Waituna Lagoon: summary of existing knowledge and identification of knowledge gaps

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R.M. Thompson and G.R. Ryder

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R.M. Thompson and G.R. Ryder

Ryder Consulting Ltd, P.O. Box 1023, Dunedin, New Zealand

ABSTRACT

Waituna Lagoon represents an exceptional example of a largely unmodified coastal lake-type lagoon within a largely intact coastal wetland system. This report reviews existing information on the Lagoon with a view to making recommendations for future research and management. The Lagoon contains important habitat for resident and migratory birds including nationally critical and endangered species. The aquatic community includes a *Ruppia*-dominated macrophyte community not well represented elsewhere and a number of native fish species, in addition to a valued recreational trout fishery. Shoreline vegetation patterns are largely unmodified and include notable cushion-bog and sand-ridge plant associations. In surrounding areas the presence of several alpine and sub-alpine species at sea level is of botanical interest. Lagoon levels have traditionally been managed by opening the Lagoon to the sea to improve local drainage and increase access for sea-run trout. In recent history the Lagoon has been open for a greater proportion of the year. The effects of these prolonged openings on the Lagoon flora and fauna are unknown but potentially significant, and require urgent study. Recent hydrological research suggests that lagoon opening may have a minimal effect on farm drainage and that a reappraisal of this activity is required. Other threats to the ecology of the Lagoon include poor water quality in the inflows due to intensification of land use in the catchment. Nutrient levels are very high and have the potential to result in eutrophication. There is evidence from within the Lagoon of high sedimentation rates and infilling of some areas. A coordinated programme involving regional authorities, DOC and local community groups is required to improve catchment land management and develop clear management goals for Waituna Lagoon.

Keywords: Waituna, lagoon, threats, hydrology, catchment, botany, birds, fish, water quality, management, South Island, New Zealand

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1. Introduction

Estuary and lagoon ecosystems are amongst those most strongly impacted by human activities. These environments are subject to the combined influences of changes throughout their catchments. In addition, lagoons and estuaries are often physically altered by management to prevent flooding, improve passage for vessels or reclaim land for agriculture or housing.

Waituna Lagoon, near Invercargill (Fig. 1) represents a largely unmodified example of a temperate, shallow coastal lagoon, within a largely intact coastal wetland system (the Awarua Wetlands). In recognition of their importance, the Lagoon and a section of the Wetlands were 'reserved for wetlands management purposes' in 1971, and in 1976 the Waituna Wetlands Scientific Reserve was one of two New Zealand wetlands to be designated of international significance under the Ramsar convention. In 1983 the area was established as a scientific reserve, and is administered by DOC. In addition to its national and international significance as a wetland of note, the Waituna Wetland is also culturally significant to the local Ngai Tahu people. The special relationship between the area and Ngai Tahu is recognised under a Statutory Acknowledgement within the Ngai Tahu Claims Settlement Act of 1998. The Lagoon is also valued by recreational fishers, particularly for the large sea-run brown trout (*Salmo trutta*) often caught there.

The Wetlands and Lagoon at Waituna were recognised by Ramsar on the grounds that they 'support an appreciable assemblage of endemic and threatened species and communities, have special value for maintaining the genetic and ecological diversity of the region and provide a habitat for plants and animals at critical stages of their biological cycles'. The Ramsar criteria in particular, value wetlands of international importance to waterfowl, those that represent a near-natural wetland type in a particular biogeographic region, and those that support rare or endangered species. The Waituna Lagoon and wetland complex are both nationally and internationally significant on those grounds (Cromarty & Scott 1996).

Despite the largely unmodified nature of the immediate surroundings of the Lagoon, the continuing protection of the lagoon/wetland complex and the biota within it requires an appreciation of the changes that are ongoing within the catchment. Intensification of agriculture and degradation of water quality have the potential to affect the physical structure of the Lagoon, the nature of its nutrient cycles and the plants and animals that live within it.

This report aims to fulfill the following objectives:

- To briefly review existing information on the Lagoon
- To identify potential risks to the Lagoon and define management priorities
- To identify knowledge gaps that need to be addressed to aid management

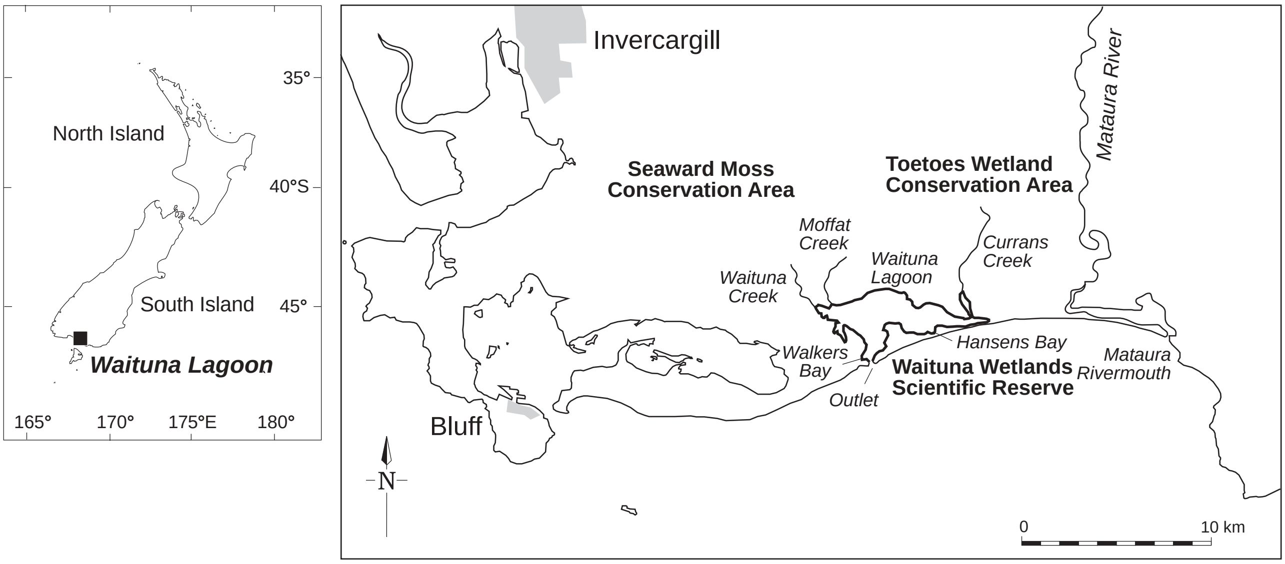


Figure 1. Location of Waituna Lagoon and accompanying wetlands, with major features of the Lagoon.

2. Review of existing information

We reviewed information from a variety of sources, including scientific reports and DOC records, data from Environment Southland, Fish and Game Southland and local residents. A site visit was made to the Lagoon in October 2001. Additional information on similar lagoons and their management was obtained through a search of University of Otago library databases.

2.1 PHYSICAL SETTING AND DEFINITIONS

Coastal water bodies can be classified into two groups, lagoons and estuaries (Kirk & Lauder 2000), based on their structure and the way in which they were formed. Estuaries are formed by the inundation of a river valley or coastal plain by sea level change, are directly affected by tidal influences (Kjerfve 1994), and have a free connection with the open sea (Cameron & Pritchard 1963). In contrast, lagoons have a restricted connection with the sea, usually through a breach in a barrier beach or bar which either forces the river to flow parallel to the coast, or causes water to pool behind the bar (Kjerfve 1994).

Kirk & Lauder (2000) reviewed the classification of New Zealand's coastal water bodies, and distinguish two types of lagoon—hapua, or 'river mouth' lagoons, and Waituna-type or 'coastal lake' lagoons. Hapua are essentially sections of the lower river which flow parallel to the coast behind a gravel bar, before breaching the bar at one end. Examples of such lagoons include the Waiau River in Southland and the mouths of many of the braided rivers of the South Island's east coast (e.g. Rakaia, Ashburton, Waitaki). Studies of lagoons of this type are summarised in Kirk (1991). Lagoons of the Waituna-type occur where pooling of water behind the barrier beach forms a coastal lake. These systems are more usually closed to the ocean than open to it (Kirk & Lauder 2000), are associated with smaller rivers than hapua, and have a range of salinities ranging from fresh to brackish. Lake Ellesmere is an example of such a lagoon, and others exist at Grassmere, Wairau, Washdyke and Wainono.

Waituna Lagoon is the archetypal example of a coastal lake lagoon in New Zealand. The Lagoon has formed on a gravel outwash plain into which three major streams discharge (Waituna Creek, Moffat Creek, Currans Creek) (Fig. 1). Longshore drift along the south coast has produced a barrier beach which restricts drainage, forming a lagoon and wetland complex covering approximately 3556 ha (Rance & Cooper 1997). The barrier beach ranges from 1500 m wide at its widest point (in the centre) to approximately 50 m wide at each end. When open to the sea the Lagoon breaches the beach at the southwest end (although it has formerly also breached at the northeastern end (Johnson & Partridge 1998)).

The physical nature of the Lagoon itself has only been described anecdotally by Johnson & Partridge (1998). The bed is predominantly composed of fine quartz gravels, bordered on the seaward side by the gravels and sands comprising the barrier beach. To the west and north however, impeded drainage has allowed a peat layer of 120 to 240 cm to accumulate (Kelly 1968). This peat forms the basis for a landscape of bogs, tarns and salt-marsh stretching inland to the north and west to connect with the Seaward Moss Conservation Area, an extensive tract of undisturbed wetlands on the Awarua Plains. To the north and east the wetlands are less extensive and have been affected by drainage and grazing, but still reach as far as the Mataura River (Fig. 1).

2.2 GEOLOGY

The gravel outwash plain on which the Lagoon and Wetlands sit dates from the last Ice Age (1.63 mya) and is bounded to the west by the volcanic intrusives of the Longwood Range, and to the north and east by Mesozoic greywackes underlying the Catlins and Hokonui Hills. Other volcanic intrusives form Bluff Hill and Bluff Peninsula, which have been connected to the mainland by the expansion of the outwash plain (Thornton 1990). Beneath the alluvial gravels there is a sequence of mid-Tertiary gravels, sands and mudstones that include a significant component of lignite (Department of Lands and Survey 1984). The area was investigated as a possible site for a coal to gas synthetic fuels plant in the 1980s (Riddell et al. 1988) but development was not pursued for economic reasons.

