Vegetation and water level regime at Waituna Lagoon, Southland

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CONTENTS

Abstract

Waituna Wetlands Scientific Reserve is a Wetland of International Importance. Waituna Lagoon, c. 10 x 3 km, is a relatively shallow coastal lagoon, with a bed of quartz gravels and fresh to slightly brackish water, which is normally closed to the sea. Like several other coastal lagoons of its type, it is now subject to a lower-than-natural water fluctuation regime, regular openings being made, especially to maintain drainage of adjacent farmland.

Shore transects, surveyed in relation to water levels, show a generalised sequence of vegetation types from aquatic beds of *Ruppia* and milfoil, to turf of semi-aquatic prostrate herbs, to *Leptocarpus* rushland, to manuka scrub, plus localised sward communities, and gravel beach colonists.

Anecdotal evidence, air photographs, and comparisons of relative plant elevation limits all indicate that *Leptocarpus* rushland has increased in extent, in response to the lowered water regime and to increased sedimentation. A corresponding downslope migration in the woody vegetation zone (including the weedy gorse) has apparently not yet occurred.

Although native plants still dominate the shore vegetation, there remains an ongoing need to maintain control of gorse infestations and vigilance against aquatic weed invasion and the threat of fire. It is not clear whether the present shore vegetation is yet in equilibrium with the current water regime, nor how it might further respond to ongoing inputs of sediment and nutrients from intensified agriculture in the catchments. Further basic hydrological data are required in order to better understand how the lagoon system operates. Whether lagoon levels should be managed to more closely match the natural regime is a question which requires further discussion and inputs from other parties and disciplines. A critical consideration for the management of Waituna, and other coastal lagoons, relates to how such systems will respond to continuing rising sea level.

1. Introduction

The need for criteria to maintain conservation values of freshwater coastal lagoons subject to periodic closure from the sea was identified in the DoC Research Agenda for 1993/94. In many coastal lagoons an unnatural water regime is now imposed by artificial opening of an outlet channel, usually initiated by the perceived drainage needs for adjacent lands.

Waituna Lagoon, on the Southland coast, is one such site for which several agencies, including DoC, have urged the need for biological research input into management guidelines for lagoon margin habitats. The Waituna Wetlands Scientific Reserve is designated as a Wetland of International Importance.

The botanical study described in this report concentrates on describing the flora and vegetation types within and around the shores of Waituna Lagoon, and interpreting zonation patterns in relation to present and previous water fluctuation regimes. This study is complementary to coastal process investigations by R.M. Kirk (University of Canterbury) and G.A. Lauder (Department of Conservation).

2. Background

2.1 WAITUNA LAGOON SETTING AND HISTORY

Waituna Lagoon – or Lake Waituna in local parlance – forms part of the vast "Seaward Moss" or Awarua Bog, occupying the coastal, southeastern portion of the Awarua Plain in Southland (Kelly 1968; Department of Lands and Survey 1984). This low-lying plain is underlain by quartz-rich gravels, capped with peat, and is variously clothed with bog, tarns, scrub, and native forest remnants. Where Awarua Bog meets the sea it merges with salt marshes fringing Bluff Harbour and Awarua Bay, with the parallel array of gravelly beach ridges of Tiwai Point, and with sandy beaches and dunes towards the Mataura River mouth at the eastern end of Toetoes Bay. Roughly central in this broad picture is Waituna Lagoon, impounded by a shingle coastal storm ridge, fed by peat-stained creeks, and stirred by the westerly and southerly gales that whip across from Foveaux Strait and the Southern Ocean.

Waituna Lagoon is almost 10 km long on its east–west axis, and up to about 3 km wide, but with a complexity of bays, peaty peninsulas, islets, and shallow gravel bars and beds. Judging from its name (Waituna = eel water) the lagoon must have offered this key food source to Maori, and in the last century and a half the area has offered other resources and challenges to those trying to make a living or sample a lifestyle. In their book *Looking Back,* Raymond Waghorn and Ross Thomson (1989) tell us that the 1860s road from Bluff to the goldfields of Central Otago actually found its easiest route past the west side of Lake Waituna and across Waituna Creek at its mouth. Gold was found there, too, and there was a gold dredge, apparently at the west end, fuelled from a large bush reserve on the north side of the lagoon. Sawmills also operated to the north of Waituna Lagoon, although some were lost to the big 1907 fire, one of many fires that have swept the area both before and since then.

Farming saw small beginnings in this most inhospitable of habitats, notably by the Hansen family, who farmed land on both north and seaward sides of the lagoon for almost 80 years from the 1870s. During the Great Depression, 1932-1935, unemployment camp workers did their bit towards farm development in the area, including the clearing of timber and scrub from bed and banks of Waituna Creek. Concerted farm development to the north and east of Waituna Lagoon commenced in the early 1950s on blocks of land acquired, broken-in, drained, ploughed, and fertilised by the Department of Lands and Survey. In the late 1960s and early 1970s Land Development Encouragement Loans saw a further intensification of topdressing and drainage in the Waituna Lagoon catchment (Raymond Waghorn, Lake Waituna, personal communication).

Waituna Lagoon has been popular for trout fishing, duck-shooting, and boating since the turn of the century. Camps and huts have been part of the Waituna way of life in that time, and the desire to improve the fishing conditions has been one of the motivations for periodic opening of the lagoon to the sea.

Recognition of the biological conservation values of Waituna Lagoon and its surrounds resulted in gazettal, originally in 1971, for wetland management purposes, and then in 1983 as a Scientific Reserve.

2.2 LAGOON GEOMORPHOLOGY AND CATCHMENT

Kirk & Lauder (1994) distinguish and name two types of South Island coastal lagoon: a "river mouth" or "Hapua-type", and a "coastal lake" which they name "Waituna-type", Waituna Lagoon being a quintessential example. Other striking examples of the Waituna-type are Waihora/Lake Ellesmere, Wairau Lagoon, Washdyke Lagoon, and Wainono Lagoon. Among the observations made by Kirk and Lauder on Waituna Lagoon and the Waituna-type, the following summary points are particularly relevant towards our understanding of vegetation processes.

Lagoons of this type are developed landwards of barrier beaches formed of coarse-grained sediments. The coast at Waituna Lagoon is undergoing long-term erosion, adjacent to a "hinge-point" around which the coastline is rotating to face dominant swell directions, and resulting in the lagoon area being very much less than it was even a few thousand years ago. Waituna-type lagoons are normally closed to the sea, and they are shallow, generally less than 3 m deep. Freshwater inflows are generally low to moderate for this class of lagoon. Kirk and Lauder suggest that sediment yields from contributing catchments are also relatively low, and dominated by fine sediments (suspension load), by wash load (e.g. organics), and dissolved load (chemicals). Waituna-type lagoons are very sensitive to changes in catchment hydrology and sediment delivery.

The three catchments contributing to Waituna Lagoon are briefly described in a Southland Regional Council report to the Department of Conservation (McCraw 1992). In summary they are: Waituna Creek catchment (12 555 ha, a long narrow catchment having a fall of only 61 m over its entire 50 km length); Moffats Creek catchment (1700 ha); and Currans Creek catchment (having the largest frontage to the lagoon, our estimate of area being 5700 ha).

2.3 LAGOON OPENINGS AND LEVELS

Openings in the barrier beaches of Waituna-type lagoons are created by accumulated head and scouring by fresh to brackish lagoon water, rather than by breaching under wave and tidal action. Under pre-European conditions most Waituna-type lagoons had higher than present average water levels and wider ranges of water levels. A history of artificial openings has increased the frequency of openings and the proportion of time for which the lagoons are open to the sea, and lowered their levels. In turn, this has greatly reduced their areas, water volumes, and the energetics of wind-driven processes such as waves, seiches, and currents in the lagoons (Kirk & Lauder 1994).

Waghorn & Thomson (1989) record some of the early history of lagoon openings:

> "In early times the lake drained naturally, letting itself out at the east end. When the water level got high, strong westerlies pushed the water to Talls [east] end and the water burst through the shingle bar into the sea. Then gravel would gradually drift across the outlet and block it again."

> "It is thought the lake was first let out by men with shovels in 1908. The idea was to start digging on the lake side of the spit with a low tide expected in the mid-afternoon. If conditions were right they would get the water flowing about midday and then widen the lake side to get a better head. Once the current started running, the rush of water increased at a dramatic rate and it was dangerous to be anywhere near the edge of the cut, so quickly did the banks wash away."

> "One year after the Hansen family had settled on the gravel spit, the break-out worked its way up towards their house, taking great pieces of land out to sea.... After that experience the lake was usually let out at Walker's Bay with horse, scoop and shovels. Attempts to dig a channel in Hansens' Bay were not successful.... On one occasion in the 1930s the lake was opened at both ends at the same time."

"Letting out the lake was sometimes easy – on one occasion when the water level was high 12 men with shovels opened it up in two hours. But if the sea was rough the diggers found the task difficult or impossible."

Prior to 1958, opening of the lagoon was organised by fishermen. Between 1958 and 1968 openings were arranged between local farmers and the Department of Lands and Survey. In April 1969 the Lake Waituna Control Association was formed to organise the openings on behalf of the Southland Catchment Board and local farmers.

Nowadays the opening of an outlet to release lagoon waters to the sea is done primarily to alleviate flooding of low-lying farmland and to ensure continued drainage outflows for adjacent land. An opening is ideally made at a time when spring tides coincide with the lack of a heavy sea. If these conditions are not met, an opening attempt may be delayed by one or more months, during which time a spell of prolonged rain can bring the lagoon level considerably higher. This happened in mid-1994, when the lagoon reached a level of 3.45 m, inundating surrounding land, and indeed covering the Currans Creek bridge to above the handrail level.

The following account of the July 1994 lagoon opening is based on a video shown to P.N. Johnson by Raymond Waghorn, and his commentary. A bulldozer is taken along the coastal beach from the east end. Initial dozing is parallel to the coast, to reduce the height of the beach ridge on the lagoon side of the crest. A channel of dozer-blade width is then cut towards the sea, the initial flow being relatively shallow until deepened, laterally, at the lagoon outlet, and then by a final push with the blade, right down the channel to the sea, whereupon the machine must exit to the side without stopping and before outpouring gravels accumulate against and within the inshore track.

In July 1994 the opening was achieved about 3 p.m., at high tide. Falling tide enables the channel to erode progressively deeper as brown lagoon water pours out to the ocean. By nightfall, 3 hours later, the channel was some 40–50 m wide, the water flow steeply convex in section, the central wall of water some 10 feet higher than at the margins, and producing a standing wave at the sea edge, some 40 feet high. By 8 a.m. next morning, the lagoon had effectively emptied, to a situation where the usual high tide fluctuation of about a foot was evident at Currans Creek mouth.

Kirk & Lauder (1994) point out that there is a very poor water level record for any of the Waituna-type lagoons. For Waituna Lagoon itself the record is based on a single staff board, not in the main water body (it is at the Currans Creek bridge, near the eastern end of the lagoon), and the elevation of which has never been reliably established and recorded.

