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THE SUBMERGED VEGETATION OF LAKES WAKATIPU, LOCHNAGAR, MOKE, DISPUTE AND ALTA; KAWARAU RIVER CATCHMENT, SOUTH ISLAND, NEW ZEALAND.

by

M D de Winton, J S Clayton, R D S Wells, C C Tanner

With notes on

PHYTOPLANKTON AND SELECTED BENTHIC ALGAL SAMPLES

by V. Cassie Cooper

Landcare Research

NIWA - Ecosystems Publication No. 1

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National Institute of Water & Atmospheric Research Ltd

NIWA - Ecosystems

100 Aurora Terrace, Hillcrest, Hamilton, P.O. Box 11-115, Hamilton New Zealand

Telephone +64-7-856 7026, Facsimile +64-7-856 0151

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NIWA - Ecosystems comprises the former Water Quality Centre, and part of the former Taupo Research Laboratory (ex-DSIR Marine and Freshwater) based on the University of Waikato campus, plus the ex-MAF Technology Aquatic Plant Group and ex-MAF Freshwater Fisheries Research Group (formerly at Rotorua) based at the Ruakura Agricultural Centre, Hamilton.

Contents

1. Executive summary

The submerged vegetation of Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta was surveyed in early 1992 using a standardized SCUBA survey technique, to identify scientific or ecological values in support of an application for a Water Conservation Order for the Kawarau River Catchment. Previously unpublished data from a 1982 survey of the submerged vegetation of Lake Wakatipu is presented and used as baseline data against which the 1992 survey is compared. This report represents the first detailed description of the submerged vegetation of Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta, and identifies a number of exceptional or unique vegetation attributes.

Although the five lakes varied considerably in size, depth, altitude, water clarity, vegetation abundance, species diversity, and maximum plant depths all the lakes had a predominantly native submerged flora. Such native dominated submerged plant communities are becoming increasingly rare in New Zealand.

In Lake Wakatipu *Isoetes alpinus* (endemic) formed extensive marginal turfs in shallow water to 9 m depth, and a rich diversity of charophytes grew as meadows from less than 10 m depth to a maximum of 60 metres. An extensive 'deep-water bryophyte community' was found from about 30 m to depths of 60 metres. Comparisons of this globally rare community with other New Zealand and international examples suggest that those in Lake Wakatipu would be one of the best examples of deep-water bryophytes in the world. *Elodea canadensis* (an introduced oxygen weed) was locally abundant only in sheltered areas where higher fertility sediments accumulated and nutrient enrichment was possible.

Lakes Moke and Dispute were rare examples of New Zealand's native submerged flora occurring in mesotrophic water. Tall-growing introduced species such as the oxygen weeds were not present. A wide diversity of short, shallow-water species were recorded with tall growing native species and a mixed charophyte assemblage. The only exotic species found was *Ranunculus trichophyllus*, which had minimal effects on native species.

The alpine lakes, Lochnagar and Alta, had an entirely native submerged vegetation. Lake Alta had a sparse plant cover and limited species diversity. Lochnagar is a remote and clear lake (20 m Secchi, single reading) with an unknown maximum depth, beyond the 55 m attained on SCUBA. The majority of the lake basin was too steep sided for significant development of submerged vegetation. At the more gently shelving south eastern end of the lake monospecific charophyte meadows of *Nitella hookeri* var. *tricellularis* (endemic variety probably only present in the South Island) were recorded from 5-55 metres. The presence of monospecific charophyte cover is unusual and possibly unique over such a wide depth range. A bryophyte community was present at this one location from 30-55 m depth (similar to Lake Wakatipu).

Threats to the submerged vegetation values of the lakes of the Kawarau Catchment include catchment activities which would lead to reductions in water clarity, and the invasion of exotic species. Plant communities in clear water lakes such as Lake Wakatipu may be particularly vulnerable to reductions in water clarity resulting from nutrient enrichment or increased sediment loads. Reductions in water clarity would result in reduction or loss of the outstanding bryophyte community present in the lake, and more limited development of charophytes. The introduction of exotic oxygen weeds, such as *Lagarosiphon major*, *Egeria densa* or *Ceratophyllum demersum* could result in replacement of the desirable short native submerged vegetation with a surface reaching tall weed growth over significant areas of lake margin.

It is of concern that so little is known of the limnology of Lake Wakatipu or its sensitivity to further catchment modification. It is an outstandingly clear lake in world terms. This may be threatened if the catchment becomes increasingly populated and developed without an understanding of the lakes functioning. Information is required to enable appropriate management actions to safeguard the outstanding natural character of this almost pristine lake.

2. Introduction

This study was instigated by the Department of Conservation in order to provide evidence for a Conservation Order on the Kawarau River Catchment, to assist preservation of its outstanding natural character. This report focuses on the submerged vegetation of Lake Wakatipu in particular, and includes information from a selection of smaller lakes within the Kawarau Catchment.

Lake Wakatipu has long been a focus for tourism and was described in the scientific literature as early as the 1870's (Hutton 1872, Russel 1876). However, the earliest description of aquatic plants in Lake Wakatipu appears to be that of Hill (1970). Hill prepared a report for New Zealand Electricity Department based on surface observations of a number of South Island lakes and described Lake Wakatipu '...as supporting quite dense stands of native vegetation, has large beds of *Elodea* in the vicinity of Queenstown Bay through Frankton Arm and the control gates'. Hill recorded the following species: *Myriophyllum propinquum*, *Myriophyllum elatinoides* (now *M. triphyllum*), *Potamogeton cheesemanii*, *P. ochreatus*, *Ranunculus fluitans* (now *R. trichophyllus*), *Elodea canadensis*, *Chara* and/or *Nitella* spp., *Isoetes alpinus*, *Mimulus guttatus*, tufted growths composed of such species as *Lilaeopsis* (ie. short shallow water community), *Rorippa* sp. (known previously as *Nasturtium* sp.).

The first SCUBA observations of the submerged vegetation of Lake Wakatipu was by Coffey (1974). Vegetation at one site in the Frankton Arm was listed: *Elodea canadensis*, *Potamogeton cheesemanii*, *P. ochreatus*, *Myriophyllum elatinoides* (now *M. triphyllum*), *Isoetes alpinus*, *Glossostigma submersum* (now *G. diandrum*), *Lilaeopsis lacustris* (now *L. ruthiana*) and *Nitella hookeri*. The depth ranges, heights, % cover and an abundance rating were given for the individual species with a maximum depth limit for plants of 15 m recorded.

In February 1982 the Aquatic Plant Group (APG) of the Ministry of Agriculture and Fisheries, provided the first descriptions of the submerged vegetation from the main body of Lake Wakatipu (APG NZ lakes computer data base) in which 50 profiles were dived (see methods). Data from this survey are included in this report as a baseline for comparison with the present survey.

The present study describes the submerged vegetation of Lake Wakatipu in late January 1992 and includes descriptions of the submerged flora of Lakes Alta, Dispute, Moke and Lochnagar. These latter lakes are described for the first time and their floristic values are discussed.

3. Study Site

Lakes Wakatipu, Lochnagar, Moke, Dispute, and Alta, lie within the Kawarau River Catchment, Central Otago (Figure 1) and their physiography is summarised in Table 1. The lakes are situated at a latitude of around 45^{o} South, and vary considerably in size, depth, and altitude. The largest and deepest, Lake Wakatipu, lies at the head of the Kawarau River, and is fed predominantly by the Dart and Rees Rivers. Lochnagar is a remote lake with no road access 44 km north of Queenstown. It lies close to the Main Divide of the Southern Alps, receives snow-melt waters and discharges via the Shotover River to the Kawarau River. Lakes Moke and Dispute are situated close to Queenstown. Lake Moke drains into the Kawarau River and Lake Dispute drains to Lake Wakatipu. Lake Alta is located within the Remarkables ski-field high in the Remarkables range (1806 m a.s.l.) and drains to the Kawarau River.

Lakes Wakatipu, Moke and Dispute can be considered as examples of montane lakes, and Lochnagar and Lake Alta as alpine lakes as they are above the timber line (Stout 1978). Lake Alta is ice and snow covered for much of the year, while Lakes Lochnagar, Moke and Dispute experience periodic freezing to varying degrees. The lakes were formed after the last glaciation in glacial depressions. Lochnagar may be of more recent origins being formed or deepened by a landslide blocking a steep sided valley (Lowe and Green 1987). Lakes Wakatipu, Moke and Dispute are in catchments which are predominantly grazed tussock grasslands with pockets of beech forest, while the catchments of the alpine lakes are largely rocky snow fields with sparse covers of tussock. Lake Wakatipu and the surrounding catchment has outstanding scenic values, and Queenstown on the shores of Lake Wakatipu is a focus for a rapidly growing tourist industry in the region. Recreational boating and fishing are also popular on Lake Wakatipu adding to the lake's value for tourism. Lakes Moke and Dispute are popular trout fishing sites, while the relative inaccessibility of Lochnagar and Lake Alta reduce their utility.

4. Methods

The submerged vegetation of Lake Wakatipu was described on 23 February 1982, using a qualitative SCUBA survey technique (Clayton 1983 a) in which 50 equidistant profiles around the margin of the lake were investigated (Figure 1). Thirty profiles (also identified in Figure 1) located as close as possible to selected 1982 profiles, were repeated from 27 to 29 January 1992. Profiles were chosen on the basis that they were well distributed around the margin of the lake and represented sites suitable for plant growth. Sites were excluded if they had steep slopes, sediment instability or localised impacts associated with stream inflows.

Lakes Moke, Dispute, Alta and Lochnagar, were visited from 29 January to 1 February 1992. The number and location of profile sites were limited by time constraints and accessibility. Three profiles were recorded in Lochnagar (Figure 1), and records of the submerged vegetation in a shallow tarn to the south-east of the lake were also made. Access to these sites with SCUBA was only feasible by air. In Lake Moke three profiles along the north-eastern shore, and four profiles in Lake Dispute, along the eastern shore, were included. The northern third of Lake Alta was explored, this lake being much smaller.

At each profile site SCUBA divers recorded features of the submerged vegetation within a 2 m wide band from shore to the maximum depth of plant growth. In Lake Wakatipu decompression constraints prevented the maximum depth of submerged vegetation (as deep as 60 m) being attained at thirty of the fifty sites in 1982 and nine of the thirty sites in 1992. The depth range, maximum and average cover and height for every species encountered, and the total plant cover was recorded for each profile. Depth measurements were obtained using a capillary tube depth gauge in Lake Wakatipu in 1982 and Lochnagar and Lake Alta in 1992. Dacor 'Microbrain' dive computers, employing altitude and temperature compensated piezo-resistive pressure transducers accurate to $\pm$ 0.1 m, were used in lakes Wakatipu, Lochnagar, Moke and Dispute in 1992. The water level of Lake Wakatipu at the time of the 1992 survey was 310.17 m above sea level. No lake level recordings of the other lakes are routinely made, but with defined outflows they are unlikely to vary greatly. Subjective estimates of plant cover were made using the Braun-Blanquet cover scale in which:

1 = 1-5%
2 = 6-25%
3 = 26-50%
4 = 51-75%
5 = 76-100% cover

In 1992 the scale was modified to record complete covers by inclusion of cover 6 = 96-100%; therefore cover 5 became 76-95% cover.

Data was entered into the APG 'New Zealand Lakes Database'.

Computations of Lake Wakatipu data (Table 2) include species frequency (% occurrence in profiles), species depth range, median average and maximum covers for 1982 (50 profiles) and 1992 (30 profiles).

Data from the four smaller lakes was not used for frequency calculations (too few profiles per lake) so an abundance score was calculated, using the following formula:

% of sites recorded	X	Species depth range / Total plant depth range (m)	X	median average cover score	=	abundance score

Where the abundance score is:

≤50 = occasional
51-200 = common
>200 = abundant

Specimens of each species recorded from each lake (except bryophyte species) were lodged in the Christchurch Herbarium of Landcare (CHR). Samples of bryophytes were collected from a range of depths and locations at each lake where encountered. Samples were sorted into similar types and forwarded to Dr Jessica Beever (Landcare Research N.Z. Ltd.), Dr John Braggins (Auckland University), Prof. Ella Campbell (Massey University), and Dr Elizabeth Brown (National Herbarium, Sydney, Australia) for identification.

