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A HISTORY OF THE LAKE-WEED INFESTATION OF THE ROTORUA LAKES AND THE LAKES OF THE WAIKATO HYDRO-ELECTRIC SYSTEM

by

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INTRODUCTION

On the volcanic plateau of the Central North Island is a series of lakes formed in the ignimbrite sheet as explosion craters or as subsidence features associated with volcanic activity. The largest are Taupo (234 sq. miles with a maximum depth of 522 ft), Rotorua (31 sq. miles with a maximum depth of 84 ft), Tarawera (14 sq. miles with a maximum depth of 285 ft), Rotoiti (13 sq. miles with a maximum depth of 230 ft). All are at an altitude of between 900 and 1,200 feet above sea level.

The main drainage of the area is by the Waikato River flowing from Taupo at 1,177 ft. Nine hydro lake generating stations have been constructed on the river utilising all its available fall and forming a series of lakes extending almost continuously from Taupo to Karapiro along 117 miles of river course.

The soils of the region are mainly formed from rhyolite pumice showers ejected by eruptions which have taken place during the last 2,000 years which mantled the whole of the Central North Island. Because of their youth the soils are weakly weathered and coarse textured and the streams and lakes carry very little suspended material. The water is clear and until recently was notably free of plant growth.

Until the turn of the century most of the catchments were densely forested or covered in manuka scrub with the exception of the tussock covered Kaingaroa Plains on the east and the "Rangipo Desert" to the south on the flanks of Mount Tongariro. Early attempts at grazing stock were unsuccessful owing to a stock disease known as "bush sickness", and it was not until the mid 1930s, when this was identified as cobalt deficiency, that farming began to prosper in the region. Meanwhile very large exotic forests, mostly *Pinus radiata*, have been planted on the tussock plains and on cut-over native forest land. These began to come into production about 1940 initially for sawmilling but later for pulp and paper manufacture as well as timber production. Large-scale land development in the late 1940s and during the 1950s converted large parts of the catchment in use for exotic forestry into sheep and dairy farmlands.

WEED INFESTATION

In the last ten years four exotic water weeds have assumed epidemic proportions in the Rotorua lakes (Fig. 1; Table 1) and the hydro-electric lakes of the Waikato River system (Fig. 2; Table 2). The sudden spread of these weeds is so reminiscent of the explosive spread of *Elodea canadensis* in Great Britain in the last century that an historical record of the events associated with the arrival of these weeds and of the initial efforts to control them would seem to be important. Rapid spread of adventives is not a new problem, but lessons may be learnt from every such occurrence.

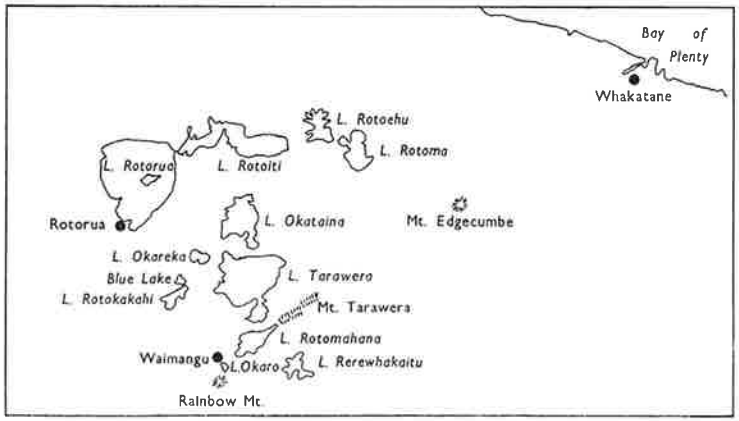

FIG. 1. Distribution of the main lakes in the Rotorua district.

TABLE 1. Main Lakes of the Rotorua District (From *N.Z. Official Yearbook*, 1969)

Name of Lake	Area (sq miles)	Maximum Depth (ft)	Maximum Height above Sea Level (ft)
Rotorua	31	84	920
Rotoiti	13	230	916
Rotoehu	3	..	968
Rotoma	4⅛	⩾80*	1,036
Tarawera	14	285	981
Okataina	4	⩾75*	1,018
Okareka	1¼	..	1,160

*Figures supplied by N.Z. Oceanographic Institute, DSIR.

TABLE 2. Waikato Power-station Details

(Data supplied by N.Z. Electricity Department—areas and heights of dams approximate only.)

Station	Year Lake Filled	Area Lake (sq miles)	Maximum Height above Sea Level (ft)	Height of Dam (ft)
Arapuni	1929	3.6	363	210
Karapiro ..	1947	3.0	176	190
Maraetai ..	1952	1.95	618	285
Whakamaru ..	1956	2.75	742	183
Atiamuri ..	1958	0.85	826	143
Ohakuri ..	1961	5.0	942	160
Waipapa ..	1961	0.61	417	110
Aratiatia ..	1964	0.22	..	Weir 15 ft

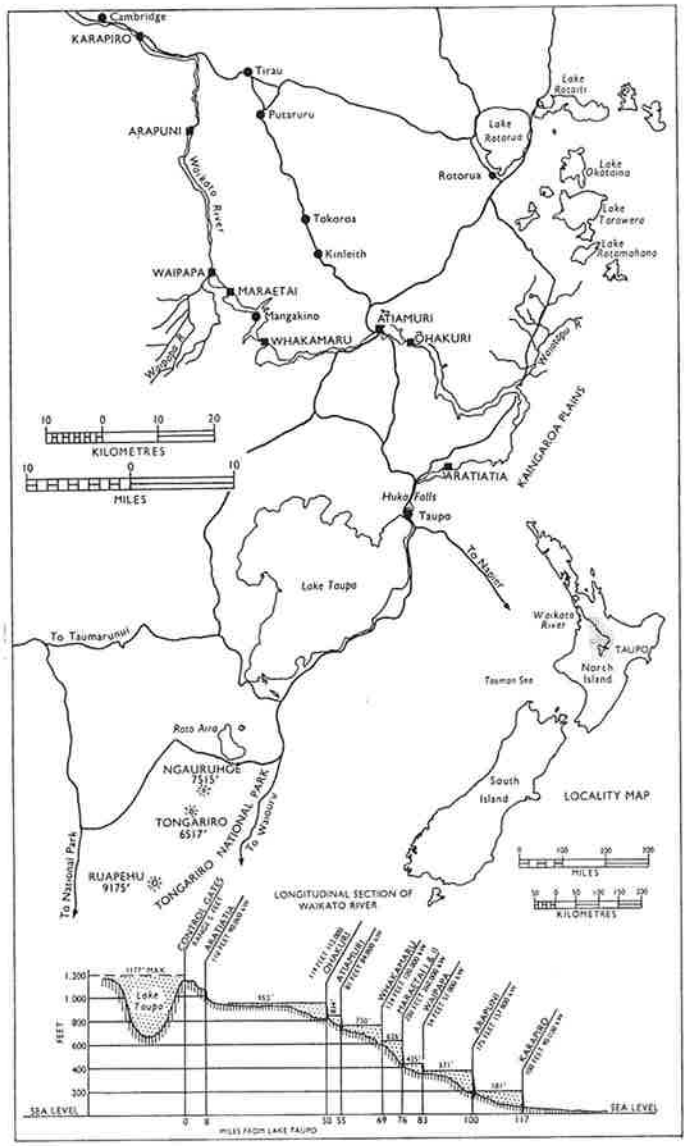

FIG. 2. Locality map of Waikato River hydro-electric power stations.

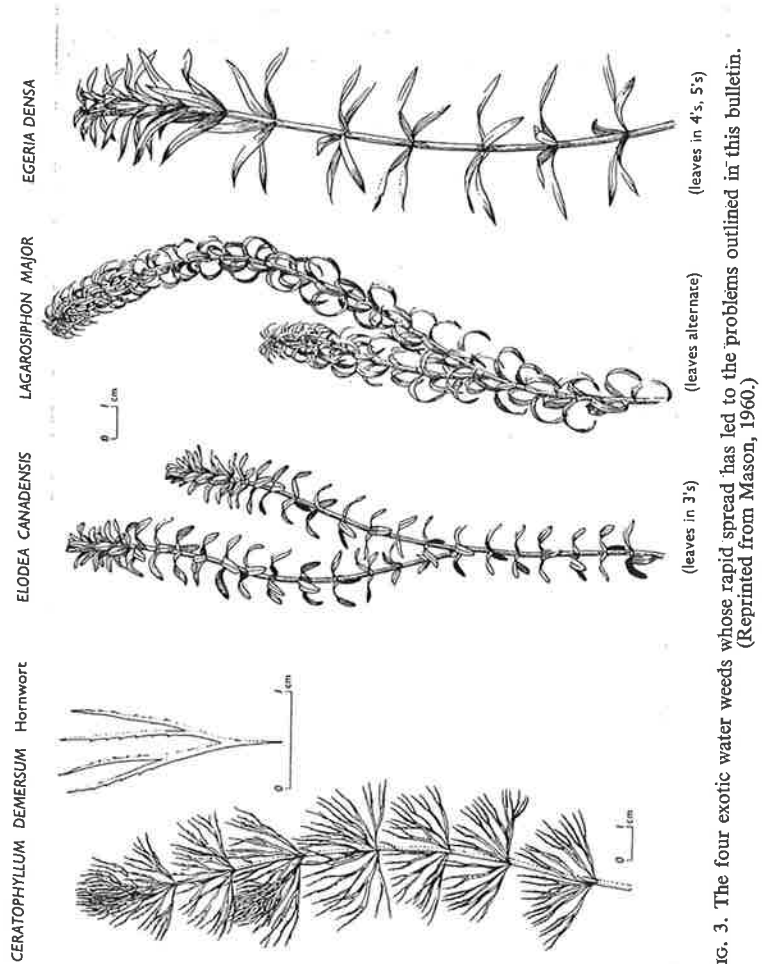

FIG. 3. The four exotic water weeds whose rapid spread has led to the problems outlined in this bulletin. (Reprinted from Mason, 1960.)

Pollution and eutrophication of fresh waters is a major problem in many parts of the world and it well may be that the sudden spread of these weeds in the Rotorua and Waikato area is a symptom of eutrophic processes.

Growth and spread have been so rapid that the problems engendered by the weeds have become a national issue. Attempts to eliminate one of the weeds, *Egeria densa*, newly arrived in Lake Maraetai, were abandoned in 1967, and now the most one can hope for is effective control measures. Few lakes have but one of these exotic species, e.g., Lake Rotomahana; most lakes where the weeds have assumed pestilential proportions usually have two species, e.g., Lake Rotoiti, and there are lakes with three, e.g., Lake Ohakuri.

THE WATER WEEDS

Elodea canadensis Michx. (Synonym *Anacharis canadensis* (Michx.) Planch.). (Figs. 3, 4)—Hydrocharitaceae.

Common names: **Canadian pondweed,** oxygen weed, American water weed, water thyme, Babington's curse.

This species is a native across the North American continent between latitudes 33° N and 55° N. It is now naturalised in the British Isles, Europe, Western Siberia, Australia, and New Zealand. The plants are attached to the lake floor by a mass of roots (approximately 2.6 % of the biomass) and a number of erect stems float in the water. The apical growing region is long and narrow, and leaf primordia occur low down on the flanks of the stem apex. The adult plant has long internodes and whorls of three leaves at each node except for the very basal nodes where there are only two leaves. Dormant buds can give rise to laterals, but there is evidence that the growth of laterals is inhibited to some extent by an apical growth hormone. The leaves are very thin and, except for veins, consist of only two cell layers. Vascular tissue is not well developed and the xylem soon collapses giving rise to a lacuna. The floating shoots when damaged or if prostrate give rise to slender unbranched adventitious roots which give rise to new centres of infection. It appears that the species grows more vigorously when rooted in mud. Spread is essentially vegetative because male plants are very rare and even when present not more than 50 % of the pollen is viable. The pollen has a waxy cuticle and air-trapping spines, so that the grains float in water and are carried in this way from male flowers to the female.