Nevertheless, a record has been kept of the recorded levels at this site at the time of each lake opening since 1972, by the Lake Waituna Control Association. These data, along with a record of how long the lagoon has remained open on each occasion, are tabled in the Appendices, Section 10.1. The highest level recorded since 1972 (apparently the highest in the last 40 years) is 3.45 m, in July 1994. The mean high level, from the records at the time of the 32 openings since 1972, is 2.4 m. In July 1995, 19 days after an opening, we observed the staff gauge level to be 0.63 m, a level that is apparently typical of low lagoon levels achieved after an opening. However, this level cannot be taken as representing a "absolute low", partly because of tidal influence. According to Raymond Waghorn (personal communication), tides cause the level to fluctuate "about a foot" when the lagoon is open to the sea. He also notes that a big wind will cause 2–3 feet of fluctuation, and that when the lagoon is closed, and even during calm conditions, fluctuation can be observed as a result of a seiche.

The present protocol for lagoon opening is stated in Resource Consent A784, granted by the Southland Regional Council in September 1993, for a period of five years. When the lagoon water level reaches 2.0 m, as measured on the gauge board attached to the Waghorn's Road Bridge, the Lake Waituna Control Association notifies the Regional Council and the Regional Conservator, Department of Conservation, that opening of the lagoon is imminent. The lagoon may be opened to the sea at about map reference F47/ 718933, when the water level reaches 2.2 m.

2.4 PREVIOUS BOTANICAL STUDIES

Vegetation of wetlands on the Awarua Plain has been briefly described in several early accounts. Cranwell & von Post (1936) and Cranwell (1953) describe bog vegetation in the context of their pioneering studies using pollen analysis to interpret vegetation history. Crosby Smith (1927) provides short descriptions of the swamp and bog vegetation types and a list of vascular plant species. Martin (1960) adds an account of the cryptogamic plants. Peatland vegetation to the west and east of Waituna Lagoon has been described in reports by Hubbard (1974) and Johnson (1976).

The vegetation and flora of Waituna lagoon edges, adjacent peatland, and sea shore, were described by Kelly (1968) in the context of his assessment of and recommendations for a representative reserve. A further brief botanical description of the Waituna Lagoon Wetlands Management Reserve was done in 1981, as part of the Biological Survey of Southland Reserves (Allen *et al*. 1989).

3. Objectives

1. To determine the relationship of shore vegetation zones and profiles to water level regime and site factors at Waituna Lagoon, from surveyed profiles and quantitative sampling of lagoon shores at representative sites.
2. To compare present with past water fluctuation patterns at Waituna Lagoon, by documenting historical records, and by seeking evidence of earlier water regimes from shore and vegetation features.
3. To interpret vegetation zonation patterns by comparison of key vegetation boundaries with other freshwater and saltwater systems, especially with inland southern lakes, Awarua Bay (fully tidal, nearby), and other South Island lagoons, both freshwater and brackish.
4. To assess the extent to which invasion by scrub weeds of Waituna Lagoon margins can be ascribed to lowered mean and peak water levels, and the extent to which marginal vegetation, especially *Leptocarpus* rushland, has adjusted to the imposed regime.
5. To develop guidelines for water level management to maintain or enhance conservation values, and advise DoC accordingly.
6. To provide botanical information to assist DoC in its roles of promoting understanding of and respect for these wetland systems.

4. Methods

A preliminary inspection of the eastern shores of Waituna Lagoon was undertaken on 3 February 1995, and the bulk of field work carried out from 3 to 9 April 1995. A further visit was made to inspect the lagoon at a time of low level on 31 July 1995. Access around the lagoon was by boat. Study sites were selected which appeared to represent the range of variation of shore types and of vegetation sequences. Nine transects were surveyed using a tripod-mounted surveyor's level and graduated staff, in order to gain an accurate measure of ground profiles at right angles to the shore. The datum for each survey was the lagoon level noted on the Currans Creek staff gauge on each day of study, or in some cases an interpolated level on those days when a change in lagoon level was apparent between morning and evening. Aquatic portions of each transect were profiled with reference to a tape extended offshore by wading and by boat.

Plant height and estimated percentage cover were estimated within contiguous 2 x 2 m plots along each transect. For low-growing turf vegetation, plant cover was recorded within contiguous plots using a 0.5 x 0.5 m gridded quadrat frame. Vertical range of plant species and of vegetation types was determined by later reference to the surveyed profiles.

The sites of shore vegetation transects are shown in Fig. 1. Additional observations were made at numerous other locations around most of the lagoon. An attempt was made to record all vascular plant species, both native and naturalised, occurring within the range of lagoon fluctuation.

Vertical air photos were examined by stereoscope to determine what vegetation changes might be apparent over time, using all the air photo runs available according to the Department of Survey and Land Information office in Invercargill.

Discussions were held with Department of Conservation staff in Invercargill, and with farmers and other local people having knowledge of the history of Waituna Lagoon.

FIGURE 1. WAITUNA LAGOON, SOUTHLAND.

REDUCED FROM NZMS 260, MAPS E47 AND F47; GRID SQUARES 1 KM. NUMBERED CIRCLES SHOW LOCATION OF SHORE VEGETATION TRANSECTS. MAP REPRODUCTION APPROVAL BY LAND INFORMATION NZ MAP LICENCE 1991/42: CROWN COPYRIGHT RESERVED.

5. Results

5.1 LAGOON SHORES AND WATER

The lagoon bed is predominantly pea gravels of brown-stained quartz pebbles, forming a very gently sloping substrate, firm underfoot, around most of the lagoon perimeter, as well as extensive banks and bars within the lagoon. Sandy substrates occur in a few places, notably along the shore running northwest from the usual lagoon-opening site, a shore which is backed by low lines of old sand dunes. Some parts of the western shore have a shallow-water lagoon bed that has been eroded into peat, seemingly an extension of the onshore peatlands, laid down under a land environment rather than as organic matter accumulated under water.

Most deeper waters of the main lagoon also appear to have a gravelly bed, judged by the ready contact made with a 2 m metal stake, suggesting only a thin veneer of fine sediments. A greater accumulation of soft material was evident in deep water of sheltered embayments, where from beneath dense aquatic vegetation a probing oar will bring up soft organic debris, typically black, almost tarry in texture, but also partly fibrous.

The water of Waituna Lagoon has a clarity indicative of a low sediment load, but it is stained deep brown with humic substances from the adjoining peatlands and lowland catchments, such that the lake bed is generally not visible beyond a depth of about 0.5 m. At the time of study (April 1995), with the water level at around 1.25 m on the staff gauge, much of the lagoon appeared to be 2 m or less deep, as measured with a staff of this length from the boat. Deeper water was noted only in Walkers Bay.

Five water samples were collected for later analysis of salinity and pH. The sites, and results are as given in Table 1.

Salinity measurements indicate a clear gradient from almost fresh on the north side and in the main body of the lagoon, to a slight saltiness (2.3 parts per thousand), then 5.1 ppt in Walkers Bay. By comparison, sea water has a salinity of 35 ppt; Lake Ellesmere is 5-7 ppt.

Acidity shows a generally similar gradient between sites, the most acid sample (pH 5.3 at Currans Creek bridge) best reflecting the acid peat from which

TABLE 1. SALINITY AND pH OF WATER SAMPLES COLLECTED AROUND WAITUNA LAGOON.

Site	Map ref. (F47)	salinity (parts per thousand)	pH
Currans Creek bridge	772 956	0.9	5.3
Near Hansens Bay, transect 1	745 949	0.9	5.8
North shore at end of Moffats Road	702 963	1.1	5.6
East side of bay north of “opening”	723 944	2.3	5.9
Walkers Bay, transect 8	709 929	5.1	6.5

inflowing waters are derived, and the highest value (pH 6.5 in Walkers Bay) correlated with the slightly more saline water close behind the gravel storm beach.

5.2 FLORA

All plant species recorded are listed in the Appendices, Section 10.2, with an indication of their relative abundance. A total of 136 vascular plant species were recorded (98 native, 38 naturalised).

A grouping of the principal plant species (leaving aside those that are locally uncommon) into guilds is presented in the Appendices, Section 10.3, in an attempt to illustrate how the Waituna lagoon habitats contain plants that are otherwise typical of situations that are either more salty or more dry. An overall separation is made between resilient species (those which tend to permanently occupy sites regardless of changing local conditions) and colonist species (those which appear, usually soon after disturbance, and which are often abundant for a short time).

Most, but not all, of the colonists are naturalised species. Our classification into guilds indicates that only one species that can be regarded as a halophyte occurs at Waituna Lagoon, and only a handful of the common species are typical of brackish water; in other words Waituna Lagoon does not have much representation of plants that are typical of fully tidal estuaries. Instead, the resilient species of Waituna shore vegetation are either what we have termed "dual purpose" species (equally able to tolerate wholly salty or wholly freshwater environments), or else belong to a "freshwater wetland" guild.

Two plant taxa recorded at Waituna Lagoon are listed nationally as being under threat, both being classified in the threat category "Vulnerable" (Cameron *et al.* 1995). They are the grass *Deschampsia caespitosa* var. *macrantha*, which is relatively common at Waituna in damp swards, and a small sedge *Isolepis basilaris* found in silty turf vegetation.

5.3 VEGETATION

Aquatic vegetation

The following observations were all made from boat or shore, assisted by specimens gleaned at arm's length in water of maximum paddling depth and by those brought up from deeper water on the end of an oar. Diving studies would provide more information on vegetation of the relatively deeper waters, as well as on lagoon bed substrates. It is likely, however, that our observations have accounted for most of the aquatic flora, for the abundant aquatic debris cast up on the strand revealed no species additional to those observed growing in situ.

The four common variants of aquatic vegetation structure and composition, (relative to lagoon level 1.25 m, and illustrated by profiles in Fig. 2) are as follows:

FIGURE 2. WAITUNA LAGOON, PROFILES OF AQUATIC VEGETATION IN FOUR SITUATIONS.

A = SHALLOW WATER (10–30 CM DEPTH); **B** = MEDIUM DEPTH (50–60 CM); **C** = DEEP WATER (C. 2M DEPTH); **D** = SHALLOW BRACKISH WATER NEAR COASTAL BAR. LAGOON LEVEL = 1.25 M.

A. Shallow water (0.1–0.4 m deep) of most shores, exposed to wind and waves, and with a gravel or sometimes sand bed, typically have a sparse (to c. 20%) cover of *Ruppia polycarpa* and *Myriophyllum triphyllum*, as plants usually c. 10 cm tall. Additional species found in this zone, as very scattered creeping plants, are *Glossostigma elatinoides, Lilaeopsis novae-zelandiae, Mimulus repens*, and *Selliera radicans*.

B. At depths of 0.5 to 0.7 m in relatively sheltered sites the co-dominants (each c. 25% cover) are *Ruppia megacarpa*, *Myriophyllum triphyllum*, and a fine filamentous green alga which grows as masses upon and among the stems of the other plants.

C. In water of 1.5 to 2 m depth there are dense beds of *Ruppia megacarpa* and *Myriophyllum triphyllum*, often together, but *M. triphyllum* tends to be the more abundant species in sheltered bays and *R. megacarpa* is dominant almost alone in beds that are subject to a greater degree of wind and wave action in the main body of the lagoon.