5. Results

5.1 Lake Wakatipu

Lake Wakatipu had a diverse, predominantly native vegetation. The vegetation was comprised of four distinguishable plant assemblages, with high cover values and exceptionally deep lower depth limits recorded (Figure 2).

a. The shallowest plant assemblage was an association of short growing, shallow-water species which usually started at a depth of 1 m or more. *Isoetes alpinus* (endemic to the South Island) dominated this assemblage, being recorded in over 80% of profiles, and forming swards of typically high cover (51-100% cover) to depths of up to 9 m (Plate 1 and Table 2). *Isoetes* was absent or recorded low covers from profiles with exposed bedrock, unstable substrates, steep slopes, and in the vicinity of stream inflows. Short, shallow-water species often associated with *Isoetes,* were *Glossostigma diandrum* and *Elatine gratioloides*. Other species including *Crassula sinclairii, Glossostigma elatinoides, Limosella lineata, Lilaeopsis ruthiana,* and *Pilularia nova-zelandiae* occurred less frequently. These species often occurred in associations of up to 4 component species, each at typically low cover (≤5%). They were confined to shallow water on the wave washed shoreward margin of the *Isoetes* sward and extended into the *Isoetes* sward, between 0.5 and 3 m depth.

b. Tall growing vascular species, *Myriophyllum triphyllum* (Plate 2) and *Potamogeton cheesemanii* (Plate 3) were frequently recorded (70-80% of profiles) but of low cover amongst the *Isoetes* sward. *Potamogeton ochreatus* was less common (10% of profiles), while both *Ruppia polycarpa* (2% in 1982 only), and the exotic species *Ranunculus trichophyllus* (3% in 1992 only), were rarely recorded and both had a restricted depth range (Table 2). These species typically had low average covers (≤5%), with *Myriophyllum triphyllum* more common in water shallower than 5 m depth and with *Potamogeton* spp. having a wider depth range extending into water 9 m deep.

The exotic oxygen weed species *Elodea canadensis* was present in both surveys. By comparing the 30 profiles common to both surveys, it had increased in frequency from 27% in 1982 to 43% in 1992, with a small increase in depth range and average cover (Table 2). In 1992 *Elodea* had the widest depth range (0.5-9.1 m) of all the vascular species, and had the second highest average cover (up to 25%) after *Isoetes alpinus*. *Elodea* formed high average covers in close proximity to stream mouths and in sheltered bays.

c. Charophytes were the most abundant community being comprised of a total of 8 species (Table 2). Sparse short charophytes were recorded amongst *Isoetes* in shallow water with high cover 'meadows' extending from the lower depth limits of the *Isoetes* sward to about 35 m, with lower covers recorded as deep as 55 to 60 metres. The charophyte meadows were typically comprised of two components; a shallow more diverse zone (Plate 4) to depths of approximately 30 m, and a deeper bed comprised of *Nitella hookeri* var. *tricellularis*. The shallower assemblage was dominated by either *Nitella hyalina* (predominantly in shallow water ≤17 m), *Nitella hookeri*, *Nitella pseudoflabellata*, or *Chara corallina*. *Chara braunii* and *Chara fibrosa* were uncommon. *Chara globularis* and *Nitella leptostachys* were recorded only in 1982 at low abundances. *Nitella hookeri* var. *tricellularis*, an endemic variety (probably restricted to the South Island), typically formed high cover beds (Plate 5), which gradually declined in cover towards the lower plant boundary.

d. Bryophytes were present at 73% of profiles (1992 survey, Table 2) and occupied two distinct depth ranges. In the shallows they were generally of low average cover (≤25%) attached to rocks or amongst *Isoetes* swards down to about 10 m depth. No bryophytes were found within dense charophyte meadows which occurred in depths of about 10-30 metres. From about 35 m depth a deep-water bryophyte community commenced where the *Nitella hookeri* var. *tricellularis* thinned out, and extended to as deep as 57 metres (60 m recorded on less accurate capillary gauges in 1982). These deep-water bryophytes grew at variable densities, as ribbons of growth across gentle slopes or tongues down steeper slopes, or as a complete cover on moderate silt slopes. The bryophytes were loosely attached to soft silt substrates, low growing (≤0.1 m) with long (up to 130 mm), tangled stems and thalli of both moss and liverwort species (Plates 6 and 7).

In the northern part of the lake, beyond Pig Island (Figure 1), deep-water bryophytes were either absent, or of shallow maximum depth (<35 m) and low average cover (≤5%). Bryophyte frequency, depth range and cover increased with distance from the turbid Rees and Dart River inflows (Figure 3). For example, all 50 m or greater depth records and highest covers for bryophytes were recorded south of Queenstown.

Some of the bryophytes collected in deep water were difficult to identify as their morphology was quite different from specimens of the same species from their 'usual' habitats. It was estimated that at least 12 and as many as 16 bryophyte species comprised the deep-water bryophyte community of Lake Wakatipu (Appendix 1). Specimens are under culture in the laboratory to facilitate development of diagnostic features required for further identification. The bulk of the bryophyte material collected from deep water consisted of 4 moss species; 2 *Bryum* spp., *Fissidens rigidulus*, and *Fissidens adianthoides*; a leafy liverwort, *Heteroscyphus triacanthus*, and the thallose liverworts *Riccardia* sp. and *Symphyogyna* sp. These species were observed to form a zonation within the deep-water bryophyte depth range with *Bryum* species usually observed in the shallower portion (30-35 m), and *Fissidens* spp. and liverworts more common in the deeper region of the depth range.

5.2 Lochnagar

Lochnagar had a native submerged vegetation of low species diversity. The margin of the lake was largely steep and rocky, and thus unsuited for submerged plant establishment. At the south-east end of the lake moderately sloping shores (Plate 8) provided a suitable habitat for submerged vegetation. The only vascular plants recorded were *Myriophyllum triphyllum* and *Potamogeton cheesemanii* (Plate 9). These species were short (≤1 m), sparse (average cover 6-25%), and found only in shallow water ≤6 m deep (Table 3). No plants were recorded from shallows < 1.5 m deep.

Nitella hookeri var. *tricellularis* was the only charophyte recorded and had a depth range of 2.5-55 m deep and formed monospecific beds at 96-100% cover between 8 and 30 m deep (Plate 10 and Figure 4). In other profiles *Nitella hookeri* var. *tricellularis* occurred at low average covers (6-25%) to depths ≤31 m.

A deep-water bryophyte community was found at the south-east end of the lake. A mixed species assemblage of three mosses, *Fissidens rigidulus*, *Distichophyllum pulchellum*, and *Achrophyllum dentatum*, and a thallose liverwort of the *Riccardia* or *Aneura* genera, were recorded from 30 to c. 55 m depth. Deep-water bryophytes were present within the *Nitella hookeri* var. *tricellularis* beds from about 30 m depth at average covers of ≤5% with maximum covers up to 50%. The cover of bryophytes increased with depth to an average cover of 51-75% at about 40 m depth. *Plumatella* sp. (a bryozoan) was present amongst the deep *Nitella* and bryophytes. The presence of dense growths of bryozoans made the determination of the bryophyte depth limit difficult as it was hard to distinguish bryophyte material from bryozoans in the low light encountered at depth. Sparse growths of *Fissidens* sp. were attached to schist rock in shallow water (1.5 to 2 m deep).

A small, shallow (~5 m depth) tarn to the south-east of Lochnagar (Plate 8) supported a more diverse submerged vegetation. *Myriophyllum triphyllum* was abundant with a high cover (96-100%) to 3 m depth, and *Potamogeton cheesemanii* then formed a band of 6-25% cover below the *M. triphyllum* to 3.5 m maximum depth. In the shallows, *Nitella pseudoflabellata* was present at an average cover of 26-50% together with occasional plants of *Lilaeopsis ruthiana*, *Limosella lineata*, and *Crassula sinclairii*. Occasional emergent plants of *Myriophyllum propinquum*, *Ranunculus amphitrichus*, *Juncus articulatus*, and *Eleocharis acuta* were noted occasionally around the tarn's margin.

5.3 Lake Moke

Lake Moke had a diverse native submerged vegetation (Table 3), with a high (76-100%) vegetation cover of charophytes and tall vascular plants (Figure 5).

Short, shallow-water species, *Glossostigma diandrum*, *Eleocharis pusilla*, *Isoetes alpinus*, *Limosella lineata*, *Lilaeopsis ruthiana*, and *Ranunculus limosella*, were present to depths of 1.5 metres, but were generally at sparse individual covers (≤5%). *Eleocharis pusilla* and *Isoetes alpinus* formed higher average covers (6-25% and 26-50% respectively) in localized areas.

A mixed assemblage of tall growing vascular species dominated by *Myriophyllum triphyllum* and *Potamogeton cheesemanii* was present from shallow water to a maximum of 6.5 metres. These plants usually had a cover of ≤25% (maximum 76-95%) and height ≤1 metre tall. *Potamogeton ochreatus*, *P. pectinatus*, *Ranunculus trichophyllus* and *Ruppia polycarpa* were also present but were less common and occupied a more restricted depth range. *Ranunculus trichophyllus*, the only exotic species present, generally had a low average cover (≤5%), although a high average cover (26-50%) was recorded at one site. *P. ochreatus*, *P. pectinatus* and *R. polycarpa* were typically low growing (< 1 m in height), and sparse (≤5% cover).

Six species of charophytes were recorded in Lake Moke (Table 3). *Chara braunii* was recorded in shallow water at one site only . Occasional plants of *Chara corallina*, *C. globularis*, *Nitella pseudoflabellata*, *N. hookeri* var. *tricellularis* and *N. hyalina* added to the species diversity of the shallow water plant assemblages (≤6 m depth) with all species except *N. hyalina* continuing into deeper water. *Chara globularis* dominated the deep-water submerged vegetation, with dense beds of high cover (76-100%) between 4 and 10 m (maximum depth range 0.3-11 m). *Chara globularis* was replaced by *Nitella hookeri* and *N. hookeri* var. *tricellularis* with low cover (≤5%) growths from 10 m to the maximum plant depth of 15 metres, although *Nitella hookeri* formed a high cover (76-95%) between 10 and 12 m on one profile. The change in charophyte species at the lower depth limit of *C. globularis* coincided with depth of the thermocline (10 m) at the time of the survey.

5.4 Lake Dispute

Lake Dispute, a small shallow lake with a Secchi disc depth of 4 m, appeared to be the most eutrophic of the lakes investigated. In-water visibility was markedly lower above the 8 m deep thermocline. Lake Dispute had similar submerged plant species to Lake Moke, but with lower species diversity (Table 3), and shallower plant depth ranges (Figure 6).

Short, shallow-water species, *Isoetes alpinus*, *Lilaeopsis ruthiana* and *Ranunculus limosella* were restricted to depths ≤2.6 m, at low individual average covers (≤25%). In depths less than 1 m these species were often disturbed by black swan (*Cygnus atratus*) grazing.

Tall vascular species *Myriophyllum triphyllum*, *Potamogeton cheesemanii*, and the exotic *Ranunculus trichophyllus* were present within depths of c. 1-5 metres. *Myriophyllum triphyllum* formed high covers (up to 100%), while the other 2 species were usually sparse (≤5% cover).

Four charophyte species were recorded from Lake Dispute. *Chara corallina* and *C. braunii* were present from the shallows to depths of 10 metres. *Nitella pseudoflabellata* extended from the shallows to 5 m in depth and *Nitella hookeri* was found in only one profile in shallow water. *Chara corallina* dominated the submerged vegetation from c. 5-10 m, forming high cover meadows, with all profiles having a maximum cover of 96-100% and average covers from 6-95%. *Chara braunii* was recorded in all four profiles, with an average cover of 51-76% and a maximum cover of 96-100% in one profile. Problems with distinguishing this species from *C. corallina* underwater are likely to have resulted in an underestimate of the abundance of *C. braunii.* The differences between the two species were more apparent when fruiting in shallow water.

5.5 Lake Alta

A depauperate submerged vegetation was recorded from Lake Alta, with *Crassula sinclairii* the only vascular species recorded (Table 3 and Figure 7). It occurred from 0-6 m in depth with a sparse average cover of ≤5%, and a maximum recorded cover of 6-25%.

Sparse bryophytes (≤5% cover) were present to a maximum depth of 12 metres. Bryophytes were recorded both as small patches on silt substrate (established plants and drift material), and as 'strings' hanging from the undersides of occasional large boulders (Figure 7). Three mosses (one identified as *Thamnobryum pandum*) a thallose liverwort, and a leafy liverwort were collected.

