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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.

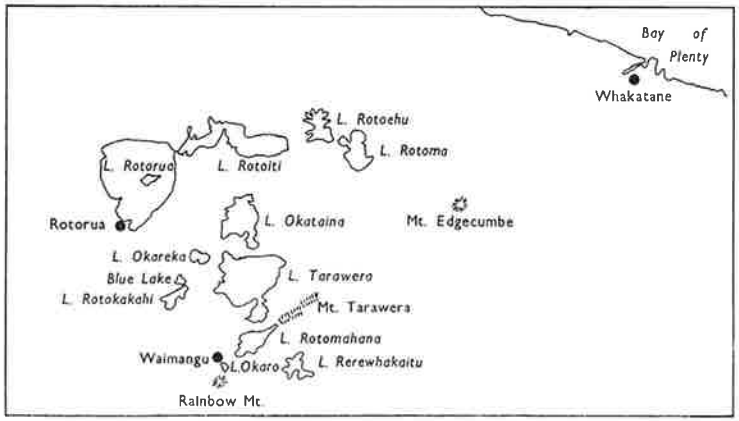

FIG. 1. Distribution of the main lakes in the Rotorua district.

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

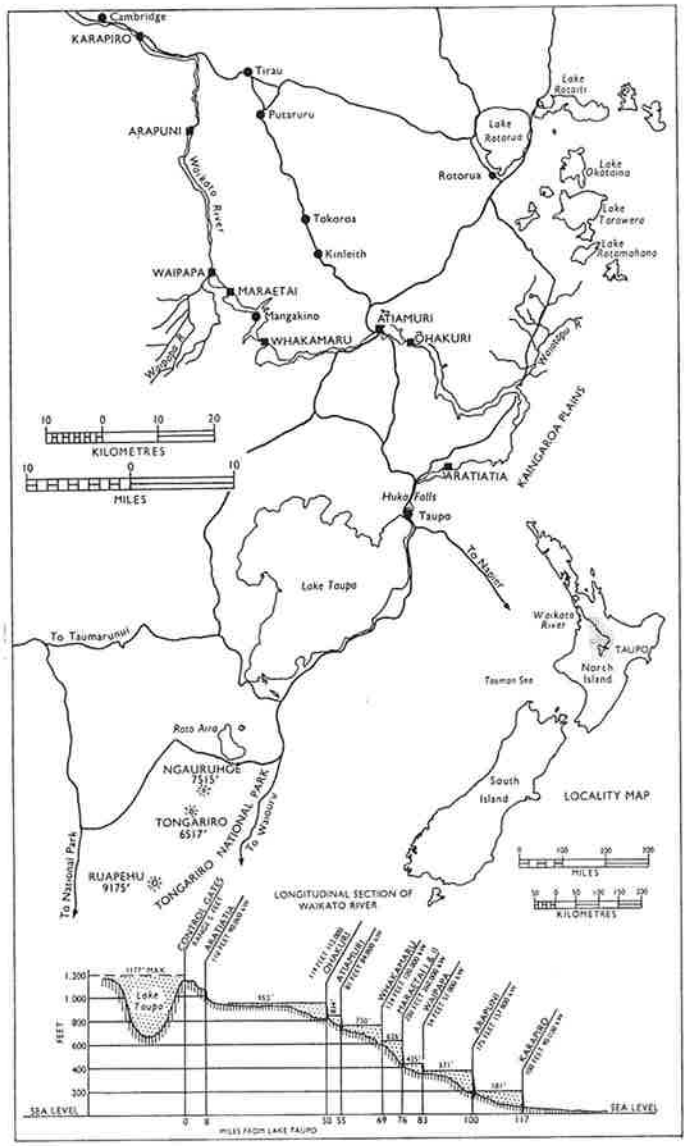

FIG. 2. Locality map of Waikato River hydro-electric power stations.