D. At similar depth to (A) above, but in water that is more salty, notably in the southwest end of the lagoon behind the coastal storm beach, *Ruppia polycarpa* is still present, its rhizomes among the gravels, but two algae are the more prominent part of the vegetation, both growing as tufts that are firmly anchored to pebble surfaces. They are *Enteromorpha* sp., having pale green tubular ribbons, and a dense, fine, brownish, filamentous alga, *Bachelotia antillarum*.

During our studies in April 1995, *Ruppia megacarpa* was flowering abundantly, its remarkable long peduncles, white and thread-like, holding the flowers at the water surface, and later retracting to spiral coils as the fruits developed. The aptness of the common name horse's mane weed becomes especially obvious every time a massed chunk of stems and foliage has to be disentangled from the outboard motor propeller.

Being the commonest aquatics, *Ruppia megacarpa* and *Myriophyllum triphyllum* must constitute a principal source of herbage for waterfowl, especially the large populations of ducks and black swans. Most of the *M. triphyllum* biomass comprised stems, with relatively few leaves remaining attached, perhaps a result of bird grazing. These two common aquatics are also the main components of the abundant drift material cast upon lagoon shores, as strand lines on gravel beaches, and as a natural mulch among the *Leptocarpus*: the *Ruppia* debris as fine mats, and the dislodged *Myriophyllum* stems as entangled braided ropes.

Aquatic vegetation was observed also at a time of low water (0.63 m level), on 31 July 1995, 19 days after the lagoon had been opened to the sea. On the north shore, around the end of Moffat Road, a gently sloping gravel shore was exposed, as a band some 60 m wide, and with c.0.6 m vertical span from water level to the base of the *Leptocarpus* zone. Under these conditions, several additional features became apparent, features of the substrate, plant growth habit, and plant response to dewatering. The substrate – mainly gravels of smooth, water-worn quartz – is compact and firm to walk upon, and has a small sand component plus a scattered veneer of quartz pebbles and cobbles. Very slight undulations in the ground surface hold shallow puddles, nourished by seepage from the *Leptocarpus* and other vegetation zones upslope. These puddles and seepage must assist survival of the semi-aquatic turf plants.

At the 1.0 to 1.2 m level, *Lilaeopsis novae-zelandiae* is apparent as patches 1-2 m in diameter. Slightly downslope (0.6 to 1.0 m level) *Ruppia polycarpa* is also present as discrete patches 2-4 m in diameter, covering about half the ground area. These patches may represent single plants or colonies of each species, or else their size and distribution might represent the physical character of lenses of finer sediments upon the gravel basement. *Ruppia polycarpa* foliage lies prostrate upon the moist ground when the lagoon level is low, and so also do the 60–80 cm long stems of *Myriophyllum triphyllum*.

Low water level exposes a further element in the aquatic vegetation. Quartz cobbles, usually brown-stained from weathering of iron compounds, are further darkened by a brown or black skin of lichens: at least two species of *Verrucaria*, a genus regularly met with in the intertidal zone of coastal rocks, and tolerant there of a twice-daily submersion and drying cycle. On the shores of Waituna Lagoon, *Verrucaria* lichens must tolerate a much more prolonged alternation of habitat conditions, being either submerged or exposed for several months at a stretch. Most cobbles are firmly embedded in the substrate and can have a complete coating of lichens. Smaller, younger lichen rosettes indicate cobbles that have been dislodged and turned relatively recently by wave action. An unusual and perhaps unexpected plant habitat becomes evident when clear quartz cobbles are turned over: coating the undersides are green algae, presumably thriving on sunlight transmitted right through the stones.

Only a few other aquatic vascular plant species were noted in the lagoon. A second feathery-leaved species of milfoil, *Myriophyllum propinquum,* is likely to be present, though no positive identifications were made of it. A pondweed, *Potamogeton ochreatus*, was seen at one site. The only naturalised aquatic seen within the lagoon was water buttercup, *Ranunculus trichophyllus*, a few plants at the east end. The naturalised starwort *Callitriche stagnalis* grows in the relatively more fertile water of drain mouths entering the lagoon.

Several aquatic plants are notably apparently absent. No charophyte algae were seen. Sea grass (*Zostera novazelandica*) is absent, probably because the lagoon is insufficiently salty for it. But nor were *Lepilaena bilocularis*, *Zannichellia palustris*, or *Potamogeton pectinatus* recorded, although these are all to be found in brackish waters, at least as far south as Otago.

Shore zonation patterns

By far the predominant shore vegetation is *Leptocarpus* rushland, but on close examination the vegetation proves to be both more diverse and less impenetrable than it first appears.

The typical zonation pattern of shore vegetation is profiled in Fig. 3. Thus, from a boat landing against small patches of turfy shore, one struggles initially with dense clumps of *Leptocarpus* on hummocky ground, then proceeds inshore through rushland on more even ground, until the land surface rises gradually and grades to a mixture of sedges and grasses, then flax, bracken and manuka scrub.

FIGURE 3. WAITUNA LAGOON SHORE VEGETATION: TYPICAL ZONATION PATTERN AND VARIANTS.

Principal variants to this basic pattern are also summarised in Fig. 3. The variation is dependent mainly on degree of shelter from, or exposure to, wind and waves, and hence to patterns of erosion and deposition of sediment (silt, sand, gravels, and organic matter). Superimposed on each type of site is the influence of fluctuating lagoon level, creating laterally elongated zones of vegetation, and particular levels at which wave erosion, debris deposition, or anaerobic ponding are concentrated.

Shore vegetation patterns and composition are further described below, with reference to profile diagrams of surveyed transects (Figs 7–15), photographs (Figs 16–28), and Tables 2 and 3 which record details of plant cover along two of the transects. In these vegetation descriptions, for the sake of brevity, plants are referred to by genus name only in situations when no confusion between species is likely. Botanical names are listed in full in the Appendices, Section 10.2.

Turf communities

Turf vegetation, of creeping or tufted ground-hugging plants, occurs most commonly where fine sediments have accumulated around the base of *Leptocarpus* pedestals, or else as scattered patches or partial cover within relatively stable gravels of gently sloping beaches (Fig. 19). More extensive turf vegetation, with greater overall plant cover, occurs where mud or silt accumulate in greater quantities, especially in small bay-heads (e.g. Fig. 20).

Composition and zonation of turf communities are best illustrated by Transect 4 (Fig. 10 & Table 2) and Transect 7 (Fig. 13 & Table 3). The main components (turf plant species having at least 5% cover at one site) are as follows. In gravelly sites, at relatively low level on the shore the dominants are *Lilaeopsis, Selliera,* and *Samolus*. Muddy ground at a comparable level has *Mimulus repens, Limosella, Crassula sinclairii,* and *Cotula coronopifolia*. On slightly higher ground, especially within the *Leptocarpus* zone, the main turf plants are *Selliera, Potentilla, Isolepis cernua, Centella, Triglochin, Leptinella dioica, Hydrocotyle sulcata,* and *H. novae-zelandiae* var. *montana*, and the moss *Fissidens asplenioides*. Higher still, especially near the upper extent of the *Leptocarpus* zone, and in moist ground subject to minimal sediment deposition, localised areas of turf are composed of *Centella, Nertera balfouriana, N. setulosa, Myriophyllum votschii, Viola cunninghamii, Pratia angulata, Galium perpusillum, G. propinquum, Schoenus maschalinus, Carex flaviformis*, and *Euphrasia repens*.

Leptocarpus rushland

Stature and growth form of *Leptocarpus* vary with plant age and growing conditions. This is most marked when the lower and upper portions of the *Leptocarpus* zone are compared, as shown in Fig. 3, and in more detail in the transects in Figs 8, 11, and 12. *Leptocarpus* plants closest to the lagoon are typically 1.8 to 2.0 m tall, growing upon hummocks usually 0.2 to 0.4 m high. These are old plants that have built the hummocks by trapping sediments among their stem bases. Wave action is concentrated upon these “foreshore” plants, so it is here that most sediment is available for hummock building. Hummock plants benefit from the nutrient replenishment from the fresh veneer of sediment, and the hummocks provide a well-aerated environment. At the same

TABLE 2. PERCENT PLANT COVER WITHIN CONTIGUOUS INTERVALS ABOVE WAITUNA LAGOON (1.30 M LEVEL), AT A SITE WITH A MUDDY SHORE GRADING TO A GRAVELLY STORM RIDGE (TRANSECT 4, NEAR WALKERS BAY; FIGS 1, 10).

Zone: (m from shore)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–12	12–14
Bare ground	40	51	58	16	10	5	7	5				
Myriophyllum triphyllum	30	15	5	5	2	1						
Lilaeopsis novae-zelandiae	20	20	20	20	29	20	2	1				
Isolepis cernua	5	5	1	1	1	10	5	2				
Mimulus repens	2	1	5	15	20	20	2					
Cotula coronopifolia	1	2	5	2	1	1						
Samolus repens	1	1			2	5	5	5				
Selliera radicans	1					5	10	10				
Limosella lineata		5	2	25	5	2						
**Agrostis stolonifera*			1	1	5	20	35	38	20	10	5	5
**Plantago australis*			1	5	10	5	1					
Chenopodium glaucum			1		1							
**Juncus bufonius*			1									
Crassula sinclairii				10	10	2						
**Anagallis arvensis*					2	1	10	5	2			
**Atriplex prostrata*					1	1						
Crassula moschata					1	1						
Leptocarpus similis						1	1					
Isolepis nodosa							15	20	10	10	15	10
Pseudognaphalium luteo-album								5	5			
**Leontodon taraxacoides*							2	5	20	25	10	15
Lachnagrostis striata								1				
Poa cita								1	35	15	17	28
**Rumex crispus*								1				
**Carex buchananii*								1				
Thuidium furfurosum									10	15	10	15
**Lotus pedunculatus*									2	10	5	5
**Galium palustre*									1			
**Anthoxanthum odoratum*										5	15	10
Hypnum cupressiforme										5	2	2
**Holcus lanatus*										2	1	
**Trifolium repens*										1	2	5
Acaena novae-zelandiae										1	2	
**Sedum acre*										1	1	
Acaena microphylla											15	5
Native species:	7	7	7	7	10	11	8	8	3	5	5	5
Naturalised species:			3	2	4	4	4	5	5	7	8	5
Total species:	7	7	10	9	14	15	12	13	8	12	13	10

* = naturalised (not native) species

time this concentration of wave action in the "foreshore" *Leptocarpus* creates channels between and around the hummocks and can eventually lead to their undercutting and collapse. The largest *Leptocarpus* clumps seen, along the exposed western shore, were 2.2 m tall, upon 0.6 m, undercut pedestals (Figs 15, 18). Because of wave and wind action, "foreshore" plants have many stems that have been laid almost prostrate, usually in an inland direction, creating a dense tangle from which subsequent new stems emerge more-or-less erect.