6. Discussion

6.1 Vegetation characteristics

Examples of New Zealand's native submerged vegetation such as found in Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta are becoming increasingly rare in New Zealand following widespread invasions by exotic plants (Howard-Williams et al. 1987). Submerged vegetation of a predominantly native character is mostly restricted to geographically isolated lakes, such as Northland dune lakes (Tanner et al. 1986), high altitude lakes (eg. Lake Rotopounamu, Michaelis 1983), and waterbodies with restricted, non-vehicular access (eg. Lake Marion, de Winton et al. 1991). No exotic species were recorded from the remote high altitude lakes, Lochnagar or Lake Alta. Within the other lakes investigated only 2 exotic species, *Ranunculus trichophyllus* and *Elodea canadensis* were recorded, both being widely distributed throughout New Zealand.

All the lakes (except Lake Alta) had at least three of four plant communities, commonly recognised on the basis of species composition and depth distribution in New Zealand lakes. These were:

a. *Short, Shallow-water species*
Diverse assemblages of short-growing species in shallow water have been described as 'amphibious swards' or a 'low mixed community' (Johnson and Brooke 1989). In Lake Wakatipu *Isoetes alpinus* dominated the shallow-water plant community with high abundance (frequently encountered and of high cover) and a deep maximum depth of up to 9 m, which is equalled only in a few other large, clear water South Island lakes such as Lake Wanaka (Clayton 1983 b). Other shallow-water species in Lake Wakatipu, including *Glossostigma* spp., *Lilaeopsis* spp., and *Elatine* spp., were mostly restricted to sparse growths on coarse substrates associated with wave exposed shallow margins. In Lakes Moke and Dispute, *Isoetes* did not form high cover swards with the result that other shallow-water species formed extensive growths. In Lake Alta, *Crassula sinclairii* was the sole representative of this community, but growth was particularly sparse with occasional deep records (6 m) likely to be debris deposited following ice scouring and dislodgement from lake margins. The absence of short, shallow-water species in Lochnagar, especially *Isoetes*, was unexpected and possibly associated with limited dispersal of plant innoculum to this remote site.

b. *Tall Vascular species*
Tall native vascular plants were recorded from all lakes except Lake Alta. They formed open covers, sometimes in isolation (eg. Lochnagar), or in association with the shallow-water community and charophyte meadows. In Lake Moke and Dispute tall native vascular plants (mainly *Myriophyllum triphyllum* but also *Potamogeton cheesemanii*) were common and provided a rare example of the unmodified native vegetation structure of mesotrophic lakes unaffected by invasion of exotic species such as *Elodea canadensis* or other oxygen weed species. Although tall native vascular plants were widespread in Lake Wakatipu, average covers were low.

Ranunculus trichophyllus which forms viable seed dispersed by waterbirds, generally formed sparse growths in shallow water with occasional tall dense clumps present in Lakes Moke and Dispute. This exotic was rare in Lake Wakatipu. *Elodea canadensis* which is dependant on spread of vegetative propagules was only recorded in Lake Wakatipu, although other nearby waterbodies, such as Diamond Lake at the head of Wakatipu, and Lake Hayes are also known to have this species. Although *Elodea* was widespread within Lake Wakatipu, significant impact was limited to areas such as Queenstown Bay, the Frankton Arm and Bobs Cove, all of which are sheltered and likely to have more fertile sediments.

c. *Charophyte meadows*

Charophytes were the most abundant group of submerged plants with highest species diversity recorded in Lake Wakatipu (8 species including the 1982 data). Lake Moke had 6 species, Lake Dispute 4, and Lochnagar only 1 species of charophyte. Substantial charophyte meadows were recorded in all the lakes except Lake Alta. Lake Moke was dominated by *Chara globularis*, Lake Dispute by *Chara corallina* and *Chara braunii*, Lake Wakatipu had a mosaic pattern with *C. corallina, N.hookeri, N. hyalina* abundant and *N. hookeri* var. *tricellularis* the dominant species at depths greater than c. 30 metres. Lochnagar was unusual, having a monospecific charophyte cover of *N. hookeri* var. *tricellularis* from shallow to very deep water.

Wood and Mason (1977), reported only two sites for *Chara braunii* in New Zealand, although it was noted that *Chara braunii* so resembles *C. corallina* that it is likely to have been 'overlooked as just another stand of that species'. Although *C. braunii* has been considered rare in New Zealand it has now been recorded in ten South Island glacial lakes (APG data base) including Lakes Wakatipu, Moke, and Dispute. Our records suggest that *C. braunii* is more abundant in Lake Dispute than any other lake in New Zealand.

Lake Wakatipu exhibited the best examples of high cover, deep growing charophyte meadows we have encountered. Few similar examples occur elsewhere in New Zealand, being restricted to other South Island glacial lakes of high water clarity and relatively stable water levels (eg. Lake Wanaka; Clayton 1983 b, Lake Ohau; Wells and Clayton 1989, Lake Coleridge; APG unpublished data). The high clarity of the water in Lake Wakatipu has resulted in this lake having the deepest growing widespread charophyte meadows known for any New Zealand lake.

Lochnagar, also an exceptionally clear lake (Secchi disc 20 m), had a deep-water (up to 55 m) monospecific charophyte meadow (*Nitella hookeri* var. *tricellularis*) at the south-east end of the lake. The steep littoral bathymetry of the lake appears to have restricted the extent of charophyte colonisation in this lake.

d. *Deep-water Bryophytes*

Lake Wakatipu and Lochnagar are among the clearest lakes in New Zealand and support good examples of deep-water bryophyte communities. Similar water transparencies are found in Lakes Wanaka, Hawea, and Coleridge in the South Island and Lake Taupo in the North Island. In Lake Taupo the maximum plant depth limit of c. 17 m and absence of bryophytes is believed to be determined by freshwater crayfish (koura) browsing (Coffey and Clayton 1988), while in Lake Hawea vegetation is detrimentally affected by 8 m (and formally 20 m) water level fluctuations (Clayton et al. 1986). Lake Coleridge has the deepest known bryophyte depth record for any New Zealand lake (ie. 70 m), exceeding Lake Wakatipu by 10 m, but it has very steep and often unstable littoral margins which limit the extent and cover of bryophytes in this lake (APG unpublished data). Lakes Wanaka and Wakatipu are therefore New Zealand's best examples of deep-water bryophytes. They were recorded on at least 60% of the 1982 profiles in Lake Wakatipu compared to 32% of profiles in Lake Wanaka (Clayton 1983 b). The bryophyte community in Lake Wakatipu is therefore notable for its high abundance and maximum depth limit.

Deep-water bryophytes are uncommon both within New Zealand and globally. Ignatov and Kurbatova, (1990) list twenty-five to thirty lakes globally where bryophytes occur in depths of 10 m or greater. No New Zealand records were included. The depth of Lake Wakatipu bryophytes was exceeded only by Lake Tahoe, USA (124.5 m), Crater Lake, USA (120 m) and Lake Geneva, Switzerland (65 m). However, depth records are likely to have markedly decreased in Lake Tahoe while deep-water bryophytes probably no longer exist in Lake Geneva due to reductions in water clarity since these records were taken (Goldman 1981; Balvay et al. 1990). It is difficult to compare overseas information with New Zealand data as descriptive accounts of abundance of deep-water bryophytes in overseas lakes are rare and most records obtained were the result of limited dredging.

Identification of overseas and New Zealand bryophytes has proved difficult on account of abnormal growth forms (eg. leaves reduced to vestigial structures) and the absence of sex organs or sporophytes. However all unidentified bryophyte specimens from Lake Wakatipu are suspected to be forms of species known from other habitats rather than previously un-described species (Dr J. Beever pers comm.).

Many of the bryophytes recorded in lakes in other countries are not normally aquatic or even amphibious (Crum 1976). Likewise the presence of *Achrophyllum dentatum, Distichophyllum pulchellum, D. microcarpum* and *Thuidium sparsum* in Lake Wakatipu was unexpected as these species are not generally recorded from permanently submerged habitats (Dr J. Beever pers comm.).

6.2 Factors affecting the submerged vegetation

A number of interrelated environmental factors promote, or restrict submerged vegetation growth in Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta. These include :

a. *Water Clarity*

Deep water vegetation is dependent on adequate light for net photosynthesis. Water clarity is therefore one of the major factors determining the maximum depth to which submerged vegetation can grow (Spence 1982, Dale 1986, Vant et al. 1986). The five lakes studied showed a range of water clarity, which was reflected by the maximum depth limit of submerged vegetation. Lakes Wakatipu and Lochnagar had Secchi disc depths of 16 and 20 m at the time of the survey (table 1) with maximum plant depths of 60 and 55 m respectively. Deep-water bryophyte communities were present in both these clear lakes. Lakes Moke and Dispute exhibited lower water clarity, and shallower maximum plant depths without deep-water bryophytes. Although Lake Alta had relatively clear water at the time of the survey, reductions of light levels by ice and snow cover over much of the year and the poor development of the submerged vegetation would have obscured any relationship between plant depths and water clarity.

The maximum depth limit of charophytes and bryophytes in Lake Wakatipu showed correlations with spatial variations in water clarity at the time of the 1992 survey. High levels of suspended sediments introduced by the Dart and Rees Rivers decreased water clarity at the Glenorchy end of Lake Wakatipu, with a Secchi disc depth reading of 4 m, compared to 16 m at the Kingston end of the lake. Increasing maximum plant depths were evident with increasing distance from the Dart and Rees Rivers. Deep-water bryophytes were absent from sites within the vicinity of these inflows (Figure 3).

The deep-water bryophyte community appeared the most severely affected by low water clarity within the northern end of Lake Wakatipu. Here dual constraints of restricted light levels at depth and competition from dense charophyte growths in shallower water saw a reduction in bryophyte depth range rather than compression of the complete vegetation sequence. This resulted in the entire loss of this community from some areas which still supported charophyte meadows (Figure 3).

b. *River influences*

River and stream inflows into Lake Wakatipu were often associated with decreased plant occurrence due to high rates of siltation, direct disturbance, or possibly temperature effects. Inflows from the Dart and Rees Rivers at the head of Lake Wakatipu are low in temperature (≥2°C lower than the main body of the lake), and high in suspended sediments (Irwin 1975b). Submerged vegetation was absent from sites where sediment scouring was observed and in areas in close proximity to the main inflows. Heavy siltation was observed on plants beyond the areas scoured by inflows. *Elodea* was commonly present in areas adjacent to river and stream inflows where increased sediment fertility might be expected.

c. *Substrate*

Interactions between substrate characteristics, gradient, and exposure influence the distribution and development of submerged vegetation (Spence 1982). Plants were absent, or present in low abundance at sites in Lakes Wakatipu and Lochnagar where steep gradient resulted in a lack of suitable substrate, or substrate instability. Plants were also excluded from the shallow margins of these larger lakes due to wave disturbance and coarse substrates. Bare rock covered wave-washed platforms extended to depths of 1.5 m around most of Lake Wakatipu. Shallow-water plants dominated by *Isoetes alpinus* which is relatively resistant to wave exposure and erosion (Brown 1979), occurred only on the outer edge of this platform and extended down the more protected drop-off zone. Smaller lakes, or shorelines with only a moderate degree of exposure were characterised by finer substrates which supported a diverse assemblage of short, shallow-water species.

d. *Disturbance*

Deep-water bryophytes have minimal attachment to the silt substrates and are particularly vulnerable to disturbance. The often uneven cover of deep-water bryophytes in Lake Wakatipu may have been caused by deep-water currents or underwater slumping. Deep-water bryophytes are also susceptible to siltation and burial (Coffey and Clayton 1988).

e. *Altitude*

Isolation of high altitude alpine lakes may limit the availability of plant innocula, contributing to the low species diversity and absence of characteristic species. In addition low temperatures, low nutrient levels, and seasonally variable light levels (due to ice and snow cover and high cloud covers) result in a short growing season and a slow growth rate for plants (Stout 1978). The native submerged vegetation of the alpine lakes, Lochnagar and Lake Alta, was also low in abundance (compared to the lower altitude lakes), probably on account of unfavourable growth conditions limiting the establishment and development of submerged vegetation in these lakes.

Bryophyte tolerance of low light and temperature conditions may enable growth within alpine lakes such as Lake Alta, which are inhospitable to higher plants. Bryophyte vegetation has been documented in similar alpine lakes including the Upper Tama Lake (Michaelis 1982) and Lower Emerald Lake (DoC staff pers comm.) at altitude within the Tongariro National Park.