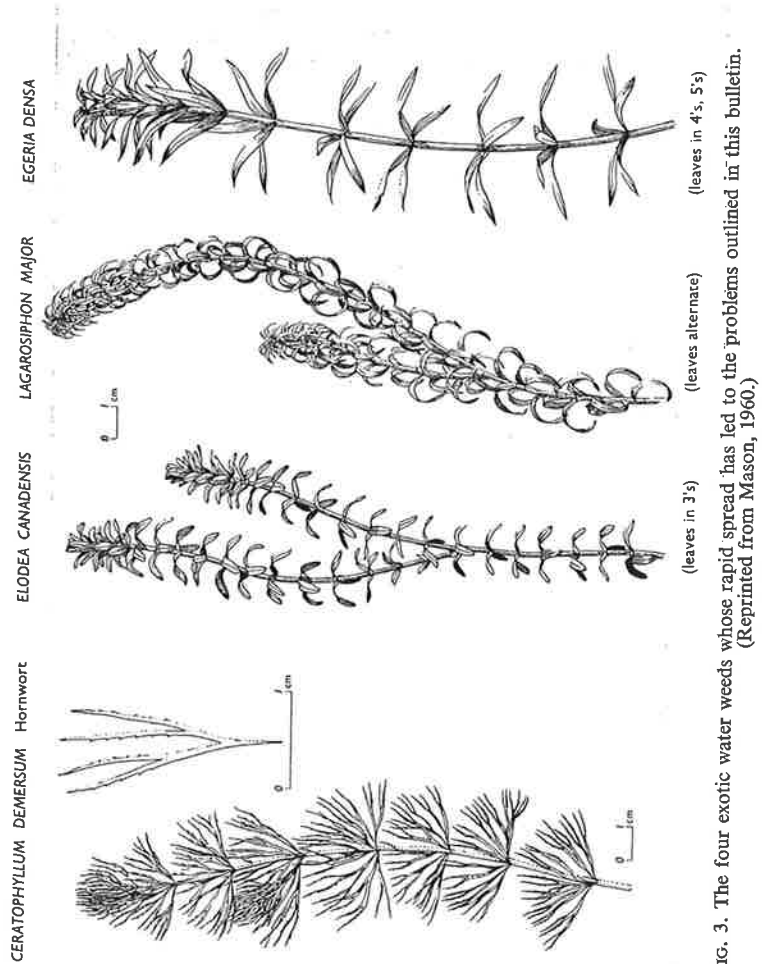

FIG. 3. The four exotic water weeds whose rapid spread has led to the problems outlined in this bulletin. (Reprinted from Mason, 1960.)

