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LAKE ROTOROA, A CANDIDATE FOR RESTORATION OR RESTRAINT?

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ABSTRACT

Lake Rotoroa first became a public concern in the 1950s when invasion by an alien macrophyte led to serious aquatic weed problems. For around 30 years weed beds were controlled to reduce their interference with recreational activities. The late 1980s saw a decline and loss of underwater vegetation, an increase in phytoplankton abundance and a reduction in water clarity. This major ecological change stimulated public concern and controversy over the present and future condition of the lake. Lake Rotoroa has been proposed as a candidate for restoration or rehabilitation. In order to determine an appropriate plan of action for this lake it has been necessary to find out what is known of its early and recent limnology, determine what additional information is needed, and to identify what the achievable and sustainable options are with respect to user interests and public expectations. These issues are discussed with results from the recently held scientific workshop including an outline of studies required to address the current state of the lake. Recommended future work includes investigating the feasibility of controlling phytoplankton abundance through the management of nutrient inputs; sustainability of a desirable lake fishery and methods to reduce pollution. Research answers, together with community consultation will identify management options which best resolve lake use conflicts and will facilitate the revision of the Lake Rotoroa Management Plan.

INTRODUCTION

Lake Rotoroa (Hamilton Lake) is a 54 hectare urban lake within the city of Hamilton which has been at the centre of public attention on many occasions. Controversy first began in the late 1950s when submerged oxygen weed beds had a profound impact on the lake, and the assistance of the New Zealand army was sought to remove nuisance growths. Contention surrounded the use of sodium arsenite as a weed control measure in 1957, and concern is still expressed over the nature of the enduring impact of the residual arsenic in the lake sediments. Public and scientific dispute arose over the use of diquat as a weed control agent, particularly following two incidents of aerial drift during the 1970s. The decline of weedbeds in the late 1980s has continued to fuel debate over the changes in the quality of the lake, with further concerns expressed over the future of the lake.

The most recent debate has centred on the present condition of Lake Rotoroa. Discussion has been coloured by inaccurate statements, poor reporting and public misconceptions. The following examples of press (Waikato Times and local) quotations serve to illustrate the controversy and confusion that exists in this "trial by media".

> *"City lake on death spiral. Hamilton lake is on a downward spiral to biological death."*

"The lake is suffering from a mystery disease that has killed off its submerged weed and exposed it to serious risk of crashing."

"If a lake's plants die, then it loses its value to both humans and wildlife."

"...building a fountain as a cure for the dying lake ...could solve the downward biological spiral that is killing it's plant life ... Urgent work is required to return the dark black lake to the tourist attraction ...when hundreds of bathers flocked to the city recreation spot."

"Hamilton's Lake Rotoroa is being over-monitored without enough action to save it."

"Contrary to rumour, the lake is not dying, it is simply evolving to a new state. Hamilton Lake is shifting from being dominated by submerged oxygen weeds to a new state of algal dominance. The overabundance of algae will be very difficult to reverse and unless a solution is found, the entire surface could become clogged..."

"We certainly prefer an algal dominated lake to one clogged up with oxygen weed."

This paper discusses changes in the status of Lake Rotoroa, identifies concerns over the potential for further deterioration, and considers the suitability of a management plan aimed at restoring the lake to a former condition as opposed to preventing further deterioration.

HISTORICAL CHANGES IN THE STATUS OF LAKE ROTOROA

Ecological changes are commonly perceived in the time scale of recent memory or of a human life span. An historical perspective of ecological change enables a better understanding of the direction and magnitude of change.

Lake Rotoroa is approximately 15,000 years old and palaeolimnological evidence based on analysis of lake sediment cores indicates that the lake has alternated between periods of high and low productivity. The principal determinants of these contrasting ecological states has been attributed to climate changes, peat development and the extent of catchment forestation, which in turn have determined the level of nutrient input from the catchment into the lake (Green and Lowe 1993). During this period, Lake Rotoroa appears to have undergone periods of either macrophyte or phytoplankton domination.

Despite the apparently large scale alterations in the ecological status of Lake Rotoroa over geological time, it is the last 100 years or less of "recent" history that are of particular relevance to public perception, scientific research and management interests.