In the Rotorua district the Canadian pondweed, *Elodea canadensis*, (or Babington's curse — so called from the professor who introduced it into the River Cam in England from whence it spread to choke up waterways) is distributed in nearly all the lakes, large or small. Introduced from Tasmania over a hundred years ago, it has spread widely throughout New Zealand since that time (Fig. 4). Most of the spread, however, has been in the last half century, for in 1906 Cheeseman recorded it as occurring in only three districts. The earliest recorded introductions appear to have been by the Canterbury Acclimatization Society (Armstrong, 1872; Thomson, 1922), who planted it in 1868 in one of their ponds (near the

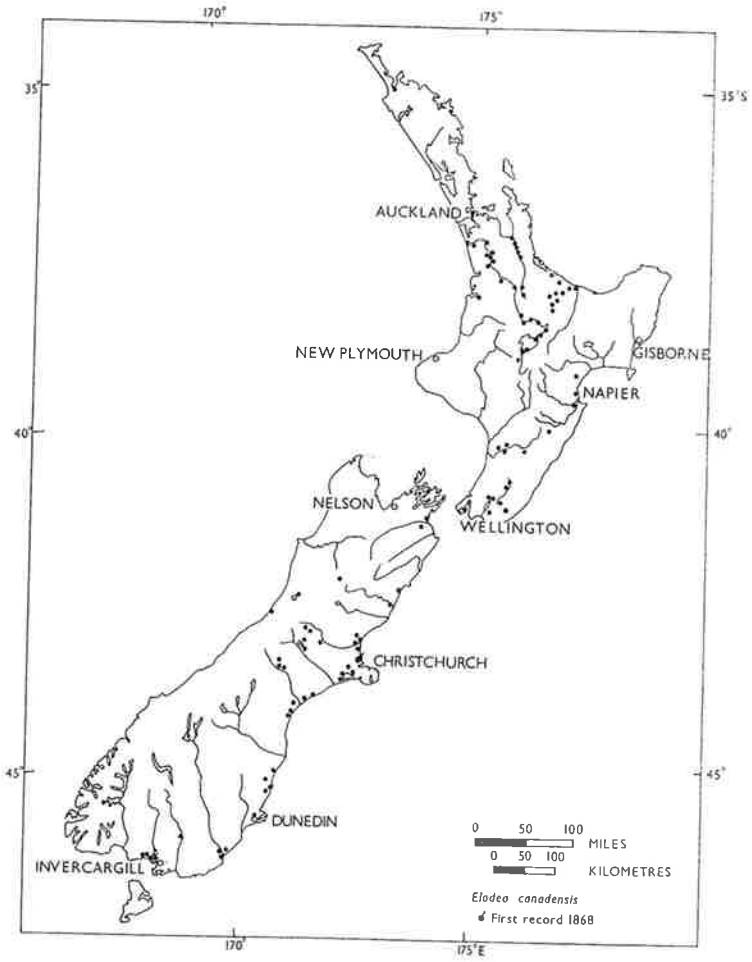

FIG. 4. Records of *Elodea canadensis* (Canadian pondweed).

Avon), from which it "was by some means conveyed into the river" (Armstrong, 1872, p. 285). Whether it was later introduced into other localities for aquaria is not recorded, but doubtless its spread has been promoted by the tipping of aquarium contents into river, pond, or lake. Once there, the weed can fragment, each fragment sending out new adventitious roots that attach it to the ground to give a new source of infection. This species so far has not become the menace that it rapidly became in Great Britain, where it literally choked waterways. It may never reach this condition, because in the last ten years it has had heavy competition from the other three exotic water weeds that are larger and much more aggressive.

It was not until 1958 that it became evident that *E. canadensis* was not the only species in New Zealand to which the term oxygen weed was being applied. During a survey at that time Miss Mason found that nearly everyone consulted thought there was only one species in the Auckland Province (Mason, 1960). Thus, all pre-1958 records for *E. canadensis* not supported by herbarium specimens in places where *Lagarosiphon major* (lagarosiphon) and *Egeria densa* (egeria) have since been found are suspect. As stated by Widgery (1967), "until Arapuni lake was filled in 1929 there was comparatively little slack water in the Waikato River, so that there could not have been much growth of water weed before then." Weed problems since that time have been popularly ascribed to "oxygen weed". Both *Elodea canadensis* and *Lagarosiphon major* are present, but it is probable that the first weed to establish was *E. canadensis*, which was identified from the Waikato much earlier than *L. major*. Originally the lower reaches of the Waikato River (and hence possibly also the upper reaches) contained very few water weeds (Kirk, 1871). The expansive growth of the weeds in the Waikato system is therefore very largely a feature of this century. Oxygen weeds "have generally given trouble only when the colder water temperatures and rougher weather of autumn have caused parts of the weed beds to break away and float down to the power stations. No significant amount of water weeds have appeared at any other time of the year, but in April and May it is expected that the screen scrapers will have to be used fairly regularly to keep screens clear. Normally no great quantity of weed is found, and if a station had to handle 10 cubic yards of weed in a season it would have been considered, until recently, a rather large amount of weed." (Widgery, 1967.)

Lagarosiphon major (Ridley) Moss — Hydrocharitaceae. (Figs. 3, 5)

Common names: **lagarosiphon,** oxygen weed.

This species is a native of Rhodesia and South Africa. It is now naturalised in the British Isles, continental Europe, and New Zealand. The plants are larger than those of *Elodea canadensis* but the habit is essentially the same — attachment by a mass of roots with a number of erect stems arising from the root mass. As the plant can grow in 15 ft of water, erect shoots are as long or longer and it can form veritable underwater forests.

Inset 1*

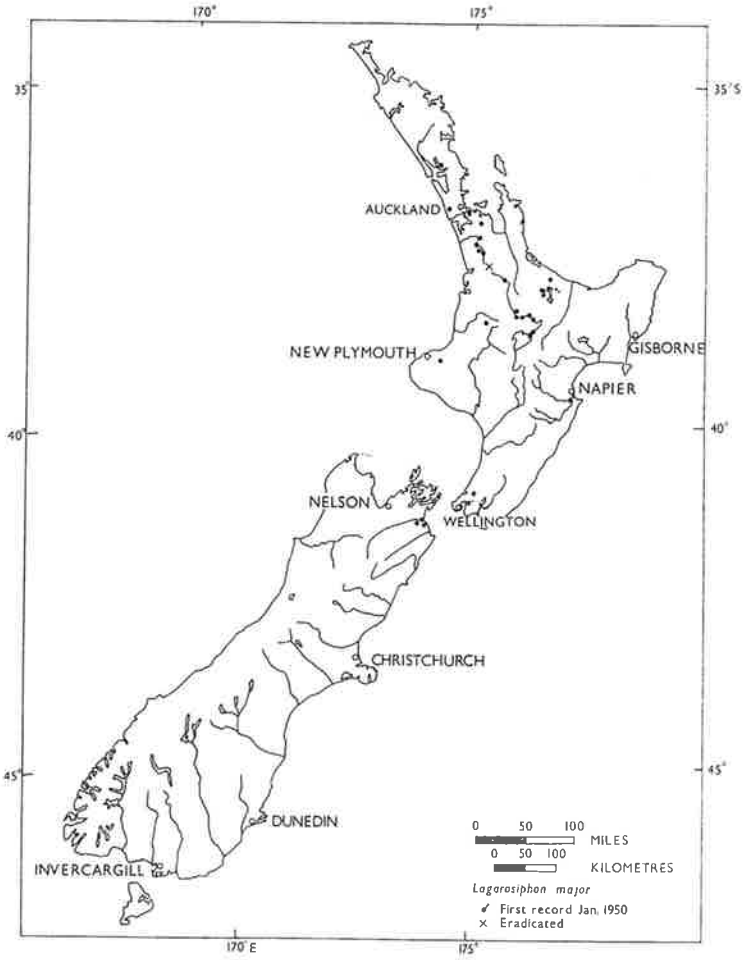

FIG. 5. Records of *Lagarosiphon major* (lagarosiphon).

The species is easily distinguished from *E. canadensis* by its greater size and the spiral arrangement of leaves instead of the whorled arrangement. The floating shoots if damaged, cut, or lying prostrate on the lake floor give rise to slender, unbranched adventitious roots, which serve as new centres of infection. Spread is by means of fragments that become rooted in this manner. The plants appear to grow equally vigorously whether in a mud, or more solid, substrate. Outside its native area spread is almost wholly vegetative because female plants are extremely rare. The pollination mechanism approaches hydrophily because the male flower breaks off and floats away in the water. No flowers of either sex had been reported in New Zealand up to 1960 (Mason, 1960), but in recent years male flowers have been found in the Rotorua lakes and at Auckland. It appears capable of growth in waters very poorly provided with nutrient: it has, in fact, all the characteristics and behaviour of a terrestrial weed species.

It is not known when lagarosiphon was first introduced. The first record of its occurrence in the wild is from Waiwhetu in the Hutt Valley in 1950. Prior to that, at least as far back as 1946, it was present in a concrete tank on the roof of the Botany Department of the then Auckland University College. About that time it was also in aquaria at the then Victoria University College (Dr R. Mason, pers. comm.). As the weed was probably originally imported for use in aquaria, and is indeed still sold for this purpose, there seems little doubt that it has been liberated from aquaria on more than one occasion. It is suggested that the lower Waikato was infected from Hamilton Lake (Lake Rotoroa), Lake Rotorua possibly as described below, the hydro-electric lakes by launches from Lakes Rotorua or Rotoiti, and the Hutt Valley and Blenheim areas separately. Every effort should now be made to ensure that the weed is not introduced into any other lakes in New Zealand.

One area where lagarosiphon soon reached proportions that required action was Hamilton Lake. Control measures are briefly described on p. 19.

The weed was first seen in Lake Rotorua in the mid 1950s. In a series of articles in *The Daily Post*, Rotorua, in April 1964 it was stated "Storms tossed up huge accumulations of weed to rot on beaches. Boating and swimming were curtailed. Public outcry against the weed began to grow in momentum — and almost from the start there was controversy". The source of infection has been a contentious issue. In 1940 a request was made by the Ngongotaha Hatchery for "oxygen weed" from Greenmeadows, the idea being that it would help oxygenate the water in the hatcheries, but as the weed was found to be the same as that already present in the ponds no supplies were sent. The weed could well have been lagarosiphon but is more likely to have been Canadian pondweed. McKenzie (1967) stated that lagarosiphon was possibly present in these hatcheries from 1930. In view of the annual flushing it would, in this event, have appeared sooner in Lake Rotorua. The then Hatchery Manager, Mr A. C. Christophers, reported (*The Daily Post*, Rotorua, 4 March 1961) that the weed [whichever species was concerned] thrived in the ponds and that it must have gone down the outlet stream into the lake once a year when the ponds were cleaned out.

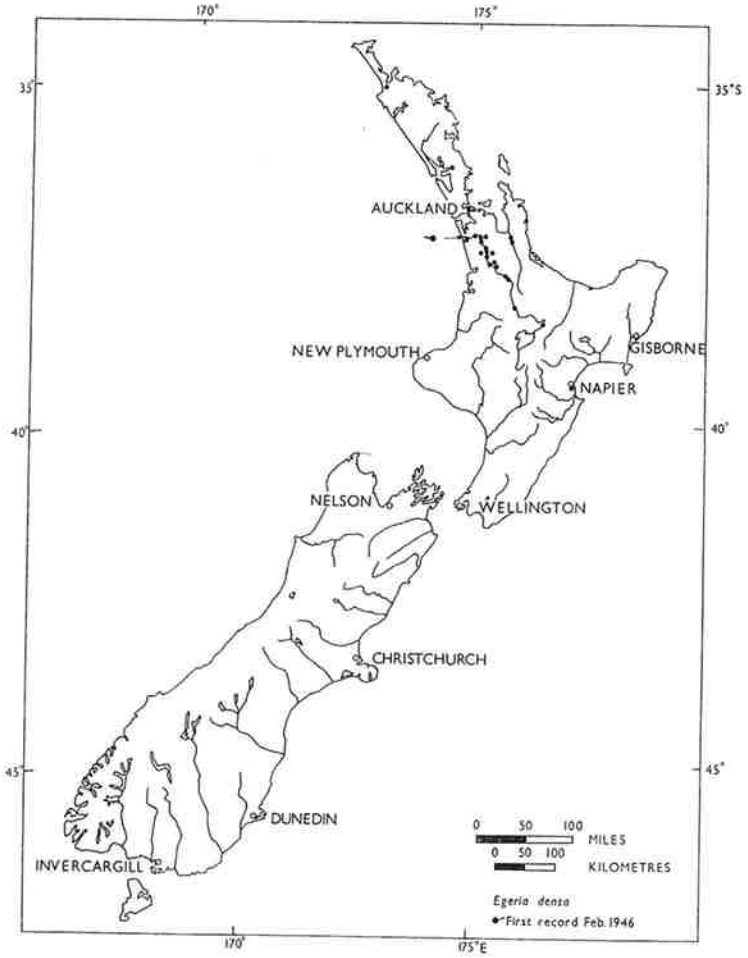

FIG. 6. Records of *Egeria densa* (egeria).

Lagarosiphon has now invaded the upper lakes of the Waikato hydro-electric system. The source of infection was probably the boat harbour at Taupo where there is a dense growth. When the weed first appeared is not known. It is now present in Lakes Ohakuri, Atiamuri, Maraetai, and Waipapa.