6.3 Changes in the submerged vegetation of Lake Wakatipu

The 1982 survey is the earliest detailed record of the submerged vegetation of Lake Wakatipu. Using this as a baseline for comparison with the 1992 survey little change is apparent over the last decade. No new exotic plant introductions were apparent, and record differences between surveys were restricted to infrequent species only. Both data sets showed similar vegetation patterns.

The depth limits for the bryophytes in 1982 and 1992 (60 m vs. 57 m) were as similar as could be expected considering that depth gauges used in 1982 were less accurate than those used in 1992. These depth limits would be the most sensitive vegetation indicator of any change in water clarity and provide the best evidence that no significant change has occurred in the last decade.

One change that was noted was an increase in the frequency of *Elodea canadensis,* although this oxygen weed was dispersed widely around the lake in 1982 (Glenorchy and Kingston). Comparing the thirty 1992 profiles in common with 1982, the frequency of profiles with *Elodea* increased from 27% (8 sites) to 43% (13 sites). *Elodea* was generally patchy and of low cover with new sites recorded on the east side of the Kingston Arm, on the southern shores of the middle of the lake and at the northern end of the lake. Although *Elodea* is likely to have been present in the lake since at least 1970, it still appears to be slowly extending its range. Abundant growths are generally restricted to sheltered sites and localised areas likely to have nutrient inputs. For example, localised abundant *Elodea* growth has been previously noted to be associated with proximity to stream mouths in the Rotorua lakes (Clayton et al. 1989). This is likely to be due to deposition of fertile sediments.

6.4 Threats to the submerged vegetation

The Resource Management Act (1991) requires managers to 'recognise and provide for ... preservation of the natural character of lakes ... and the protection of areas of significant indigenous vegetation'. In this context, threats to the natural character and notable features of the vegetation in lakes in the Kawarau Catchment include:

a. Activities in the catchment leading to reduced water clarity or increased nutrient status of water or sediments.
b. Further invasions by exotic species (including plants, herbivorous fish and wildfowl).
c. Large water level fluctuations.

a. *Water clarity or nutrient changes*
Clear lakes, such as Lake Wakatipu, can be susceptible to even minor changes in the catchment. Even the world's largest lakes (Lake Baikal, Siberia, and the Great Lakes, North America) are being or have become polluted (Tilzer and Serruya 1990). Tourist development of Lake Tahoe, a similar ultra-oligotrophic mountain lake on the California-Nevada border, has resulted in a 1/3 reduction in water

clarity in association with a doubling of phytoplankton growth rates (Goldman 1981). This has occurred despite complete export of sewage from the catchment over the last 30 years. Catchment practices need to be managed carefully in relation to nutrient and sediment inputs to Lake Wakatipu in order to preserve its high water clarity and low nutrient status. Preventing excessive sediment and nutrient input is crucial in protecting the presence of deep-water plant communities in Lake Wakatipu and in avoiding high density growths of *Elodea.*

Information on nutrient and sediment sources to Lake Wakatipu is needed so that these can be quantified and minimised if they pose a potential threat. Agricultural land practices such as top dressing of lake-side flats, spray irrigation of wastewaters, and accelerated erosion may have significant localised impacts and contribute to long-term water quality changes. Leaks from sewage systems and seepage from septic tanks in the area and seepage or run-off from any future land application of treated sewage would contribute nutrients, while runoff from construction sites, and stormwater from settlements and roading contribute sediment. These nutrient and sediment inputs to Lake Wakatipu could become significant if future tourist development proceeds within the Queenstown area.

b. *Plant and animal invasions*

Lakes Moke and Dispute are likely to be particularly vulnerable to *Elodea* invasion since wave exposure and sediment nutrient availability (as in Lake Wakatipu) would not prevent the development of tall dense growths in these smaller mesotrophic waterbodies. *Lagarosiphon* is also a threat and could be easily transferred from Lake Wanaka or the newly formed Lake Dunstan to Lake Wakatipu by recreational boat traffic. The creation of Lake Dunstan has increased the risk of *Lagarosiphon* transfer to Lake Wakatipu. This plant is most likely to threaten the shallow water species (0-6.5 m) in Lake Wakatipu particularly in the Frankton Arm and in sheltered bays, and be a major threat to Lakes Dispute and Moke. Additional species such as *Egeria densa* and *Ceratophyllum demersum,* which have displaced native vegetation to depths of 14 m in parts of Lake Tarawera (APG unpublished data), could be a major threat to lakes in the Kawarau catchment. If the proposed Biosecurities Act does not result in retention of a national ban on the sale and distribution of oxygen weed species then regions such as Otago should retain prohibition to reduce the chance of their introduction to the area. High public awareness of the threats of oxygen weed are required and surveillance at likely sites of introduction of new species is required for early detection to enable effective control or removal.

The introduction of noxious fish (eg. rudd and koi carp) or invertebrates such as koura (*Paranephrops* spp.) could have a marked impact on the submerged vegetation. Following the large-scale harvest of eel populations in these lakes, it is possible that koura could now establish if introduced, with the potential to completely destroy the deep-water bryophyte communities.

In Lake Dispute, black swan (*Cygnus atratus*) browsing appears to have damaged shallow water indigenous vegetation to 1 m depth. Black swans could also influence deeper growing plants by detrimentally affecting water quality if numbers were to increase in these small lakes.

c. *Water level changes*

Catchment developments that alter the natural water level regimes of these lakes, such as water abstraction or hydro-electric schemes, could have a deleterious impact on the submerged vegetation. Water level fluctuations affect the littoral zone directly by desiccation or hydrostatic pressure damage and indirectly by causing erosion and increased suspended sediment. Lake Hawea is an example where both shallow-water species and deep-water species have been impacted by water level fluctuations (Clayton et al. 1986). Plants cannot colonise the de-watered zone with the result that shallow-water plant species are absent, vascular plants are excluded from most shoreline areas, and the minimum depth limit of charophytes is depressed. The habitat for deep-water submerged plant species in Lake Hawea has also been adversely affected by the mobilization and re-distribution of fine inorganic bottom sediments associated with large artificial water level fluctuations. In Lake Hawea deep-water bryophyte growth is limited by high siltation rates despite comparable water clarity to Lake Wakatipu (mean Secchi of 18.8 m, Livingstone et al. 1986).

6.5. Conclusion

This is the first detailed description of the submerged vegetation of Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta. It identifies outstanding features of their indigenous submerged plant communities and some rare and unique vegetation features. These resources are vulnerable and require protection from a number of possible threats.

Monitoring key sites, plant species or submerged vegetation features within the lakes would enable deleterious impacts to be identified at an early stage, since submerged plants integrate information about the lake environment. For example, plant depth limits are sensitive indicators of long-term water clarity and reductions in these depths would indicate significant water clarity deterioration. Future monitoring of the deep-water bryophytes in Lake Wakatipu, including marking depth limits at specific sites, would be a sensitive biological indicator to monitor water clarity changes. Future nutrient enrichment in the littoral zone would be expected to lead to a marked increase in *Elodea* abundance. Regular monitoring would provide an early warning of changed nutrient status, and enable rapid detection of the introduction of any new invasive exotic species.

The proposed Conservation Order on the Kawarau River Catchment would help protect the natural heritage of these lakes, however additional initiatives maybe necessary to safeguard the submerged vegetation and careful planning of catchment development will be required to safeguard the submerged vegetation resources of these lakes.

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Table 1. Location, and physiography of Lakes Wakatipu, Lochnagar, Moke, Dispute and Alta, Central Otago (from Irwin 1972, Irwin 1975a, Irwin 1982, Irwin and Hutchinson 1982, Livingstone et al. 1986, Viner 1987, APG data 1992).

Lake	Grid ref. NZMS 260	Altitude (m a.s.l.)	Area (km^2)	Maximum depth (m)	Lake origin	Secchi disc depth (m)
Wakatipu	E41 478696	310	289.17	380	G	4-18
Lochnagar	E40 597157	1068	2.5	>57.0	G+L	20
Moke	E41 607691	524.2	0.83	44.2	G	9.5-11
Dispute	E41 594640	481.6	0.5	16.2	G	4
Alta	F41 801632	1806	0.09	>12.0	G	7+

G = Glacial

L = Landslide

Table 2. Summary of submerged vegetation data for Lake Wakatipu from 1982 (50 sites) and 1992 (30 sites) surveys, listing species frequency (% of sites), depth range (m), median average cover, and maximum cover in parenthesis.

Species	Frequency		Depth range		Cover[1]	
	1982	1992	1982	1992	1982	1992
Tracheophytes						
Crassula sinclairii (Hook.f.) A.Druce et Given.	-	3	-	2.0-2.4	-	1 (1)
Elatine gratioloides A.Cunn.	44	37	1.0-4.0	0.5-2.7	1 (4)	1 (2)
†*Elodea canadensis* Michaux	25	43	1.0-8.5	0.5-9.1	1 (5)	2 (5)
Glossostigma diandrum (L.) O. Kuntze	71	50	0.5-5.0	0.5-3.0	1 (4)	1 (3)
Glossostigma elatinoides Benth.	-	3	-	1.2-2.7	-	1 (2)
Isoetes alpinus Kirk	90	83	0.5-9.0	0.7-8.5	5 (5)	4 (6)
Limosella lineata Glück	-	20	-	0.5-2.2	-	1 (2)
Lilaeopsis ruthiana Affolter	8	7	0.5-2.0	0.7-1.5	1 (2)	1 (1)
Myriophyllum triphyllum Orch.	75	73	1.0-9.0	0.5-7.0	1 (2)	1 (3)
Pilularia nova-zelandiae Kirk	2	7	1.5-3.0	0.5-1.5	1 (2)	1 (1)
Potamogeton cheesemanii A. Benn.	73	80	1.0-9.0	0.7-9.0	1 (3)	1 (3)
Potamogeton ochreatus Raoul	8	10	2.0-9.0	3.0-8.7	1 (2)	1 (2)
†*Ranunculus trichophyllus* Chaix	-	3	-	1.2	-	1 (1)
Ruppia polycarpa R.Mason	2	-	6.0-7.0	-	1 (4)	-

Species	Frequency		Depth range		Cover[1]	
	1982	1992	1982	1992	1982	1992
Charophytes						
Chara braunii C. Gemlin	50	23	5.0-35.0	6.0-29.0	1 (5)	1 (3)
Chara corallina Kl. ex Willd., em. R.D.W.	58	67	3.0-35.0	0.5-43.0	2 (5)	2 (5)
Chara fibrosa Ag. ex Bruz., em. R.D.W.	56	33	2.0-25.0	2.5-24.0	2 (5)	2 (5)
Chara globularis Thuill.	2	-	22.0	-	1 (1)	-
Nitella leptostachys A.Br., em. R.D.W.	4	-	1.5-8.0	-	1 (1)	-
Nitella hookeri A.Br.	23	47	1.0-37.0	0.8-38.0	1 (4)	2 (5)
Nitella hookeri var. *tricellularis* (Nor.) R.D.W.	85	93	1.0-60.0	2.0-55.0	3 (5)	3 (6)
Nitella hyalina (D.C.) Ag.	42	67	1.0-22.2	1.2-17.2	1 (5)	2 (6)
Nitella pseudoflabellata A.Br.	94	93	1.0-60.0	0.5-32.0	1 (5)	1 (4)
Bryophytes[2]						
Shallow-water	70	53	0-12.0	0-10.0	2 (5)	2 (4)
Deep-water	60	73	10.0-60.0	11.0-57.0	2 (5)	1/2 (6)

1 = Braun-Blanquet cover scale (see methods) N.B. 1982 cover scale 5 =76-100%, 1992 cover code 5 =76-95%, and a maximum of 6=96-100% was included.

2 = Data includes sites where maximum depth limits were not attained.

\- = No record

† = Exotic species

Table 3. Summarised submerged vegetation data for Lakes Lochnagar, Moke, Dispute, and Alta, including species depth range and abundance score. (Refer to methods for abundance score, A = abundant, C = common, O = occasional).