2.3 WATER CHEMISTRY

There has traditionally been little water chemistry data gathered on the Lagoon or Wetlands. Environment Southland have maintained a sampling site on Waituna Creek at Marshall's Road since 1995. Water samples are taken at monthly intervals and measured for a suite of variables (Table 1). The Waituna Landcare Group in

TABLE 1. SUMMARY OF WATER QUALITY DATA GATHERED BY ENVIRONMENT SOUTHLAND FROM WAITUNA CREEK (MOFFAT RD. BRIDGE), JULY 1995–JUNE 2001.

	MEAN	RANGE
Temperature (°C)	11.2	5.6–19.9
pH	6.7	6.0–7.8
Conductivity (µS/cm)	206.6	157.7–268.0
Visual clarity (m)	0.53	0.13–1.15
Turbidity (NTU)	12.2	1.7–26.0
Nitrate (mg/L)	0.30	0.01–3.50
Ammonia (mg/L)	0.15	0.01–2.40
Dissolved reactive phosphorus (mg/L)	0.03	0.01–0.16
Dissolved oxygen (%)	84.6	64.8–121.8

association with Environment Southland have recently initiated a sampling programme including all of the major tributaries and the Lagoon itself.

The water quality entering the Lagoon through Waituna Creek is generally circum-neutral (Table 1) with a distinct seasonal cycle in water temperatures, peaking in February and March (Environment Southland, unpubl. data). The inflow shows evidence of the effects of land use in the catchment. Nitrate and ammonia levels are generally high, with peaks that exceed the national water quality guidelines (Australia and New Zealand Environment and Conservation Council (ANZECC) 2000). Dissolved reactive phosphorus is present in appreciable amounts, and increases during high flow events (Environment Southland, unpubl. data).

Measurements of enterococci and faecal coliforms have only been taken in Waituna Creek since July 2000, however they indicate levels that are of concern. Counts of faecal coliforms ranged from 58 to 16 000 cells/100 mL (median = 610), and counts of enterococci ranged from 52 to 7 500 (median = 530). These median values exceed levels considered acceptable for primary contact (e.g. swimming) and in the case of enterococci, for secondary contact (e.g. boating and fishing) (ANZECC 2000). The maximum values exceed the guidelines for secondary contact by 16 times (faecal coliforms) and 33 times (*E. coli*). Values from Waituna Creek were comparable to those recorded in meat works' effluent in the Mataura River (Ryder 1998) and are strongly suggestive of point source discharges of effluent to the stream at some point.

Changes over time in the water quality entering the Lagoon are also apparent (Fig. 2). In particular, there has been an increase in the amount of ammonia entering the Lagoon, probably as a result of agricultural effluent. Prior to 1999 ammonia levels in Waituna Creek had reached a maximum of 0.32 mg/L. Since that time levels have exceeded 0.5 mg/L, the level at which some invertebrates suffer toxicity from ammonia (ANZECC 2000) on five separate occasions, and have twice exceeded 0.88 mg/L, the toxic level for fish (ANZECC 2000). Salmonid fish are particularly sensitive to ammonia and suffer both sub-lethal (reduction in growth, reduction in breeding success) and lethal effects (ANZECC 2000).

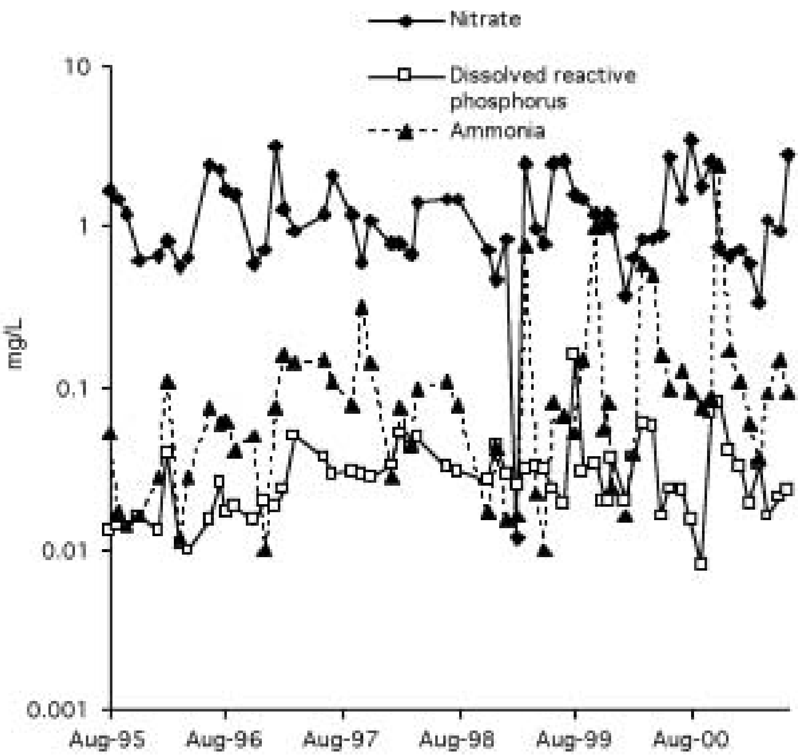


Figure 2. Concentrations of major nutrients (log scale) in Waituna Creek since regular water quality monitoring was initiated (Environment Southland, unpubl. data).

Dissolved oxygen levels in the Creek are generally relatively high, although the water is not super-saturated, reflecting the relatively sluggish nature of the flow. However, the situation within the Lagoon, where there are large, still water areas, is largely unknown. The body of the Lagoon was first sampled for pH and salinity by Johnson & Partridge (1998) and an additional set of conductivity measurements was taken by Environment Southland in 2001 (converted to salinity in this report). Salinities ranged from 0.9 ppt in Currans Creek to 5.1 ppt near the usual outlet at Walkers Bay (c.f. sea water at 35 ppt) when the Lagoon was closed to the sea (Table 2). Measurements of pH revealed acid inflows from the peat bogs around Currans Creek, with pH increasing towards Walkers Bay. Recently the Waituna Landcare Group, in conjunction with Environment Southland, have begun sampling the body of the Lagoon on a regular basis.

TABLE 2. SALINITY AND PH MEASUREMENTS TAKEN FROM THE BODY OF WAITUNA LAGOON WHILE CLOSED TO THE SEA IN APRIL 1995 (MARKED *) (JOHNSON & PARTRIDGE 1998), AND IN JULY 2001 (ENVIRONMENT SOUTHLAND, UNPUBL. DATA).

	SALINITY (PPT)	PH
Currans Creek bridge*	0.9	5.3
Waituna Creek	0.9	–
Waituna Creek outlet	0.9	–
Hansens Bay*	0.9	5.8
North shore (Moffat Rd.)*	1.1	5.6
North shore	1.2	–
East shore*	2.3	5.9
Walkers Bay*	5.1	6.5

There is limited knowledge about the water chemistry of the Lagoon and the way in which this changes in response to whether the Lagoon is open or closed, the quality of water inputs, and the level of the Lagoon. One of the defining attributes of a Waituna-type lagoon is its relatively oligotrophic (nutrient-poor) nature (Kirk & Lauder 2000). It has been suggested that water chemistry changes associated with land use may have caused changes in the distribution of some plant species and the invasion of others (Johnson & Partridge 1998).

In addition to the nutrient component of incoming waters, there is a need to understand sediment inputs to the Lagoon. There is anecdotal evidence of increased rates of siltation in the Lagoon affecting fishing holes (R. Waghorn, pers. comm.) and some evidence of expansion of rush beds associated with build-up of silt (Johnson & Partridge 1998). Environment Southland have monitored turbidity and water clarity in Waituna Creek since 1995 (Table 1), and have shown peaks in turbidity and low water clarity associated with high flow events. This presumably reflects inputs of sediment into the Lagoon, which may alter in response to catchment land use. A short-term study (Environment Southland, unpubl. data, June–July 2001) of sedimentation rates in Waituna Creek and the Lagoon revealed high rates of sedimentation of fine silts and sand (Table 3).

TABLE 3. SEDIMENTATION RATES IN WAITUNA CREEK AND LAGOON, JUNE–JULY 2001 (ENVIRONMENT SOUTHLAND, UNPUBL. DATA).

	MEAN (± SEM) SEDIMENTATION RATES (mm/DAY)
Waituna Creek (near bridge)	0.736 (0.104)
Waituna Creek (lower section)	0.582 (0.049)
Lagoon (Waituna Creek mouth)	1.544 (0.761)
Lagoon (northern shore)	1.045 (0.073)

There is no information on where sediments are accumulating in the Lagoon, or how these patterns have changed through time, although Johnson & Partridge (1998) provide some evidence for infilling of the Lagoon with sediment. Such sedimentation has important consequences, in that it may smother macrophytes or benthic habitat, and is also important in the nutrient balance of the Lagoon. Fine sediments are important stores of nutrients that are resuspended by the action of wind or waves. In most shallow lakes, the nutrients accumulated in the sediments from years of high nutrient inputs are such that current management of inflows has little immediate effect (Ward & Taylor 1993; Ogilvie & Mitchell 1998). Waituna appears to be fortunate in that fine sediments are not widespread in the Lagoon (Johnson & Partridge 1998).

There is evidence that the quality of the water from Waituna Creek is poor. Management of the Lagoon will require management of the entire catchment, particularly with regard to intensification of agriculture and the risk to water quality that this represents. The effects of high levels of nutrients on Waituna-type lagoons are not well understood, but studies on a similar system (Tomahawk Lagoon near Dunedin) (Mitchell et al. 1988; McKinnon & Mitchell 1994) have shown the potential for sudden and catastrophic changes as a result of nutrient inflows. High nutrient levels in the Waituna Lagoon water column could result in phytoplankton proliferation, causing shading and loss of macrophyte beds. Lake systems which have been affected in this way have switched permanently from a clear water phase dominated by macrophytes, to a cloudy water phase dominated by phytoplankton (Scheffer et al. 1993). The potential for such a shift exists when Waituna Lagoon is closed for long periods.

An understanding of the nutrient buffering capacity of the Lagoon and Wetlands, sedimentation rates, internal circulation patterns and water residence time are needed to effectively manage the Lagoon. Ultimately, opening of the Lagoon may be as necessary to shed nutrients and silts as to control lagoon levels.

2.4 HYDROLOGY

The Lagoon and Wetlands form at the confluence of several small creeks, the three most substantial of which are Waituna Creek (catchment area 12 555 ha), Moffat Creek (1700 ha) and Currans Creek (5700 ha). Historically these waterways fed into the Lagoon, which increased in depth until it overtopped the gravel barrier beach, breaching it and emptying the Lagoon (Johnson & Partridge 1998). This natural regime would have involved the Lagoon rising as much as 4 m above sea level before emptying.