Egeria densa Planch. – Hydrocharitaceae. (Figs. 3, 6)

Common name: **egeria**

This species is a native of South America, where it occurs in eastern Argentine, southern Uruguay and in south-eastern Brazil. It is now naturalised in Mexico, the U.S.A., British Isles, Europe, Kenya, Japan, and New Zealand. Some limit is probably set by water temperature, for in the British Isles it is restricted to warm water from an electric power station cooling system. In New Zealand it is restricted to the northern part of the North Island (Fig. 6). In habit the plant is the largest of the three species so far considered, though the erect stems do not seem to reach the great length of those of lagarosiphon. The leaves, which are arranged in whorls usually of four but occasionally up to six, are much longer and broader than in the other two species. Detached leaves rapidly become senescent. Dormant buds occur at every 12th node, their growth probably being inhibited by an apical growth hormone. Growth of buds begins as soon as the stem is fragmented. Attachment of the plant is the same as in Canadian pondweed and lagarosiphon. The erect shoots of all three species contain abundant air spaces, and the contained air keeps the shoots floating erect. In the air lacunae of egeria an excess gas pressure of 0.2 atm has been reported by Angelstein (1911). In this species four dormant root primordia are associated with each lateral bud at every 12th node. These develop only when the axis containing them is detached. Growth can, however, be induced by treatment with the growth-promoting compounds indole propionic acid (IPA), indole butyric acid (IBA), indole acetic acid (IAA), and naphthalene acetic acid (NAA), IPA being the most and NAA the least effective.

Egeria is dioecious but is strictly entomophilous, the conspicuous white flowers being borne above the water surface. Spread seems to be almost wholly vegetative, because female plants of egeria are very rare.

This weed was probably introduced into New Zealand for aquarium purposes and may have been thrown out into one of the natural lakes around Huntly (e.g., Lake Kimihia). From there is has spread throughout the lower Waikato system where it can choke the smaller drains.

One does not normally expect aquatic weeds to move upstream, and its appearance in Lake Karapiro in 1965 was greeted with great concern. It appeared there at the launching ramp and was undoubtedly brought on a launch propellor or boat trailer. In November 1966 it was reported to the Rotorua Interdepartmental meeting that egeria had appeared off the boat ramp area at Lake Maraetai. As soon as it was noticed the area was chemically sprayed by officers of the Department of Internal Affairs, but the weed has since returned. When the writer inspected the area in early December 1966 clumps of plants were to be seen. A further spray was

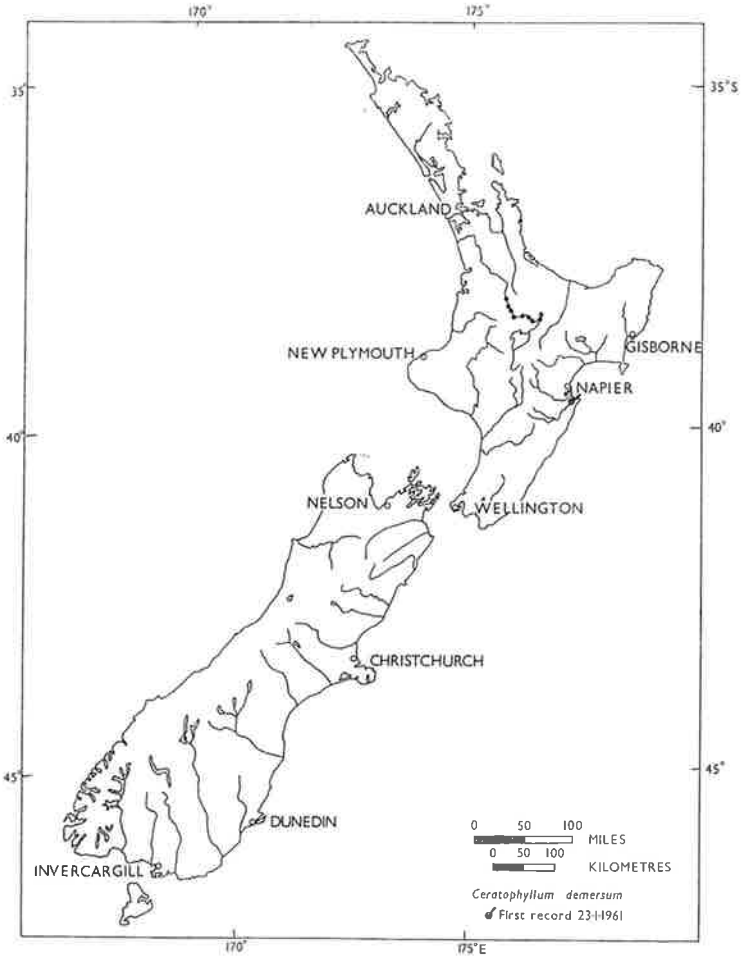

FIG. 7. Records of *Ceratophyllum demersum* (hornwort).

carried out, but presumably plants were present in deeper water and these plants must have served as re-infectant foci, because in April 1967 the weed was back in such quantity that it was clearly impossible to eradicate it. It now (1970) occupies about 100 acres (see Rodger, 1969).

Ceratophyllum demersum L. — Ceratophyllaceae. (Figs. 3, 7)

Common names: **hornwort**, coontail

This species is widespread in the tropics and subtropics and has penetrated into temperate waters in Great Britain and New Zealand. In Malaya it is found from sea level up to 1700 m (Sculthorpe, 1967), and in New Zealand it occurs in Lake Ohakuri at 1,000 ft (330 m). *Ceratophyllum demersum* differs from the other species involved in that it is free-floating, often forming extensive mats. Plants can become entangled in egeria and lagarosiphon beds and also around snags provided by submerged tree branches. The leaves, which are highly dissected and needle-like, are borne in whorls of three. Each segment has an apical multiseriate gland that secretes an oil. The lower internodes are long and they decrease in length towards the apex. In the seedling the first leaves are only two and are simple, linear, undivided. The second whorl consists of three similar leaves, and segmentation commences only with the third whorl. The leafy shoots sometimes possess basal lateral branches, the leaves of which are extremely finely divided into whitish thread-like segments. It is claimed that these penetrate the substrate and may aid absorption and anchorage. The base of shoots can certainly become anchored by covering with mud but no true roots develop.

Structurally the epidermis of hornwort is richer in plastids than are any of the other hydrophytes. It is also interesting in possessing an outer cortex of collenchyma, support tissue being unusual in such plants. The air spaces in the stem are arranged in a ring, and it is claimed (Sculthorpe, 1967) that the rate of downward diffusion of gases is governed by the steepness of the concentration gradient and the resistance of diaphragms. This generalised claim is based upon work with one submerged aquatic, and it certainly should be investigated for hornwort. The adult stele is greatly reduced, and lacks vessels and tracheids. The plants are monoecious, and pollination is a true hydrophily. The flowers, male and female, are solitary and borne in axils at different nodes. The female flower consists of one ovule surrounded by 10–15 perianth segments: the male bears 10–20 stamens inside the perianth. The anthers dehisce on reaching the surface and the pollen sinks onto the female flowers below. Fruits are produced only in conditions of high water temperatures. Flowers are found in New Zealand, but no fruits have been reported. The embryo lacks a radicle, and seeds sink immediately they are liberated. Vegetative reproduction takes place by means of very dense branch apices packed with excess starch. These are not true winter buds or turions, but they behave as such. They break off, sink to the bottom, and remain dormant until the dormancy is broken by a rise in water temperature. Stem fragments also regenerate, so that multiplication is rapid.

The first record of hornwort in natural waters in New Zealand is as recent as 1961, when it was found in the Napier area. It was recognised in the Waikato at Mihi Bridge in 1963, and may have been introduced into the river at Golden Springs above Orakeikorako, where it could have been tipped out from an aquarium. In very recent years hornwort has become a menace in the Waikato hydro-electric lakes (see p. 40).

PROBLEMS IN THE ROTORUA LAKES: MEASURES TAKEN

The weed problem in the Rotorua Lakes is due to the growth of lagarosiphon, which was first seen in Lake Rotorua in the mid 1950s and subsequently spread through the Ohau Channel to Lake Rotoiti, where it was first recorded in 1957.

By 1958 the growth of the weed in Lake Rotorua had reached such proportions that in February the Rotorua Chamber of Commerce addressed an inquiry to the Department of Internal Affairs concerning control of the lake weed. A large deposit of weed on the shores between the (Queen Elizabeth) Rotorua Hospital and Ngongotaha in March 1958 that drew complaints from citizens was responsible for the request. (McKenzie, 1967.)

In November 1958 an attempt was made to fix responsibility by court action of the Rotorua County Council. According to a letter dated 23/3/59 from the Secretary of Marine to the Secretary, DSIR, the Health Inspector of the Rotorua County Council had, before the court case, requested the Supervising Officer for the Motor Launch Regulations 1958 (authorised under the Harbours Act 1950, administered by the Marine Department) to have the weed removed or proceedings would be taken against him. No action was taken to have the weed removed, and on 13 November the Health Inspector (Mr R. A. Hall) instituted proceedings under section 30 of the Health Act 1956 against the Supervising Officer, Mr B. Vercoe, for "failing to remove an accumulation of decaying vegetable matter in an offensive state from the foreshores of Rotorua". In his judgment of the case the Magistrate stated that "The defendant ... is under no duty whatsoever to remove lake weeds from the bed of Lake Rotorua or of any other lake, or in any way is he responsible for any nuisance caused by failure to remove lake weeds." And further that "No evidence was adduced to show that this particular nuisance was originated by the Government or by any official in the Government service. The absence of such proof is a further reason for exempting the Crown or any Crown servant from responsibility."

Needless to say, public outcry over the weed at Rotorua persisted. Many people were impatient and wanted action, and in April 1959 the *Daily Post* printed an open letter to the then Minister of Internal Affairs, Mr Anderton, suggesting that his Department had actually planted the weed in Lake Rotorua, and saying that unless he took some action forthwith to remove it it would be named "Anderton's Curse". Simultaneously a deputation of lakeside dwellers met the Hon. R. Boord, M.P. for Rotorua, who promised to find out which Government department was responsible for removal of the weed. On 27 April 1959 Cabinet

clarified the position and directed that as the title of the bed of the lake is vested in the Crown the Department of Lands and Survey is responsible for dealing with any noxious weeds growing on it. At this time the weed, though growing vigorously, was still confined to the southern end of Lake Rotorua and probably did not occupy more than 100 acres.

The Years 1959 and 1960

The Department of Lands and Survey, now formally saddled with a major problem, turned to the Department of Agriculture, and Mr L. J. Matthews of this Department was charged with finding a suitable control measure. Mr Matthew's efforts were initially with hormones.

Early in 1957 the Department of Agriculture had co-operated with Hamilton City Council in the testing of hormones on lagarosiphon in small plots in Hamilton Lake. These had little effect — according to Mashlan (1960) "not sufficient to warrant the carrying on of the experiments any further" — but L. J. Matthews (pers. comm.) thought that the techniques used could be improved.

In August 1959, however, Hamilton City Council, on the basis of overseas inquiries by Dr H. E. Annett (then Chairman of the Parks and Reserves Committee) and after a successful trial on a small bay in the lake, used Penite 6x sodium arsenite solution, applied at 10 ppm, to produce a complete kill of the weed. (This work is recorded by Mashlan, 1960.*) Bird life suffered no ill effects. No fish were killed initially, but a month later 23 dead fish were found and eventually some 150 were recovered. It is believed that these fish were not poisoned but died as a result of oxygen depletion in the water, due to rapid decay of the vegetation (most of which had completely disappeared within two months of the spraying). If the weed decayed rapidly, one might have expected the fish to die sooner, so there may have been some other cause of the mortality.

The cost of spraying 96 acres of Hamilton Lake using 2,450 gal of Penite 6x was £2,958 or £31 per acre.

There is no doubt that this poison is effective, but the Department of Health subsequently ruled that it could not be used in the Rotorua Lakes. Still seeking a solution by the use of hormones, Mr Matthews carried out trials with fenac, fenoprop, and 2,4-D in Lake Rotorua in December 1959 (see Matthews, 1962), but without success. In 1960 weed in Lake Rotoiti was unsuccessfully sprayed with fenoprop from a Cessna aircraft.

Dr H. E. Annett stated at a meeting in Rotorua convened by the Department of Internal Affairs that all submerged water weeds, having no sap circulation, are immune to hormone attack. Some water movement may occur, however, but this could be related to adjustments of water balance in the tissues or to root pressure (Sculthorpe, 1967). L. J. Matthews has reported (1962 and pers. comm.) that fenac, fenoprop, and 2,4-D are required to be maintained at a concentration of 10 ppm for 48 hours or more for effective control of lagarosiphon, egeria, and hornwort and, like arsenicals, are effective in small bodies of static water.

*Note that Mashlan wrongly identified lagarosiphon as *Anacharis (Elodea)*.

Failure to produce any worthwhile results had aroused public reaction, and on 3 January the Society for Lake and River Weed Eradication was formed at a well attended meeting at Moose Lodge. Mr L. P. Leary, Q.C., was elected President and Mr C. M. Taylor Secretary. Dr H. E. Annett was appointed adviser to the society, and resolutions were passed demanding government action with sodium arsenite, used successfully at Hamilton.

Warnings were also given to the meeting by Mr Leary that lack of vigorous action could result in a spread of the weed to the hydro-electric lakes. If the weed was not already there at the time — and it is not known from the records — the prophecy has certainly since been fulfilled.