Species	**Lochnagar**		**Lake Moke**		**Lake Dispute**		**Lake Alta**	
	Depth range (m)	Abundance	Depth range (m)	Abundance	Depth range (m)	Abundance	Depth range (m)	Abundance
Tracheophytes								
Crassula sinclairii (Hook. f.) A. P. Druce et Given							0-6.0	O
Eleocharis pusilla R. Br.			0.2-1.0	O				
Glossostigma diandrum (L.) O. Kuntze			0.1-1.0	O				
Isoetes alpinus Kirk			0.2-1.5	O	0.7-2.5	O		
Limosella lineata Glück			0.1-1.0	O				
Lilaeopsis ruthiana Affolter			0.2-1.5	O	0-2.6	O		
Myriophyllum triphyllum Orch.	1.5-3.5	O	0.2-6.0	C	0.9-3.6	C		
Potamogeton cheesemanii A. Benn.	1.5-6.0	O	0.2-6.5	C	0.7-5.0	O		
Potamogeton ochreatus Raoul			2.5-5.5	O				
Potamogeton pectinatus L.			0.5-2.5	O				

Species	Lochnagar		Lake Moke		Lake Dispute		Lake Alta	
	Depth range (m)	Abundance	Depth range (m)	Abundance	Depth range (m)	Abundance	Depth range (m)	Abundance
Ranunculus limosella Kirk			0.2-0.5	O	0.3-2.0	O		
†*Ranunculus trichophyllus* Chaix			0.5-2.5	C	1.5-2.8	O		
Ruppia polycarpa R.Mason			2.5-3.7	O				
Charophytes								
Chara braunii C. Gemlin			3.0-4.0	O	1.0-10.0	C		
Chara corallina Kl. ex Willd., em. R.D.W.			0.2-10.0	C	0.2-10.0	A		
Chara globularis Thuill.			0.3-11	A				
Nitella hookeri A.Br.			6.0-12.0	O	2.8	O		
Nitella hookeri var. *tricellularis* (Nor.) R.D.W.	1.5-55.0	A	1.5-15.0	C				
Nitella hyalina (D.C.) Ag.			0.1-4.5	O				
Nitella pseudoflabellata A.Br.			0.2-10.0	C	0.2-5.0	O		
Bryophytes	1.5-55.0	O			0-0.5	O	0-12.0	O

† = Exotic species

Figure 1. A map illustrating the locations of Lakes Wakatipu, Lochnagar (in insert), Moke, Dispute, and Alta within the Kawarau River catchment. Fifty profiles surveyed in Lake Wakatipu in 1982 are shown, ★ indicates profiles re-surveyed in 1992. Positions of three profiles in Lochnagar are indicated.

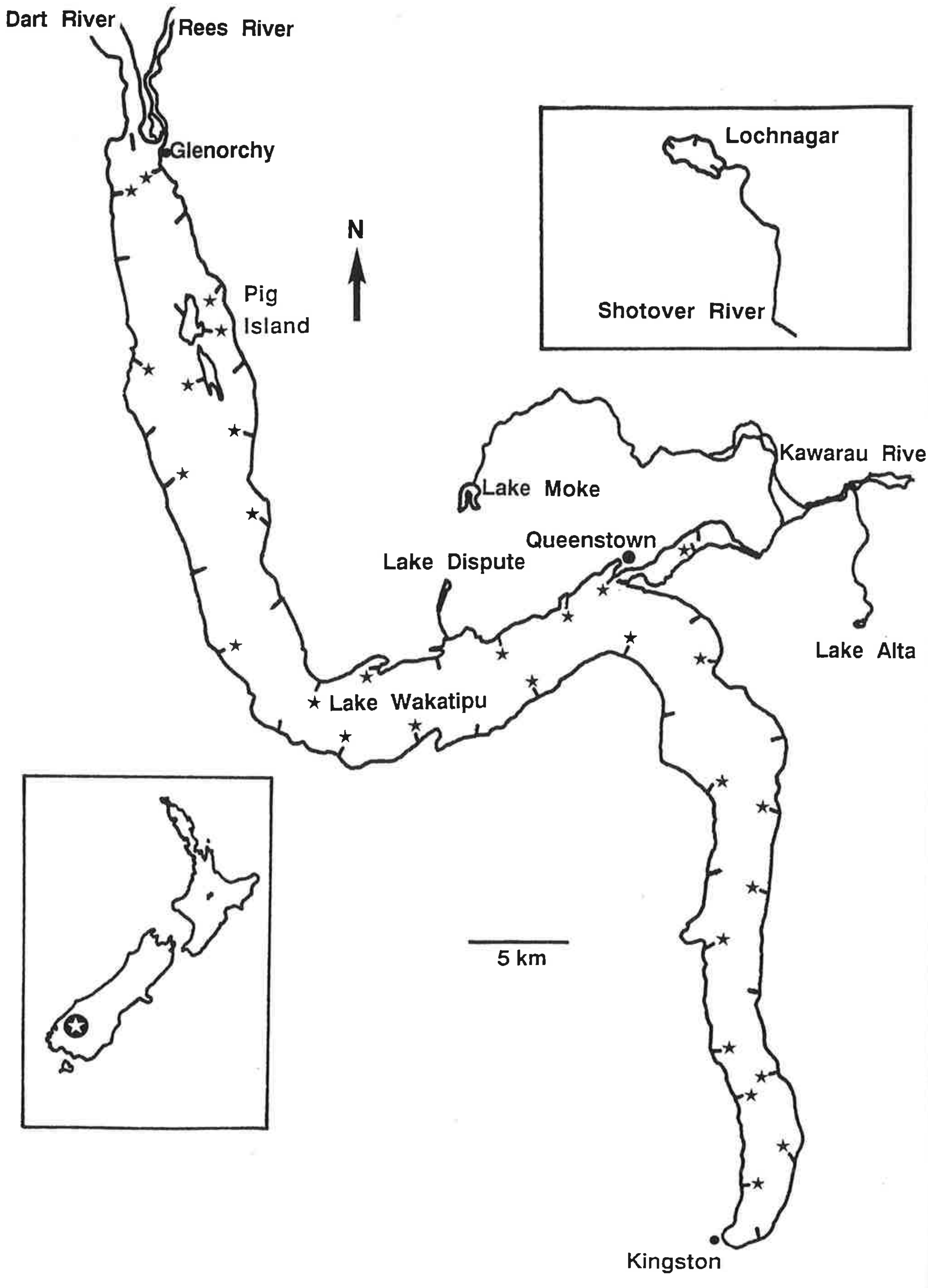


Figure 2. A stylised illustration of the submerged vegetation of Lake Wakatipu. Note plant heights are not to scale.

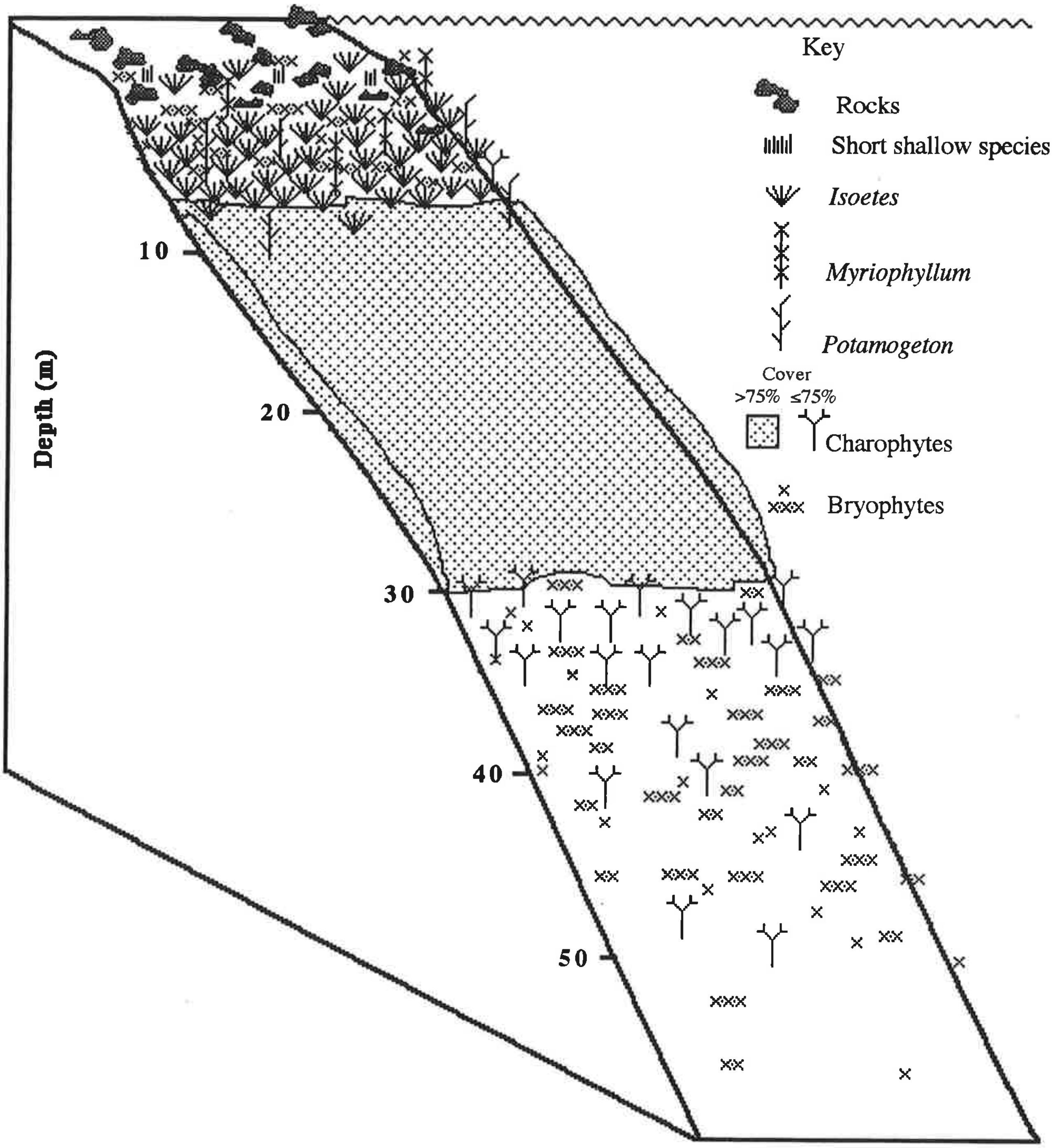


Figure 3. Maximum depth limits (m) for deep-water charophytes and bryophytes from the 1992 surveys of Lake Wakatipu. ☆ charophytes comprise maximum depth (deep-water bryophytes absent), ★ bryophytes comprise the vegetation at the maximum depth.

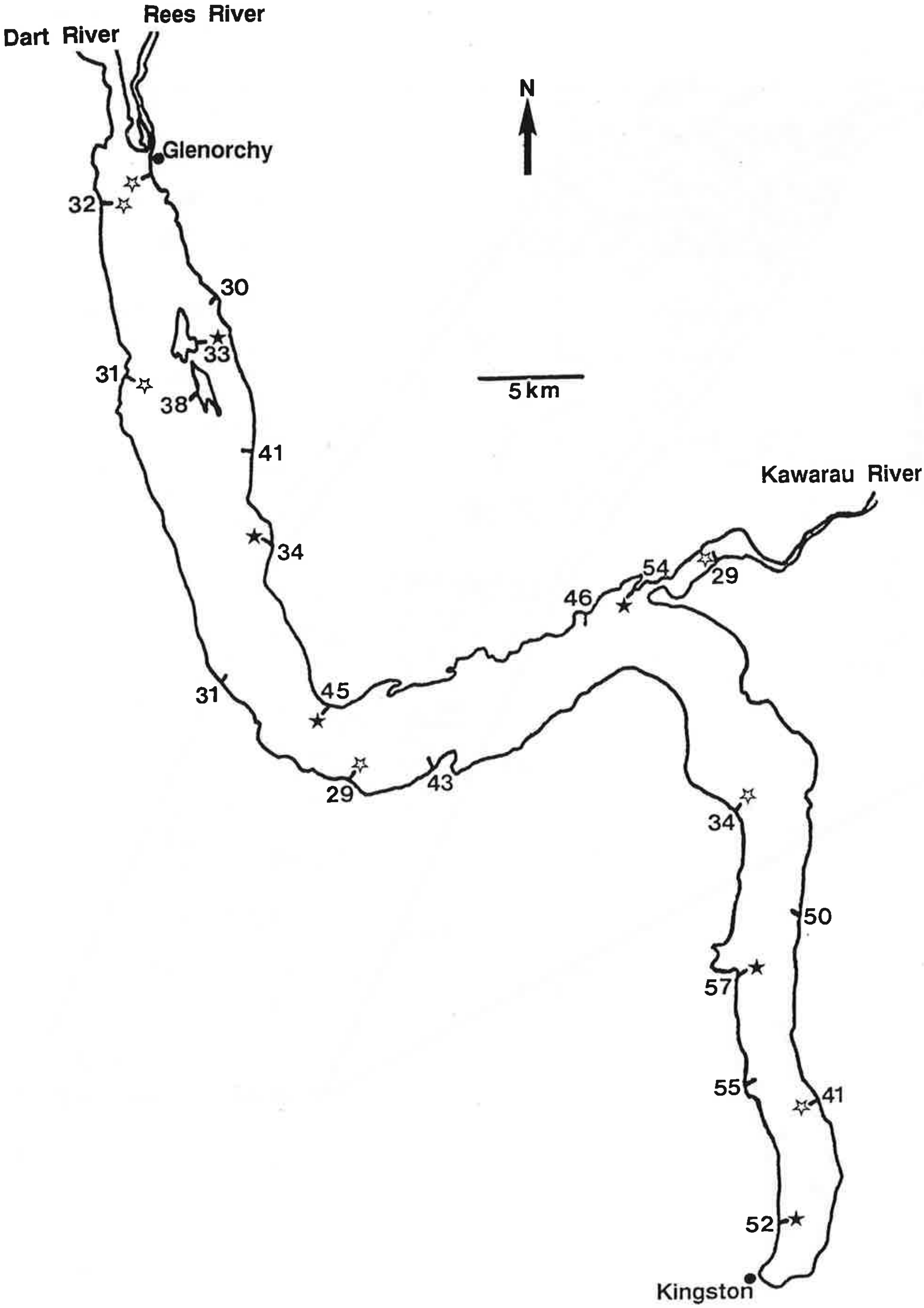


Figure 4. A stylised illustration of the submerged vegetation in the south-east sector of Lochnagar. Note plant heights are not to scale.