The first artificial breach of the barrier beach was made in 1908, in an effort to improve the fishing in the Lagoon. Thereafter the Lagoon was opened periodically by fishermen until the Department of Lands and Survey took responsibility in 1958. This situation lasted until 1968 when the Lake Waituna Control Association was formed to manage Lagoon levels, mainly to ensure free drainage of surrounding farmland. Initially the Lagoon was opened annually, then in later years a trigger value was applied to dictate when the barrier was breached. This evolved into the current protocol, governed under Resource Consent A784 that was granted by Environment Southland in September 1993. The consent states that when the Lagoon reaches 2 m on the Waghorns Road bridge staff gauge, DOC should be informed that a breach is imminent; and that when the gauge reads 2.25 m the barrier beach should be breached.

The current management regime has seen significant variation in water levels, and the Lagoon remaining open to the sea for varying periods. Throughout the 1970s and 1980s the Lagoon water level was between 2 and 2.5 m and it was opened approximately annually. In 1994 the Lagoon water level reached 3.45 m, inundating some land near Currans Creek. The Lagoon was artificially opened that year and in subsequent years. In 1997 the Lagoon was opened to the sea in December and remained open for the longest time on record, finally closing in May 2000. After closure the Lagoon rose rapidly, reaching the trigger value on 14 October 2000. The Lagoon was opened and remained open until December 2001 (Environment Southland, unpubl. data). Over time, it appears that the Lagoon has been open for a greater proportion of the year (Fig. 3A) and that the time that the Lagoon remains open after the barrier beach is breached is increasing (Fig. 3B). There have been no natural breaches of the Lagoon barrier beach since 1972.

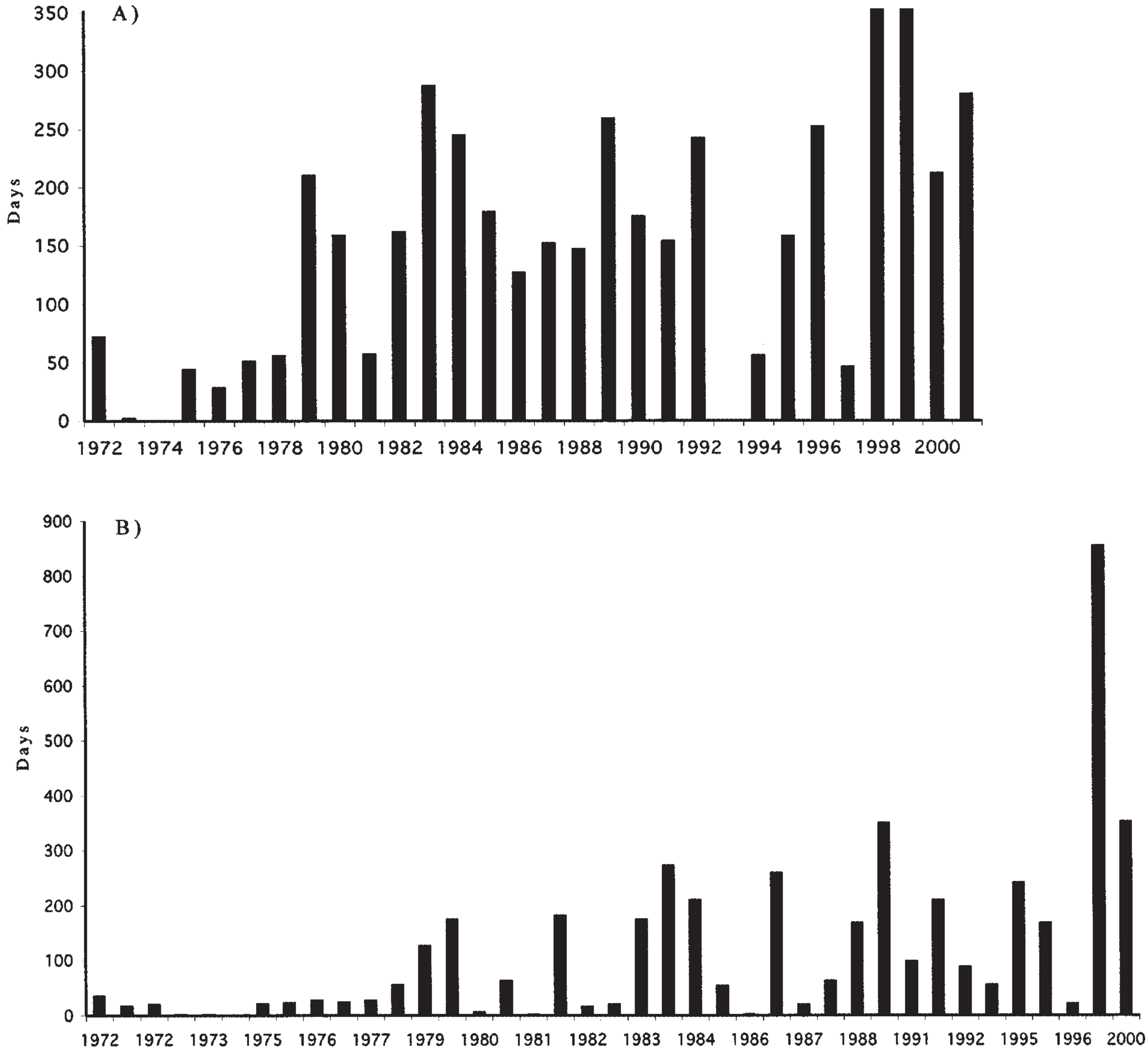
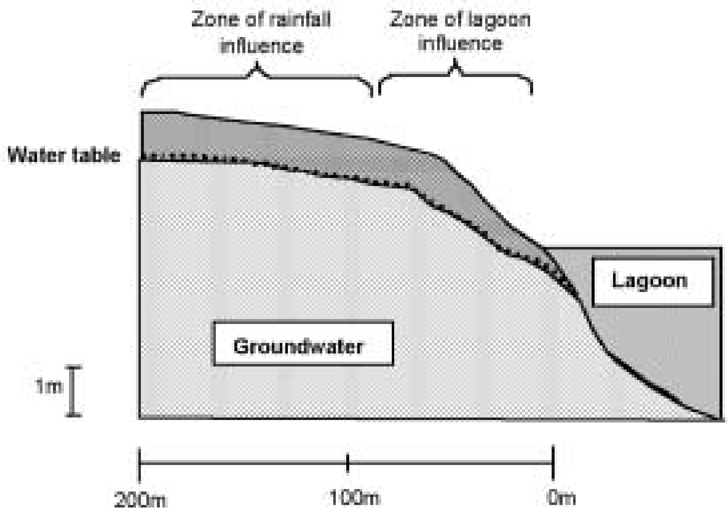


Figure 3. Status of Waituna Lagoon with regard to the barrier beach being breached (lagoon open) or intact (lagoon closed). A) Number of days in each calendar year that the Lagoon was open. B) Number of days that the Lagoon stayed open after the barrier beach was breached.

Given that the Lagoon's levels are managed largely to improve drainage, DOC contracted Landcare Research in 1999 to investigate the relationship between Lagoon levels and local drainage patterns. That study (Jackson et al. in press) used soil water tensiometry to detect hydraulic gradients within the areas around the Lagoon. A low hydraulic gradient indicates slow movement of water through the soils. The results of Jackson et al.'s (in press) study are summarised in Fig. 4. This shows a very shallow (0.15–0.80 m) water table that is 'perched' above the water level in the Lagoon. The low hydraulic gradient in the soils indicate that water is slow to drain because of slowly permeable subsoils (Jackson et al. in press).

The response of the area to rainfall operates on two time scales. Firstly, rainfall lifts the level of the water table until it reaches the surface, causing flooding. At the same time, the Lagoon fills. This has an influence on soil drainage, but only over long time periods (months). Although there is a correlation between

Figure 4. Diagrammatic representation of the hydrological situation around Waituna Lagoon, showing perched water table and zones of influence of the Lagoon and rainfall. (Based on Jackson et al. in press.)



Lagoon levels and flooding, in Jackson et al.'s (in press) opinion, one does not cause the other i.e. if the Lagoon was empty there would still be flooding.

After the opening of the Lagoon in October 2000, the water level dropped from the trigger value of 2.25 to 1.7 m. Water tables dropped immediately by approximately 0.5 m in the zone immediately adjacent to Moffat Creek, but 200 m away from the Creek water tables took almost 3 months to lower (Jackson et al. in press). In contrast to this extremely slow response, 10 mm of rainfall in a day increased water tables immediately by almost 10 mm, and took more than a week to drain. The Lagoon increased in depth during the same event by 100 mm, reflecting the fact that it is gathering water from a catchment almost 10× its own area. Modeling based on this data suggests that the influences on water table height are dominated by rainfall alone at distances of > 60 m from the Lagoon or its major tributaries (Fig. 4) (Jackson et al. in press).

The work by Jackson et al. (in press) has remedied many of the concerns over the lack of data about the effect of the Lagoon on surrounding hydrology. The hydrological model for the Lagoon has the potential to be modified and integrated into a decision-making tool that includes many aspects of lagoon management, including water levels and factors such as nutrient concentrations and siltation. Other hydrological factors that are likely to be important to the long-term management of the Lagoon are the movement and distribution of groundwater with respect to the implications of land disposal of effluent in the catchment. Such knowledge would guide the Regional Council in assessing future requests for consents for such activities, and allow a better understanding of the degradation of water quality in the inflows.

2.5 BOTANICAL KNOWLEDGE

There have been extensive botanical surveys of the Lagoon and surrounding wetlands, (Crosby-Smith 1927; Kelly 1968; Department of Lands and Survey 1984; Johnson & Partridge 1998). As a result, the botanical aspects of the Lagoon and its surroundings are perhaps the best understood part of its ecology. The area is notable for the presence of the interesting cushion-bog vegetation and sand-ridge plant associations (pingao (*Desmoschoenus spiralis)*, tussock (*Chionochloa* spp.) and locally uncommon species of mat-daisy (*Raoulia* spp.)). In particular, the presence of several alpine and sub-alpine species at sea level (Appendix 1) is of botanical interest (Rance & Cooper 1997). Two hundred and thirty-six species of plants, moss and algae have been recorded from the Lagoon and surrounding wetlands (Appendix 1). Of these only 45 are naturalised (exotic species), and three species are considered to be declining (*Isolepis basilaris*, in serious decline; *Deschampsia cespitosa* var. *macrantha* and *Urtica linearifolia* in gradual decline) (Molloy et al. 2001) (Appendix 1).