The first advertised public meeting of the society was held on 11 January and was attended by local representatives of the government departments involved. Dr W. C. Davidson of the Department of Health strenuously opposed the use of arsenic as a weed killer, having regard to the maximum recommended arsenic content of 0.2 mg/l for drinking water given by the World Health Organisation. Residents pointed out that the unpleasant taste of the water — derived, they thought, from decaying weed — had for some time stopped them using lake water for drinking purposes. Dr Annett pointed out that the sodium arsenite in Penite 6x changes form almost immediately in water, combining with dissolved oxygen to become sodium arsenate, a much less poisonous compound. Further, he said, by acting on the weed it became absorbed and converted into an organic compound and in this condition was virtually harmless.

As an outcome of these meetings, a deputation from the society waited upon the Minister of Internal Affairs and asked for action. Despite assurances that action would be taken, there was no change in policy in respect of sodium arsenite, and spraying continued with hormone only.

At the end of January 1961 the *Daily Post* reported a "strange machine chugging its way about a secluded bay of Rotoiti". This was, in fact, a weed cutting machine developed by the Department of Internal Affairs and the Ministry of Works, and it was hoped by the former that with further development it might be an answer to the lake weed problem. Unfortunately the prototype did not collect the weed but left it to be swept ashore. Most lake dwellers knew that chopping up weed was tantamount to a sowing campaign. As the *Post* reported — "their enraged howls echoed all the way to Wellington — and the weed machine was summarily recalled from its voyaging". This was perhaps unfortunate but understandable in the light of the existing public temper. Harvesters cum collectors are used most successfully in the U.S.A. and such a machine could have been effective here.

Biological control of pests, which has been practised in other parts of the world for some time, was first put forward in February 1961 by the *Daily Post*, which suggested the use of an herbivorous fish, the Chinese grass carp (*Ctenopharyngodon idellus*), which was known to be effective overseas. This suggestion was strongly opposed by anglers, many of whom confused the fish with the European carp, which does not normally eat

growing water plants. This again was unfortunate, and events might have taken a different course had the proposal been put up initially as a scientific experiment with all the necessary safeguards.

At the second public meeting of the Society for Lake and River Weed Eradication, 2 April 1961, chaired by Mr Lapwood, M.P. for Rotorua, a motion was passed in which the society reaffirmed its former proposals for the use of sodium arsenite under proper precautions and for the immediate ordering of 10 tons for use in an experimental area. The drinking water standard was again challenged, it being pointed out that the concentration of sodium arsenite used in Hamilton Lake was only 10 ppm and that a person would have to drink 10 gallons to suffer any ill effect. On this occasion Dr Davidson, Department of Health, said he would not stand in the way of a controlled experiment.

In early July two 1-acre test plots were sprayed at Kawaha Point, Lake Rotorua, and another in Lake Rotoiti, without effective results (Fish, 1963). Dr Fish stated (p. 415) "A concentration throughout the water column of 10 ppm was intended but . . . only 5 ppm was recovered in water samples taken an hour after the completion of application. This concentration dropped to 1.0 ppm after 24 hours and to 0.006 ppm after one week. None of the fish or crayfish that were caged in the experimental plots, nor of the animals present naturally (snails or mussels) were affected, and no significant destruction of the weed resulted . . . Concentrations of arsenic as low as 2.0 ppm and commonly at 5.0 ppm . . . are effective against similar weed growths elsewhere. However control is usually attempted in the early summer and . . . the relatively cool water temperatures . . . could have reduced the rate of metabolism and therefore that of the absorption and translocation within the plant tissues to a level which prevented the poison from acting effectively as a herbicide during the time when the arsenic was at a lethal concentration in the surrounding water." Another possible factor discussed by Dr Fish was that the "plants may have already developed some tolerance to arsenic since relatively high arsenic levels were found in the bottom deposits and in the tissues of the plants in these lakes." Fish reported 6.5–57.0 ppm generally in bottom deposits; in the Lake Rotoiti plot 20–30 ppm were recorded.

One can agree with Dr Fish's comment (p. 417) that "the value of the weed to the trout fishery seems to be slight"; and in fact it could be argued that the complete removal of the exotic weeds would do no harm to the ecosystem. Eradication of lagarosiphon seems no longer feasible, however, even if it were possible (as L. J. Matthews (pers. comm.) maintains) by using sufficient diquat.

The first test of diquat as an aquatic herbicide was made in 1960 by L. J. Matthews, with the co-operation of Marine Department, who undertook fish toxicity tests (L. J. Matthews, pers. comm.). In March 1961 the first large-scale field trial was conducted (in Lake Rotorua)—with conspicuous success—and this was followed by further trials in both Lakes Rotorua and Rotoiti in July and November (Matthews, 1962).

When the results of the spraying to date were discussed informally with officers of the Department of Internal Affairs in Rotorua in October

it was considered that chemical control could only be a temporary measure and that limnological research was essential.*

The success Mr Matthews had had with diquat (Anon. 1962; Matthews 1962) led Mr J. A. B. Hellaby to apply some in November around his jetty at Kawaha Point. The results were spectacular within 24 hours, and in January 1962 the then Minister of Lands, Mr Gerard, made a personal inspection of the area.

The Year 1962

On 12 February 1962 a major storm washed hundreds of tons of weed ashore on Lake Rotorua, and 300 residents signed a petition demanding government action. Other residents, having learnt about the diquat remedy, took their own local action with the aid of watering cans, knapsacks, and garden sprays.

On 1 May 1962 the *Daily Post* reported the second proposal to use Chinese grass carp, made by Mr B. T. Cunningham of the Marine Department at the Annual Bay of Plenty - Rotorua Fishing and Shooting Conference.

According to McKenzie (1967) the Department of Lands and Survey spent during 1962 approximately £1,000 in seeking for and experimenting with control measures.

The Year 1963

Early in 1963 a major spray of 32 acres in Okawa Bay was carried out from the air with diquat, using a helicopter as the spraying vehicle. The area was subsequently inspected by the Minister of Lands, officers from government departments involved, and representatives of the Weed Eradication Society.† The spraying was highly successful and L. J. Matthews recommended the use of diquat, applied at 0.5 ppm, until a better or less expensive chemical came on the market. On 7 August 1963 the Commissioner of Crown Lands for Hamilton announced that diquat was to be used on a large scale on both Lakes Rotorua and Rotoiti. Though it might now be impossible to eliminate the weed, it would be controlled. (During this year £2,000 was approved for the diquat spraying programme.) The announcement was followed almost immediately by a leader in the *Daily Post* of 23 August commenting upon a public meeting of the previous night. This leader was headed, "Is Eradication of the Lake Weed Wise?". The following month the County

*It is recorded in a letter from the Minister of Lands to the Minister of Science, 21/8/64, that in November 1961 the Director-General of Lands had approached the Director, Botany Division, DSIR, suggesting that as the problem of oxygen weed appeared to be New Zealand wide, research should perhaps be undertaken on its growth and possible biological control. The Director, Botany Division, had replied in January 1962 that owing to staffing difficulties his division could not undertake the project, but he offered the services of one of his officers for consultation. However, another two years elapsed before research into the biology of the weed was started.

†The Society's first name "Society for Lake and River Weed Eradication", proved to be excessively long, and through 1962 it was gradually shortened to the Weed Eradication Society, though the name was not formally changed until 1967, when it became the Weed Control Society.

Engineer also expressed fear of enrichment and "death" of the lakes if all the weed were removed.

In September two important developments took place. One was the transfer of weed control from the Department of Agriculture to a Rotorua interdepartmental committee initially headed by the Conservator of Wild Life at Rotorua and originally set up on 31 July 1963. From February 1964 chairmanship has rested with the District Field Officer, Rotorua, responsible to the Commissioner of Crown Lands at Hamilton. The second important development was a decision to make a complete survey of the weed in order to plan its control. This task proved to be not as heavy as it might have been, because a three-day storm in June 1962 had torn loose most of the huge, long-standing weed islands. At the time of the survey only the beginnings of a new weed crop could be discerned well below the surface of the water. It was agreed, therefore, to leave Lake Rotorua untreated and to concentrate upon Lake Rotoiti. In particular, Okere Falls Channel, Te Akau Point Bay, and Otaramarae Bay were selected in August for heavy spraying by helicopter at a suitable time.

The Year 1964

As a result of the August decision, 107 acres of Lake Rotoiti were sprayed by helicopter on 8 March 1964, using 230 gal of diquat. The Minister of Lands was requested the next day to authorise additional supplies in order to complete the operation. A further 200 gal were made available and in addition to the main areas Te Ti Bay, Pukemoiti Bay, Papakaroro, Punaruakaroia Bays, Okawa Bay entrance, and Sulphur Bay were included. In December, Dr Fish of the Marine Department sprayed, by boat, the heavily infested western arm of Te Weta Bay (20.6 acres), leaving the equally infested eastern arm as a control. An account of this spray (which was highly effective) and its results was later published (Fish, 1966).

The decision to leave Rotorua Lake untreated rebounded, as new weed growth there exceeded expectations. Furthermore there was a major storm on 11 March and huge deposits of weeds later drifted ashore to putrefy along the beaches. Press photographs and a *New Zealand Herald* leader and cartoon appeared at Easter. Officers of the Department of Health removed weed from in front of the Queen Elizabeth Hospital: City Council gangs tried to push the weed back into the lake but after two days reversed the procedure and raked it out of the lake to cart it away. It was about this time that the present writer urged experiments to see if Chinese grass carp would be successful as agents of biological control.

Against the mounting pressure for total eradication of lagarosiphon, one of the arguments used by opponents was the possibility of an algal bloom, which, if composed of toxic algae such as *Microcystis aeruginosa*, could lead to death of fish. It is worth recording that a bloom was reported on Lake Rotorua on 20 May 1964, a major one on 29 October at Mission Bay, and two days later a small bloom at the end of Keith's Road.

However, these blooms were probably quite independent of any lake-weed death and decay due to storms and were related to the general nutrient build-up in the lakes as a whole. In any event these were not the first blooms to appear on Lake Rotorua, one having been recorded in 1948 before the weed menace had appeared. That the lakes were reaching a stage of nutrient enrichment favourable to algal blooms was demonstrated by a bloom in Lake Rotomahana in 1956 and by the gradual deterioration (eutrophication) of the small Lake Okaro over the preceding 10 years and the increasing frequency of algal blooms on it (the *Daily Post*, 9 November). These blooms encouraged the *Daily Post* to conduct a survey of the extent of sewage pollution of the lake. A number of sources of pollution were reported, but the general consensus of opinion was that so long as the pollution was not harmful to fish and humans it could continue. This represents a short-term view, but because of what is happening to lakes elsewhere in the world it cannot be the long-term view.

Conflicting information and views both for and against removal of the lake weed continued to build up, and eventually Auckland University Extension Department organised a two-day seminar on the lake weed problem on 14 and 15 October 1964.

The seminar was well attended, the discussions lively and constructive. Farming interests and local bodies were represented. Fears were duly expressed that the lakes could be permanently damaged through unrelated actions conflicting one with another. The present writer made the unchallenged statement that the seminar had "demonstrated our abysmal lack of knowledge on all basic lake problems".

Immediate results of this recommendation were a Marine Department grant to the Botany Department of Auckland University for research on the weed and the participation of the present writer with Dr Fish in the Te Weta Bay experiment.

Another immediate outcome of the seminar was a question put in the House of Representatives, early in November, by Mr Lapwood, M.P. for Rotorua, asking for an urgent meeting of all interested Departments. Moves towards such a meeting had already begun on 21 August when the Minister of Lands sent a letter to the Minister of Science, in which he outlined the problems, stating that the first essential was for the research, up till now carried out by Marine, Internal Affairs, Health, and Agriculture Departments, to be co-ordinated by DSIR, and asking the co-operation of the Minister of Science in having such a programme put into effect. After some appraisal of the situation by its divisions of Soil, Entomology, and Botany the department in a letter to the Minister of Science on 22/9/64 expressed agreement with recommendations put forward at various times by those concerned about the problem, viz:

"Complete cessation of discharge of sewage and industrial drainage effluent into the lakes;

"Declaration of the weed(s) as noxious, with a compulsory halt to sale throughout New Zealand;

"Continuation of chemical poisoning;

"Exploration of possibilities of biological control;"

PLATE 1A. Amphibian trying to land over a lake-weed pile up.

PLATE 1B. Raw sewage outfall, Rotorua.

Photos, Daily Post, *Rotorua*

Inset 2

PLATES 2A, B. Removing lake-weed drift after a storm.