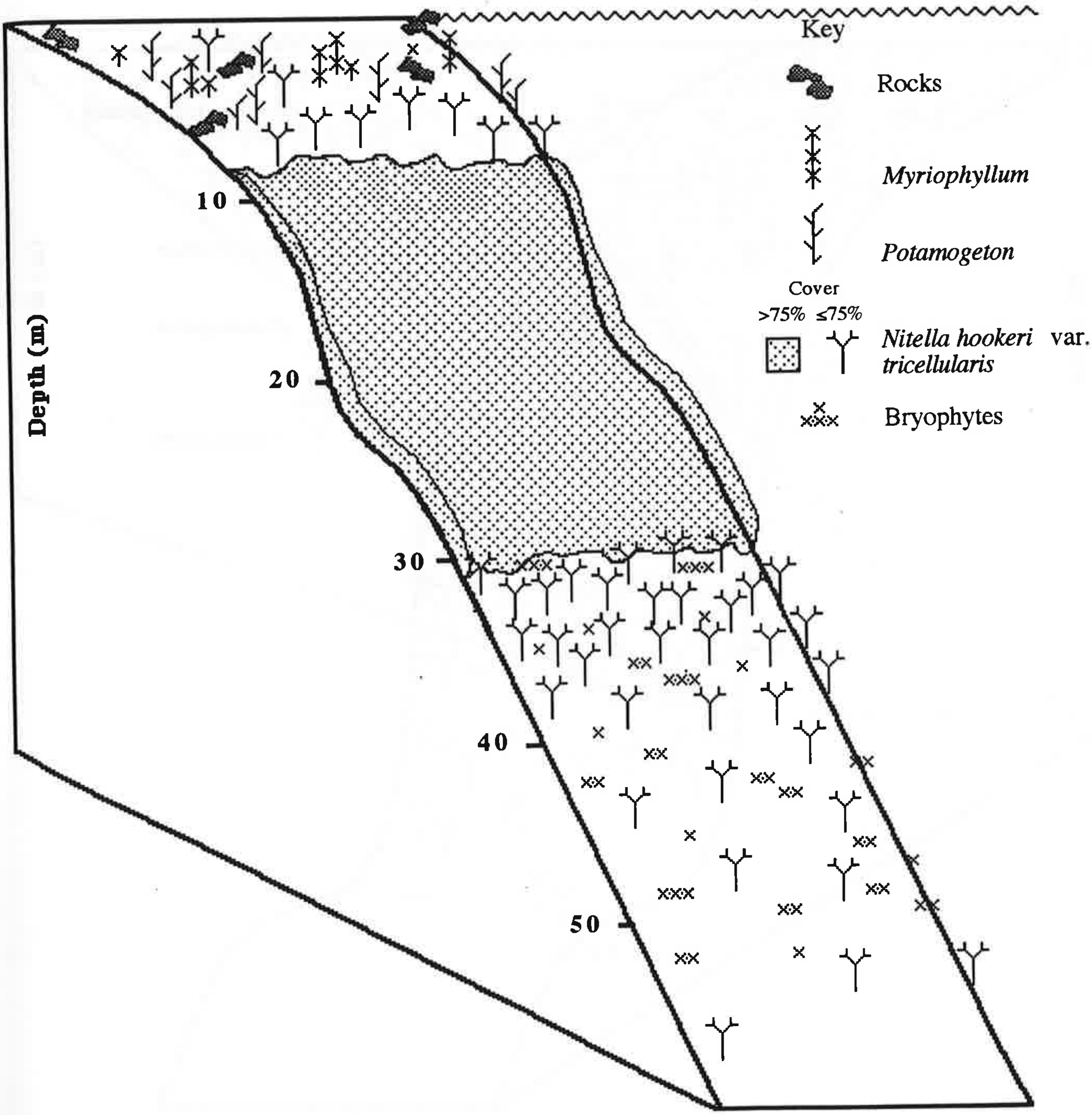


Figure 5. A stylised illustration of the submerged vegetation of Lake Moke. Note plant heights are not to scale.

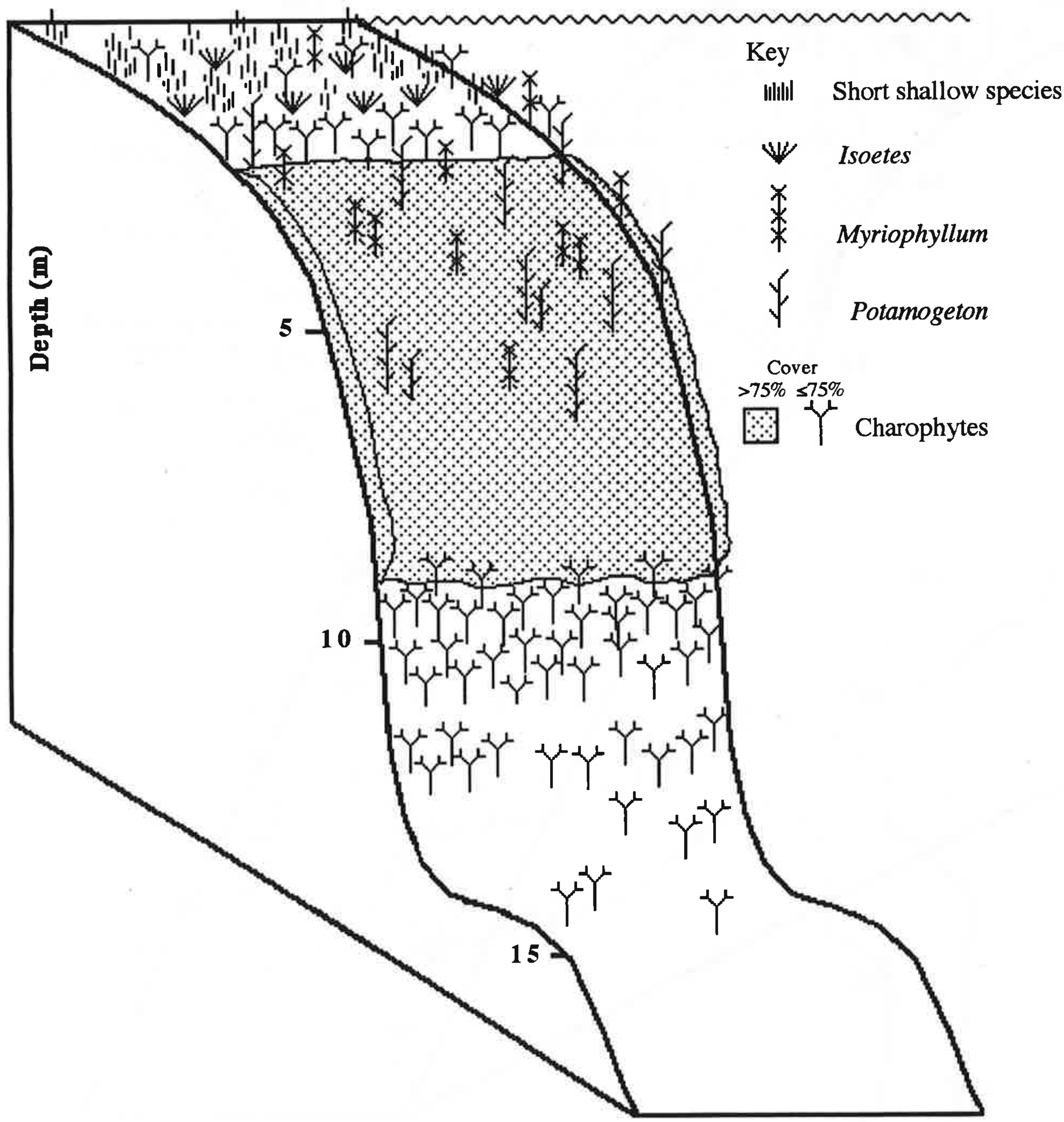


Figure 6. A stylised illustration of the submerged vegetation of Lake Dispute. Note plant heights are not to scale.