Lake Rotoroa has undergone significant ecological change, culminating in a switch to phytoplankton dominance within the last 3-5 years. Although unidirectional and cyclical changes in nutrient status and primary producer dominance are likely to have occurred before, there are aspects of recent change that are clearly unique. For example, invasion and large scale displacement of native vegetation by tall-growing oxygen weed (Hydrocharitacean) species had an unprecedented impact from the 1950s through to the late 1980s (Fig. 1). Likewise, a temporary period of herbicidally-induced (sodium arsenate) devegetation; the introduction and proliferation of various species of coarse fish (e.g. rudd, *Scardinius erythrophthalmus*; catfish, *Ictalurus nebulosus*; common carp, *Carassius auratus*; perch, *Perca fluviatilis* and tench; *Tinca tinca*) and the most recent decline of an oxygen weed dominated vegetation are all novel phenomena for Lake Rotoroa (Fig. 2).

Replacement of bottom-rooted vegetation by planktonic green algae has resulted in notably more turbid water than was previously observed (Fig. 2). A major concern since the decline of macrophyte domination is over the stability of the green algae dominated state of Lake Rotoroa, and whether the lake is at risk of undergoing further transformation with blue-green algal blooms becoming common-place (Fig. 1).

PLANT DECLINE – POSSIBLE CAUSAL FACTORS

Decline of submerged vegetation is a widely reported phenomenon and is now common amongst shallow lakes of the Waikato Region (de Winton and Champion 1993). Causal mechanisms are mostly unconfirmed since studies on the phenomenon are rare and retrospective elucidation is not generally possible. Factors likely to have contributed to plant decline in Lake Rotoroa can be conveniently grouped as either **abiotic** or **biotic**.

Abiotic factors include **decreased water clarity, toxin inputs** and **meteorological events**. **Decreased water clarity** is characteristic of waterbodies undergoing eutrophication and is associated with an increase in planktonic algal abundance from increased nutrients within the water column. Catchment activities (e.g., farming, mining, deforestation and urban development) also result in increased inorganic suspended solids entering into nearby lakes, with the outcome that either algae and/or suspended solids reduce the clarity of water and therefore the available light for plant photosynthesis. Macrophytes are bottom-rooted plants and their depth of growth is directly proportional to water clarity. **Meteorologic events** such as high winds or rain can act as a catalyst initiating a macrophyte decline, especially if other predisposing influences are present. **Toxin inputs** (e.g., herbicides, heavy metals) can also provide additional or intolerable stresses on plant growth. For example, rooted submerged macrophytes are known to accumulate heavy metals and other elements, and high levels of arsenic and boron were recorded in *Egeria densa* in Lake Rotoroa.

The following **biotic** factors may also have contributed to plant decline in Lake Rotoroa. **Plant population cycles** are a natural phenomenon resulting in loss of plant vigour within non-sexually reproducing populations. **Resource depletion** may occur from sustained plant growth resulting in a deficiency of essential elements (e.g., nutrients). Domination by one species such as *Egeria densa* may also lead to **resource modification**, causing unfavourable growing conditions, such as flocculent or unconsolidated sediments due to enhanced settlement and accumulation of organic matter. **Competition** (e.g., for inorganic carbon), **allelopathic interactions** (harmful effects by one plant upon another through the release of chemical compounds) and **disease** are additional factors likely to cause decline, although **grazing** is one of the most probable mechanisms contributing to the decline in Lake Rotoroa. Freshwater crayfish (*Paranephrops* spp.), black swans (*Cygnus atratus*) and

Figure 1 Stylised changes in the condition of Lake Rotoroa over the last 100 years.

fish are known to have major impacts on aquatic plant abundance (Coffey and Clayton 1988, Mitchell 1989, Wright and Phillips 1992). In Lake Rotoroa, circumstantial evidence connects rudd with the decline in macrophytes. Rudd were illegally released around 1977, and this was followed by a rapid expansion of the population, particularly prior to the decline of macrophytes (Fig. 2). The gut contents of rudd examined from Lake Rotoroa had >80% aquatic macrophyte content prior to the decline (Wise 1990).