Photos, Daily Post, *Rotorua*

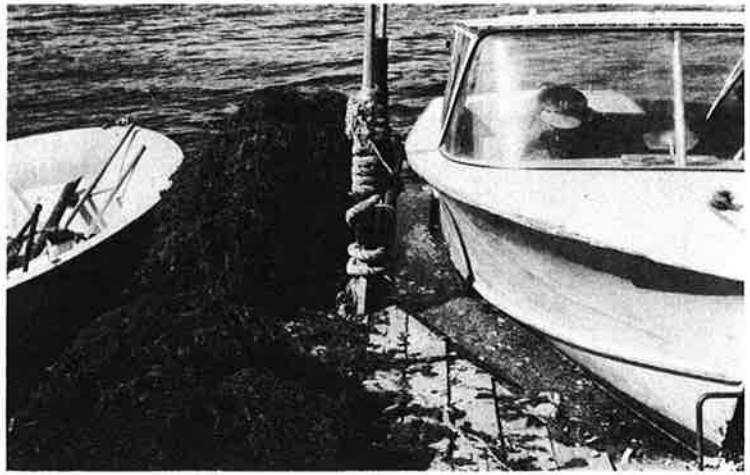

PLATE 3A. Hornwort on the landing, Orakeikorako.

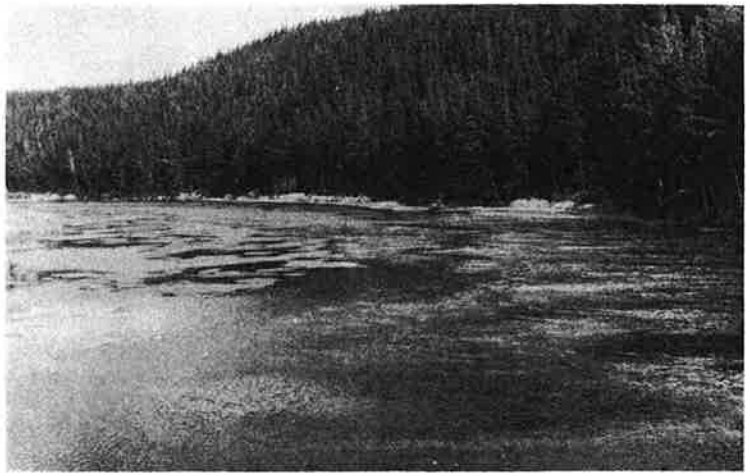

PLATE 3B. Hornwort mats on Lake Atiamuri.

Photos, Daily Post, *Rotorua*

PLATE 4B. Sewage from milk factory pouring into stream going into Lake Rotorua.

Photos, Daily Post, *Rotorua*

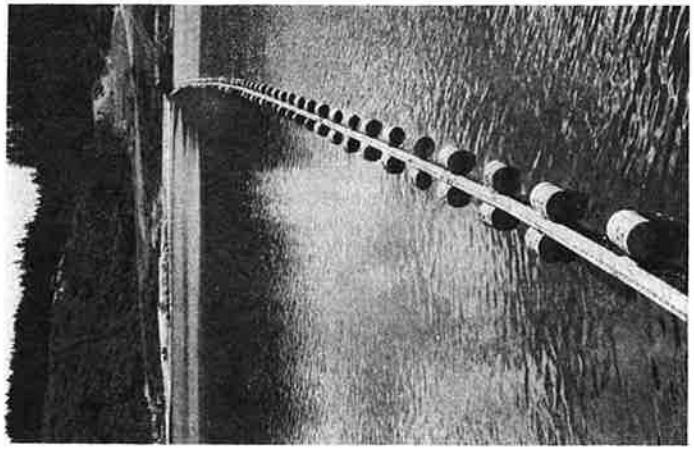

PLATE 4A. Weed boom at dam, Ohakuri.

and suggested that after receipt of possible suggestions by the Commonwealth Institute of Biological Control* an interdepartmental meeting be called.

As a result of Mr Lapwood's question in the House, the Minister of Lands, on 12/11/64, made a formal request to the Minister of Science that DSIR convene a meeting of the departments that were concerned with the weed problem in the Rotorua Lakes.

THE YEAR 1965

After a further request on 5/2/65 from the Department of Lands and Survey, DSIR convened a meeting for 30/3/65 to be attended by representatives of the departments of Marine, Internal Affairs, Health, Agriculture, Lands and Survey, and DSIR. The scope of the meeting was shortly extended to New Zealand Electricity Department, who had approached DSIR on allied problems of weeds on Ohakuri dam. Also at the meeting was Dr D. C. Lloyd of the Commonwealth Institute of Biological Control.

The meeting considered:

The existing situation,
factors contributing to the growth of weed,
trials conducted to date and their results,
possible approaches to solution of the problem, and New Zealand Electricity Department problem.

A number of resolutions were carried, including the following:

"That this committee recommends to Government, and to the interdepartmental committee for weed eradication, that the broad policy for control of weeds in the Rotorua Lakes be to continue the present programme of minimum control by chemical means, pending developments from any research work that can be undertaken on the problem. This recommendation does not abrogate any discretionary action that the local committee may need to take in special circumstances."

"That unless further research indicates to the contrary, the committee recommends that no immediate investigation be undertaken on mechanical systems of eradication because chemical control is at present efficient in areas where control is needed."

"That a publicity campaign be undertaken drawing attention of the public, and particularly aquarium clubs, to the need for avoiding disposal of weeds from aquaria into waterways."

*The first inquiry regarding the possibilities of biological control of water weeds was made by B. B. Given, Entomology Division, to the Commonwealth Institute of Biological Control in early September 1964 for information on the natural controls of *Lagarosiphon major*. At that time some survey work was being done on water weeds in India including *Nethamandra* (=*Lagarosiphon*) *roxburgii*, which was known to be attacked by certain caterpillars and aquatic snails. For an effective survey of the natural enemies of *L. major* the work would need to have been done in South (or East) Africa and this would have entailed an entirely new project. It appears that owing to lack of staff and financial provision for a new project at that time nothing more was done.

"That the committee does not consider it desirable to issue permits for use of diquat by private individuals and that if there is a problem on a lake frontage the approach should be to the local committee for any remedial action to be taken."

Chemical control, supported by this meeting, using diquat spray, has in fact been used every year as policy since 1964, when the Rotorua Interdepartmental Committee took charge.

It was also agreed that DSIR should call a meeting of scientific and technical personnel to plan a programme of co-ordinated research, to obtain basic information, with participants from Soil Bureau, Botany Division, Chemistry Division, and Plant Physiology Division of DSIR, Marine Department, Department of Agriculture, Department of Health, Ministry of Works, and Botany Department of the University of Auckland. (This meeting was not called until 1966.)

During 1964 the Weed Eradication Society had employed Mr K. R. Davis as their consultant chemist. At the Annual General Meeting of the Society in January 1965, he reported that in his opinion and from his analyses of lake water samples the proper course would be to destroy the weed chemically on a short-term basis and to introduce a weed-eating fish as the long-term answer to control. He also estimated that in an acre of water 10 ft deep the average amount of weed was equivalent to 2,000 lb dry wt and that this contained 36 lb of nitrogen. On this basis he argued that when the weed was killed this material would be retained at the lake bottom and very little nutrient would appear on the upper waters. These figures are almost certainly an underestimate because samples obtained from the Kawaha Point bed (see p. 32) and dried and weighed gave a yield of approximately 5 tons dry weed per acre instead of approximately 1 ton on Davis's figures. The weed-spraying programme for 1965 was based on minimum control only, and the areas sprayed were, with the exception of Gisborne Point, those listed in the *Daily Post* of 8 December 1964.

In May 1965 some grass carp arrived for the Botany Department, University of Auckland, from the Commonwealth Fisheries Laboratory in Malaya. They did not acclimatise readily to the cold New Zealand waters, but some did survive. These fish, however, require a considerable volume of water in which to live and grow; in aquaria they remain in a retarded condition. At first they required chopped weed and "pet" fish food. Eventually they started to show some growth and to eat weed in greater quantity. Early in 1967 approval was given to transfer them to a pond in the Auckland Zoo, but after the pond was prepared an accident occurred to the aquarium in the University greenhouse, and the fish were killed. Approval was then sought to introduce some more, as it is my firm opinion that Chinese grass carp are probably the best long-term answer to control of weed.

In October 1965 the writer informed the Minister of Marine of an American Lake Weed Harvester, which not only cut the weed but transferred it to a barge for removal. The cost may have proved too high in relation to the cost of spraying, for no further action has been taken.

In November 1965 the Pollution Advisory Council took an important step in advising Rotorua City and County they should put their sewage into the Kaituna River below Okere Falls in order to save the lakes from further rapid eutrophication. The possibility was investigated, but it seems that the cost of doing this by pipes and pumping stations was prohibitive. However, such a scheme may be essential if the lakes are to be preserved as a tourist and angling attraction.

Late in December the Weed Eradication Society received reports (subsequently circulated to members) from Mr K. R. Davis and Mr R. Hicks of the Auckland Regional Authority Drainage Board. The Board was concerned about the necessity to keep the lake surface clear of weed so that boats could break up any algal bloom that might appear. Mr Davis reported that the weed does not remove any organic pollution and grows irrespective of any pollution: in fact it requires very little in the way of nutrients. Students of the present author have confirmed this last finding. Mr Davis also reiterated that algal blooms could appear irrespective of lake weed.

The Year 1966

At the Annual General Meeting of the Weed Eradication Society in January it was argued that a single Government department rather than an interdepartmental committee should be made responsible for removing or controlling the weed, and that all emergent weed should be sprayed, in preference to keeping to the minimal area policy that was then in vogue. It was also suggested (and subsequently agreed to by the Minister of Lands) that the present writer be added to both the Rotorua and Wellington Interdepartmental Committees.

At the beginning of February the Minister of Marine, Mr W. J. Scott, made an inspection of the larger weed beds.

On 25/2/66 DSIR called a technical meeting (as asked for by the Interdepartmental Committee a year earlier) of representatives of several DSIR divisions and Fisheries Research Laboratory, Marine Department, to draw up specific proposals for future studies. Their report was placed before the 2nd Interdepartmental Committee meeting held on 4 March 1966. In the light of the fact that the National Research Advisory Council was considering a report on Oceanography, Limnology, and Fisheries and was expected soon to make recommendations to the Government on the organisation of long-term basic and applied freshwater research the Interdepartmental Committee agreed to undertake an immediate programme on a co-operative basis and to advise NRAC that basic and applied limnological research was a matter of national urgency. The studies to be undertaken immediately by the Committee were as follows:

1. To determine the nutrient requirements of the weed to see whether reduction in nutrient level below minimum requirements is attainable in practice. (Professor Chapman with assistance from Soil Bureau if required.)

2. To determine the origin of the nutrients and whether the inflow could be significantly reduced. (Department of Agriculture to devise and carry out limited sampling and analysis of waters flowing into the lake.)
3. To investigate water movement patterns to see where the nutrients are going. (Oceanographic Institute and Marine Department in collaboration.)
4. To determine the extent of weed growth on lakes and rivers. (Aerial survey techniques to be devised by Lands Department, Professor Chapman, and Soil Bureau. Internal Affairs to co-operate with field assistance.)
5. To determine the environmental limits of lagarosiphon. (Professor Chapman.)
6. To spray 100 acres of Lake Rotorua with diquat and to observe the immediate and long-term effects on the lake as a whole. On the evidence gained the Committee was to give consideration to revision of the limited-control policy. The spraying programme was to be carried out by the local committee and to be designed and observed by Professor Chapman (University of Auckland), Dr Fish (Marine Department), and Miss Mason (Botany Division, DSIR).

It was agreed at the March meeting to intensify the publicity campaign and to ensure that lake-front residents desisted from using their private supplies of weed killer. As well as being illegal, this practice militated against efforts of the Committee to measure the results of experimental sprays.

The big bed of weed finally selected for the 100-acre spray was in the bay south of Kawaha Point. This area was sprayed, inshore by boat, but the main area by aeroplane, in May. In all, 103 acres were sprayed: 107 gal of diquat were used, and the operation cost 19/6 an acre. The writer undertook periodic examination of the weed, and Dr Vivienne Cassie, also of the Botany Department of the University of Auckland, undertook to follow the pattern of the phytoplankton. Photo coverage by aerial survey was made of Lake Rotorua (and especially of the 100 acres) by the Department of Lands and Survey in April and again in May.

In September, Dr M. Allessio, who had been appointed as a University of Auckland Post-doctoral Research Fellow, arrived and started work at Rotorua. She initiated a number of experiments, but unfortunately, for personal reasons, she returned to the U.S.A. in March 1967. Her programme was subsequently continued by the present writer assisted by a research student.

In October Dr G. Prowse, Director of the Commonwealth Fish Culture Laboratory, holidaying in New Zealand, saw the lakes and had discussions with departmental officers. Dr Prowse kindly prepared a report (20/11/66) for the Chairman of the Wellington Interdepartmental Committee for consideration at its meeting on 29/11/66. This report (quoted with the author's kind permission) dealt with the interrelated problems of the build-up of lake weed and algae, due primarily to the extensive use of fertilisers on pastures and possibly to pollution by sewage in more

populated areas. He stated "The dangers from noxious algae have perhaps not been fully appreciated in New Zealand, but in my opinion they constitute a much more serious threat than lake weed." Of the blue-green algae, "*Anabaena flos-aquae, Aphanizomenon flos-aquae* . . . have been shown to be definitely toxic to mammals and to fish, *Microcystis aeruginosa* being the most toxic. The position is particularly dangerous when the algae accumulate in bays, blown there by the wind, and the local concentrations may be lethal to any animals drinking in these bays. . . . The danger in blue-green algae build-up is that, although the early stages may be slow, the change over from non-toxic moderately dense phytoplankton to toxic blooms is often sudden, involving only a small addition of nutrients."