TABLE 2. (BELOW AND OPPOSITE) PERCENT PLANT COVER WITHIN CONTIGUOUS INTERVALS ABOVE WAITUNA LAGOON (1.19 M LEVEL), AT A SITE GRADING ON TO THE REAR SLOPE OF THE IMPOUNDING COASTAL BEACH RIDGE (TRANSECT 7, HANSENS BAY; SEE FIGS 1, 13).

Zone (m from shore)	0–5	5–10	10–14	14–16	16–20	20–25	25–30	30–35	35–40	40–45	45–52	52–60	60–70	70–110
Bare ground	80	10	20	5									15	
Schoenoplectus pungens	20	43	40	10							+			
Myriophyllum triphyllum	+													
Lilaeopsis novae-zelandiae		20	10											
Selliera radicans		15	20	10			5				2			
**Agrostis stolonifera*		10	10	5	5	5	20	+						15
Potentilla anserinoides		2	+	+	30	30	5	+	10					
**Anagallis arvensis*		+	+	+										
**Atriplex prostrata*		+												
Chenopodium glaucum		+												
**Cirsium arvense*		+												
Cotula coronopifolia		+												
Hydrocotyle hydrophila		+												
Isolepis cernua		+												
Limosella lineata		+												
**Sonchus asper*		+												
**Leontodon taraxacoides*			+	10			10		5		5	+	10	
Leptocarpus similis				60	80	80	60	40	35	30	20	5		
Isolepis nodosa				5	5		+	10	15	5		5	+	25
**Plantago major*				+										
Coprosma propinqua					5	10		15	15	25		2		
Plagianthus divaricatus					5	5		5	30	30				
Fissidens asplenioides					5									
Phormium tenax						+	5	10	5	5	2	5		
**Lotus pedunculatus*							20	30	10	5	+	5		
Centella uniflora							20		20	20	10	5		
Pratia angulata							5		5		5			
**Galium palustre*							5							
**Trifolium repens*							2						1	
Carex flaviformis							+				15	10		
**Parentucellia viscosa*							+							
**Plantago australis*							+							
Blechnum minus								5	20	20	2			
Galium propinquum								5	5	5				
Cortaderia richardii								5	2	5	2			
Acaena novae-zelandiae								5					+	
**Prunella vulgaris*								+						
**Holcus lanatus*								+			1		10	10
Carex flagellifera									2					
Carex virgata									2					
Riccardia sp.										5				
Myriophyllum votschii											20			
Nertera balfouriana											15			
**Ulex europaeus*											5	80	5	25
**Anthoxanthum odoratum*											2	2	50	
Galium perpusillum											2			
Schoenus concinnus											2			

Zone (m from shore)	0–5	5–10	10–14	14–16	16–20	20–25	25–30	30–35	35–40	40–45	45–52	52–60	60–70	70–110
Schoenus maschalinus											2			
Juncus planifolius											2			
Lepidosperma australe											2			
Nertera setulosa											1	20		
Leptospermum scoparium											1			
**Centaurium erythraea*											+			
Euphrasia repens											+			
Gaultheria macrostigma											+			
Gonocarpus aggregatus											+			
**Juncus articulatus*											+			
Luzula picta											+			
Triglochin striata											+			
**Dactylis glomerata*												2		5
Microtis unifolia												+		
Poa cita													5	10
**Hypochoeris radicata*													5	
**Sedum acre*													2	
**Rumex acetosella*													+	
**Ammophila arenaria*														20
Calystegia soldanella														5
**Festuca rubra*														5
**Cerastium fontanum*														2
Native species:	2	9	4	5	6	5	8	10	13	10	23	8	3	3
Naturalised species:	0	5	3	4	1	1	7	4	2	1	7	5	8	7
Total species:	2	14	7	9	7	6	15	14	15	11	30	13	11	10

* = naturalised (not native) species

By contrast, *Leptocarpus* rushes in the "inshore" portion of their zone, grow upon much more smooth ground. The stems are less dense, uniformly erect, and have an even top height of usually 1.7 to 1.8 m. The plants here often have a more yellowish appearance, and it is less easy to distinguish individual plants on the basis of growth form (though this might be achievable by observing the extent of the separate male and female plants at flowering time).

Where do young *Leptocarpus* plants occur? We observed seedlings, a few centimetres tall, at only one site (Transect 4, Fig. 10), on a gravelly storm ridge. The only other obviosly young stand noted was as a 1 m-tall sward, in a small gravelly embayment, the result presumably of one localised gravel deposition event. Being long-lived plants, *Leptocarpus* would not be expected to display especially frequent or obvious recruitment.

Certainly, death does occur within *Leptocarpus* rushland, often over expanses of 5–10 (–40) m across, and usually in the "inshore" part of the rushland zone, on ground that has a slight degree of concavity, such that ponding may occur. Organic drift material can accumulate in these sites, and when partly decomposed it becomes an evenly spread deposit, finely floccose and often slightly orange on the surface, overlying a black, putrid, and anaerobic layer, sometimes to 20 cm thick above underlying gravels. Death of *Leptocarpus* is probably caused when this organic layer seals off the rooting zone from effective aeration.

Incipient ponding of this sort is shown in Fig. 17, and a later stage in the process in Fig. 28, and by Transect 1 (Fig. 7). A former presence of *Leptocarpus* is evident from the basal remains of stubby stem bases upon prostrate rhizomes. Dead shrubs of *Plagianthus divaricatus* can be found in the same areas. These "bad ground" areas become colonised by two annual weeds, most commonly orache (*Atriplex prostrata*) but also bachelor's button (*Cotula coronopifolia*), and by a perennial sward of creeping bent (*Agrostis stolonifera*). How, or whether *Leptocarpus* recolonises the sites is not clear to us, although vegetative re-invasion from peripheral surviving plants would be likely, once wave-flushing of these hollows or embayments had again created favourably aerated substrates.

The distinction between hummocky "foreshore" and smoother ground "inshore" portions of *Leptocarpus* zone will be discussed further in Section 5.4 when sequential air photo interpretation is described.

Within the *Leptocarpus* zone generally, the most frequent associated plants are creeping bent grass, the sedge *Carex virgata*, and scrambling herbs such as *Lotus pedunculatus, Galium palustre, Potentilla anserinoides*, and *Centella uniflora*. Gently sloping shores, such as that at Transect 6 (Fig. 12) illustrate how the plant composition of the *Leptocarpus* zone changes in the gradual progression inshore, with steadily increasing numbers of other tall herbs, especially flax (*Phormium tenax) and* toetoe (*Cortaderia richardii*); of shrubs (*Plagianthus divaricatus, Coprosma propinqua*, and manuka, *Leptospermum scoparium*); of sedges (e.g. *Carex coriacea, C. sinclairii, Lepidosperma australe*); and of ferns (e.g. *Blechnum minus*, and bracken, *Pteridium esculentum*).

Sedge, rush, and grass communities

Swards of three square (*Schoenoplectus pungens*) often form pure stands, a few metres in extent, in loose gravels of small bays, fronting the *Leptocarpus* zone (Figs 13, 27), or in muddy parts of the lower shore (e.g. Transect 5, Fig 11). Rushland is just a minor feature around Waituna Lagoon. An example was noted near Currans Creek bridge (Transect 5, Fig. 11), where *Leptocarpus* backs on to pasture. At this site, trampling disturbance and nutrient enrichment by cattle are responsible for the occurrence of wet swards of *Juncus articulatus* and *J. bufonius*, and may encourage the tall rushes *J. gregiflorus* and *J. pallidus* to co-exist with the *Leptocarpus*.

Several species of *Carex* dominate small areas of sward, either alone or together. *C. pumila* and *C. buchananii* occur on the upper parts of relatively stable gravel beaches, at the east end of the lagoon (Fig. 22). Swards of *C. gaudichaudiana, C. coriacea*, and *Eleocharis acuta* occur along parts of the exposed western shore which are subject to much wave-disturbance of gravels (Figs 15, 21). Two grasses tolerant of a mild degree of flooding can also occur as small patches or lineal bands, alone or together, along the top of stable gravel beaches. They are silver tussock (*Poa cita*) and tall fescue (*Festuca arundinacea*).

A mixed community of sedges and grasses occurs in two situations, both at around the 2.0 m lagoon level. The first situation is on the crests of gravel bars

(Figs 10, 20; Table 2), Common plants in this community are knobby clubrush (*Isolepis nodosa*); the grasses silver tussock, creeping bent, *Deschampsia caespitosa*, sweet vernal (*Anthoxanthum odoratum*), and Yorkshire fog (*Holcus lanatus*); herbs such as lotus and *Leontodon taraxacoides*; and mosses, especially *Thuidium furfurosum*. The second situation is as a narrow zone where *Leptocarpus* rushland abuts on to scrub (e.g. Transect 3, Fig. 9; and Transect 6, Fig. 12). This ecotone has a rich flora, of the above-mentioned species plus sedges such as *Lepidosperma australe, Carex coriacea, C. sinclairii,* and *C. flaviformis*, numerous turf herbs, and red tussock (*Chionochloa rubra*). It appears from the accumulation of driftwood sticks and litter that this ecotone is at a level that is not as high as the highest recorded lagoon levels, but one which is relatively high and which might be maintained for long enough periods, creating a zone of disturbance where neither the wetland nor the scrub floras are solely dominant, and where a somewhat open canopy allows for this additional diversity of both native and naturalised plant species.

Red tussock has a mainly scattered distribution within the uppermost level of the *Leptocarpus* zone, but it does occur as a red tussock grassland over limited areas of upper shore, mainly on sandy substrates, along the east side of the south-western arm of the lagoon.

Gravel beaches

Shores of mobile gravel are concentrated along the inland margin of the coastal storm ridge which encloses the lagoon, especially at Walkers Bay and in the eastern arm of the lagoon, and locally at the head of Hansens Bay. The lowest portions of the coastal storm ridge are periodically breached by high seas. Otherwise, wind and wave action of the lagoon itself cause ongoing disturbance of shore gravels, and create changing patterns of miniature storm ridges, cusps, and embayments. Regular disturbance encourages ruderal plants – often naturalised species – which have the ability to colonise and grow rapidly, and to seed freely and abundantly. Vegetation pattern is often determined by seasonal timing of erosion, deposition, and differential seed availability, so that particular plant species can be dominant along sequential strand lines, each of which relates to a single storm or windy weather event, followed by a falling lagoon level. Thus in Walkers Bay, Transect 8 (Figs 14, 23) illustrates former strand lines dominated respectively by orache (*Atriplex prostrata*), scarlet pimpernel (*Anagallis arvensis*), and Californian thistle (*Cirsium arvense*).

Above the influence of lagoon level the rear side and crest of the coastal storm ridge are variously covered with patches or swards of marram grass and clubrush, gravel mat plants such as *Calystegia soldanella, Muehlenbeckia axillaris,* and *Sedum acre*, and by patches of gorse (*Ulex europaeus*; Figs 13, 14, 22, 24).

Scrub communities

Although there is a shrub component of scattered *Plagianthus divaricatus* and *Coprosma propinqua* within the *Leptocarpus* rushland zone, Waituna Lagoon does not have a more dense and distinct zone of this *Plagianthus* (salt marsh ribbonwood) such as would typically occur above a *Leptocarpus* zone in a fully tidal estuarine site.