Waterbodies characteristically age at different rates, evolving towards higher fertility in proportion to the degree and rate of catchment development and nutrient input to the waterbody. Over the last 50 years, the catchment of Lake Rotoroa has undergone substantial urban development (Plates 1 and 2) with removal of trees and marginal wetland plants, stop-banking, roading and housing development, and establishment of stormwater inflows to the lake. Inevitably the lake has undergone nutrient enrichment with an increase in chlorophyll *a* and reduced water clarity (Fig. 2). Against this background of progressive decline in water clarity, a number of potential factors causing macrophyte decline are likely to have contributed additional stresses of an accumulative or synergistic nature.

A major obstacle in understanding the decline phenomenon in Lake Rotoroa is differentiating between cause and effect. For example, although water clarity reduction can be attributed to urban catchment development and increased enrichment, any corresponding decline in area of submerged aquatic plant growth would in turn contribute to further water clarity reduction. This can arise by way of increased sediment exposure with a higher potential for resuspension of bottom sediments from wind and wave action, or by reduced refugia for zooplankton leading to an increase in phytoplankton.

Figure 2 Stylised summary (submerged plant and rudd abundance) and actual records (chlorophyll a and Secchi depth) of major events and impacts on the Lake Rotoroa ecosystem, 1950 to 1993 (..... no data).

Plate 1 **Lake Rotoroa photographed from the north, circa 1909, with extensive fringes of reeds and a rural catchment (photo source Waikato Museum of Art and History).**

Plate 2 **The lake today, from a similar vantage, shows considerable shoreline modification and urban development (photo source NIWA Ecosystems).**

Contrary to perceptions on the condition of Lake Rotoroa as implied by statements such as "mystery disease" or "downward spiral to biological death", the phenomenon of alternative stable states in freshwater systems is reasonably well known and reported in the scientific literature (Shapiro 1990, Scheffer 1990). Shallow water lakes supporting extensive bottom cover of submerged vegetation are particularly prone to exhibiting sudden changes in water clarity with a concurrent and rapid decline in macrophytes. Over a range of intermediate nutrient levels, two alternative equilibria exist: one with macrophytes, and a more turbid state without vegetation. At low nutrient levels, only the macrophyte dominated equilibrium exists, whereas at high nutrient levels, there is only the turbid equilibrium (Scheffer 1990). At intermediate nutrient levels, either stable state may prevail, with feed-back mechanisms that help maintain the existing state. If nutrient levels continue to rise, the stability of the clear state decreases and even slight perturbations are enough to cause a switch to the turbid equilibrium state (Scheffer 1990). Attempts to reverse such changes by restoring the previous nutrient level alone are unlikely to be successful.

PLANT DECLINE – WHY NOT SOONER?

Lake Rotoroa is the latest of a number of lakes in the Waikato District to have undergone macrophyte decline. When it is considered that Lake Rotoroa was probably the first of the Waikato lakes to be invaded by any tall growing oxygen weed species, then this lake has probably had the longest recorded domination by dense growths of oxygen weed of any lake in the Waikato district.

Although it is not possible to explain the longer duration of oxygen weed domination in Lake Rotoroa compared to many other lakes, it is conceivable that the magnitude and diversity of impacts on weed growth may have helped to retain greater plant vigour. Disturbance of plant stands has been observed to encourage growth and extend the duration of nuisance weed beds, while "leave alone" policies have been promoted as weed control strategies (Johnstone 1982).

The aquatic vegetation in Lake Rotoroa has experienced a wider range and frequency of impacts from inadvertent influences (e.g. heavy metals associated with storm water inflows, and a diversity of liberated coarse fish) as well as from deliberate control measures (sodium arsenite, diquat) than in any other lake in the region. If uncontrolled weed growth over a period of years can result in an irreversible change to habitat character that is unsuited to long-term growth, then periodic or regular removal of weed beds may thereby prevent or delay the onset of such deleterious changes.