He noted dense algae populations at Lake Tutira in northern Hawke's Bay (possibly at a critical stage), and in the Waikato River at Karapiro dam and below it. In Lake Taupo "the extensive growth of filamentous algae at Kinloch, and dense growth of filamentous algae on the water weeds in many parts of the lake suggest that nutrient enrichment is still going on and that the problem in this lake might eventually be one of noxious algae".

For lake weed, he recommended trials with Chinese grass carp *Ctenopharyngodon idellus*, which can consume large quantities of lagarosiphon and hornwort and because of their non-interference with other fish would have no deleterious effect on the trout fishing. For the algal problem he recommended a phytoplankton feeder, the silver carp (*Hypophthelmichthys nolitrix*). "While *Anabaena flos-aquae, Aphanizomenon flos-aquae*, and *Microcystis aeruginosa* are not digested, diatoms, many flagellates, and some green algae are", and by removal of nutrients from the water "the build up to the critical level for the toxic algae can be prevented".

He also stressed the need for a limnological team to work full time on water problems, such a team to comprise at least a hydrologist/chemist, phycologist, invertebrate zoologist, and soils chemist.

On 15 October the Extension Department of Auckland University organised a second seminar in Rotorua, which was very well attended. On this occasion attention was paid not only to the Rotorua lakes but also to the hydro-electric lakes and Lake Taupo. Over the previous 2 years there had been increasing concern at the possibility of Lake Taupo being enriched in the same way as Lake Rotorua, and a proposal was discussed and supported that a buffer zone should be set aside around the lake and on each side of streams draining into the lake. In this buffer zone there should be no topdressing, stocking, or other sources of enrichment so that the zone would trap run-off of nutrient from topdressing of surrounding land. The proposal was subsequently adopted in principle by Government.*

At the seminar members of the Botany Department of the University of Auckland reported on their findings to date. The weed grows under minimal nutrient conditions. 25° C is the optimum growth temperature, and carbon assimilation increases with increasing light intensity and

*First implementation of this proposal was undertaken in 1969.

HCO_3^- supply up to specific limits. The main interest, however, centred around reports on the area of the 100-acre spray. There had been very nearly 100% kill, but some patches of weed had survived and were starting to regrow. The plankton counts reported by Dr Cassie showed a decrease rather than an increase, and this was associated with an increasing clarity of the water, commented upon freely by the local residents. At the conclusion of the seminar a resolution was passed and forwarded to the Wellington Interdepartmental Committee that one-third of all weed areas in Lakes Rotorua and Rotoiti should be sprayed every year, so that over a 3-year period each lake was sprayed for all weed areas. This seminar was regarded of sufficient importance for the University to arrange publication of its proceedings*.

The Wellington Interdepartmental Committee met again in November. It agreed to ask the Department of Internal Affairs to erect notices at all launching ramps urging launch owners not to carry weed from lake to lake on either their launches or boat trailers (notices erected December 1966); and supported the draft publicity pamphlet drawn up by the Lands and Survey Department (published early in 1967). Marine Department presented charts of Lakes Rotorua and Rotoiti prepared from bathymetric surveys conducted in co-operation with the N.Z. Oceanographic Institute of D.S.I.R. Arrangements were made to obtain air photos of the lakes in order to check with the ground survey and so obtain an estimate of the quantity of weed present. In reports of activities relating to the programme laid down at the March meeting it was noted that the sampling programme proved insufficiently comprehensive to secure a clear picture.

On 23 December the *Daily Post* reported an algal bloom on Lake Tarawera. This was certainly unexpected, as the area surrounding Lake Tarawera is not much topdressed, and very little if any sewage enters the lake. (Algal blooms apparently appeared on the lake after the great eruption at the end of the last century, and there is evidence that the lake is rich in nutrients, probably as a result of the eruption.) Comparable blooms also appeared about the same time in December in Lakes Okaro and Ngapouri. It was reported at the Rotorua Interdepartmental Committee meeting in April 1967 that fishing was poor for some weeks after the bloom. The same phenomenon also occurred in Okawa Bay, Lake Rotoiti, after the December spray there.

The Year 1967

At the Annual General Meeting of the Weed Eradication Society in January 1967 it was resolved to send a deputation to wait upon the four Ministers (Lands, Internal Affairs, Marine, and Science) concerned with lake weed. The main purpose of the deputation was to persuade the Government to appoint one person with plenary powers to deal with the weed problem. It was also agreed that, since eradication was no longer possible and perhaps not really desirable, the society change its name to the Weed Control Society.

Some weeks later the deputation met the Ministers, who were sympathetic but made it clear that they were not prepared to depart from the existing system of interdepartmental control.

The National Research Advisory Council in its annual report of 1967 recommended that DSIR take immediate steps towards the establishment of a freshwater research unit to undertake basic and applied limnology studies. At the April 1967 meeting of the Wellington Interdepartmental Committee, the Chairman, Mr I. L. Baumgart, announced that Dr D. Spiller, DSIR, would be leading a small team to make a reconnaissance of New Zealand's freshwater environments, to gain some preliminary information on the processes operating and their implications for these environments, and to prepare recommendations on whether a research programme should be undertaken in DSIR and how it should be organised. Work began on this project in November 1967.

Towards the end of March the writer carried out a partial survey, with echo-sounder equipment, of some of the beds in Lake Rotoiti. From this survey it was estimated that Lake Rotoiti contained approximately 5,000 tons dry weight of weed, of which 21 tons would be phosphate. On the same basis Lake Rotorua then contained only approximately 1,439 tons, of which 8 tons would be phosphate.

During 1967 diurnal field surveys on Lake Rotoiti, instituted by the author in 1966, to measure oxygen concentrations in open lake and weed beds, were continued more intensively. Five such surveys were carried out during the year by Dr Allessio. Experiments were also carried out to determine the effect of concentrations of major nutrients upon the growth of lagarosiphon.

The Year 1968

The diurnal-survey work was continued throughout the year by Mr I. Johnston. Up to the present time (1970) surveys have been undertaken on Lake Rotoiti over three successive summers (1966/67, 1967/68, 1968/69), and all the results indicate that in dense beds oxygen is more likely to be depleted than increased. This is related to respiration needs of the weed and reduction of water movement in a dense bed. Dense weed therefore provides no improvement in water conditions (oxygenation) so far as the fish population is concerned. Fish (1963) had already referred to oxygen depletion in dense weed in African lakes, so that this effect in Lake Rotoiti was not unexpected.

In April Dr Spiller recommended to the Wellington Interdepartmental Committee that the policy of minimal area spraying be abandoned in favour of spraying large areas in autumn and winter. This proposal was adopted, and large areas in Lake Rotoiti were sprayed (Te Weta Bay, Okawa Bay, Otaramarae, Gisborne Point) and were subsequently observed by diving parties from Auckland University (Botany Department) engaged on a new programme of investigating the submerged lake-weed communities.

*"Rotorua and Waikato Water Weeds. Problems and the Search for a Solution." Edited by V. J. Chapman and C. A. Bell. University of Auckland, 1967.

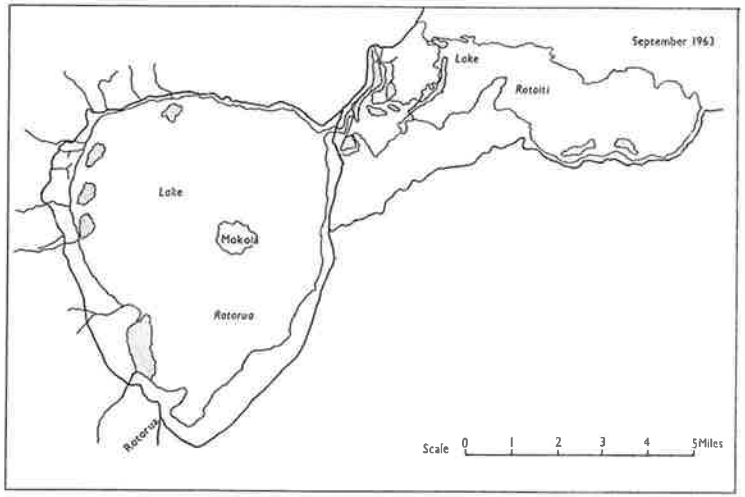

FIG. 8. Distribution of lake weed in Lakes Rotorua and Rotoiti, September 1963.

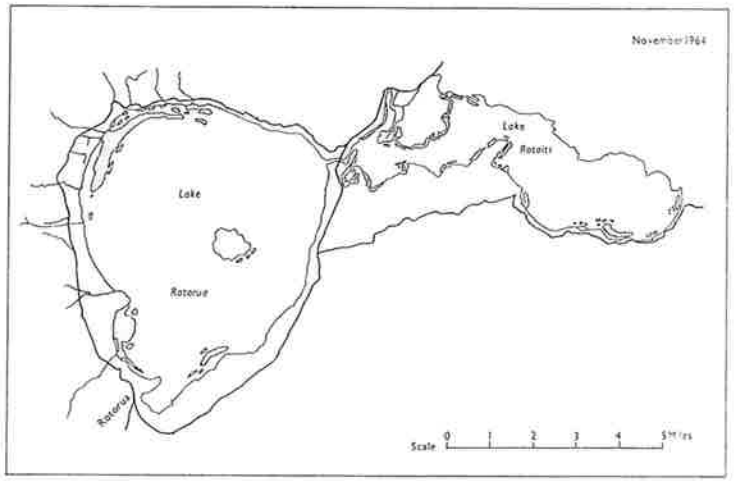

FIG. 9. Distribution of lake weed in Lakes Rotorua and Rotoiti, November 1964.

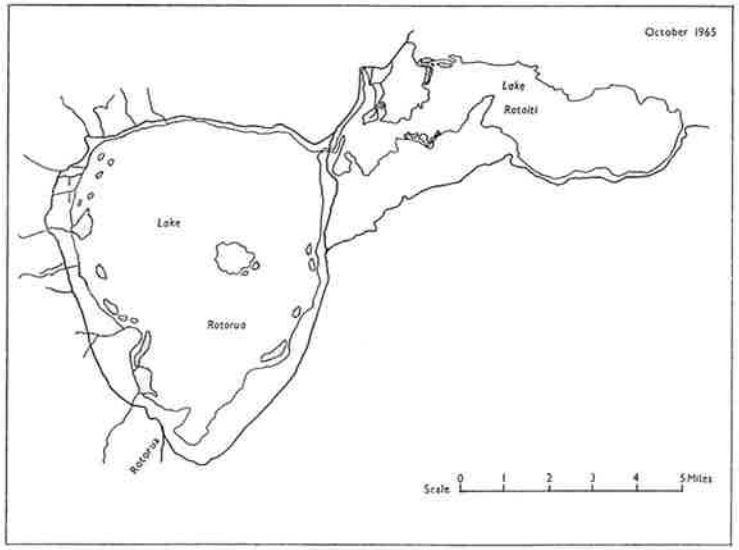

FIG. 10. Distribution of lake weed in Lakes Rotorua and Rotoiti, October 1965.

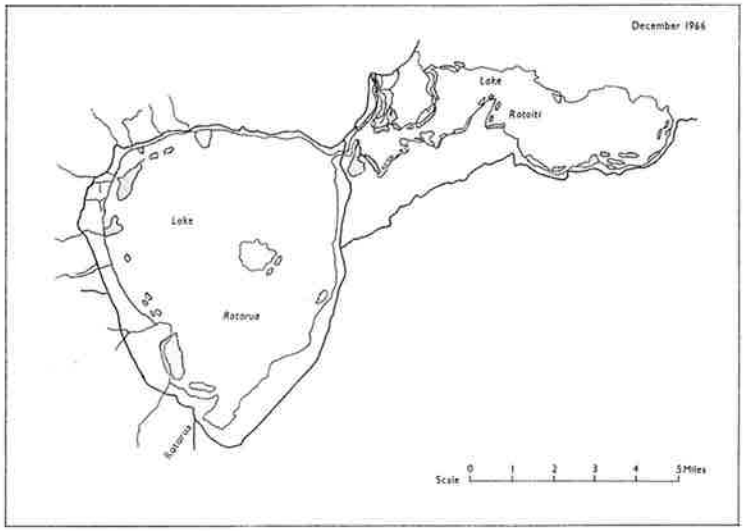

FIG. 11. Distribution of lake weed in Lakes Rotorua and Rotoiti, December 1966.