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

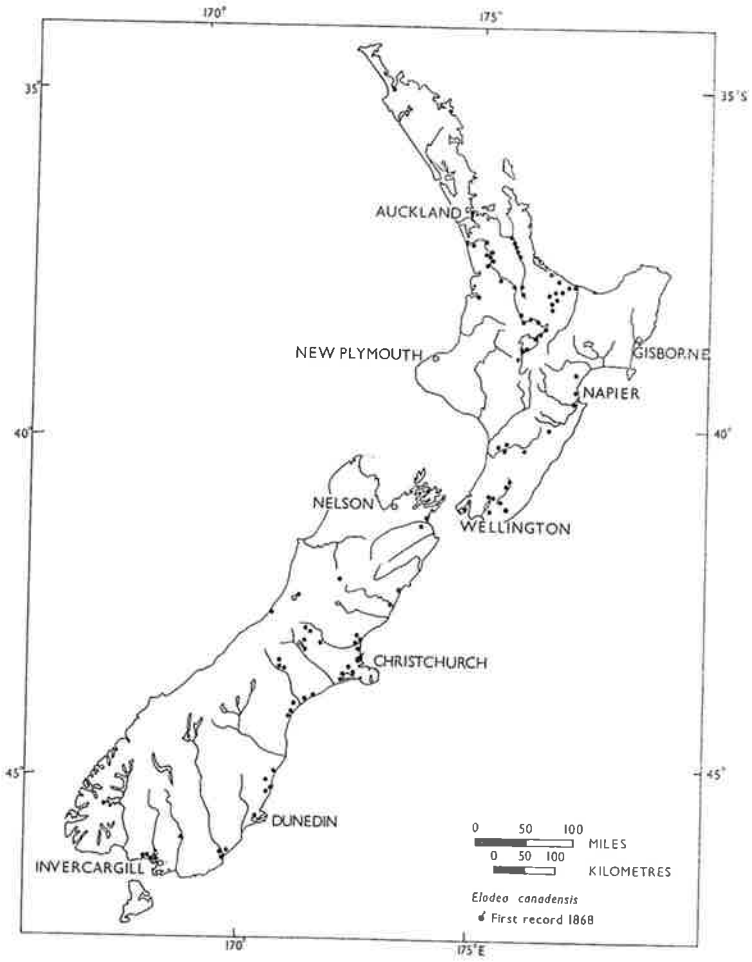

FIG. 4. Records of *Elodea canadensis* (Canadian pondweed).

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*

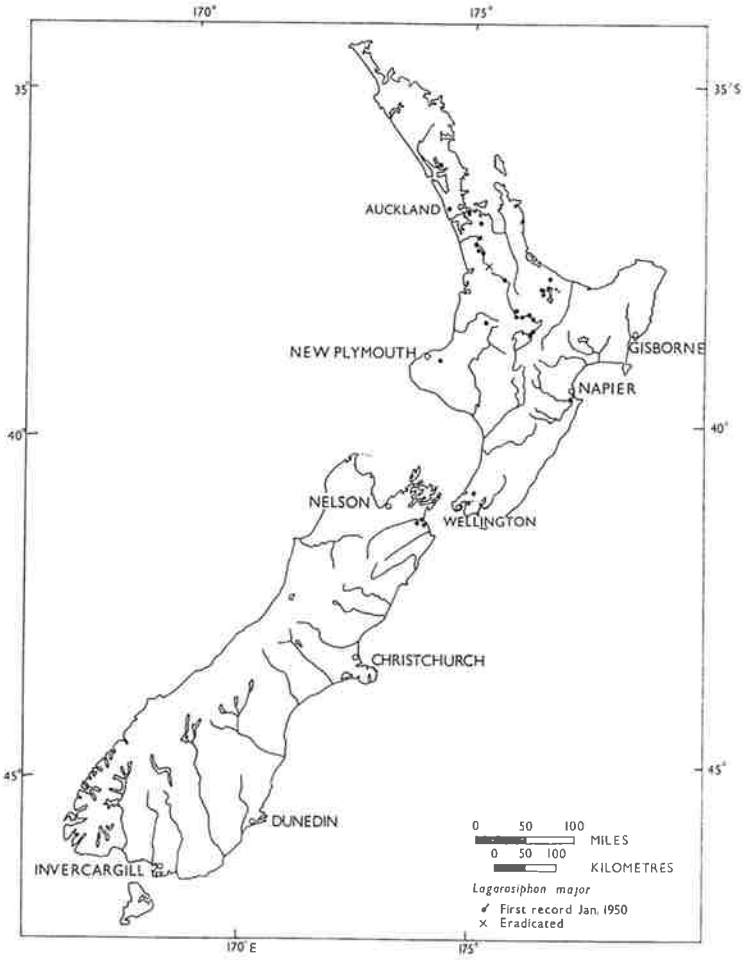

FIG. 5. Records of *Lagarosiphon major* (lagarosiphon).

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.