The dense manuka scrub which grows on the peatland surrounding most of Waituna Lagoon is quite uniform in structure and composition. Manuka may be accompanied by inaka (*Dracophyllum longifolium*), as on Transect 3 (Fig. 9), where canopy height of the scrub is c.2 m. More often, manuka alone forms a canopy 3.5 to 4 m tall, with dense stems of 8-10 cm diameter. There may be a sparse shrub understorey of mingimingi (*Cyathodes juniperina)* in well-lit places, and there is usually some tall bracken fern present, either etiolated beneath the manuka or as dense patches beneath any canopy openings (Figs 8, 15, 18, 26).

Gorse occurs as scattered shrubs or as patches in various habitats, but especially within and near the lower margin of manuka scrub, and on the rear slopes of the coastal storm ridge.

Vertical ranges of plants

The vertical ranges of principal plant species, as determined by their presence along the surveyed transects, are shown to the nearest 0.1 m of elevation in Fig. 4. Aquatic species are shown on the left, and the order of plants progresses to the right as their lower elevation limits are progressively higher upslope, and in effect, as they are progressively less tolerant of periodic inundation.

Comparison of this array of species with those similarly recorded from Lakes Manapouri and Te Anau (Johnson 1972) indicates that for seven indicator species common to the three sites (Table 4), a general concurrence is evident in

TABLE 4. COMPARISON OF LOWERMOST ELEVATION LIMITS OF SHARED PLANT SPECIES ON THE SHORES OF WAITUNA LAGOON, LAKE MANAPOURI, AND LAKE TE ANAU.

Waituna Lagoon scale relative to staff gauge, Lake Manapouri, and Lake Te Anau scales in metres above sea level. These vertical elevation scales are aligned such that the last three species (which indicate a common lower limit at each site) share a common level on the table. The plant species are: *Selliera radicans, Eleocharis acuta, Leptocarpus similis, Coprosma propinqua, Juncus gregiflorus, Centella uniflora*, and *Leptospermum scoparium*. Lower limits are indicated for each species with the site abbreviations: W = Waituna, M = Manapouri, T = Te Anau.

Elevation on shore (m)			Plant species						
Waituna Lag	L. Manapouri	L. Te Anau	*Sell rad*	*Eleo acu*	*Lept sim*	*Cop prop*	*Junc greg*	*Cent uni*	*Lept scop*
1.9	177.8	202.1							
1.8	177.7	202.0				MT	WMT	WMT	WMT
1.7	177.6	201.9				W			
1.6	177.5	201.8							
1.5	177.4	201.7			MT				
1.4	177.3	201.6							
1.3	177.2	201.5		M					
1.2	177.1	201.4		WT	W				
1.1	177.0	201.3							
1.0	176.9	201.2	W						
0.9	176.8	201.1	T						
0.8	176.7	201.0	M						
2.8	4.57	3.50	(Maximum fluctuation)						
c.1.8	2.74	2.10	(Mean annual fluctuation)						
?	177.77	202.19	(Mean level)						

FIGURE 4. VERTICAL RANGES (IN 0.1 M STEPS) OF THE PRINCIPAL PLANT SPECIES ON THE SHORES OF WAITUNA LAGOON.

the order and relative levels of the species. A notable difference is apparent, however, when the lower elevation of *Leptocarpus* is compared with that of manuka (*Leptospermum scoparium*). At Lakes Manapouri and Te Anau, *Leptocarpus* descends to a level 0.3 m below the lower limit of manuka, but at Waituna Lagoon, *Leptocarpus* descends 0.6 m lower than manuka, despite the lesser fluctuation range of Waituna Lagoon and the otherwise more compressed vegetation zones than at these large Fiordland lakes. This is indicative of a recent downslope colonisation by *Leptocarpus* at Waituna, one which has not yet been accompanied by a downward shift in elevation limit by shrubs such as manuka and *Coprosma propinqua*.

5.4 VEGETATION CHANGE:AIR PHOTO INTERPRETATION

The following runs of vertical air photos were examined:

15 March 1951: 1626/ 23-32;

1 March 1962: Survey 1454, 3573/ 21-32, 3574/ 22-31, 3575/ 22-24;

26 February 1977: SN5084 A/ 20-21;

17 October 1985: SN 8542 D/ 13-19.

FIGURE 5. COMPARATIVE EXTENT OF *LEPTOCARPUS* RUSHLAND (BLACK) AT HANSENS BAY, SOUTH SHORE OF WAITUNA LAGOON, BASED ON AIR PHOTOS OF 15 MARCH 1951 AND 1 MARCH 1962. SHADED AREAS ARE PEATLAND WITH MAINLY SCRUB VEGETATION. DASHED LINES INDICATE LAGOON SHORE OR SANDBARS.

Despite differences in scale of air photos, as well as in lagoon level and hence in amount of exposed shore and gravel bars between air photography dates, it is possible to observe several types of change since the earliest (1951) air photos. The increase in developed farmland is apparent, especially to the north of Waituna Lagoon. Some changes in patterns of sediment deposits in and around the lagoon are also evident, though we have made no attempt to document these. The 1951 photos show complex patterns of fires having affected manuka scrub in particular, especially to the west of the lagoon. Later air photos indicate a general recovery of manuka scrub to a taller and more evenly dense cover on most of the surrounding peatlands, but there is no clear evidence that manuka scrub has increased in its extent towards the lagoon edges.

A very pronounced change shows in the extent of *Leptocarpus* rushland around much of the lagoon shore. This is illustrated for one site, near Hansens Bay, in Figs 5 and 6, drawn from four sequential sets of air photos wherein *Leptocarpus*

FIGURE 6. COMPARATIVE EXTENT OF *LEPTOCARPUS* RUSHLAND (BLACK) AT HANSENS BAY, SOUTH SHORE OF WAITUNA LAGOON, BASED ON AIR PHOTOS OF 26 FEBRUARY 1977 AND 7 OCTOBER 1985. SHADED AREAS ARE PEATLAND WITH MAINLY SCRUB VEGETATION. DASHED LINES INDICATE LAGOON SHORE OR SANDBARS. CIRCLED NUMBERS SHOW LOCATION OF TRANSECTS 1 AND 7.

shows distinctly because of its dark tones. In 1951 *Leptocarpus* rushland formed a discontinuous fringe against the scrub vegetation of the shore, but was present also as discrete clumps, partly coalescing, upon the gently sloping shore platforms. On the 1951 air photos these shore platforms are exposed by a low lagoon level and appear mainly white, just as the coastal beach appears white from its high component of quartz pebbles. In addition, the 1951 air photos illustrate patches of pale grey tone, probably indicative of turf vegetation, in the vicinity of the some of the *Leptocarpus* clumps. This supposed turf vegetation was too diffuse to be confidently drawn on Fig. 5.

In the ensuing 11 years, up to the 1962 air photos, individual *Leptocarpus* clumps had increased in diameter and further coalesced, some of them growing as elongations along sediment deposition lines. Fifteen years later, in 1977 (Fig. 6), a great amount of infilling had taken place, leading to a broad and almost continuously dense band of *Leptocarpus* rushland. By 1985, a slight further increase in *Leptocarpus* cover had taken place. Over the last decade there appears to have been no significant further increase in *Leptocarpus* extent, as judged by our observations on the ground at the site of Transect 1, and from oblique air photos of the Hansens Bay area taken by P.N. Johnson in March 1995.

Although the *Leptocarpus* increase is illustrated from just one site in Figs 5 and 6, the air photos show that a similar increase has occurred around most of the lagoon shores, most markedly so along the northeast shore, and especially along the 4–5 km of gentle shore to the west of Currans Creek mouth.

It is of interest to note that the increase in *Leptocarpus* rushland, most rapid between 1951 and 1977, has not taken the form of a gradual outward or downslope movement of a front of *Leptocarpus* rushland, but instead mainly via an early phase when there were scattered *Leptocarpus* clumps, and then by an infilling process within that initially colonised extent.

5.5 VEGETATION CHANGE: LOCAL KNOWLEDGE

The late Gordon Watson of Invercargill visited Waituna Lagoon over much of his life as a duck-shooter, and devoted his latter years to photographing the flora. He was aware of the impacts of farm development and fire on the peatlands of the general area and had observed (personal communication to P.N. Johnson) that the lagoon shores had once been more accessible, with less wiwi (*Leptocarpus*). A long-time friend of Gordon Watson, David McNaughton, has written the following notes in July 1995, as faxed to his son, Roger McNaughton, Kapuka, Invercargill, and passed on to P.N.J.

> "Early writers of pamphlets on the Waituna Lagoon gave us a good description of the Lagoon and its surrounding area. As a teenager [1920s] I can recall the miles of white gravel beaches almost free of rushes and no gorse."

> "The drainage close to and through the Reserve has been a disaster for the wetlands and has made an environment for the growth of manuka. Examples of manuka growth can be seen in an area just west of Waghorn woolshed, one in the reserve and the second in a once-cultivated paddock in Waghorns. Again at Crack's Road the growth of manuka is considerable. I believe that

stunted manuka and seedlings assists largely in drainage of its immediate area and in turn assist in growth of these and other plants."

"The drainage of Waituna, Moffat, and other creeks, along with farming practices such as dairying, fertilizers, and heavy stocking, are causing creeping action which assists drainage of the immediate water in the wetlands, and again growing grasses, etc. assists with this drainage."

"The dairying along these above creeks with heavy stocking and use of nitrates could be the cause of loss of much of the plant life in the lagoon."

"About 15 years ago, along with a friend, Gordon Watson, I visited the area east of the smelter and we were amazed at the beauty of the cushions there, but by the end of a 5–6 year period we were very disappointed that the quality of these cushions had diminished. A nearby seagull rookery had fouled many with the growth of fog (grasses) on them. Also stunted manuka grow on many. The water level had appeared to have lowered."

"I do not believe that the lake level as at present is a factor for diminishing wetland areas. The damage has been done by drainage and the creeping effect I have mentioned."

"Lake levels had been held at 1–2 metres for at least 50% or better during my lifetime."

"I visited an area east of the fishing huts (break-out) some 12 years ago – a very wet area with a carpet of low growing plants and free from manuka which would be good for a study on plant life and the effects of water level. It is an area free from drainage."

Roger McNaughton (personal communication) notes that there has been increased dairying in Waituna Creek catchment, leading to increased siltation near the creek mouth, and that Waituna Creek now runs dirty in a flood, more than it once did.

An increase in lagoon siltation has also been noted by Raymond Waghorn (personal communication):

"The late 1960s, a time of increased drainage of farmland, also saw increased siltation within the lagoon, and an increase in rushes (*Leptocarpus*) around Waituna Lagoon, over a 5–8 year period. Aquatic weed beds increased then also. Flounders were once more common in the lagoon, associated with many sandy beds. Lawson Bay, once good for flounders, became very weedy in the mid-70s. Eel weed [*Ruppia*] storm deposits to 1 m deep, turned to black pulp. Fishing holes formerly present at mouth of Waituna Creek, and at the mouth of Shand Bay are now gone, all silted up. In 1974 a digger took the Currans Creek drain up beyond the initial 1 km. Silt then flowed into the lagoon, whereas in previous times it had been trapped in the swamp."