During the year two Chinese grass carp in a submerged cage were fed with specific weeds over 14-day trial periods. At the same time weed was grown outside the cage in order to establish growth rates. The order of preference shown by the carp was egeria, lagarosiphon, hornwort. With egeria the carp consumed 14 times the amount of new growth recorded over the same period, and with the other two species seven to eight times the amount of new growth. Further work with carp is under way, and their preference seems to be changing.

Early work on the biology of lagarosiphon has been summarised in the annual reports to the Wellington Interdepartmental Committee and in the papers by Chapman (1967) and Chapman and Brown (1966). Later field studies in 1967 and 1968 have shown that the plant becomes established by the sinking of detached or cut stem portions, which then put out adventitious roots and initiate a new plant centre. The minimum size of "innoculum" stem has not yet been fully established. In both 1967/68 and 1968/69 homogeneous areas of lagarosiphon at different depths have been subjected to cropping after various periods. There is decreased rate of growth recovery with increasing depth, and monthly cropping exercises most control. It seems possible that cropping may affect the relative proportions of lagarosiphon and Canadian pondweed in a bed, and this work is being continued.

Because of the emergence of *Nitella hookeri* as a thick cover to areas after lagarosiphon has been killed, work has now commenced upon the biology of this species, especially its growth rate under different nutrient conditions.

In 1969 more extensive experiments with a new lot of grass carp were carried out by B. Coffey. The six fish consumed from 310 to 1,653 gr of wet weed per day depending on the species offered to them. The increase in weight of the fish over fortnightly periods ranged from 13–113 gr per fish. The order of preference shown by the fish was (1) young lagarosiphon and Canadian pondweed, (2) old lagarosiphon, (3) *Vallisneria gigantea* (4) *Myriophyllum propinquum*.

It is clear that in the Rotorua lakes eradication of lagarosiphon is no longer feasible. Any conflict at present is concerned with whether there should be major chemical destruction of the weed from time to time, risking the chance of algal blooms and other disturbances of the ecosystem, or whether mechanical or biological control should be regarded as the long-term solution, the weed being kept down to depths below the water surface where it no longer is an inconvenience. Evidence obtained by the writer from the U.S.A. suggests that biological or mechanical control is the most desirable; in the meantime chemical control is reasonable on a short-term basis.

*PROBLEMS IN THE WAIKATO HYDRO-ELECTRIC SYSTEM: MEASURES TAKEN

"Historical and geographical details of the existing power stations on the Waikato River are summarised in Table [2], but mention must also be made of the first hydro-electric power station built on the Waikato. This was the Horahora Power Station, which was in service from 1913 to 1947. It was built by the Waihi Goldmining Company, alongside the Horahora rapids, some 15 miles south of Cambridge, mainly to supply power for the mines at Waihi. As the station made use only of the naturally occurring fall of water over the rapids, some 24 ft, it was not necessary to build a dam, but a groyne was built part way across the river to divert water into the station. In 1919 the station was taken over by the Government, and 3 years later the groyne was extended fully across the river, so that the year 1922 marks the first occasion on which the Waikato was completely diverted for the uses of mankind. However, even with a weir across the river, the water level was raised only about 3 ft, and such a small rise in level did not really form a lake. The Horahora station was submerged in 1947 when Karapiro was filled.

"A search of annual reports to Parliament since the Government took over the Horahora Scheme in 1919 shows that as far back as 1921 the inconvenience caused to power stations by weeds interfering with the water flow was serious enough to warrant mention [in the Annual Report of the Public Works Department the Chief Electrical Engineer reported that weeds were able to choke the water intake screens, but unfortunately there is no record of the type of weed. In all probability it was a mixture of aquatics such as *Potamogeton* and semi-aquatic reed swamp plants.] At Arapuni weeds became a serious enough problem in 1941–42 to justify a reference in the Annual Report of 1942, and at Karapiro weed troubles started within a year of commissioning. [Again no details are provided as to the type of weed causing the trouble.] Although Parliamentary reports do not mention the matter, it is safe to say that the hydro-electric power industry is perennially afflicted with water weeds.

"Fortunately, this does not normally cause a great deal of inconvenience, because the protective measures employed have generally been sufficient to keep the problem under control, and, until 1965, the difficulties caused by drifting patches of water weeds were dealt with as a matter of course at all power stations and very rarely excited comment. There had been times, of course, when the amount of drifting weed in the river was rather plentiful and involved power station staff in extra work dealing with it, and many years ago the Horahora station was shut down because debris blocked the water intakes, but 1965 was the first occasion on which a power station [Ohakuri] had been temporarily put out of action because of aquatic weed alone.

*The major part of this section is taken from the paper Water Weeds versus Water Power, by D. E. Widgery, 1967, pp. 57–68 in "Rotorua and Waikato Water Weeds: Problems and the Search for a Solution". University of Auckland.
Comments or revision by the present author are shown in square brackets.

"[*Ceratophyllum demersum* first came to public notice on 11 January 1965 when the] Ohakuri Power Station had to be shut down for a few days because a sudden infestation of weed blocked the intake screens. . . . Although the screen cleaner was put into continuous operation, the build-up of weed was faster than the equipment could cope with, and in a matter of a few hours one generator after another had to be shut down because the load of weed on the intake screens endangered the machinery. By mid afternoon all four generators had been taken off load and the station had ceased to generate power. . . .

"As soon as the seriousness of the situation was known, steps were taken to mobilise any available equipment which might be helpful in clearing away the weed from the screens. . . . At the same time a temporary boom was constructed and stretched in front of the station intakes. From this a 6 ft wide wire mesh fence was hung into the water to stop more weed approaching the station. By the time the water between the intake screens and the wire mesh boom was clear of floating weed, which took about 48 hours working day and night, the screen cleaner had cleared a portion of the weed from two of the screens, and on the morning of the third day the station was able to get two generators into operation."

[In May 1968 Aratiatia station was also forced to close because of weed (in this case lagarosiphon) accumulating on the intake screens. At Whakamaru the station was reduced in load for 4 days in June while 1,000 tons of weed were removed from the boom, and in February 1969 weed was driven over and under the boom at Ohakuri resulting in a 3-day 50% drop in output (Rodger, 1969).

[It is clear that the removal of snags and large plants to which hornwort can become attached would materially aid control of this species because plants would arrive at the power sites in quantities small enough to be coped with. The weed would also be less likely to develop into big dense mats as at present, when rafts of 200–300 ft^2 may be seen: such rafts being up to 15 ft deep, pose a serious threat to power-water intakes. As the weed is a floating one, fragments can pass through the penstocks or over the spillways. Up to the beginning of 1967 the infestation had spread in this manner from Lake Ohakuri to Lake Maraetai. At Maraetai the penstock intake is a long way below the surface of the water (150 ft), and it was hoped that so long as the spillway was not used the weed could be contained at this point. Very heavy rains in February 1967 caused major flooding, and all the spillways had to be brought into use. It is almost certain that, because of this, hornwort will have passed into the lower lakes, Waipapa, Arapuni, and Karapiro, and will develop there.*]

"The growth habits of *Ceratophyllum demersum* are not yet fully known under New Zealand conditions, but so far it seems from direct observation that the plant is dormant from April until about November. This confirms overseas information which shows it does not grow unless the water temperatures are 15°C or more. On the upper Waikato lakes this temperature requirement is met from late spring until mid autumn, and the growth of the weed during the hot summer months is very prolific. An estimate

*It has since been reported in Lake Waipapa (1968).

based on European figures shows that one ton of weed could be produced each day in every acre of weed bed. On a lake system having 200 miles of shore line, there is a large area of comparatively shallow water (say out to 15 ft deep) capable of supporting the growth of *Ceratophyllum*. The total area of the Waikato lake system, not including Taupo, is of the order of 12,000 acres, but no official assessment is available of the area of shallow water. However, from figures which have been made available to the author it seems reasonable to assume that something like at least one quarter of the surface of the lakes, say 3,000 acres, is able to support the growth of *Ceratophyllum*. [The extent of the infestation of these lakes is now so serious that during 1966 the Electricity Department and the Departments of Lands and Survey and Internal Affairs made a complete survey of the Waikato Lake System.] It should be noted here that although the weed has no roots and, therefore, could grow in water of any depth at all, in actuality wind and current together combine to drive most of the floating weed towards the shallower water, where it lodges around obstructions, or else catches in the soft bottom mud as previously mentioned. Hence in generalising about the potential for weed production one should consider only the area of the shallower waters. Whether weed production rates in New Zealand conditions approach anything like this frightening amount is not yet known, but if the time does arrive when all the shallow waters are completely infested with *Ceratophyllum*, then it may be supposed that if only the surplus production were to break free and come down the lakes to the power stations, the Electricity Department could be faced with the problems of hauling out and disposing of a quarter of a million tons of weed each year [see Fig. 12]. This frightening prospect has an ironical aspect in that they would be removing potential electric power from the lakes as most of the weight of the plant is in its water content alone, the plant having a dry weight of about 2½% to 3% of its net weight.

"The presence of *Ceratophyllum demersum* in large quantities in some of the hydro-electric lakes poses a permanent threat to the continuity of electric supply, and when the extent of the infestation was realised it was immediately appreciated that until a means of eliminating the weed could be found and applied, the power stations would have to adapt to the new conditions and learn to live with 'the weed'. Defensive tactics such as the installation of wire netting booms to trap weed just above the threatened stations, and improving the efficiency of intake screen raking machinery are at the moment the only practical means of control, with, where warranted, small applications under strict supervision, [of diquat, proposed by the *Daily Post* in May 1965 and independently adopted at the same time by the NZED].* Booms have been installed on the [three] most affected lakes, Ohakuri, Atiamuri [and Whakamaru]. Undoubtedly as time goes on, lakes further down the river will become infected with *Ceratophyllum*, unless it can be eradicated, so booms will have to be established at [the] other power stations. Booms alone are not a sufficient answer

*It has since been agreed (1968) that large areas can be sprayed with diquat and that minimal chemical control is not necessary on a short-term basis.

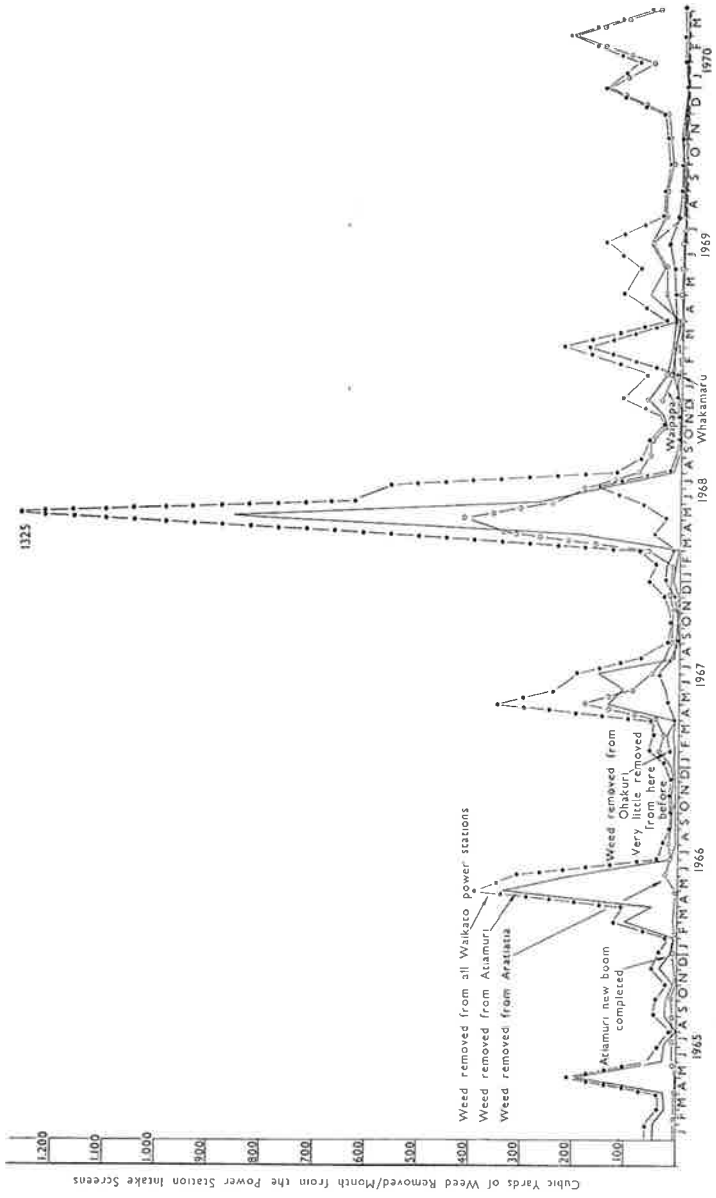

FIG. 12. Quantities of weed removed from Waikato power-station lakes, January 1965 to April 1967.

even at present, as was shown [in the summer and autumn of 1966] when the boom at Atiamuri became so choked with weed that fresh weed coming down the lake was carried underneath the boom and accumulated on the intake screens where it was removed by continuous operation of the screen cleaners for days at a time. An underwater inspection of the weed on the Atiamuri boom showed that the mat of weed caught on the 12 feet deep netting of the boom was, in fact, a little more than 12 feet deep at the net, and sloped off on the underside to a thin edge near the water surface 30 to 40 feet upstream. Fresh weed coming down [from] the lake simply rolled along the sloping underside of this wedge and the boom was no longer efficient. As the weed was coming on to the boom faster than it could be removed by a boat fitted with a grab arrangement, a decision was finally made to try to clear the boom by the use of weed killer, and with the approval of the various authorities concerned . . . a small amount of chemical was applied. Fortunately for the station, but unfortunately for the progress of experimental investigation, the wind changed next day and blew all the weed off the boom and dissipated it further up the lake, [so it has not been possible] to determine the effectiveness of chemical control in these circumstances. [Figure 12 shows the total amount of weed removed from the screens of the power stations since January 1965.]