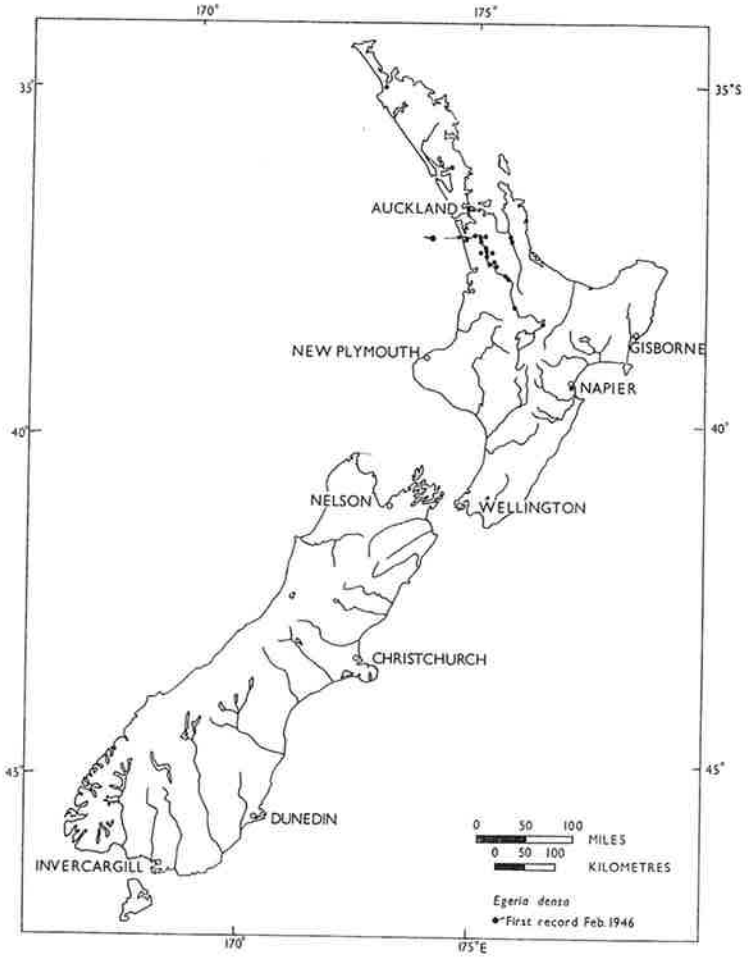

FIG. 6. Records of *Egeria densa* (egeria).

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

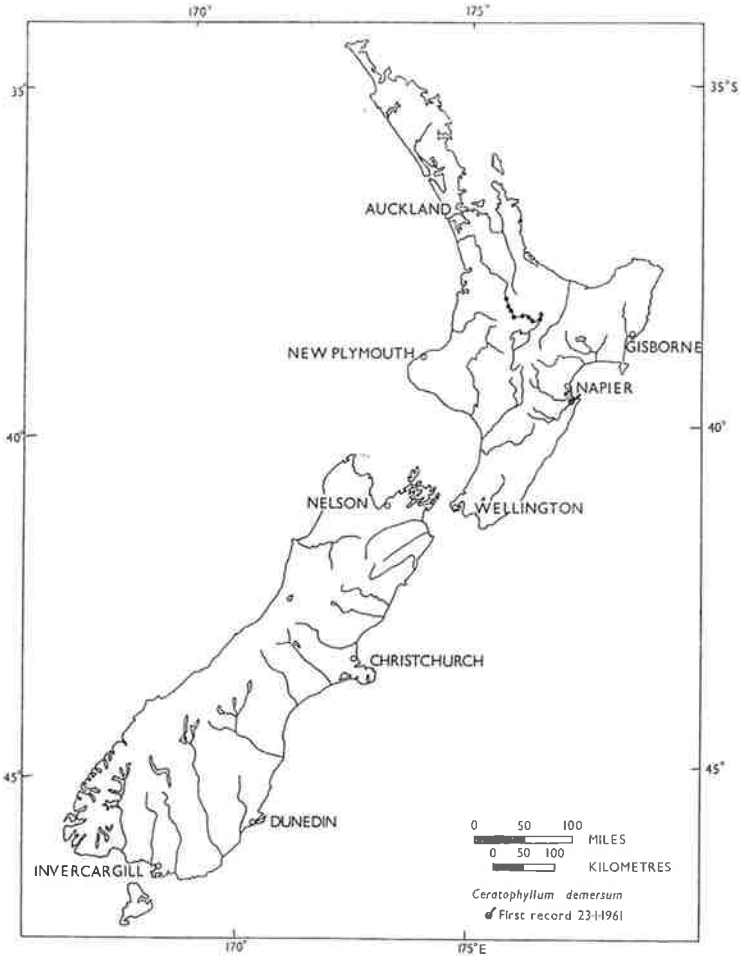

FIG. 7. Records of *Ceratophyllum demersum* (hornwort).

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)*.