2.5.1 Aquatic vegetation

The vegetation of the Lagoon itself was first described in detail by Johnson & Partridge (1998). They considered the Lagoon unique because of its intact *Ruppia megacarpa* (horse's mane weed)-dominated macrophyte communities. At the time of Johnson & Partridge's study (April 1995) the Lagoon was closed to the sea and it is unknown what effect the prolonged opening in 1997–2000 had on the macrophytes. The aquatic vegetation is dominated by predominantly freshwater species, although the brackish-water tolerant algae, *Enteromorpha* spp. and *Bachelotia antillarum*, were present near the Lagoon's outflow at Walkers Bay (Johnson & Partridge 1998). The communities observed in Waituna are more typical of those described from freshwater lakes (Johnson 1972), although charophyte algae are not present in the Lagoon (but they are in the catchment: (Riddell et al. 1988)). Other lagoons (e.g. Lake Ellesmere) in New Zealand tend to be more saline, with localised high salinity areas due to evaporation (Johnson & Partridge 1998). In the cooler climate at Waituna freshwater plants dominate most of the Lagoon.

Johnson & Partridge (1998) described a macrophyte zonation pattern varying with depth in the Lagoon, with deeper areas dominated by *Ruppia megacarpa* and *Myriophyllum triphyllum.* Shallower silty bays are dominated by a more diverse community that includes *Lilaeopsis novae-zelandiae* and *Glossostigma elatinoides* (Table 4). Three naturalised species are present, although not abundant. Of these *Ranunculus trichophyllus* probably has the greatest potential to invade, especially if nutrient levels in the Lagoon were to increase (Johnson & Partridge 1998). The predominantly freshwater nature of the Lagoon places it potentially at risk of invasion by aquatic weed species, and vigilance and education of boat owners is required. There has been no research to date on the phytoplankton communities in the Lagoon. Phytoplankton are useful indicators of nutrient enrichment, which can result in 'blooms' (excessive proliferations) and may favour species which are toxic to livestock and humans (e.g. some species of cyanobacteria). There are anecdotal reports of blooms of cyanobacteria around the margins of the Lagoon, and aerial photographs taken in the summer of 2001 showed blooms occurring in shallow areas, although the species responsible was not identified.

2.5.2 Terrestrial and wetland vegetation

The vegetation patterns ascending the shoreline of the Lagoon have been well described by Johnson & Partridge (1998) and are generalised in Fig. 5. Most species present are not typical estuarine species but are either 'resilient' or

TABLE 4. DEPTH DISTRIBUTION OF AQUATIC PLANTS IN WAITUNA LAGOON. DOMINANT PLANTS AT EACH DEPTH ARE SHOWN IN BOLD. PLANTS ARE NATIVE UNLESS THEY ARE MARKED AS BEING NATURALISED (N).

DEPTH (m)	TYPICAL SPECIES
0.1–0.5	***Ruppia polycarpa***
	Myriophyllum triphyllum
	Glossostigma elatinoides
	Lilaeopsis novae-zelandiae
	Mimulus repens
	Selliera radicans
	Brown/black lichens e.g. *Verrucaria* spp.
	Ranunculus trichophyllus (N)
	Callitriche stagnalis (N)
>0.5–0.7	***R. megacarpa***
	M. triphyllum
	Green filamentous algae
	(saline conditions = *Enteromorpha* sp.,
	Bachelotia antillarum)
	Potamogeton ochreatus (N)
>0.7–2.0	***R. megacarpa***
	M. triphyllum

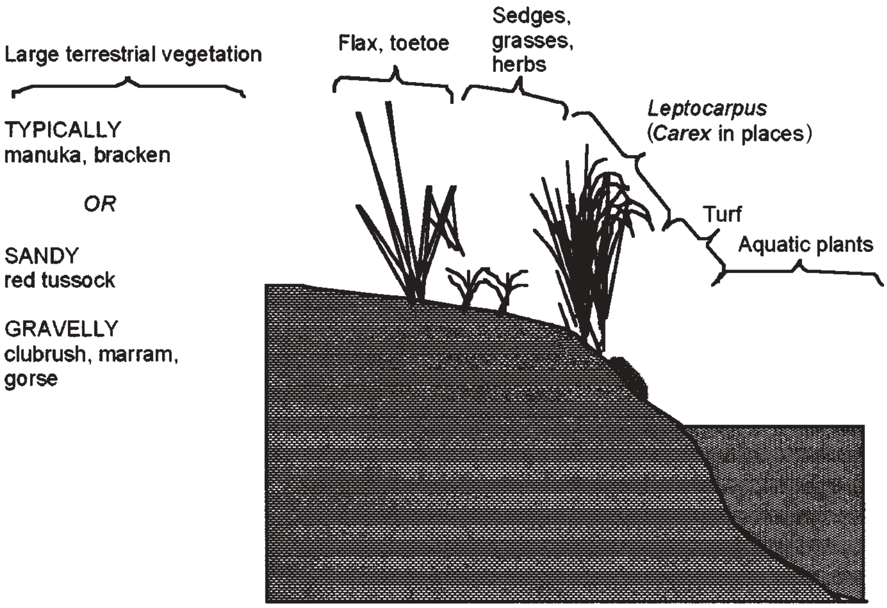


Figure 5. Typical shoreline zonation pattern at Waituna Lagoon (generalised from Johnson & Partridge 1998).

'freshwater wetland' species (Johnson & Partridge 1998). Around the edge of the Lagoon there is typically a low turf community, which grades into *Leptocarpus* rushland, which may form mounds or pedestals. The cushion-bog community around the Lagoon and larger pools is similar to that found at Lake Te Anau (Johnson 1972) and contains many sub-alpine and alpine species (Rance & Cooper 1997). Low-lying sites are generally dominated by sedges, rushes and bryophytes around ponds or pools, and a component of flax (*Phormium* sp.) and toetoe (*Cortaderia* spp.) (Rance & Cooper 1997). In drier parts of the wetland the most extensive vegetation type is wire rush (*Empodisma* *minus)* with tangle fern (*Gleichenia dicarpa)*. In sandier locations, tussock and mat-daisies are dominant. Further away from the water's edge there is an ecotone (boundary) to shrublands dominated by manuka (*Leptospermum scoparium*) and inanga (*Dracophyllum longifolium*). *Urtica linearifolia* has recently reappeared in the margins of the Lagoon after not being observed for over 70 years (W. Cooper, pers. comm.). This may be due to the saline influence from the prolonged period of opening from 1997. The typical saline zonation of *Plagianthus* sp. (saltmarsh ribbonwood) is not present (probably due to reduced saline influence) (Johnson & Partridge 1998).

The maintenance of this zonation pattern is probably due to the hydrological regime of the Lagoon (Johnson & Partridge 1998). Although most species present are tolerant of wet soils and boggy conditions, only species on the lower part of the shore are tolerant to flooding. Downshore expansion of *Leptocarpus* is probably limited by the fact that the rush cannot survive prolonged (> 300 days) periods of inundation. The ecotone between the wetland and shrubland vegetation types may also be maintained by the latter's inability to tolerate flooding (Johnson & Partridge 1998).

Given the apparent importance of Lagoon levels in structuring shoreline plant communities, changes in those patterns due to Lagoon management are not unexpected. Waituna is notable for the wide band of *Leptocarpus* in the lower mid-shore. Johnson & Partridge (1998) state, 'the abundance which *Leptocarpus* rushland has achieved at Waituna … probably reflects a response that was initiated by the earliest artificial Lagoon openings, and accelerated by increased availability of sediment and probably also nutrients.' It appears that lower Lagoon levels have facilitated the downward migration of rushes, as evidenced by aerial photo analysis (Fig. 6), and some invasion by gorse (Johnson 1986). It could be expected that manuka will also expand, the fact that it has not may suggest that there is competitive resistance to invasion of *Leptocarpus* by manuka (Johnson & Partridge 1998).

The expansion of *Leptocarpus* may also be due in some degree to infilling of the Lagoon by fine sediment. Johnson & Partridge (1998) describe evidence of significant sedimentation on the Lagoon over 50 years, and the latest images suggest that this process may be ongoing (Fig. 6). *Leptocarpus* expansion may be facilitated by increased availability of silt and nutrients; and the presence of the rush lower in the shore acts to trap sediment and further facilitate expansion. The effect on *Leptocarpus* expansion of the prolonged salt water phase in 1997–2000 has not been described, but it is one of the species more able to cope with brackish conditions, so may have been further advantaged. *Juncus* had been observed to be invading some *Leptocarpus* stands, possibly due to disturbance and nutrient enrichment from cattle trampling and grazing (Johnson & Partridge 1998) and from disturbance by gulls (Johnson 1986). Such disturbance may also facilitate the invasion of *Leptocarpus* by woody species higher on the shore.

The natural role of fire in the Waituna system is unclear. Fires were certainly lit in the wetland in the early part of the 20th Century (Johnson & Partridge 1998), and fire was regarded by Kelly (1968) as an important factor in maintaining *Empodisma minus* and *Gleichenia dicarpa* in the community. Johnson & Partridge (1998) hypothesise that without fire some manuka may progress back to lowland forest. With fire manuka will be maintained, but each fire will