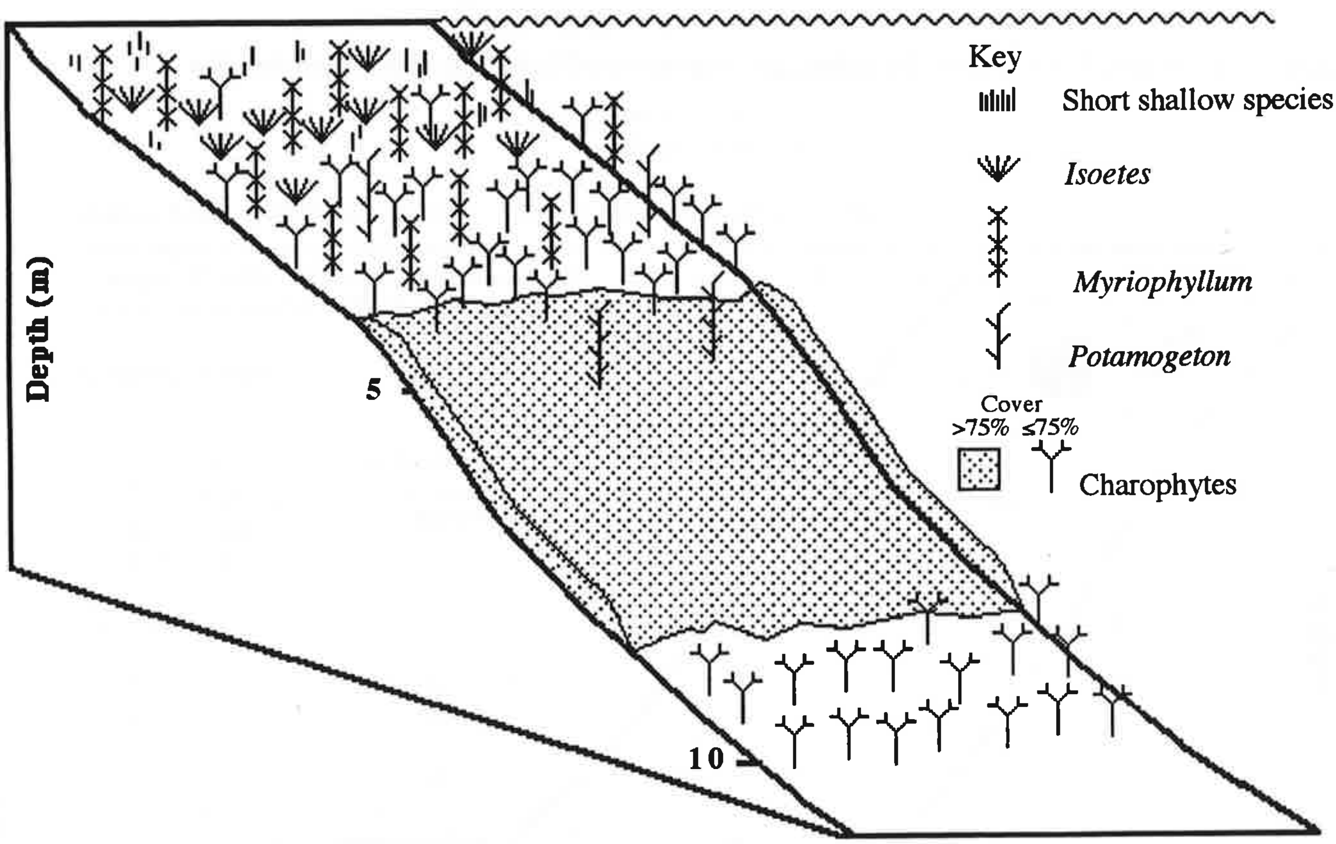
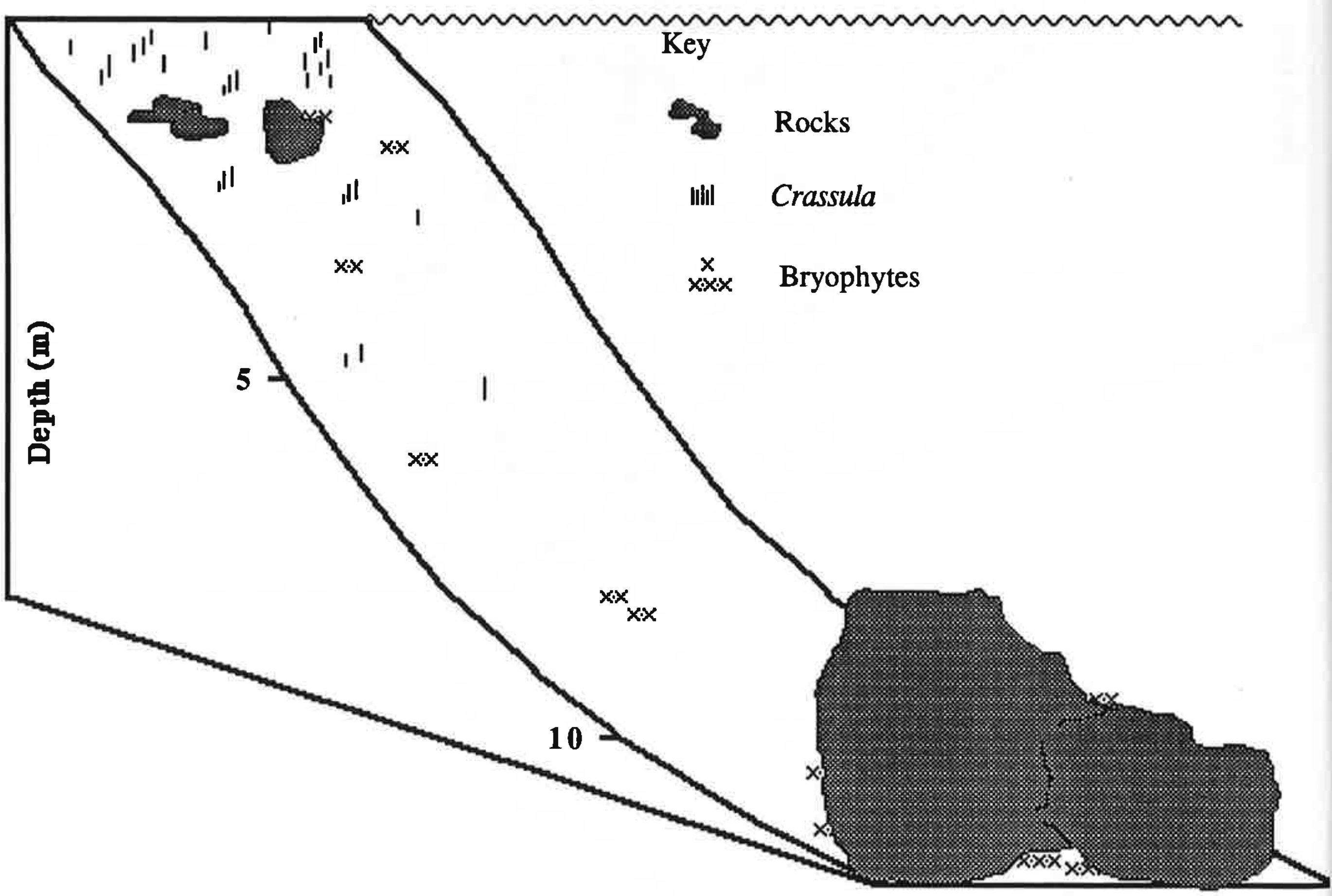


Figure 7. A stylised illustration of the submerged vegetation of Lake Alta. Note plant heights are not to scale.



ANNEX 1: Phytoplankton and selected benthic algal samples.

Identifications of Freshwater Algae from South Island lake samples
collected by members of the former Aquatic Plant Group, MAFTech, Ruakura,
(now Ecosystems Division, NIWAR)
during January - February 1992

Vivienne Cassie Cooper
Landcare Research

Lake Alta 1860 m. above S.L. in Remarkables Range.

Sample 1) a,b,c. Phytoplankton net tow. Coll. R. Wells, R. Hoetjes.
Diatom dominated. Much detritus. Many zooplankters.

Chlorophyceae

	Abundance, 1-5 scale
Cosmarium sp. cf. *tuddalense* Strom.	1
Pleurotaenium sp. cf. *minutum* (Ralfs) Delp.	1
Spirogyra sp.	1
Staurastrum sp.	1

Bacillariophyceae

Achnanthes lanceolata (Breb.) Grunow	1
Achnanthes oblongella Oestrup	1
Amphora sp.	1
Cyclotella stelligera Cleve et Grunow	3-4
Diploneis oblongella (Näegeli) Cleve-Euler	1
Epithemia adnata (Kütz.)Brebisson	1
Fragilaria (= Staurosirella) pinnata Ehrenberg	2
Fragilaria (= Synedra) tabulata (Kütz.) Lange-Bertalot (marine)	1
Frustulia sp. cf. *vulgaris* (Thwaites) De Toni	1
Gomphonema acuminatum Ehrenberg	1
Navicula sp. cf. *radiosa* Kützing	2
Navicula sp (parallel striae)	1
Neidium sp. (or Navicula)	rare
Nitzschia (2 spp.)	1-2
Pinnularia gibba Ehrenberg (v. large, +280 mm)	3
Pinnularia microstauron (Ehr.) Cleve	2
Pinnularia viridis (Nitzsch) Ehrenberg (v. large, +180mm)	3
Stauroneis sp. cf. *anceps*	1
Surirella sp. cf. *angusta*	1

Note: Disintegrated dinoflagellate cells indicated a previous occurrence of this group.

V.C. Herbarium No.3534 a, b, c.

Lake Alta

Sample 1) d,e,f. Periphyton (around moss).
3 samples, hand-collected by divers.

Cyanobacteria

Nostoc microscopicum Carmichael (tiny globules)	2
Scytonema mirabile (Dillw.) Bornet	5
+ epiphytic *Characium* and *Eunotia* spp.	

Bacillariophyceae

Achnanthes minutissima Kützing	1
Amphora sp.	1
Cyclotella sp. (probably *stelligera*)	2
Cymbella 2 spp.	1-2
Diatoma mesodon (Ehr.) Kützing (long chains)	2
Eunotia sp. (long chains)	2
Epithemia sorex Kützing	1
Gomphonema acuminatum Ehrenberg	1
Gomphonema sp. cf. *truncatum*	rare
Frustulia cf. *rhomboides* (Ehr.) De Toni	1
Navicula sp.	2
Navicula sp. cf. *striolata* (Grunow) Lange-Bertalot	rare
Nitzschia 2 spp.	1-2
(Signs of sexually reproducing cells, rarely observed in natural populations).	
Pinnularia spp.	3
Stephanodiscus sp.	1
Surirella sp.	1

Chlorophyceae

Cosmarium sp. (small)	1
Pediastrum sp. (cf *Boryanum*)	rare
Spirogyra sp. (no epiphytes. 6-7 spiral turns)	1
Mougeotia sp. (short cells, thick walls)	1
Oedogonium sp. (with epiphytic *Gomphomena* on stalks)	1

Note: Blue-green filaments dominated these samples. Diatoms were the most widely represented group of micro-algae. Only the epiphytic diatoms had healthy plastids - presumably because they would be better able to receive light.

V.C. Herbarium No. 3534 d, e, f.

Lake Wakatipu **Shallow end. Glenorchy.**

Phytoplankton net tow vertical haul through 10 m on a very rough day. Coll. C. Tanner, J. Clayton. In direct path of silt-laden water from Rivers Dart and Rees. River conditions, eliminating mosses, etc. Visibility poor, Secchi disc down to 4 m.

Sample 2) a, b. Sparse in number of cells and species. Dominated by desmids and chlorococcalean greens.

Chlorophyceae

**Eutetramorus planktonicus* (Korsch.) Bourrelly	2
Staurastrum johnsonii var. *altius* Fritsch et Rich	2-3
Staruastrum limneticum Schmidle var. *aculeatum* Lemmermann	4

Chrysophyceae

Dinobryon divergens Imhof var. *schauinslandii* (Lemm.) Brunnthaler (Mainly dead loricas)	2

Bacillariophyceae

Aulacoseira sp. cf. *ambigua* (long cells)	1
+*Cyclotella stelligera* Cleve et Grunow (in chains, separated by mucilginous threads)	2
Fragilaria ulna (Nitzsch) Lange-Bertalot (=*Synedra ulna* (Nitzsch) Ehr.)	1

V.C. Herbarium No. 3535 a, b.

Note: * *Eutetramorus planktonicus* is a tentative identification only. According to G. M. Smith (Reference in Bourrelly 1966) *Eutetramorus* is only a stage in division of *Sphaerocystis schroeteri.*

+ *Cyclotella* chains have not been observed elsewhere in my freshwater samples. A similar organization occurs frequently in marine species of *Thalassiosira.* Lemmermann (1900) identified *Cyclotella comta* from pools and puddles at the Glenorchy end of Lake Wakatipu. Under SEM the cells resemble *Cyclotella radiosa* (Grunow) Lemmermann.

***Lake Wakatipu* Mid-lake near Kingston. Kingston Arm.**

Phytoplankton vertical net haul. Coll. C. Tanner. Visibility very good. Secchi disc visible down to 16 m. Bryophytes down to 57 m.
Sample 3) a, b.

Chlorophyceae

Actinotaenium sp.	1
Cosmarium sp.	1
**Eutetremorus planktonicus* (Korsch.) Bourrelly	3
Staurastrum limneticum var. *aculeatum* Lemmermann	3
Staurastrum johnsonii var. *altius* Fritsch et Rich	2
Nephrocytium sp. cf. *agardhianum*	1

Bacillariophyceae

Anomoeoneis vitrea (Grunow) Ross	1
Anomoeoneis styriaca (Grunow) Hustedt	1
Asterionella formosa Hassall	rare
Aulacoseira sp. cf. Italica	2
Aulacoseira sp. cf. *ambigua*	2
Cyclotella sp. (in chains)	4
Cyclotella sp. cf. *radiosa*	1
Cymbella sp. cf. *tumida*	1
Fragilaria (=*Synedra*) *ulna* (Fritsch) Lange-Bertalot	1
Fragilaria (=*Synedra*) *tabulata* (Kütz) Lange-Bertalot (marine)	

Dinophyceae

Peridinium sp. (dead, eroded thecae)	1

Chrysophyceae

Dinobryon cylindricum Imhof (dead loricas)	1

V.C. Herbarium No. 3536 a, b.

Note: *If this is *Eutetremorus*, cells and colonies were encapsulated in spheres of mucilage, as if under stress.
Cell composition of each half of this pooled sample was different.
Species tended to sink at different rates?

Lake Wakatipu **Mid-lake near Kingston. Kingston Arm.**

Sample 4) a. Periphyton.
Sample 4) b. Sediments. Collected by divers.
Both 4a and 4b consisted almost entirely of diatoms, except for tangles of *Oscillatoria*, especially on the sediments.