[The presence of these weeds in the hydro-lakes and the need to co-ordinate control measures generally resulted in the addition in 1965 of Electricity Department representatives to both Wellington and Rotorua interdepartmental committees.]

"Whilst the Electricity Department was looking after the immediate practical problems at the affected power stations, the Interdepartmental Committee on lake weed problems, meeting in Wellington [in 1965], decided that it was necessary:

(1) To experiment with chemical control of *Ceratophyllum demersum* with the weed killer Diquat.
(2) To prepare maps of the hydro-electric lakes showing the incidence of aquatic weeds and the types predominating in the various localities, partly so that the extent of weed infestations could be made known, but mainly for checking against future surveys so that the development of the problem could be measured.
(3) To teach power station staff the identification of the common weeds of the Waikato so that reports could be obtained as to weed types causing problems at the station.

"With the co-operation of the Internal Affairs and Agriculture Departments, trial spraying of selected areas of *Ceratophyllum* has been carried out. Some short term trials with Diquat were inconclusive, as the chemical kills off the underlying oxygen weeds in which beds of *Ceratophyllum* grow, and the material drifts away before the effects can be properly studied. Longer term trials are now under way within wire netting barriers and it is hoped that the sprayed material, which was undoubtedly affected by the Diquat, will stay located in its pens until with the warmer waters of summer it can be seen whether or not the damaged remains of the weed [regenerate. Present indications are that they do].

"For the second point, a combined operation by Internal Affairs, Lands and Survey, and Electricity Departments in 1966 resulted in an extensive survey being made of the lakes from Karapiro through to Aratiatia, parts of Taupo, and all of Lake Roto Aira, and maps and a report on weed incidence were prepared to record this basic data and make it available to interested agencies.

"The third point made by the Interdepartmental Committee resulted in the publication of a booklet, 'Selected Water Plants of the Waikato', by Miss R. Mason. . . This booklet . . . has enjoyed a wide circulation among other users of lakes, which testifies to the interest there is in this problem outside of the Electricity Department.

"One of the early decisions made following the discovery of severe infestations of *Ceratophyllum*, was that a long term solution to the problem required a proper study to be made, not only of the habits of this plant under New Zealand conditions but also of the limnology of the artificial chain of lakes created on the Waikato River.

"Elimination of *Ceratophyllum demersum* may or may not be possible, but even if it were cleaned out, other types of aquatic plant might take over in later years. A proper appreciation of the situation cannot be made before this fundamental knowledge is available, so that until we have this information the Electricity Department is really only conducting a holding operation against the weed.

"At the beginning of [1966] the Minister of Electricity approved two studentships being offered to the Botany Department of the University of Auckland for two years each, one for the study under controlled conditions of the growth habits of *Ceratophyllum* and the other for [a] study of [the] hydrology of the Waikato lakes and the practical relationships between such hydrology and the weed in question."

The Electricity Department established a temporary field laboratory at Lake Ohakuri, and Mr Hill of the Botany Department of the University of Auckland has been carrying out the limnological studies from this base. He has shown (Hill, 1969) that topdressing in the Whirinaki Stream may result in a high level of phosphate intake to the lake system. It may well be necessary, therefore, to establish buffer zones along supply streams to trap surplus run-off after aerial topdressing. An artificial stream has been constructed at the University of Auckland and is being used for work on growth of hornwort under controlled conditions of light, day length, and rate of water flow. From this, Carr (1967, 1969a) has established that hornwort is essentially a shade plant flourishing in gently flowing water.

Carr was also able to show that maximum production of hornwort occurred at 2.5–5 m below the water surface. There is an optimum current speed that results in maximum carbon assimilation which is somewhere within the range 0.05–1.58 cm sec. Hornwort grows best at low pH values, and above pH 8.0 there is a rapid fall off in productivity. Hill (1969) has shown that there are two growth forms of hornwort, a coarse one that grows even during the winter months, and a finer one that appears in spring and summer. The main growth period is from August to March. The depth extinction point for this plant is around 7 m, which is deeper

than the values found for lagarosiphon, Canadian pondweed, and *Potamogeton* sp.

At the November 1966 Wellington Interdepartmental meeting it was agreed that Mr L. J. Matthews of the Department of Agriculture should attempt the complete eradication of hornwort from its uppermost point at Golden Springs. If this were successful an attempt would then be made to eliminate it progressively down the lakes system. Despite the very best efforts, it was found impossible to eliminate the weed from these upper reaches. The rate of water flow is such that the chemical is removed from the site before it can act properly on the plants. Higher concentrations might be active but they could well reach a point where health hazards could be involved, because the water is used at different points for supply to towns and villages.

In April 1967 approval had been given for the author to import the large water-weed-consuming snail *Marisa cornuarietis* from the Commonwealth Institute of Biological Control in Trinidad (suggested in November 1966) based on work in Florida (Seaman and Porterfield, 1964). Permits were issued in May but the first two consignments in 1967 were not successful, the snails being dead on arrival. Those of the first one probably died because of cold temperatures in the aircraft cargo hold. With different packing techniques some 21 snails arrived alive in the third consignment in February 1968. Eggs were laid, and a thriving population of snails has been established at the University of Auckland. Some cercariae larvae were seen soon after the first adults arrived. This fact, together with the fact that the snails do not consume weed in the same quantity as the Chinese grass carp and have also been known to eat smaller snail species renders them unsuitable for weed control in New Zealand.

Whilst booms are currently reasonably effective in keeping large masses of weed away from the dams, it is doubtful if they are a really satisfactory long-term solution. Because of the water flow (as compared with the Rotorua Lakes) chemical control is not really feasible, and on a long-term basis biological control by Chinese grass carp or mechanical harvesting will probably provide an answer. In the early months of 1969 an attempt was made to control the weed by lowering each of the lakes in turn and removing the exposed weed mechanically. This proved very successful except at the mouths of streams, where inflowing water kept the weed moist (H. F. Rodger, pers. comm.). Because of this, lake lowering has been adopted again for the 1969–70 summer season, and it seems that this technique may prove to be the best at present.

It is also clear that in future more attention will have to be paid to the water conditions when new lakes are formed. This need has already been recognised for dams on the Rangitaiki River, where water analyses are to be carried out as soon as a lake is filled.

CONCLUSIONS

It is evident now that complete eradication of any of the weeds, even if considered desirable, is no longer possible. A 100% kill in any one area cannot be guaranteed and pockets would inevitably be left to act as a source of re-infection. In the early stages of the invasions eradication may have been possible. In the hydro-electric lakes the weed had assumed massive proportions before the menace it presented was appreciated. In the Rotorua lakes the protracted argument over responsibility and the lack of basic scientific information about the behaviour of the weed under New Zealand conditions both militated against rapid action. At the present time lagarosiphon can be controlled by spraying with the herbicide diquat at a concentration of not more than 1 ppm. Whilst this is the quick and satisfactory short-term solution it can be argued that continual application of a chemical, even at two- or three-year intervals, is not the correct long-term solution. There is little doubt that the weed can be harvested mechanically, but effective machines are expensive. There is good evidence that all four weeds can be controlled biologically through the Chinese grass carp, and it is here that we may have a satisfactory long-term solution, since these fish are normally herbivorous and would not interfere, so far as one can see, with that part of the ecosystem essential to the trout fishery. They should not be introduced without careful screening, especially with respect to consumption of food other than aquatic weeds.

Whilst the weed "explosion" has stimulated much research in a field that hitherto has been too much neglected, it has also served to demonstrate how much more research requires to be done. Basic information about the hydrology and limnology of the lakes is only just coming to hand and must continue to do so in the future. The response of the weeds to nutrient status requires much more study. So far only lagarosiphon and hornwort have been investigated: Canadian pondweed and egeria require intensive study also, and native weeds such as *Nitella hookeri* and *Myriophyllum* spp., which may replace the exotics when these are killed, must also be investigated. The growth of these weeds is related, at least in part, to the eutrophication processes going on, processes that cannot be reversed.

ACKNOWLEDGMENTS

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APPENDIX

SYNOPSIS OF LAKE WEED HISTORY

Lagarosiphon (*Lagarosiphon major*) present in tanks at Victoria University College and Auckland University College	1946 and perhaps earlier
1st record of lagarosiphon in natural habitats at Waiwhetu (Hutt Valley)	1950
Lagarosiphon in Lake Rotorua	mid 1950s
Lagarosiphon a menace in Lake Rotorua	late 1957
Lagarosiphon reported in Lake Rotoiti and storm "pile-up"	March 1958
Lagarosiphon a menace in Hamilton Lake	early 1959
Magisterial case against Conservator at Rotorua for weed nuisance	January 1959
Lands Department made responsible for beds of lakes and hence plants growing on them	April 1959
Hamilton Lake sprayed with sodium arsenite	August 1959
Lagarosiphon treated at Kawaha Point	December 1959
Weed in Lake Rotoiti: sprayed by air with 2,4-D (unsuccessful)	June 1960
Weed Eradication Society formed	January 1961
Deputation to Minister of Internal Affairs	January 1961
Prototype harvester tried by Internal Affairs Department	January 1961
1st record of hornwort (*Ceratophyllum*) in nature at Napier	1961
Grass carp suggested to control weed	February 1961
Kawaha Point spray with sodium arsenite	July 1961
1st trial of diquat in Lakes Rotoiti and Rotorua	March 1961
Minister of Lands inspects J. A. B. Hellaby's sprayed area	January 1962
Major storm and petition after weed "pile-up"	February 1962
2nd proposal for grass carp	May 1962
Major storm and weed "pile-up"	June 1962
Diquat accepted as chemical answer to problem	April 1963
Okawa Bay sprayed with diquat	early 1963
Hornwort recorded at Mihi Bridge on Waikato	1963
Diquat authorised on large scale on Lakes Rotorua and Rotoiti	August 1963
Rotorua Interdepartmental Committee formed	September 1963
57 acres Lake Rotoiti sprayed including Te Weta Bay experiment	March 1964
Major storm and weed "pile-up"	March 1964

Bloom on Lake Rotorua	May 1964
1st Lake Weed Seminar	October 1964
1st Marine Department Grant to Botany Department, University of Auckland, for weed research	November 1964
Bloom on Lake Rotorua at Mission Bay	November 1964
Minister of Science announces attack on problem	November 1964
Davis recommends short-term spray control and long-term grass carp control	January 1965
Shut-down Ohakuri Power Station from weed	11 January, 1965
Grass carp arrive in Auckland but do not acclimatise	May 1965
Pollution Advisory Council recommend Rotorua City to stop putting sewage effluent in Lake Rotorua	November 1965
Studentship offered to Botany Department, University of Auckland, by Marine Department for study of lagarosiphon	December 1965
Egeria (*Egeria densa*) first reported in Lake Karapiro	1965
Minister of Marine inspects beds in Rotorua lakes	February 1966
2 studentships for study of hornwort offered to Botany Department, Auckland University, by Electricity Department	February 1966
Storm and weed "pile-up" at Ngongotaha	March 1966
Kawaha Bay 100 acres sprayed	May 1966
Field Laboratory established at Ohakuri	May 1966
Arrival of Dr Allessio	September 1966
Visit of Dr G. Prowse	October 1966
2nd Lake Weed Seminar	October 1966
Egeria reported in Lake Maraetai	November 1966
Notices to launch owners at all ramps	December 1966
Algal blooms Lakes Tarawera, Otaro, and Ngapouri	December 1966
Weed Eradication Society becomes Weed Control Society	January 1967
Deputation from Weed Control Society to Government	February 1957
Survey of Rotoiti beds	Feb–April 1967
Departure of Dr Allessio	March 1967
Hornwort recorded from Ohakuri to Maraetai	April 1967
Major storm in Waikato Basin and all spillways opened	April 1967
1st student thesis on hornwort complete	September 1967
Establishment of lake investigation unit under Dr D. Spiller	November 1967
Approval of large-area spraying	April 1968
Regeneration studies of lagarosiphon and diurnal oxygen studies	April–Dec 1968
Marisa cornuarietis studies	all 1968
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