6. Discussion

6.1 INCREASE IN *LEPTOCARPUS* RUSHLAND

What factors might have contributed to the increase in extent of *Leptocarpus* rushland, evident both from the observations of local people and from the air photo record?

Might the increase be part of a natural cycle whereby *Leptocarpus* rushland comes and goes on a periodic basis? This is unlikely on a grand scale, considering that *Leptocarpus similis* appears to require precise conditions to establish from seed, and is slow-growing. Yet it is a resilient species, tolerant of many environmental extremes once established, capable of holding its ground, and of resisting invasion or replacement by other plant species. Any such natural cycle would have to be on a time scale of many decades.

Although we did observe areas of rushland that had died apparently as a result of anaerobic conditions beneath accumulations of organic matter, this seems to be a localised phenomenon. Such death occurs specifically within the "inshore" portion of the *Leptocarpus* zone, on smooth and gentle ground surfaces, within stands that have been part of the "infilling" colonisation over the last 45 years, occupying ground between the "foreshore" hummocky stands and the original *Leptocarpus* zone closer to the scrub margin.

Might the increase in rushland be a response to decreased frequency of fire? Probably not, for although fire will consume above-ground foliage of *Leptocarpus*, the rhizomes survive, especially in moist ground, and regeneration of former stands takes place readily, as observed by P.N. Johnson following fires that have encroached upon *Leptocarpus* rushland beside nearby Awarua Bay.

Generally lower lagoon water levels (lesser mean, lower peaks, shorter durations at higher elevations) are a likely factor, the result of artificial openings being more frequent than under the natural opening regime. Comparison of relative lower elevation limits of *Leptocarpus* and manuka with Lakes Manapouri and Te Anau (Table 4) suggest that the lower extent of *Leptocarpus* at Waituna has adjusted in a downslope direction, while the manuka scrub zone has remained at a higher level, as determined by the previous fluctuation regime. Even though the expansion of *Leptocarpus* might have been triggered by the onset of artificial lagoon openings early this century, there has been a lag in the colonisation response, with initial slow and patchy colonisation down as far as its present lower limit, followed by an infilling and density increase over the last 45 years, the period illustrated by sequential air photos. Because *Leptocarpus* rushland persists within its former elevation range, i.e. in the upper portion of its now broader zone, there has probably been competitive resistance to a corresponding downslope invasion by manuka scrub.

The timing of the major increase in *Leptocarpus* rushland may relate to the availability of sediment inputs. If silt input to the lagoon has increased, and local observations support this, then an increase in *Leptocarpus* would be expected in view of the manner in which this plant can trap silt, build up its pedestals to a level where root aeration is improved yet water is still readily available, and benefit from nutrients derived from the silt. Indeed, at Waituna Lagoon it is the outermost stands of *Leptocarpus*, those that are most exposed to wave action and to a supply of fresh or reworked fine sediment, which form the tallest pedestals and achieve greatest height and vigour. The lagoon shores and bed are predominantly composed of ancient and well-worn quartz pebbles, surely one of the most inert and nutrient-poor substrates for plant growth. Of course, the situation for plants is improved by the presence also of fine inorganic sediments as well as organic matter. But if a former situation prevailed where fine sediment was in very limited supply, then there may not have been enough to support extensive beds of *Leptocarpus* rushland, and what little there was would have been preferentially appropriated by scattered *Leptocarpus* clumps in those shore situations most favourable for sediment supply and deposition. Thus even a slight increase in the proportion of fine sediments within Waituna Lagoon might be sufficient to account for the observed increase in rushland. Indeed, Kirk & Lauder (1994) suggest that, for Waituna-type lagoons, sediment yields from contributing catchments are relatively low, and that such lagoons are very sensitive to changes in catchment hydrology and sediment delivery.

One further factor might be relevant, namely the change in energetics of wind-driven processes such as waves, seiches, and currents in the lagoon consequent upon the lowered levels of an artificial opening regime (Kirk & Lauder 1994). Under the natural regime, there may well have been very long periods with the lagoon level consistently high, perhaps in the absence of the right combination of wind, storm, lagoon waves, coastal storm beach height, and sea conditions for a natural breach to occur. Perhaps the lagoon might have remained high for several years at a time, and perhaps natural openings were of quite erratic occurrence. If so, the wholesale demise of marginal *Leptocarpus* rushland might have occurred because of flood duration exceeding flood tolerance of the species. (On the shores of Lakes Manapouri and Te Anau, *Leptocarpus* descends to an elevation where maximum recorded flood durations are in the order of 300 days; Johnson 1972.) Alternatively, *Leptocarpus* stands might have been subject to massive disturbance by the erosion power of wave action during an occasional violent storm at a time of high lagoon level. If such an event then resulted in an opening to the sea, a massive evacuation of fine sediments would be expected from the lagoon.

Assuming a scenario of extreme fluctuations, sustained high levels, and irregular openings, we would expect the lagoon shores to have been vegetated with a predominance of turf plants, tolerant of alternate submergence and emergence, and also capable of relatively rapid upslope adjustment in elevation range during extended periods of high level, and of recolonisation following a time of low lagoon level. No doubt *Leptocarpus* rushland has always been present around Waituna Lagoon, at least as a narrow zone. The abundance which *Leptocarpus* rushland has achieved at Waituna Lagoon, especially during the 1960s and 1970s, probably reflects a response that was initiated by the earliest artificial lagoon openings, and accelerated by increased availability of sediment and probably also of nutrients.

6.2 COMPARISON WITH OTHER SOUTH ISLAND LAGOONS

The South Island has many lagoons around its coasts (lagoons are uncommon in the North Island), as well as a considerable number of estuaries, with which lagoons are often confused. The main difference is that estuaries are open to the sea, while lagoons are partially or completely enclosed. Much confusion between the two has arisen because the same plant species usually occur in both. Despite such similarities, lagoons and estuaries have completely different behaviours, especially in terms of inundation regimes, salinity patterns, and sediment and nutrient behaviour.

Most South Island estuaries have fairly similar vegetation patterns and behave in a similar way. Even with two broad types, depending upon the presence of *Juncus maritimus* in only the northern South Island, analyses of vegetation patterns have revealed that all salt marshes comprise the same set of broad ecological gradients, mostly related to tidal salinity gradients. Differences occur only with less important factors, such as sediment type, or cultural influence, and the consequences of these are minor.

However, it is not so well known whether the same sets of principles apply to lagoons. Are all lagoons the same, or do they differ so much that the lessons learned from one are inapplicable to others? In recent years there have been studies of vegetation in a number of South Island lagoons, with intensive studies on vegetation patterns at Lake Ellesmere (Clark & Partridge 1984; Taylor 1996). These studies have found that although the same plant species that occur within estuaries occur also at Lake Ellesmere, and although salinity is a controlling factor in their distribution, the arrangement of vegetation zones is completely different from that in estuaries. This is because, instead of the tide/river behaviour governing salinity patterns as in estuaries, the opening/closing regime of lagoons produces completely different salinity patterns.

So, since lagoons all have different opening/closing regimes, including managed, it might be expected that they all comprise different vegetation patterns as a result of local variations. Comparison of lagoon systems allows broad patterns to be determined, and local differences to be highlighted. This is done below for the main large lagoons for the South Island from the perspective of Waituna Lagoon.

Lake Ellesmere, Canterbury

This is New Zealand's largest lagoon, with a managed opening regime developed using guidelines as determined by a Conservation Order (NWASCA). Its waters are approximately a fifth of sea water salinity, but the margins comprise vegetation that ranges from salt-tolerant to freshwater (Clark & Partridge 1984; Taylor 1996). Salt-tolerant species predominate where large essentially flat areas are sometimes exposed and at other times inundated. Upon exposure, soil water and ponded water evaporate, concentrating the salt to result in increasing sediment salinities, the most extreme of which reach the salt crust stage. In areas where freshwater constantly flows into the lagoon, salinity is kept low, and freshwater species predominate. These flows occur along river margins, around springs, and where the groundwater aquifer outcrops into the lake waters. These extremes are not found in such combinations in lagoons elsewhere in the South Island, although they are common overseas (e.g. Victoria, Australia). All other lagoon systems tend to have either predominantly saline or freshwater vegetation. Waituna Lagoon is at the freshwater extreme. *Leptocarpus similis* occurs around the margin of Lake Ellesmere, but is nowhere in extensive stands as at Waituna Lagoon.

Washdyke Lagoon, South Canterbury

This lagoon, disappearing because of coastal erosion, has mainly grazed pasture plus a narrow band of predominantly exotic species around the margin. A few salt-tolerant plants are confined to the gravel beach of the enclosing bar. This lagoon is virtually freshwater, but differs from Waituna Lagoon by being almost completely modified, with few native species remaining, and having only a narrow band of marginal vegetation.

Hoopers Inlet, Otago

This is an estuary partially enclosed by a bar, so that only the high tide can enter, and the lower part of the tidal range is absent. Sediment deposition is considerable, and salinity is intermediate between Waituna Lagoon and a typical estuary. The vegetation has many similarities with Waituna Lagoon, with some stands of *Leptocarpus*, but still retains the salinity and inundation patterns typical of estuarine marshes, only not as well developed.

Saltwater Lagoon, Westland

Here, freshwater turf predominates around the margins, this vegetation type being relatively uncommon at Waituna Lagoon. *Leptocarpus* stands do occur in sheltered areas. Salt-tolerant species occur only around the mouth. Yet Saltwater Lagoon and similarly Okarito Lagoon are both very much open to the sea. Freshwater plants predominate because of the surplus of freshwater from rivers and groundwater flows relative to sea water, probably a function of the climate.

Lake Grassmere, Marlborough

Salt-tolerant species dominate the margin, mainly because salt water is actively added for the salt extraction industry located here, and also because of the evaporative climate. The zonation patterns are, however, very similar to those of the saltings at Lake Ellesmere, with the most salt-tolerant species in the middle zone, and plants less tolerant of salt in the lower and upper zones. *Leptocarpus* is present but is not a major component. The other Marlborough lagoons are similar, but much of their margins has been developed for agriculture, there being narrow fluctuations in water level.

Using just these few examples, it becomes clear that the lagoons of the South Island are all very different. Most have some vegetation in common with Waituna Lagoon, but none contain the extensive stands of *Leptocarpus* that is such a feature there. There seem to be three broad types:

(a) Those of constant water level and thus comprising little marginal vegetation (e.g. Washdyke Lagoon).

(b) Those of the drier east coast with salt-tolerant species present. These east coast lagoons also tend to have high levels of suspended sediment and nutrients.

(c) Those of the West Coast and Southland where fresh water predominates, and where sediment loads are not great, and nutrient levels are low.

Waituna Lagoon belongs in (c), and is therefore most similar to the lagoon-like estuaries of Westland, where freshwater predominates. Evaporative conditions do not occur within these systems. The other place where extensive stands of *Leptocarpus* occur are in some estuaries, and in freshwater lakes. In estuaries the relatively salt-intolerant *Leptocarpus* is confined to upper salt marsh zones, where it can occur as extensive stands, or along rivers that flow into the estuary, and where fresh water dominates.

