blue-green algae, by altering nutrient regimes.

8. Would this affect other species?

- Enhancement of mussel populations can potentially affect other species through impacts on consumers (e.g., through accumulation of blue-green algal toxins (microcystins), as well as heavy metals in various tissues within the mussel). There is renewed interest in the use of mussels as a traditional food source. In addition, bioaccumulation of contaminants at multiple trophic levels (e.g., koura consuming kakahi) may represent a risk to consumers.
- Ecological impacts may also occur, specifically on phytoplankton populations, either as the result of direct consumption through their filtering activity or indirectly by altering nutrient cycling. Any alteration to phytoplankton community composition is likely to manifest at higher trophic levels, with potentially dramatic ecosystem effects. A detailed knowledge of the food-web structure of the waterbody is desirable to be able to predict likely effects.

9. Would this affect nutrient levels in the lakes?

- There is considerable evidence indicating that freshwater mussel species alter nutrient ratios in lakes.

10. Are there other freshwater mussels (native or exotic) or other species that could be effective?

- Introduction of exotic species of freshwater mussels is not recommended, considering overseas experiences and New Zealand's already burgeoning list of exotic species.

5. Recommendations

While there are considerable limitations to the practical application of using mussels for biomanipulation of algal biomass in the Te Arawa lakes, their use in at least some of the shallower lakes with existing mussel populations is considered worthy of further investigation. We therefore make the following recommendations:

1. Initiate a focused biomanipulation experiment on a small, shallow lake, preferably with an existing mussel population and a moderate algal problem, so that changes can be detected. Work in Lake Omapere initially attempted to address this issue using caged mussels, but results to date have focused on surveying lake mussel populations rather than examining biomanipulation potential *per se* (T. Gray, pers comm, Nov 2006). Mussels appear to be absent from many of the smaller Te Arawa lakes. However, potentially suitable candidate lakes include lakes Rotoehu, Rerewhakaaitu and Ngahewa. Lake Rotoehu has poor water quality and frequent algal blooms (Scholes and Bloxham, 2005). However, the recent hornwort invasion (Clayton et al. 2005) would potentially make enhancement of existing mussel populations or the use of caged populations difficult if this exotic macrophyte spreads. Lake Rerewhakaaitu has average water quality (Scholes and Bloxham, 2005) and a reduced LakeSPI score due to invasion over the last 17 years by *Lagarosiphon* (Clayton et al. 2005). Lake Ngahewa recorded a poor LakeSPI condition rating, largely as it had been de-vegetated at the last survey (2004/2005) (Opus, 2006). Lake Ngahewa is not regularly monitored for water quality or algal blooms (Opus, 2006).
2. Provide support for investigations into culturing of mussels, building on research efforts already underway within NIWA.

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