Bacillariophyceae	4a	4b
Achnanthes sp.	1	1
Aulacoseira crenulata (Ehr.) Thwaites	1	1
Aulacoseira italica (Ehr.) Simonson	2	2
Aulacoseira spp. *italica* and *ambigua?*	5	-
**Aulacoseira* sp. cf. *pyxis* (O. Müll.) Simonsen	1	-
Cocconeis placentula Ehr.	-	2
Diatoma mesodon (Ehr.) Kützing	2	-
Diatoma mesodon (Ehr.) Kützing		1
Diploneis elliptica Kützing		1
Epithemia sorex Kützing	-	1
Fragilaria (=*Synedra*) *ulna*	-	2
Fragilaria sp. (small cells, in chains)	-	2
Cymbella 2 spp.	1	3
Frustulia rhomboides (Ehr.) De Toni	1	1
Navicula sp. cf. *radiosa*	-	2
Nitzschia sp. (long, straight)	1	2
Rhopalodia sp. cf. novae-zeelandiae	-	3
Cyanobacteria		
Oscillatoria 2 spp. (very long filaments)	2	5
Chlorophyceae		
Desmidium sp.	1	-
Staurastrum limneticum Schmidle	1	-

V.C. Herbarium No. 3437, a, b.

Note: **Aulacoseira pyxis* (O. Muell.) Simonsen, identified by K. Thomasson (1981) from Lake Wakatipu and other South Island lakes (4), was described by Skuja (1976) from Lake Taupo, but is not mentioned by Krammer and Lange-Bertalot (1991) in their update of Pascher's Süsswasserflora Mitteleuropas. Confirmation of *A. pyxis* is needed from SEM studies.

Lake Moke.

A fairly large lake, 840 m above sealevel in mountains behind Queenstown. Secchi disc visible to 9.5 - 10 m. Phytoplankton net tow. Coll. R. Wells. Rich aquatic vegetation. Tussock catchment, grazed by sheep.
Sample 5) a, b, c.
Green algae predominate in numbers of cells and species.

Chlorophyceae

Cosmarium botrytis Menegh.	1
Eudorina elegans Ehr.	5
Eutetremorus planktonicus (Korsch.) Bourrelly	3
Oocystis sp. cf. *marssonii* Lemm.	3
**Pseudoquadrigula lacustris* (Chod.) G M Smith	5
Raphidocelis mucosus (Korsch.) Kom.	1
(= *Kirchneriella lunaris* var. *dianae* Bohlin)	
Staurastrum johnsonii var. *altius* Fritsch et Rich	1
Volvox sp. (no visible cell connections)	1

Chrysophyceae

Dinobryon sp. (mainly dead loricas)	1

Bacillariophyceae

Aulacoseira italica (Ehr.) Simonsen	2
Aulacoseira sp. (dead)	1
Cyclotella sp.	2
Cyclotella radiosa (Grunow) Lemmermann	1
Cocconeis placentula Ehrenberg	1
Cyclostephanos (=*Stephanodiscus dubius* (Fricke) Round	1
Diploneis elliptica (Kütz.) Cleve	1
+*Fragilaria crotonensis* Kitton (dead chain)	1
Navicula sp. cf. *radiosa* (dead)	1
Nitzschia sp. (long, straight, dead)	1
Tabellaria flocculosa (Roth) Kützing (dead)	1

V.C. Herbarium No. 3538 a, b.

Note: * The elongated single cells in parallel groups look like *Pseudo-quadrigula lacustris* as figured by Komarek & Fott (1983).
+ *Fragilaria crotonensis*, though dead in this sample, has obviously been present at an earlier date. According to Vollenweider, this represents a change to eutrophy. Abundant green algae point to a more eutrophic state than in the previous lakes.

Lake Dispute. **29.1.92 Coll. R. Wells**

This is a managed lake. A *Typha* reed bed has been sprayed and the level has been raised by DoC. There is a tussock catchment, with low intensity farming. Many swans and wild fowl are present. A layer of turbid water exists down to 8 m; water is clear below. The lake has been stocked with game fish. Access is difficult. Drainage is into Lake Wakatipu.

Sample 7) a, b. A phytoplankton net haul contained a rich and varied green algal and diatom flora.

Chlorophyceae

Botryococcus braunii Kütz.	3
Cosmarium sp. (extra large, 237 mm long)	rare
Eutetremorus planktonicus (See note for Lake Wanaka)	4
Sphaerocystis schroeteri Chodat	5
Staurastrum johnsonii var. *altius* Fritsch et Rich	3
Staurastrum limneticum Schmidle	1
Volvox sp. (Very large spheres, up to 300mm diameter, with no visible cell connections)	1

Dinophyceae

Peridinium sp. (large brown cells)	3

Bacillariophyceae

Amphora sp. cf. *ovalis*	1
Aulacoseira italica (Ehr.) Simonsen	1
Aulacoseira valida (Grunow) Krammer	1
Cocconeis placentula var. *euglypta* Ehrenberg	1
Cyclotella radiosa (Grunow) Lemmermann	2
Cyclotella stelligera Cleve et Grunow	1
Diploneis elliptica Kützing	3
Epithemia sorex Kützing	1
Eunotia diodon Ehr. (short chains, small cells)	1
Fragilaria ulna var.	1
Fragilaria sp. cf. *construens* f. *venter* (Ehr.) Hustedt	1
Melosira varians Agardh	1
Navicula sp. cf. *rhynchocephala*	1
Nitzschia sp. (long, straight)	1
Pinnularia gibba Ehrenberg (very large)	1
**Surirella contorta* Kitton	1
Surirella sp. cf. *angusta*	rare
Tabellaria flocculosa (dead)	rare

Cyanobacteria

+*Anabaena solitaria* Klebahn	1

V.C. Herbarium No. 3540. a, b.

Note: **Surirella contorta*, common in central North Island lakes, and in freshwater fossil deposits, has not been recorded in the South Island before, although K. Card, an SEM operator, has produced SEM photos of it from Bank Peninsula (V. Lovis, pers comm.)
+*Anabaena solitaria* was found by Thomasson (1981) only in Lake Middleton.

Lake Lochnagar. **c1000m above sealevel. Coll. R. Wells.**

Mountainous terrain. Divers dropped in by helicopter. Lake area: 2.5 sq. km. in a deep valley blocked by a landslide. Lake visibility extremely clear - Secchi disc visible to 20 m. Higher plants down to 6 m: *Potamogeton, Myriophyllum, Nitella hookeri* var. *tricellularis*. Bryophytes at 30 - 55 m. Several species of zooplankton.

Dinobryon colonies dominant, but mostly dead or dying.

Sample 8) a, b, c. Phytoplankton net tow. Very sparse plankton.

Chrysophyceae

Dinobryon cylindricum Imhof (Mainly dead colonies)	5

Bacillariophyceae

Achnanthes sp. cf. *oblongella*	1
Cyclotella sp.	1
Cyclostephanos dubius (Fricke) Round	1
Epithemia sp. cf. *adnata*	1
Fragilaria angustissima group	5
(= *Synedra acus* var. *radians* (Kütz.)Hustedt)	
Fragilaria leptostauron (Ehr.) Hustedt	1
Navicula sp. cf. *radiosa*	1

Chlorophyceae

Cosmarium sp.	1
Oocystis sp. (2-4 celled colonies)	2
Staurodesmus sp.	1
Mougeotia sp. (very narrow filament, almost one quarter the usual diameter)	

Dinophyceae

empty theca of *Peridinium*	rare
encysted gymnodinioid cell	rare

V.C. Herbarium No. 3541, a,b,c. (all combined into one tube).

Note: Krammer & Lange-Bertalot (1991) have transferred *Synedra* to *Fragilaria*. Duthie & Stout (1986) recorded *Synedra acus* var. *angustissima* Grunow from the Waitaki Hydro-electric lakes, along with numerous other taxa.

Acknowledgements:

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Appendix 1. Bryophyte species recorded from Lake Wakatipu (? = uncertain record).

Deep-water bryophytes

Mosses

Achrophyllum dentatum (Hook. f. & Wils.) Vitt & Crosby

Bryum (billardierei?) Schwaegr.

Bryum (laevigatum?) Hook. f. & Wils.

Bryum (pseudotriquetrum?) (Hedw.) Schwaeger.

Campylium polygamum (B. S. G) C. Jens.

Distichophyllum microcarpum (Hedw.) Mitt.

Distichophyllum pulchellum (Hampe ex C. Muell.) Mitt.

Fissidens adianthoides Hedw.

Fissidens rigidulus Hook. f. & Wils.

Fissidens sp.

Hypnodendron sp.

Hypnodendron sp.

Racopilium convolutaceum (C. Muell.) Reichdt.

Thuidium (sparsum?)

Liverworts

Anura sp. ?

Heteroscyphus triacanthus (Hooker F. & Taylor) Schiffner

Riccardia sp. ?

Symphyogyna sp.

Shallow-water bryophytes

Mosses

Bryum (billardierei) Schwaegr.

Bryum (laevigatum?) Hook. f. & Wils.

Campylopus sp. ?

Ditrichum sp.

Fissidens adianthoides Hedw.

Fissidens asplenioides Hedw.

Fissidens rigidulus Hook. f. & Wils.

Fissidens tenellus Hook. f. & Wils.

Hypnodendron sp.

Liverworts

Unidentified thallose and leafy species

Plate 1. A dense sward of *Isoetes alpinus* at 6 m depth in Lake Wakatipu, with a low cover of *Potamogeton cheesemanii* present.

Plate 2. Growths of *Myriophyllum triphyllum* at 2.5 m depth in Lake Wakatipu form an open cover above short, shallow-water species, mainly *Isoetes alpinus*.

Plate 3. *Potamogeton cheesemanii* forming low cover growths above mixed charophyte species at approximately 8 m depth in Lake Wakatipu.

Plate 4. Mixed charophyte species were the dominant vegetation at 9 m in Lake Wakatipu. A dense sward of *Isoetes alpinus* is seen as a dark band in the background.

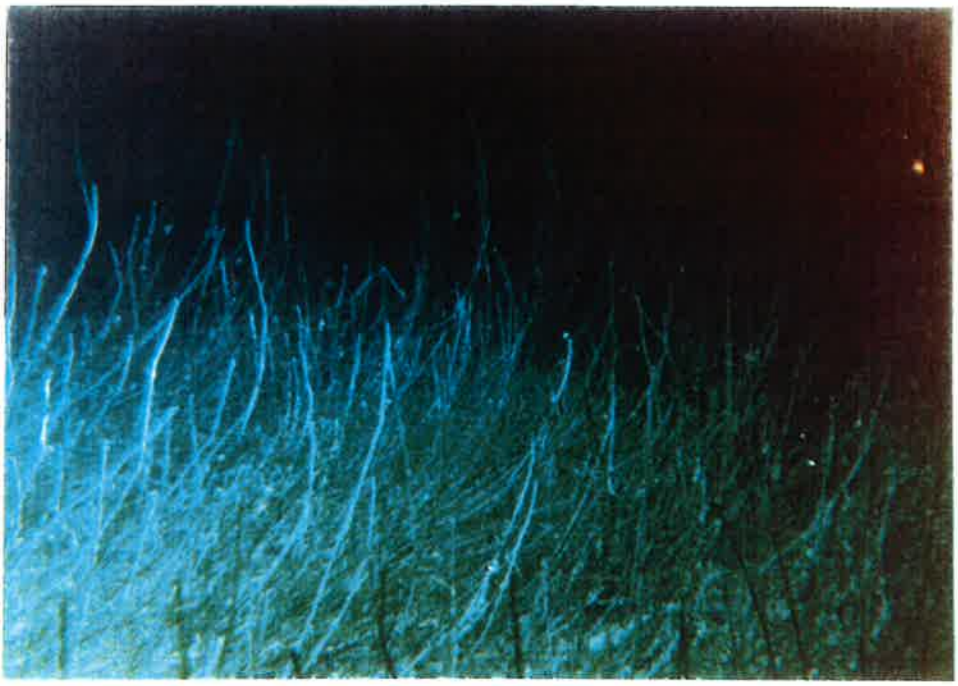

Plate 5. High cover meadows of *Nitella hookeri* var. *tricellularis* at 30 m depth in Lake Wakatipu.

Plate 6. Clumps of deep-water bryophytes lie beneath *Nitella hookeri* var. *tricellularis* at c. 35 m depth in Lake Wakatipu.

Plate 7. Deep-water bryophytes c. 45 m depth in Lake Wakatipu, in association with sparse plants of *Nitella hookeri* var. *tricellularis.*

Plate 8. Lochnagar, a steep sided alpine lake, is viewed from the south-east. A small, shallow (c. 5 m) tarn is seen in the foreground.

Plate 9. Sparse plants of predominantly *Potamogeton cheesemanii* at 3 m depth in Lochnagar.

Plate 10. A dense, monospecific bed of *Nitella hookeri* var. *tricellularis* at 15 m depth at the south-east end of Lochnagar.