7. Conclusions

The natural and recreational values of Waituna Lagoon are well known, and the biological conservation significance is exemplified by its status as a "Wetland of International Importance". In his 1986 book, *Wetlands, Discovering New Zealand's Shy Places*, Gordon Stephenson gives a chapter to Waituna, and notes: "..it is ironic that it was originally made a reserve for botanical reasons, but achieved international status for its birdlife! This makes Waituna doubly valuable." He also comments, "There is not another lagoon comparable to Waituna south of Lake Ellesmere." Our comparisons support this statement, and we can go further by concluding that, despite its environs having been modified by fire and by agricultural development, and despite an imposed artificial water regime, Waituna Lagoon still supports predominantly native vegetation types. Its submerged vegetation is essentially free of troublesome aquatic weeds and is still dominated by *Ruppia* species, unlike Lake Ellesmere where the *Ruppia* beds were destroyed by the Wahine storm, never to recover once the water had become too permanently clouded by sediment. Our observations show that Waituna Lagoon has a diversity of vegetation types, and of zoned sequences, on its different types of shore, and that it is a dynamic environment for plants.

Nevertheless, we have shown from several lines of evidence that the nature of the lagoon margin vegetation has changed in response to a generally lower lagoon level, combined with apparent increases in sedimentation. The resilient *Leptocarpus similis* rushland has responded to these changes, by increasing its extent, and maintaining, at least so far, a predominantly native feel to the lagoon shores.

But the critical questions are: to what extent is Waituna likely to be further altered, by ongoing or by new sets of threats, and how might management options affect its long-term future?

Fire is an ever-present threat, not so much to the immediate marginal vegetation, but certainly to the surrounding peatland vegetation. Given sustained freedom from fire, some of the manuka scrub would probably progress back to a more diverse (and eventually more fire-resistant) low broadleaved forest. With recurrent fire, manuka scrub would basically keep on replacing itself, but with each burn the opportunity is greatly enhanced for gorse to become more abundant, and to gain a greater foothold around the lagoon shores as well as on the peatlands in general.

Grazing and trampling, especially by cattle, were noted within lagoon shore *Leptocarpus* rushland, especially on the northeast shore.

As noted above, aquatic weeds are not a problem, although water buttercup (*Ranunculus trichophyllus*) may have the potential to colonise further, especially if nutrient status of lagoon waters was to increase. Aquatic habitats, especially near road access points, should be monitored regularly for any presence of naturalised aquatic plants.

Steps should be taken to monitor, and to minimise, sediment and nutrient inputs to the lagoon. Intensification of agriculture, especially of dairying with its associated application of nitrogenous fertilisers and disposal of dairy shed effluent, are incompatible with the long-term health of a basically low-nutrient status coastal lagoon system.

Has the imposition of a regime of lower water levels encouraged the colonisation of weeds, especially gorse around the lagoon margin? Our conclusion is that, although *Leptocarpus* rushland has migrated downslope partly in response to lower water levels, woody plants – manuka and gorse included – have not done so to the same extent, largely because of an inability to invade ground that is still occupied by rushland. But such invasion might yet occur. Alternatively, might there be an argument for re-instigating a higher water regime on the grounds that this would help prevent downslope encroachment of gorse on to the shore? In view of the fact that gorse is not restricted to the immediate shore, that it can withstand a certain degree of soil wetness and of flooding duration, and would not be completely prevented from establishing and spreading by adoption of a higher lagoon level regime, then we are inclined to think that gorse control would be better targeted using existing methods.

Should the current water level management be allowed to continue? Or should an endeavour be made to go at least part of the way towards reinstating a lagoon level regime that is closer to the original? In one sense it could be argued that the shore vegetation has already largely adjusted to the artificial lagoon opening procedures. But do we really know this? What further changes might still be taking place in response to the lower-than-natural lagoon levels? At present, the lagoon is artificially opened once soon after the level reaches 2.2 m. Yet in 1994 the lagoon level reached 3.45 m, still without breaching naturally, which gives some indication of the much higher peak levels that must once have been the norm. If Waituna Lagoon was allowed to return to a regime of extended high levels, then what might happen to the *Leptocarpus* rushland that has come to occupy so much of the present shore? To what extent would the drainage requirements for existing farms on low-lying land be permanently compromised if the lagoon was to be managed at higher levels? Perhaps the most critical question is this: in the apparently likely event of sea level continuing to rise, will Waituna Lagoon have any long-term future if moves are not taken to allow for higher lagoon levels?

We are aware that more questions are being asked, than answered, at this point. But this is partly deliberate, insofar as we envisage the discussion stage of possible management scenarios needing additional inputs of information and considered opinion from other people.

One of the constraints to a fuller understanding of the workings of Waituna Lagoon and its vegetation is the absence of basic hydrological data. We encourage DoC to initiate such data gathering.

8. Acknowledgements

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10. Appendices

10.1 LEVELS AND OPENINGS OF WAITUNA LAGOON

Based on Table 4 in Kirk and Lauder (1994); source: Lake Waituna Control Association records supplemented by information supplied by Southland Regional Council. Except where specified in this table all openings have been made at the western end of the lagoon.

Date opened	Date closed	Level (m)	Days open	High tide
25 April 1972	31 May 1972	2.4	35	1400
22 July 1972	8 August 1972	2.2	17	1200
20 Sept. 1972 (East end)	10 Oct. 1972	2.2	20	1200
8 June 1973	9 June 1973	-	1	2100
16 July 1974	beaten by tide	-	-	-
17 July 1974	-	-	-	-
29 May 1975	19 June 1975	2.2	21	1730
17 Sept. 1975	10 Nov. 1975	1.9	23	-
26 July 1976 (Hansens Bay)	23 Aug. 1976	2.4	28	1400
12 May 1977	6 June 1977	2.0	24	2145
7 Oct. 1977	3 Nov. 1977	2.0	27	1000
14 Aug. 1978	10 Oct. 1978	2.2	56	1020
24 Feb. 1979	1 July 1979	1.85	126	1030
26 Sept. 1979	22 March 1980	2.2	175	0900
22 June 1980	27 June 1980	2.2	5	1000
27 Aug. 1980	30 Oct. 1980	2.6	63	1500
24 July 1981	8 Sept. 1980	2.15	47	0845
21 Oct. 1981	26 April 1982	2.0	182	1015
2 July 1982	18 July 1982	2.1	16	1150
13 Sept. 1982	3 Oct. 1982	2.2	20	1132
3 Jan. 1983	30 June 1983	2.2	175	1900
5 Sept. 1983	1 June 1984	2.1	273	1240
4 Oct. 1984	1 May 1985	2.02	210	1034
26 July 1985	17 Sept. 1985	2.35	52	0910
16 May 1986	8 June 1986	2.3	23	0730
14 Aug. 1986	4 May 1987	2.65	259	0910
5 Aug. 1987	23 Aug. 1987	2.35	17	1025
19 May 1988	19 July 1988	2.75	63	1042
20 Sept. 1988	8 March 1989	2.3	168	1000
24 June 1989	10 June 1990	2.6	350	0740
23 Feb. 1991	1 June 1991	2.5	98	0940
21 Oct. 1991	23 May 1992	2.22	210	1300
10 Aug. 1992	24 Oct. 1992	2.7	86	1200
5 July 1994	5 Sept. 1994	3.45	62	
12 July 1995		3.0		

10.2 LIST OF PLANT SPECIES ON MARGINS OF WAITUNA LAGOON

DICOTYLEDONS			
	Acaena microphylla	r	bidibid
	Acaena novae-zelandiae	o	bidibid
*	*Anagallis arvensis*	f	scarlet pimpernell
	Apium prostratum	r	native celery
*	*Atriplex prostrata*	a	orache
	Callitriche petriei	r	native starwort
*	*Callitriche stagnalis*	r	starwort
	Calystegia soldanella	o	shore bindweed
	Cassinia vauvilliersii	r	cottonwood
*	*Centaurium erythraea*	o	centaury
	Centella uniflora	a	
*	*Cerastium fontanum*	o	mouse-ear chickweed
	Chenopodium glaucum subsp. *ambiguum*	f	glaucous goosefoot
*	*Cirsium arvense*	f	Californian thistle
*	*Cirsium vulgare*	f	Scotch thistle
	Coprosma propinqua	f	
	Coprosma sp. aff. *intertexta*	r	
*	*Coronopus didymus*	r	twin cress
	Cotula coronopifolia	f	bachelor's button
	Crassula kirkii	r	
	Crassula moschata	o	
	Crassula sinclairii	o	
	Cyathodes juniperina	o	mingimingi
	Euphrasia repens	r	
*	*Galium palustre*	f	marsh bedstraw
	Galium perpusillum	r	
	Galium propinquum	o	
	Gaultheria macrostigma	r	snowberry
	Gentiana grisebachii	r	
	Glossostigma elatinoides	r	flicks
	Gonocarpus aggregatus	r	
	Haloragis erecta	o	
	Hydrocotyle hydrophila	o	
	Hydrocotyle novae-zeelandiae var. *montana*	f	
	Hydrocotyle sulcata	f	
*	*Hypochoeris radicata*	r	catsear
*	*Leontodon taraxacoides*	f	hawkbit
	Leptinella dioica	f	cotula
	Leptospermum scoparium	a	manuka
	Lilaeopsis novae-zelandiae	a	
	Limosella lineata	f	
*	*Lotus pedunculatus*	f	lotus
*	*Lupinus arboreus*	r	tree lupin
	Mentha cunninghamii	r	native mint
	Mimulus repens	f	
	Muehlenbeckia axillaris	o	creeping muehlenbeckia
	Myriophyllum propinquum	o?	milfoil
	Myriophyllum triphyllum	a	milfoil
	Myriophyllum votschii	o	mini-milfoil
	Nertera balfouriana	o	
	Nertera depressa	o	
	Nertera setulosa	o	
*	*Parentucellia viscosa*	r	tarweed
	Plagianthus divaricatus	f	marsh ribbonwood
*	*Plantago australis*	o	swamp plantain
*	*Plantago lanceolata*	r	narrow-leaved plantain
*	*Plantago major*	r	broad-leaved plantain
	Plantago triandra	r	starweed
	Potentilla anserinoides	f	silverweed
	Pratia angulata	o	panakenake
*	*Prunella vulgaris*	r	selfheal
	Pseudognaphalium luteoalbum	f	cudweed
	Ranunculus acaulis	r	sand buttercup
	Ranunculus glabrifolius	r	
*	*Ranunculus trichophyllus*	r	water buttercup
	Rorippa palustris	f	marsh yellow cress
*	*Rumex acetosella*	r	sheep's sorrel
*	*Rumex crispus*	o	curled dock
*	*Sagina procumbens*	o	pearlwort
	Samolus repens	a	
	Schizeilema cockaynei	r	
*	*Sedum acre*	o	stonecrop
	Selliera radicans	a	selliera
*	*Senecio jacobaea*	r	ragwort
*	*Sonchus asper*	o	prickly sow thistle
*	*Spergularia rubra*	r	sand spurrey
*	*Trifolium repens*	o	white clover
*	*Ulex europaeus*	f	gorse
	Viola cunninghamii	f	native violet
MONOCOTYLEDONS			
*	*Agrostis stolonifera*	a	creeping bent
*	*Ammophila arenaria*	o	marram grass
*	*Anthoxanthum odoratum*	f	sweet vernal
	Carex buchananii	f	
	Carex coriacea	f	rautahi
	Carex dipsacea	r	
	Carex dissita	o	
	Carex flagellifera	r	
	Carex flaviformis	o	
	Carex gaudichaudiana	o	
	Carex pumila	r	sand sedge
	Carex sinclairii	r	
	Carex virgata	f	
	Chionochloa rubra	o	red tussock