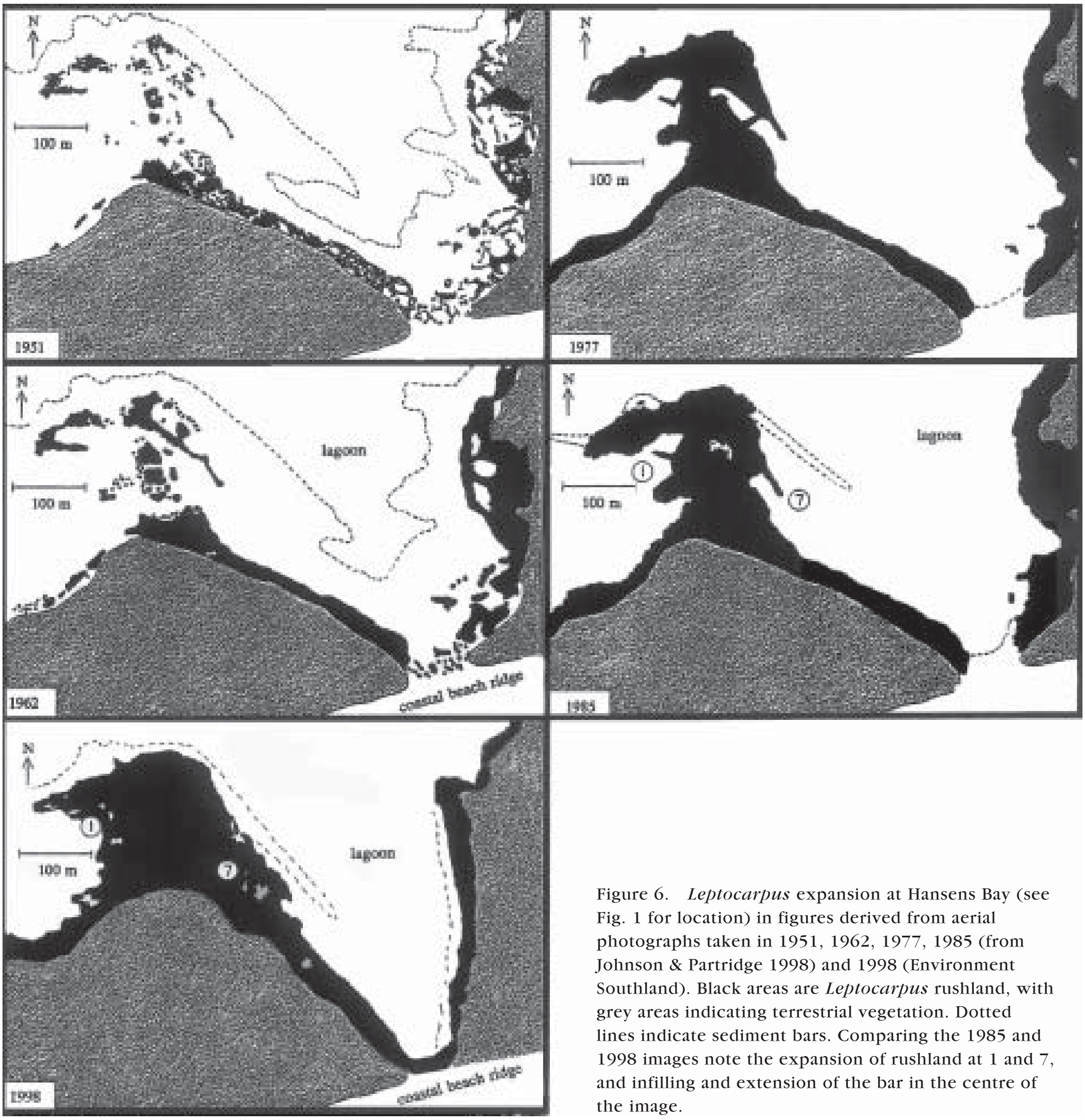


Figure 6. *Leptocarpus* expansion at Hansens Bay (see Fig. 1 for location) in figures derived from aerial photographs taken in 1951, 1962, 1977, 1985 (from Johnson & Partridge 1998) and 1998 (Environment Southland). Black areas are *Leptocarpus* rushland, with grey areas indicating terrestrial vegetation. Dotted lines indicate sediment bars. Comparing the 1985 and 1998 images note the expansion of rushland at 1 and 7, and infilling and extension of the bar in the centre of the image.

increase the likelihood of gorse invasion. Facilitation of public access to the Lagoon area needs to assess the risk of fire seriously.

Waituna is at the freshwater extreme of lagoons and has a plant community that is adapted to freshwater conditions. In this, it is most similar to the lagoons of the West Coast, where freshwater predominates, and sediment loads and nutrients are low (Robertson et al. 1991). Management of Lagoon levels that result in prolonged opening of the Lagoon will increase the role of salt water in the system. Land use change in the catchment will potentially increase sediment loads and nutrient loadings to the Lagoon. These factors have the potential to disrupt the natural patterns of the vegetation around the Lagoon, and to facilitate invasion by weed species. These risks led Johnson & Partridge (1998) to conclude 'steps should be taken 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.'

2.6 TERRESTRIAL FAUNA

There have been no detailed studies of the terrestrial fauna of the Lagoon and surroundings. Sub-alpine insect species have been reported associated with bog vegetation (Department of Lands and Survey 1984), and the Seaward Moss/ Toetoes/Waituna Wetlands complex is home to over 80 species of moth, and is the type locality for a number of them (Rance & Cooper 1997). It can probably be assumed that, given the same degree of taxonomic attention, other invertebrate groups could show similar diversity. Two species of mammals have been reported from the wetlands (hares and possums), and other species (mustelids, rodents) are almost certainly present (Department of Lands and Survey 1984). The reptilian fauna is also unknown, but the area is potential habitat for forest geckos, common geckos and common skinks.

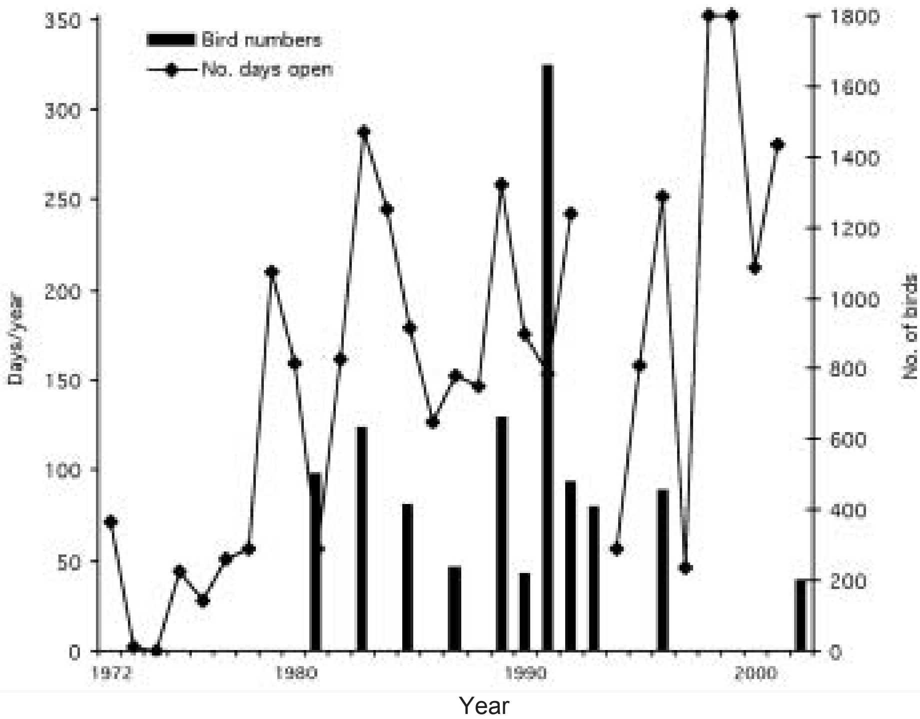
2.7 BIRDS

The Waituna Lagoon area is a significant area for birdlife both in terms of resident species and its role in the migratory routes of several rare species. Seventy-three species of birds have been recorded (21 naturalised), including both international and internal migratory waders (Appendix 2). The migratory bird fauna is notable for several species including the Mongolian dotterel (*Charadrius mongolus)*, grey plover (*Pluvialis squatarola*), marsh sandpiper (*Tringa stagnatilis*), sanderling (*Calidris alba*) and Asiatic whimbrel (*Numenius phaeopus variegatus*) (Rance & Cooper 1997). A number of nationally critical species (New Zealand dotterel (*Charadrius obscrurus obscurus*), white heron (*Egretta alba modesta*)) and nationally declining species (banded dotterel (*Charadrius bicinctus bicinctus*), black-fronted tern (*Sterna albostriata*), white-fronted tern (*Sterna striata*)) are also present on the Lagoon (Molloy et al. 2001; Rance & Cooper 1997).

The Lagoon has significant populations of waterfowl, including black swans (*Cygnus atratus*) and a variety of duck species. It is considered one of the most important grey duck (*Anas superciliosa*) sites in Southland (Rance & Cooper 1997). Grey duck are in serious decline (Molloy et al. 2001) and the presence of significant populations of mallards (*Anas platyrhynchos*) on the Lagoon puts the population at risk from hybridization (Rhymer et al. 1994). The wetlands also provide important habitat for nationally critical brown teal (*Anas chlorotis*), endangered Australasian bittern (*Botaurus poiciloptilus*) and vulnerable New Zealand shoveler (*Anas rhynchotis*) (Molloy et al. 2001), in addition to a number of species that are nationally declining (Appendix 2).

Changes in the level of the Lagoon have the potential to significantly alter available wading bird habitat. When open to the sea there are extensive tidal mudflats, which form an important summer wader habitat (Rance & Cooper 1997). At high Lagoon levels, inundation of the *Leptocarpus* rushes around the

Figure 7. Numbers of birds recorded on Waituna Lagoon by the Ornithological Society of New Zealand during biennial summer counts from 1981–1993, plus additional counts in 1990, 1992, 1996 and 2002. Also shown is the number of days that the Lagoon was open in each year.



shoreline provides preferred habitat for white-faced heron (*Ardea novaehollandiae*), Australasian bittern, spotless crakes (*Porzana tabuensis plumbea*) and marsh crakes (*P. puzilla affinis*). A summary of the birds of the Lagoon is currently in preparation (W. Cooper, DOC, pers. comm.).

Summer bird counts have been undertaken by the Ornithological Society of New Zealand approximately every two years since 1981. An analysis comparing the number of days that the Lagoon was open in a calendar year versus the number of wading birds revealed no clear relationship (Fig. 7). The highest numbers of wading birds were observed in 1991, when the Lagoon was open for 154 days. There were no counts carried out during the prolonged opening in the late 1990s.

Other significant threats to bird populations in the Lagoon include mammalian predators (which are almost certainly present) and fire. At present birds that are nesting in the Lagoon area appear to be doing well, although this is based on anecdotal reports. It is likely that the abundant islands and wetland pools in the areas surrounding the Lagoon provide some degree of protection from predation. The risk of fire is always present, and fires have previously impacted bird nesting areas (Johnson 1986). The relative isolation of the Lagoon provides some protection against fires caused by human activities.

It can be assumed that wetland birds require the maintenance of the existing wetland vegetation patterns to ensure good quality habitat, and that wading birds are favoured by management that maintains the Lagoon as a tidal system, open to the sea. The effects on vegetation patterns of prolonged opening of the Lagoon are not known, nor are the effects on wetland bird numbers.