The successful management strategy based on targeted control of *Egeria densa* weed beds during the 1970s and 1980s provided evidence of deflected plant succession to an earlier pre-invasion condition with partial recovery of low growing native charophytes (Tanner *et al*. 1990). This approach was encouraged as a management strategy and may have been instrumental in helping to retain higher plant diversity and greater vigour of invasive weed species. The progressive reduction in the area of weedbeds targeted for control (54 hectares in the 1970s to <8 hectares in 1980s) and the use of viscous diquat formulations helped to minimise the extent of impact on weedbeds by greater placement accuracy. Direct herbicide mediated weedbed decline (Coffey and Edgar 1993) is therefore unlikely, however reduced frequency and magnitude of weed management impacts may have contributed to loss of weedbed vigour or permitted the onset of irreversible and unfavourable habitat changes.

MANAGEMENT OPTIONS

The Lake Rotoroa management plan (HCC 1985) aimed to maintain and improve the lake's water quality, encourage a diversity of species and maintain the lake sot hat recreation activities could continue. A revised Lake Rotoroa draft management plan (March 1994) is now available (HCC 1994). Following the significant change in lake status and public concern over the welfare of the lake, it is appropriate to reconsider the options available for management.

One of the simplest management initiatives can be referred to as **restraint** (to keep in check or under control), while **restoration** (to bring back to an original state or former condition) would require major intervention. Restraint is based on **slowing** or **terminating** change; while restoration implies **reversal**. **Rehabilitation** has been used synonymously with restoration, although it more commonly implies **recovery** (to bring back to good condition, working order or prosperity, to make fit after disablement). A further management option is **protection** (to maintain in an existing state) which aims to **preserve** by protecting against undesirable changes.

Selection of the most appropriate management options for Lake Rotoroa is not the purpose of this paper. Lake Rotoroa simply illustrates some of the conflicts and difficulties involved in selecting options. Possible guidelines for alternative management approaches are discussed below.

Protection or Conservation

Although protection or conservation is not an option advocated for Lake Rotoroa, the following are examples of criteria that should be present in a waterbody in order to be considered for such an approach:

1.High species diversity.
2.Community or species representativeness or uniqueness.
3.High degree of indigenous state.
4.Minimum modification (e.g., natural catchment and unmodified lake margin).
5.High cultural or scientific value.
6.Sustainability (i.e. low risk of change).

These criteria should be applied to the current status of the waterbody under consideration. Lake Rotoroa does not possess features that would meet such criteria (Clayton and de Winton 1993) and would not qualify for protection or conservation status.

Restoration or Rehabilitation

The decline in ecological status and public perception of lake health and quality has prompted controversial debate and agitation for managers to restore or rehabilitate Lake Rotoroa. The appropriateness of adopting this course of action may be measured against the following criteria:

1.Previously High Status. This applies particularly to the protection values noted above, such as high species diversity, unique or representative species or communities, degree of indigenous state, and cultural or scientific values.

2.Intolerable Present State. User conflicts arise over identification of an acceptable lake condition. Following the decline of submerged vegetation in Lake Rotoroa and loss of nuisance weedbeds in particular, there has been a notable reduction in the number of public complaints. Lake users such as yachties and windsurfers are reported as preferring the lake in its present condition, thereby challenging the notion of an intolerable present state. Intervention to restore water clarity to former conditions would almost certainly be accompanied by re-establishment of alien weed species requiring annual weed control.

3.Feasibility. Restoration and rehabilitation studies report both successes and failures. A major concern over the feasibility of restoration is the increasing evidence for the high level of buffering which helps to maintain lakes in one of two alternate states. Submerged vegetation versus planktonic dominated states have been found to resist change by means of negative feedback mechanisms that help restrain any given waterbody in its current state (Hosper 1989, Scheffer 1989, Moss 1990).

A moderate level of nutrient increase is unlikely to cause macrophyte dominated systems to switch to planktonic dominated systems, since other impacts are usually required to trigger the change (e.g., grazing, storm event). Similarly, any decrease in nutrients alone is usually insufficient to reverse states, due to establishment of new buffers. For example, loss of macrophytes is likely to have resulted in a loss of zooplankton refuges so that former levels of phytoplankton grazing cannot be restored. Edgar (1993) found approximately 85% of the algal biomass of Lake Rotoroa was comprised of the large colonial green *Botryococcus*, with very few blue-green algae present. *Botryococcus* colonies were too large to be consumed by small copepod (*Calamoecia*) browsers, which resulted in low zooplankton browsing pressure on phytoplankton. The biomanipulation microcosm experiments used by Edgar (1993) have little relevance to the potential rehabilitation of Lake Rotoroa, since strategies aimed at increasing grazing pressure by herbivores are unlikely to increase utilisation of the phytoplankton while *Botryococcus* remains dominant.