* = naturalised (not native); a = abundant; f = frequent; o = occasional; r = rare

	Cordyline australis	o	cabbage tree
	Cortaderia richardii	f	toetoe
*	*Dactylis glomerata*	o	cocksfoot
	Deschampsia caespitosa var. *macrantha*	f	tufted hair grass
	Eleocharis acuta	f	sharp spike-sedge
	Eleocharis gracilis	o	slender spike-sedge
*	*Elytrigia repens*	o	couch
*	*Festuca arundinacea*	o	tall fescue
	Festuca rubra	r	red fescue
	Hierochloe redolens	r	holy grass
*	*Holcus lanatus*	o	Yorkshire fog
	Isolepis aucklandica	r	
	Isolepis basilaris	r	
	Isolepis cernua	f	slender clubrush
	Isolepis distigmatosa	r	
	Isolepis nodosa	a	knobby clubrush
*	*Juncus articulatus*	r	jointed rush
*	*Juncus bufonius*	r	toad rush
	Juncus gregiflorus	f	
	Juncus pallidus	o	
	Juncus planifolius	o	
	Lachnagrostis striata	o	wind grass
	Lepidosperma australe	f	square sedge
	Leptocarpus similis	a	leptocarpus
	Luzula picta	r	wood rush
	Microtis oligantha	r	onion orchid
	Microtis unifolia	r	onion orchid
	Phormium tenax	a	flax
*	*Poa annua*	r	
	Poa cita	f	silver tussock
	Potamogeton ochreatus	r	blunt pondweed
	Prasophyllum colensoi	r	leek orchid
	Ruppia megacarpa	a	horse's mane weed
	Ruppia polycarpa	a	horse's mane weed
	Rytidosperma gracile	o	danthonia
	Schoenoplectus pungens	f	three-square
	Schoenus concinnus	r	
	Schoenus maschalinus	r	dwarf bog-rush
	Triglochin striata	f	arrow-grass
FERNS			
	Blechnum minus	f	swamp kiokio
	Gleichenia dicarpa	o	tangle fern
	Lindsaea linearis	r	
	Pteridium esculentum	f	bracken
BRYOPHYTES			
	Fissidens asplenioides	f	
	Hypnum cupressiforme	o	
	Riccardia sp.	o	
	Thuidium furfurosum	o	
ALGAE			
	Bachelotia antillarum?	o	
	Enteromorpha sp.	o	

10.3 GUILDS OF PLANT SPECIES ON SHORES OF WAITUNA LAGOON

A. RESILIENT SPECIES:

Halophyte	Brackish	Dual purpose	Freshwater wetland	Dryland
Samolus repens				
	Crassula moschata			
	Isolepis cernua			
	Isolepis nodosa			
	Mimulus repens			
	Plagianthus divaricatus			
	Ruppia megacarpa			
		* *Agrostis stolonifera*		
		Carex virgata		
		Centella uniflora		
		Deschampsia caespitosa		
		* *Elytrigia repens*		
		Eleocharis acuta		
		* *Festuca arundinacea*		
		* *Holcus lanatus*		
		Hydrocotyle "montana"		
		Juncus gregiflorus		
		Juncus pallidus		
		Leptinella dioica		
		Leptocarpus similis		
		Lilaeopsis novae-zelandiae		
		Potentilla anserinoides		
		Ruppia polycarpa		
		Schoenoplectus pungens		
		Selliera radicans		
		Triglochin striata		
			Blechnum minus	
			Carex coriacea	
			Carex flaviformis	
			Carex gaudichaudiana	
			* *Centaurium erythraea*	
			Chionochloa rubra	
			Coprosma propinqua	
			Cordyline australis	
			Cortaderia richardii	
			Crassula sinclairii	
			Eleocharis gracilis	
			* *Galium palustre*	
			Galium propinquum	
			Gleichenia dicarpa	
			Hydrocotyle hydrophila	
			Hydrocotyle sulcata	
			Lepidosperma australe	
			Leptospermum scoparium	
			* *Lotus pedunculatus*	
			Myriophyllum triphyllum	
			Myriophyllum votschii	
			Nertera balfouriana	
			Phormium tenax	
			Pratia angulata	
			Pteridium esculentum	
			Viola cunninghamii	
				Acaena novae-zelandiae
				* *Anthoxanthum odoratum*
				Calystegia soldanella
				Carex dissita
				Cyathodes juniperina
				* *Dactylis glomerata*
				Nertera depressa
				Nertera setulosa
				Poa cita
				Rytidosperma gracile
				* *Trifolium repens*
				* *Ulex europaeus*

B. COLONIST SPECIES:

Halophyte	Brackish	Dual purpose	Freshwater wetland	Dryland
	Cotula coronopifolia			
	* *Plantago australis*			
		* *Atriplex prostrata*		
		Chenopodium glaucum subsp. *ambiguum*		
		Lachnagrostis striata		
		Limosella lineata		
			Rorippa palustris	
			* *Rumex crispus*	
			Carex buchananii	
			Juncus planifolius	
				* *Anagallis arvensis*
				* *Cerastium fontanum*
				* *Cirsium arvense*
				* *Cirsium vulgare*
				Haloragis erecta
				* *Leontodon taraxacoides*
				Muehlenbeckia axillaris
				Pseudognaphalium luteoalbum
				* *Sagina procumbens*
				* *Sedum acre*
				* *Sonchus asper*

10.4 PROFILE DIAGRAMS OF TRANSECTS, FIGS 7–15

FIGURE 7. WAITUNA LAGOON, TRANSECT 1.

FIGURE 8. WAITUNA LAGOON, TRANSECT 2.

FIGURE 9. WAITUNA LAGOON, TRANSECT 3.

FIGURE 10. WAITUNA LAGOON, TRANSECT 4.

FIGURE 11. WAITUNA LAGOON, TRANSECT 5.

FIGURE 12. WAITUNA LAGOON,
TRANSECT 6.

FIGURE 13. WAITUNA LAGOON, TRANSECT 7.

FIGURE 14. WAITUNA LAGOON, TRANSECT 8.

FIGURE 15. WAITUNA LAGOON, TRANSECT 9.

10.5 PHOTOGRAPHS, FIGS 16–28

FIGURE 16. WAITUNA LAGOON, WEST SHORE OF SHAND BAY, A SHELTERED SITE WHERE *LEPTOCARPUS SIMILIS* RUSHLAND DESCENDS TO A LOW LEVEL AND IS HERE SEEN GROWING EMERGENT FROM 0.4 m DEPTH OF WATER. AQUATIC BEDS OF MILFOIL (*MYRIOPHYLLUM TRIPHYLLUM*) AT LEFT. LAGOON LEVEL = 1.3 m.

FIGURE 17. *LEPTOCARPUS* RUSHLAND ON EVEN GROUND WITH SWARD OF CREEPING BENT (*AGROSTIS STOLONIFERA*). TRANSECT 1, SOUTH SHORE.

FIGURE 18. *LEPTOCARPUS* UPON WAVE-ERODED PEDESTALS, WITH A VENEER OF GRAVEL UPON PEAT BETWEEN THEM. EXPOSED WEST SHORE NEAR TRANSECT 9.

FIGURE 19. WAITUNA LAGOON, VEGETATION ON SHORE OF WALKERS BAY, NEAR TRANSECT 3. THIS IS A COMMON SEQUENCE OF VEGETATION ON GENTLE GRAVEL SHORES: SCATTERED TURF AND *LEPTOCARPUS* CLUMPS, GRADING TO FLAX, THEN MANUKA SCRUB ON PEATLAND.

FIGURE 20. A GENTLE TURF-COVERED SHORE, GRADING UP TO KNOBBY CLUBRUSH AND GRASSES ON STORM RIDGE AT LEFT. TRANSECT 4, WALKERS BAY, WAITUNA LAGOON.

FIGURE 21. EXPOSED SHORE WITH A NARROW AND INTERRUPTED ZONE OF *LEPTOCARPUS*, EMBAYMENTS OF GRAVEL VENEERED OVER PEAT, *CAREX* SWARD ABOVE ERODED LOW BANK, THEN MANUKA SCRUB. WAITUNA LAGOON, WEST SHORE, TRANSECT 9.

FIGURE 22. WAITUNA LAGOON, VEGETATION ZONES AT EASTERNMOST END. GRAVELLY SHORE WITH DRIFT MATERIAL, SPARSE TURF AND SCATTERED *LEPTOCARPUS* CLUMPS. MID-LEVEL ZONE HAS *CAREX PUMILA*, THEN GRASS TUFTS (*DESCHAMPSIA CAESPITOSA*, TOETOE), THEN FLAX AND GORSE ON SCARP.

FIGURE 23. COLONISTS ON REAR OF COASTAL GRAVEL BAR ENCLOSING WALKERS BAY, WAITUNA LAGOON (TRANSECT 8). FORMER STRAND LINES ARE MARKED BY ZONES OF ORACHE (CENTRE), SCARLET PIMPERNELL (INTERRUPTED LINE OF PLANTS), THEN SCOTCH THISTLE (LEFT, AMONG MARRAM GRASS).

FIGURE 24. GORSE SCRUB ESTABLISHED AT UPPER MARGIN OF *LEPTOCARPUS* ZONE, AGAINST REAR SIDE OF COASTAL BEACH RIDGE, HANSENS BAY, SOUTH SHORE OF WAITUNA LAGOON, TRANSECT 7.

FIGURE 25. WAITUNA LAGOON, ERODED NORTH SHORE OF WALKERS BAY SHOWING THE LAYERS OF PEAT AND QUARTZ GRAVELS UPON WHICH THE ADJACENT PEATLAND VEGETATION HAS DEVELOPED.

FIGURE 26. A PORTION OF THE WESTERN SHORE MARKEDLY ERODED INTO MANUKA SCRUB AND REVEALING c. 2 m OF PEAT, CONTAINING BURIED WOOD, OVERLYING FINE SILTS.

FIGURE 27. ACTIVE SHORE PROCESSES: STORM-DEPOSITED GRAVELS WITH THREE-SQUARE, OVERLAID WITH DISLODGED AQUATIC MATERIAL IN A BAYHEAD AMONG *LEPTOCARPUS*. TRANSECT 7.

FIGURE 28. DEAD PATCHES OF *LEPTOCARPUS* ON GENTLE PART OF NORTH SHORE, NOW BEING COLONISED BY ORACHE AND CREEPING BENT.