2.8 AQUATIC FAUNA

The aquatic fauna of the Lagoon has not been studied in detail, although there is information available from local anglers and fisheries studies. As the name of the Lagoon (Wai = water, tuna = eel) suggests, there are both longfin (*Anguilla dieffenbachii*) and shortfin (*A. australis*) eels present, and Kelly (1968) suggests that the Lagoon was once an important source of eels for local Maori. The importance of the location for mahinga kai (and other) resources is acknowledged via a Statutory Acknowledgment in Schedule 73 of the Ngai Tahu Claims Settlement Act 1998. Other native fish present in the catchment include significant populations of giant kokopu (*Galaxias argenteus*) and banded kokopu (*Galaxias fasciatus*) (Department of Lands and Survey 1984; Riddell et al. 1988). Inanga (*Galaxias maculatus*), common smelt (*Retropinna retropinna*), redfin bullies (*Gobiomorphus huttoni*), lowland bullies (*G.cotidianus*) and lamprey (*Geotria australis*) are also present, in addition to species more commonly associated with estuarine conditions: yellow-eyed mullet (*Aldrichetta forsteri*), cockabully (*Grahamina nigripenne*), kahawai (*Arripis trutta*), stargazer (*Leptoscopus macropygus*), parrotfish (*Pseudolabrus celidotus*) and black (*Rhombosolea retiaria*), yellow (*R. leporina*) and sand (*R. plebia*) flounder (Galloway et al. 1971; Riddell et al. 1988).

Of the native fish, all except kokopu have been recorded using the Lagoon as habitat (Riddell et al. 1988). Both kokopu species are found only in the tributaries, but may use the Lagoon and wetlands to spawn (B. David, pers. comm.). Black flounder were common in the lower reaches of Waituna Creek and in the Lagoon in 1985 (Riddell et al. 1988), but apparently numbers are now declining (Johnson & Partridge 1998). Freshwater crayfish (*Paranephrops zelandicus*) are also found in the catchment and wetlands, but not in the Lagoon itself (Riddell et al. 1988).

The exotic fish fauna of the Lagoon includes brown trout which forms the basis of a popular recreational fishery. Trout were liberated in the Lagoon in 1900, and had formed a self-sustaining population by 1918 (Riddell et al. 1988). The current population is a mixture of sea-run and freshwater fish, and has breeding redds and nursery grounds in the tributary streams. Fish as large as 8 kg have been caught in the Lagoon, but fish average 2.2–2.8 kg (Southland Acclimitisation Society 1964), although catch rates tend to be low (Riddell et al. 1988). Perch (*Perca fluviatilis*) have also been found in the Lagoon although they are not common (Riddell et al. 1988).

The effect of lagoon opening and closure on native fish is unknown, but it is unlikely that bullies or kokopu can tolerate truly saline water. When the Lagoon is open it is probable that the fish move up the tributary streams in response to increasing salinity. Opening of the Lagoon is likely to be important to the recruitment of native species present in the Lagoon and wetland, all of whom undergo a marine migration as part of their life history. The effects of openings on the trout fishery have not been studied, but closure of the Lagoon obviously prevents sea-run fish from moving into the catchment to spawn. Riddell et al. (1988) recorded large spawning runs in 1985 when the outlet was closed, suggesting that the Lagoon has a viable resident population of brown trout.

The aquatic benthic invertebrate fauna of the Lagoon was sampled from three sites in Waituna Lagoon in 1985 (Riddell et al. 1988). Invertebrates were uncommon and the community was dominated by amphipods, with the snail, *Potamopyrgus antipodarum*, plus various platyhelminth flatworms, isopods, caddisflies and oligochaete worms also present (Riddell et al. 1988). Decapod marine crabs have also been reported in the Lagoon (Riddell et al. 1988). Results from the Environment Southland monitoring site on Waituna Creek reveal a community dominated by the amphipod snail, *Paracalliope fluviatalus*, oligochaetes and chironomids.

Several indices are used by Regional Councils and other water managers to indicate ecosystem health. These indices all rely on attributing scores to individual taxa

TABLE 5. MACROINVERTEBRATE COMMUNITY INDEX (MCI) AND SEMI-QUANTITATIVE MCI (SQMCI) VALUES FOR WAITUNA CREEK, WITH INTERPRETATIONS (DEGREE OF ORGANIC ENRICHMENT). (ENVIRONMENT SOUTHLAND, UNPUBL. DATA.)

YEAR	MCI	INTERPRETATION	SQMCI	INTERPRETATION
1996	86	Moderate	3.4	Severe
1997	82	Moderate	4.4	Moderate
1998	76	Severe	5.0	Mild
1999	74	Severe	3.8	Severe
2000	90	Moderate	4.5	Moderate
2001	73	Severe	4.4	Moderate

which represent their tolerance to organic pollution. The Macroinvertebrate Community Index (MCI) and Semi-Quantitative MCI (SQMCI) (Stark 1993) are used by Environment Southland to assess stream communities. Results from Waituna Creek are relatively poor, indicating some degree of organic enrichment (Table 5).

It can be assumed that the prolonged opening of the Lagoon in 1997–2000 had a profound effect on its benthic invertebrates. Most insects are stenohaline (able to tolerate a narrow range of salinities) and are unable to tolerate salt water. Two of the species found in the Lagoon (*Potamopyrgus antipodarum* and *Paracalliope fluviatalus*) can tolerate brackish water environments but cannot live in salt water. In contrast, most typical intertidal organisms cannot live in fresh water. The effect that being fully open to the sea has on lagoon salinities is not known, but will be crucial in determining effects on benthic fauna.

There have been no studies of the pelagic invertebrate fauna (zooplankton) of the Lagoon, although it can be assumed that the fauna is similar to that of coastal lakes and estuaries in southern New Zealand (Jeppesen et al. 1997). Changes in salinity have been shown to be important in structuring zooplankton communities in a tidal lake in Otago (Hall & Burns 2001a). Many zooplankton respond to unfavourable salinity by forming resting eggs which hatch when conditions become more suitable. The response of zooplankton to changes of the nature likely to result from Lagoon opening will be rapid (Hall & Burns 2001b). As such, zooplankton may be one of the few reliable food sources for species such as smelt and bullies during the opening or closure of the Lagoon.

3. Gaps in existing knowledge and recommended research

Although knowledge of some aspects of Waituna Lagoon's ecology (i.e. shoreline and aquatic vegetation, bird fauna) and functioning (i.e. hydrology) have been well studied, there are some gaps in the existing knowledge. Based on our assessment of these gaps, we make the following recommendations for further research by Departmental staff.

3.1 PHYSICAL STRUCTURE AND COASTAL PROCESSES

Recommendation 1: That a detailed physical survey of the Lagoon be undertaken, taking into account the extent of different substrate types in the Lagoon, and describing the current bathymetry.

This information is needed to provide a baseline for studying possible changes in the Lagoon. Repeating this survey at intervals (2–5 years) and under different conditions (Lagoon open or closed) will allow direct measurement of sediment infilling of the Lagoon .

Recommendation 2: That review of any historical information on Waituna Lagoon and of international literature be undertaken detailing the coastal processes involved in lagoon closure. Should such information not be available, that a study be undertaken in conjunction with a research provider (e.g. univerisities, private consultants) to determine the likely processes involved.

The extended period that the Lagoon remained open in 1997–2000 raises the concern that Lagoon may become open to the sea permanently. The coastal processes driving Lagoon closure are not understood and need to be examined. The connection of the Lagoon to the sea is critical to the life history of fish, and is likely to be important with regard to macrophytes, marginal vegetation and residence time of sediment and nutrients in the Lagoon.

3.2 WATER CHEMISTRY AND CATCHMENT MANAGEMENT

Recommendation 3: In conjunction with the survey in *Recommendation 1*, that water chemistry should be measured from all regions of the Lagoon, for levels of nitrate, total nitrogen, ammonia, phosphorus, dissolved reactive phosphorus, salinity, pH, dissolved oxygen and chlorophyll a. This should be carried out when the Lagoon is closed, and when it is open to the sea.

Recommendation 4: That in conjunction with Environment Southland and the Waituna Landcare Group, a programme be established to monitor water chemistry at three locations in the Lagoon (Walkers Bay, Moffat Road and Waghorns Road) on an at least three-monthly basis.

Recommendation 5: That in conjunction with Environment Southland and the Waituna Landcare Group, monitoring of nutrients at Waituna Creek should be supplemented by sampling at Currans Creek and Moffat Creek.

Water chemistry is likely to be a crucial indicator of the state of the Lagoon, and should be monitored over time in conjunction with the current Environment Southland monitoring programme on Waituna Creek. Measuring nutrient concentrations will provide an assessment of the water quality entering the Lagoon and would be required for modeling residence times of nutrients. Measuring chlorophyll a provides an assessment of the trophic state of the Lagoon. Waituna Landcare Group, in conjunction with Environment Southland, commenced sampling the Lagoon and inflows in late 2001. This programme should be encouraged by DOC and all assistance given in interpretation and reporting of results to all agencies concerned.

Recommendation 6: That in conjunction with a research provider (e.g. universities, private consultants) a detailed programme be developed to study the circulation patterns and residence times of nutrients in the Lagoon. This should be incorporated into a predictive model for the Lagoon using existing information on water quality and hydrology.

It is also important that an understanding is gained of the movement of sediment and nutrients within the Lagoon while it is open and closed. This is necessary to model the likely residence time of nutrients in the Lagoon, indicating the usefulness of opening the Lagoon for flushing of sediments and nutrients. Models have been developed for shallow lakes both internationally (Gough & Ward 1995; van der Molen et al. 1994) and in New Zealand (M. Schallenberg, University of Otago, pers. comm.) which can predict nutrient status and the likely consequences of this in a lagoon.

Recommendation 7: That, in association with Environment Southland, a survey of the Lagoon catchment be undertaken, describing water chemistry (nitrate, total nitrogen, ammonia, dissolved reactive phosphorus, total phosphorus) and other indicators of effluent discharge (faecal coliforms, enterococci). If point sources of nutrients are identified, these should be reduced where possible. If point sources cannot be identified, a study should be initiated on the possible effects of groundwater contamination from land disposal of effluent.

It is clear from existing water quality data that there are significant catchment management issues. Reducing sediment and nutrient levels in the inflows is crucial to the ongoing health of the Lagoon, and reducing faecal coliform and enterococci levels is necessary to ensure its ongoing recreational use. There is a need for research to determine the threshold level of maximum acceptable degredation with nutrients, silt and contaminants.