4.Sustainability. Changes in lake status (macrophyte versus phytoplankton) can be induced artificially, but unless appropriate buffering mechanisms are also established, the change in status may be short-lived. Although successful biomanipulation results have been reported, concerns have also been expressed over the instability of some results (Shapiro 1990). In the case of Lake Rotoroa, removal of coarse fish (potentially a major obstacle to rehabilitating macrophyte growth) is likely to pose public objections since the lake is a valued coarse fishery. Even if this option were pursued, additional factors are likely to preclude macrophyte re-establishment unless further management measures are taken (e.g., reinstatement of seedbanks, or modification of substrates).

6.Cost. Any restoration or rehabilitation programme must examine the value of the benefits to be achieved relative to the costs. Before any meaningful cost benefit analysis can be carried out for Lake Rotoroa, further research is required on basic issues associated with foodweb interactions and on the feasibility of any rehabilitation option.

With respect to Lake Rotoroa, the question to be asked by managers, researchers and the public is, "restore what?" and "to what?". Public expectations on restoring water quality can be unrealistic (e.g. desired water colour or clarity unattainable for a peat-stained lake), and also in conflict with some users (e.g. those who prefer turbid water so as to avoid nuisance weedbeds). Rehabilitation of the original fisheries status raises difficulties over "desirability" of certain coarse fish species (e.g. recent release of tench and previously illegal release of rudd may have been instrumental in triggering macrophyte decline). Rehabilitation of conditions suitable for submerged vegetation regrowth raises the inevitability of alien weed re-establishment and subsequent domination, followed by the need to reinstate control measures for macrophytes. Weedbeds and their control raised more public concern and complaint to City Council than any other matter associated with Lake Rotoroa. Finally, it must be recognised that Lake Rotoroa is an urban lake within a highly modified catchment. Restoration to an earlier pre-urban condition is not feasible due to the irreversible nature of catchment development and impacts.

Restraint

Management measures aimed at restraint are based on the premise that a high risk exists for significant deterioration to take place if no intervention or action is taken. A hypothetical application of restraint criteria is illustrated in Table 1 by comparing Lake Rotoroa to a

Table 1 Hypothetical examples of how suggested criteria for *restraint* might be applied to 3 lakes of differing susceptibility to unfavourable changes in the near future (Scale 0 to 5 represents low to high risk, respectively).

	A	B	C	D	E	F	Total
Lake Rotoroa	5	5	4	4	4	3	25
Lake Omapere	2	1	2	2	2	2	11
Lake Rotoma	0	0	0	0	0	0	0

APotential for increased algal blooms in near future
BPotential for undesirable change in species composition (e.g. blue-green algae)
CPotential for increased deleterious impact on desirable biota (e.g. fish kills)
DPotential for increased recreational interference
EPresent and future potential for public complaint
FPresent and future health risks to humans or ecosystem (e.g. heavy metals, faecal coliforms).

eutrophic and an oligotrophic lake (Lakes Omapere and Rotoma, respectively). A high risk that selected problems develop, either singularly or in combination, would indicate the need for restraining measures to be implemented by management. The risk of deterioration of Lake Rotoroa is assessed against the following:

1. Increased algal blooms. Although phytoplankton have become more abundant within Lake Rotoroa following macrophyte decline, algal densities have not yet commonly reached proportions that are referred to as blooms (sufficiently abundant to cause marked discolouration of the water) or surface scums.

2. Species composition change. Domination by undesirable blue-green algae is an associated concern. Blue-green algae comprise many nuisance species which cause problems with toxin, bad taste or odour production, and bloom or scum formation. Lake Rotoroa has a high potential for blue-green algae to dominate, particularly if phosphorus levels in the lake water were to increase.

3. Increase in harmful ecological impacts. Periodic large fish kills can arise from deoxygenation of water or from toxic effects associated with blue-green algal blooms.