3.3 AQUATIC AND TERRESTRIAL BOTANY

Recommendation 8: That a thorough botanical survey of both aquatic and terrestrial vegetation be carried out, updating the work of Johnson & Partridge (1998). Establishment of permanently marked transects for the monitoring of ongoing change in vegetation patterns would be desirable. The results should be couched in terms of the UNEP-GRID protocols which are being adopted for New Zealand wetlands (Ward & Lambie 1999).

The effects of the recent prolonged opening of the Lagoon on aquatic and marginal vegetation have not been investigated. A repeat of Johnson & Partridge's (1998) survey would ascertain what effect increased salinity in the Lagoon can be expected to have on plant communities.

Recommendation 9: That, in conjunction with Environment Southland's current aerial photo programme, ongoing analysis of the extent of *Leptocarpus* beds and sediment bars in the Lagoon be carried out. This information will provide an assessment of rates of infilling of the Lagoon.

The information presented in Section 2.5.2 provides evidence of expansion of rush beds in the Lagoon. Taken in conjunction with the high rates of sedimentation recorded by Environment Southland, infilling rates in the Lagoon are of concern. Analysis of historical and future aerial photographs provides an inexpensive and effective way of documenting changes and, together with use of satellite imagery, is identified as an important stage in New Zealand wetland management (Ward & Lambie 1999).

Recommendation 10: That aquatic habitats, especially near road access points, be monitored regularly for any presence of naturalised aquatic plants. Information should be provided to boat owners, informing them of the risk to the Lagoon from macrophytes.

The intact *Ruppia*-dominated macrophyte community is a distinctive feature of Waituna Lagoon. There is a significant risk to this community from invasive macrophyte species which should be guarded against.

Recommendation 11: That baseline descriptions of phytoplankton communities in zones of different salinity are established, against which future changes can be compared.

3.4 FAUNAL SURVEYS

Recommendation 11: That surveys of the aquatic communities of the Lagoon be carried out at varying distances from the inlet while the Lagoon is open and closed. These surveys should include benthic invertebrates, zooplankton and small fish (smelt, bullies, inanga).

Biological communities in the Lagoon should be studied while the Lagoon is open and closed. The invertebrate and small fish communities are likely to be the basis of the trout fishery (Jeppesen et al. 1997; R. Stoffels, University of Otago, pers. comm.). Understanding the effects of Lagoon opening and closure on these communities is important in safeguarding the productivity of the fishery.

Recommendation 12: That, in conjunction with Fish and Game Southland, trout populations be assessed using creel surveys and residence rates at breeding redds. Short-term changes (correlated to Lagoon opening/closure) and long-term trends (e.g. declining numbers due to water quality degradation) should be determined.

In addition to the effects of Lagoon opening and closure on the diet of trout, there are potential direct effects on trout populations. Current water chemistry parameters (particularly ammonia levels) also have the potential to reduce trout condition and reproduction.

Recommendation 13: That, in conjunction with Fish and Game Southland and the New Zealand Ornithological Society, bird counts be continued, with the aim of completing at least biennial counts. These should be analysed in the context of their relationship to the open or closed status of the Lagoon.

The effects of opening or closing the Lagoon on the populations of resident and migratory birds are an important component in decisions on future management of the Lagoon.

Recommendation 14: That, in conjunction with Fish and Game Southland and the New Zealand Ornithological Society, the proportion of grey and mallard ducks on the Lagoon be assessed. Limited genetic analysis to assess the degree of hybridisation between the species would be useful. Active management of mallard numbers may be necessary to maintain the integrity of the grey duck populations on the Lagoon.

4. Recommendations and priorities for future management

Successful management of the Lagoon will require clear management objectives and priorities. Our recommendations are set out in this section.

Current management of water levels in the Lagoon is primarily aimed at reducing water levels to improve drainage of surrounding farms. Recent hydrological work (Jackson et al. in press) suggests that this is largely unnecessary, as flooding in surrounding farmland is likely to be predominantly caused by heavy rainfall, regardless of Lagoon depth. Management of Lagoon levels should be reassessed in the light of the new hydrological evidence.

Management of Lagoon levels to ensure the health of the trout fishery has also been carried out historically. There is no clear evidence that the fishery has been improved by opening the Lagoon, although this clearly allows sea-run fish to enter. A viable resident population of trout is present in the Lagoon itself, as evidenced by successful breeding in years when the Lagoon has been closed. However, there is a recreational demand for fishing aimed at catching large sea-run fish. Opening the Lagoon artificially to allow entry for those fish is desirable for fishermen, but a lack of knowledge of the processes involved in closing the Lagoon means that artificial openings carry the risk of a permanent breach of the bar.

Management Priority 1: Departmental staff to meet with Environment Southland, Southland Fish and Game, Waituna Landcare Group, iwi and the local community to outline the current state of knowledge and attempt to achieve a consensus on the future management objectives for the Lagoon. (Initial meetings with community groups have already occurred.) These objectives should include:

- Determining whether artificial opening of the Lagoon remains appropriate, or whether there is a need for research to investigate this issue.
- Clearly identifying the threat of continued degradation of inflow water quality, and involving local landowners in addressing this threat.
- Illustrating the natural values of the Lagoon and Wetlands on a national and international scale to the interested parties, and addressing how best to protect those values.

A major challenge to the ongoing health of the plant and invertebrate communities of the Lagoon is the quality of the inflows. Waituna-type lagoons are, by definition, low nutrient, low sediment input, systems. There is evidence that land use change in the catchment of the Waituna Lagoon has resulted in increases in both nutrients and sediment. Levels of ammonia and nitrate entering the Lagoon are now of concern, and have the potential to endanger the Lagoon's fishery. Management of the catchment with specific attention towards preventing point source pollution and minimising non-point source pollution is an immediate priority. Monitoring of nutrient levels in the Lagoon should be initiated immediately to gain an appreciation of longer-term trends in Lagoon water quality.

Management Priority 2: DOC and Environment Southland staff to meet to design and implement a water quality survey of the Lagoon and its catchment. This survey should include:

- Establishment of a water quality monitoring site on Waituna Lagoon itself (Environment Southland and the Waituna Landcare Group have begun this process).
- Identification of any point sources of nutrients in the catchment, and immediate action to ameliorate them.
- A water quality survey of the Lagoon when open and closed to assess residence times and circulation patterns of nutrients.
- Identification of any non-point sources in the catchment and development of a strategy to reduce those sources over the next 2–3 years.

Given the high loadings of nutrients and sediment to the Lagoon, the possibility that the Lagoon will need to be opened to prevent eutrophication needs to be considered. 'Flushing' sediments and nutrients out of the system by breaching the bar is an option, although research on the residence times of nutrients and patterns of sediment deposition and water circulation in the Lagoon are needed to determine how effective such flushing would be. Probable benefits of allowing opening to reduce nutrient loadings would need to be balanced against the effects of increased salinity and possible long-term sea water influence. Active management of the bar to close the breach may also need to be considered.

Assessment of changes in the Lagoon caused by the recent prolonged opening to the sea is important in providing information for future management decisions. The baseline work of Johnson & Partridge (1998) provides an excellent opportunity to assess those changes. Information on other aspects of the Lagoon including bathymetry, fish and invertebrate species present, patterns of wading and gamebird habitat usage, and sediment distribution and deposition are needed to create a baseline for measurement of future change and to aid in informed decision making by managers. These surveys should be placed, where relevant, within the classification framework for New Zealand wetlands (Ward & Lambie 1999).

Management Priority 3: Departmental staff or contractors to carry out extensive survey work on the Lagoon including botanical, bathymetric, sedimentation and faunal surveys.

Management of shallow coastal Lagoon systems is carried out on many systems internationally, and modeling techniques are well developed. There is an opportunity to develop an informative, predictive model for the Lagoon which can be used to inform management decisions.

Management Priority 4: Departmental staff to work with Environment Southland and a research provider (e.g. universities, private consultants) to investigate the design and implementation of research on the Lagoon aimed at producing a predictive model for Lagoon hydrology, nutrient dynamics and trophic status.

Objectives need to be clearly established for the management of the Lagoon, including setting thresholds of maximum acceptable degredation. Managing it to protect the natural values for which Waituna is valued internationally, may be at odds with managing to protect an exotic fishery or for a perceived benefit in terms of land drainage. There is an imminent risk to the Lagoon from declining water quality that needs to be addressed immediately. In the longer term the encroachment of intensifying agriculture on the Lagoon, and the management of the Lagoon in the wider context of the Seaward Moss/Toetoes/Awarua Wetlands complex will need to be addressed in an integrated fashion.

5. References

Australian and New Zealand Environment and Conservation Council (ANZECC) 2000: Australian and New Zealand guidelines for fresh and marine water quality. ANZECC, Canberra, Australia.

Cameron, W.M.; Pritchard, D.W. 1963: Estuaries. Pp. 306–324 in Hill, M.N. (Ed.): The sea, vol. 2. John Wiley & Sons, New York.

Cromarty, P.; Scott, D. 1996: A directory of wetlands of New Zealand. Department of Conservation, Wellington, New Zealand.

Crosby-Smith, J. 1927: The vegetation of Awarua Plain. *Transactions and Proceedings of the New Zealand Institute 58*: 55–56.

Department of Lands and Survey 1984: Draft Waituna Wetlands Management Plan. Department of Lands and Survey, Wellington, New Zealand.

Environment Southland. State of the Environment Water Quality Data. Held at Southland Regional Council, Invercargill, New Zealand.

Galloway, J.R.; Dougherty, R.A.; Wing, S.J.; Johnson, W.S.; Hawke, S.P.; Webb, P.R.; Jellyman, D.J.; Little, R.W. 1971: Freshwater fisheries survey of Waituna Lagoon. New Zealand Marine Department Freshwater Fisheries Advisory Service Investigation No. 62. New Zealand Marine Department Fisheries Advisory Service, Wellington. 11 p.

Gough, J.D.; Ward, J.C. 1996: Environmental decision-making and lake management. *Journal of Environmental Management 48*: 1–15.

Hall, C.J.; Burns, C.W. 2001a: Effects of salinity and temperature on survival and reproduction of *Boekella hamata* (Copepoda: Calanoida) from a periodically brackish lake. *Journal of Plankton Research 23*: 97–103.

Hall, C.J.; Burns, C.W. 2001b: Hatching of *Boekella hamata* (Copepoda: Calanoida) resting eggs from sediments of a tidally influenced lake. *New Zealand Journal of Marine and Freshwater Research 35*: 235–238.

Jackson, R.; Phillips, C.; Ekanayake, J. in press: Hydrology of Waituna Lagoon. *Department of Conservation Science Internal Series*. Department of Conservation, Wellington, New Zealand.