4. Increased recreational interference. Water-based recreational activities (e.g. a wide variety of boating activities, fishing) can be significantly impaired by water quality deterioration arising from algal blooms, water level changes and fish kills.

5. Present and future public complaint. This factor would score highly in urban lakes where changes or potential problems would be readily noticed.

6. Current or future health deterioration. Health risks may refer to the ecosystem in general (e.g. biotic accumulation of heavy metals from urban stormwater inputs) or a human health issue in particular (e.g. faecal coliforms in excess of permissible levels for contact recreation).

It can be seen that susceptibility of an oligotrophic lake to such imminent unfavourable change is low, while highly eutrophic lakes already exhibit substantial deterioration.

RETAIN CURRENT STATUS?

If protection of Lake Rotoroa is inappropriate and restoration or rehabilitation presently unjustifiable, then some management restraining measures are highly advisable in order to arrest or reduce the risk of further deterioration. Although the case for restoration or rehabilitation cannot be assessed without further information on issues such as feasibility, sustainability and cost effectiveness relative to ecological and user benefits; the advantages of maintaining or managing the lake in its present state are already evident and include:

1. Enhanced recreational benefits for major user groups (e.g. Yacht Club, Coarse Water Anglers).
2. No weed interference or drowning hazard to the public.
3. No weed control required.

4.Less public complaint.
5.Retention of a diverse self-regulating population of coarse fish.
6.Low cost option compared to restoration or rehabilitation.

7.FUTURE DIRECTIONS

A technical workshop for parties involved in research on Lake Rotoroa was held on 23 November 1992. One objective was to review and summarise past studies on the lake for future reference (Clayton and de Winton 1993), while another was to identify future research requirements for the lake. As a result, a number of management-oriented research recommendations were presented to the Hamilton City Council (HCC) in December 1992. These were largely endorsed at the subsequent meeting called by HCC and are noted below. In addition to the management-oriented research topics, Lake Rotoroa was also considered as a site suited to research of a more fundamental nature including:

- the causes of macrophyte decline;
- food web changes in de-vegetated versus vegetated lakes;
- restoration methodology, including the role of fish foraging/browsing and
- role of plant inocula/seed banks in macrophyte recovery.

As a part of HCC's process of reviewing the "Hamilton Lake Management Plan" a further meeting was invited for research and management organisations on 10 June 1993. The research areas identified by the workshop were endorsed and Council incorporated these into an issues paper prepared as a basis for public consultation on the future of the lake. This document, titled "Lake Rotoroa Management Plan Review-water quality issues and objectives" informed the public what management may feasibly achieve and what information is required to assess the outcome of possible management actions, before seeking community views on the desired condition and uses of the lake. More information is required on the following topics, in priority order:

1.Nutrients and hydrology. Identification of critical or growth limiting nutrients (e.g. phosphorus) and the major source of nutrient input, together with sources and sinks of water. The feasibility of controlling phytoplankton abundance through management of nutrient inputs (especially phosphorus) and consequent impact on flushing rate and lake level can then be assessed.

2.Fish. What is the present status and role of the fish population. Information will enable the identification of a management strategy to maintain a lake fishery of desirable size and species composition compatible with identified uses.

3.Heavy metals and other pollutants. Assessment of techniques to reduce stormwater contribution of heavy metals, and identification of other potential pollutants.

4.Human health. An assessment of health hazards associated with lake user activities (e.g. bacterial pathogens, levels of pollutants in fish tissue).

5.Shoreline vegetation. Control methods and enhancement techniques for shoreline vegetation in keeping with identified lake uses and values such as species and habitat diversity.

6.Beauty, waterfowl and family outings. Determine the desirable size for waterfowl populations and methods of maintaining bird numbers.

7.Sediment. Investigate the role of sediments in determining water clarity, their sources and possible control measures.

The Hamilton City Council recognises that major management changes are ill advised until answers to these questions are obtained, but that it is important to prevent additional ecological impacts. The document also proposes an eventual management philosophy of "rehabilitation" that will suit the urban nature and competing uses of Lake Rotoroa. The Council intends that the multitude of lake uses be recognised, the community be consulted in finding a balance between uses, and the lake be managed "to accommodate the uses in a sustainable manner".

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