Jeppesen, E.; Lauridsen, T.; Mitchell, S.F.; Burns, C.W. 1997: Do planktivorous fish structure the zooplankton communities in New Zealand lakes? *New Zealand Journal of Marine and Freshwater Research 31*: 163–173.

Johnson, P.N. 1972: Applied ecological studies of shoreline vegetation at Lakes Manapouri and Te Anau, Fiordland. II. The lake edge flora—habitats and relation to lake levels. *Proceedings of the New Zealand Ecological Society 19*: 120–142.

Johnson, P.N. 1986: Waituna Lagoon Reserve: botanical report on gull colony, bog vegetation, lagoon margin. Department of Scientific and Industrial Research, Dunedin (unpublished). 5 p.

Johnson, P.N.; Partridge, T.R. 1998: Vegetation and water level regime management at Waituna Lagoon, Southland. Landcare Research Contract Report LC 9596/011 (unpublished). 55 p.

Kelly, G.C. 1968: Waituna Lagoon, Fouveaux Strait. *Bulletin—Wellington Botanical Society 35*: 8–19.

Kirk, R.M. 1991: River-beach interaction on mixed sand and gravel coasts: a geomorphic model for water resource planning. *Applied Geography 11*: 267–287.

Kirk, R.M.; Lauder, G.A. 2000: Significant coastal lagoon system in the South Island, New Zealand. Coastal processes and lagoon mouth closure. *Science for Conservation 146*. Department of Conservation, Wellington, New Zealand. 47 p.

Kjerfve, B. (Ed.) 1994: Coastal lagoon processes. Elsevier Oceanography Series 60. Elsevier, Amsterdam. 577 p.

McKinnon, S.L.; Mitchell, S.F. 1994: Eutrophication and black swan (*Cygnus atratus* Latham) populations: tests of two simple relationships. *Hydrobiologia 279/280*: 163–170.

Mitchell, S.F.; Hamilton, D.P.; MacGibbon, W.S.; Nayar, P.K.B.; Reynolds, R.N. 1988: Interrelations between phytoplankton, submerged macrophytes, black swans (*Cygnus atratus*) and zooplankton in a shallow New Zealand lake. *Internationale Revue der gesamten Hydrobiologie 73*: 145–170.

Molloy, J.; Bell, B.; Clout, M.N.; de Lange, P. J.; Gibbs, G.W.; Given, D.R.; Norton, D.A.; Smith, N.; Stephens, R.T.T. 2001: Classifying species according to the threat of extinction: a system for New Zealand. New Zealand Department of Conservation, Biodiversity Recovery Unit, Wellington, New Zealand.

Ngai Tahu Claims Settlement Act 1998: Crown Law Office, Wellington, New Zealand.

Ogilvie, B.G.; Mitchell, S.F. 1998: Does sediment resuspension have persistent effects on phytoplankton? Experimental studies in three shallow lakes. *Freshwater Biology 40*: 101–113.

Rance, B.; Cooper, W. 1997: Waituna Wetlands Scientific Reserve. Case Study 3 in Hails, A. J. (Ed.): Wetlands, biodiversity and the Ramsar Convention. Ramsar, New Delhi, India. www.ramsar.org/lib_bio_9.htm#cs3

Resource Consent A784. 1993: Held at Environment Southland, Invercargill, New Zealand.

Rhymer, J.M.; Williams, M.J.; Braun, M.J. 1994: Mitochondrial analysis of gene flow between New Zealand mallards (*Anas platyrhynchos*) and grey ducks (*A. superciliosa*). *Auk 111*: 970–978.

Riddell, J.M.; Watson, N.R.N.; Davis, S.F.; 1988: Fisheries investigations of the Ashers-Waituna, Benhar, and Hawkdun lignite deposit areas. *New Zealand Freshwater Fisheries Report No. 94*. Ministry of Agriculture and Fisheries, Christchurch, New Zealand. 216 p.

Robertson, A.W.; Mark, A.F.; Wilson, J.B. 1991: Ecology of a coastal lagoon to dune forest sequence, South Westland, New Zealand. *New Zealand Journal of Botany 29*: 17–30.

Ryder, G. 1998: Lower Mataura River. Water quality investigation 1996–1998. Report for Southland Regional Council (unpublished). 250 p.

Scheffer, M.; Hosper, S.H.; Meijer, M.L.; Moss, B.; Jeppesen, E. 1993: Alternative equilibria in shallow lakes. *Trends in Ecology and Evolution 8*: 275–279.

Sheffield, A.T.; Healy, T.R.; McGlone, M.S. 1995: Infilling rates of a steepland catchment estuary, Whangamata. *New Zealand Journal of Coastal Research 11*: 1294–1308.

Southland Acclimatisation Society 1964: Annual Report. Southland Acclimatisation Society, Invercargill, New Zealand. 7 p.

Stark, J.D. 1993: Performance of the Macroinvertebrate Community Index: effects of sampling method, sample replication, water depth, current velocity, and substratum on index values. *New Zealand Journal of Marine and Freshwater Research 27*: 463–478.

Thornton, J. 1990: Field guide to New Zealand geology. Heinmann Reed, Auckland.

van der Molen, D.T.; Los, F.J.; van Ballegooijen, L.; van der Vat, M.P. 1994: Mathematical modelling as a tool for management in eutrophication control of shallow lakes. *Hydrobiologia 275/276*: 479–492.

Ward, J.C.; Lambie, J.S. (Eds) 1999: Monitoring changes in wetland extent: an environmental performance indicator for wetlands. Ministry for the Environment, Wellington, New Zealand. 37 p.

Ward, J.C.; Taylor, K.J.W. 1993: Nutrients in Lake Ellesmere: measuring trends and inflows. *New Zealand Limnological Society Newsletter 29*. New Zealand Limnological Society. 10 p.

Appendix 1

Plant species found at Waituna Lagoon by: (1) Johnson & Partridge 1998; (2) Kelly 1968; (3) Crosby-Smith 1927; or (4) Department of Lands and Survey 1984. Naturalised species are shown in bold, species classified as declining (Molloy et al. 2001) are underlined. Common species habitat preferences (BB = salty, B = brackish, F = , D = dryland) and type of life history (C = colonist, R = resilient) (Johnson & Partridge 1998) are shown. Species marked † are considered more typical of alpine settings (Kelly 1968).

GROUP	COMMON NAME	HABITAT	TYPE	SOURCE
DICOTYLEDONS				
Acaena anserinifolia	bidibid			4
Acaena microphylla	bidibid			1,4
Acaena novae-zelandiae		D	R	1,2,4
Actinotus novae-zelandiae				2,4
Anagallis arvensis	scarlet pimpernell	D	C	1
Apium prostratum	native celery			1,4
Atriplex hastata	orache	BF	C	1
Callitriche petriei	starwort			1,2,4
Callitriche stagnalis	shore bindweed			1
Calystegia soldanella	cottonwood	D	R	1,2,4
Cardamine debilis	bittercress			4
Cassinia vauvilliersii	centaury			1,3,4
Celmisia gracilenta	pekapeka			2,4
Centaurium erythraea		F	R	1
Centella uniflora		BF	R	1,2,4
Cerastium fontanum	mouse-ear chickweed	D	C	1,4
Chenopodium glaucum	glaucous goosefoot	BF	C	1,4
Cirsium arvense	Californian thistle	D	C	1,4
Cirsium vulgare	Scotch thistle	D	C	1,4
Colobanthus sp. (nr. *mulleri*)				2,4
Coprosma acerosa				4
Coprosma parviflora				4
Coprosma propinqua		F	R	1,2,4
Coprosma pumila	creeping coprosma			4
Coprosma sp. aff. *intertexta*				1
Coronopus didymus				1
Cotula coronopifolia	twin cress	B	C	1,4
Crassula kirkii	bachelor's button			1
Crassula moschata		B	R	1,2,4
Crassula sinclairii		F	R	1
Cyathodes empetrifolia				2,3,4
Cyathodes juniperina	mingimingi	D	R	1,2,3,4
Cytisus scoparius	broom			4
Dianella sp.		F		2
Donatia novae-zelandiae[†]				2,3,4
Dracophyllum longifolium	inanga, turpentine shrub			2,3,4
Drosera binata	forked sundew			2,3,4
Drosera spathulata				2,3,4
Epilobium sp.[†]	willow-herb	F		2,4

GROUP	COMMON NAME	HABITAT	TYPE	SOURCE
Eucalyptus johnsoni				4
Euphrasia sp. (nr. *dyeri)*				2,4
Euphrasia repens				1,2,4
Galium palustre	marsh bedstraw	F	R	1
Galium perpusillum				1,4
Galium propinquum		F	R	1
Gaultheria antipoda	bush snowberry			4
Gaultheria macrostigma	snowberry			1,2,3,4
Gentiana grisebachii	marsh gentian			1,2,4
Gentiana lineata				2,4
Gentiana saxosa	shore gentian			2,4
Geranium sessiliflorum var. *arenarium*	cranesbill	D		2,4
Glossostigma elatinoides	flicks			1,2,4
Gnaphalium luteo-album	cud-weed			2,4
Gonocarpus aggregatus				1,2,4
Gonocarpus micranthus		F		2,4
Gunnera prorepens		F		2,3,4
Haloragis erecta		D	C	1
Helichrysum filicaule	slender everlasting	D		2,4
Hydrocotyle hydrophila		F	R	1,2,4
Hydrocotyle novae-zelandiae var. *montana*		BF	R	1,2,4
Hydrocotyle sulcata		F	R	1,4
Hypochoeris radicata	catsear			1,4
Lagenifera pumila	papataniwhaniwha	D		2,4
Leontodon taraxacoides	hawkbit	D	C	1,4
Leptinella dioica	cotula	BF	R	1,2,4
Leptospermum scoparium	manuka	F	R	1,2,3,4
Leucopogon fraseri	patotara			2,4
Lilaeopsis novae-zelandiae		BF	R	1,2,3,4
Limosella lineata		BF	C	1,2,4
Lotus pedunculatus	lotus	F	R	1,4
Lupinus arboreus	tree lupin			1
Mazus radicans				2
Melicytus lanceolatus	narrow-leaved mahoe			4
Mentha cunninghamii	native mint			1,2,4
Mimulus repens		B	R	1
Muehlenbeckia axillaris	creeping pohuehue	D	C	1,2,4
Muehlenbeckia complexa	scrub pohuehue			4
Myosotis pygmaea var. *pygmaea*†	dwarf forget-me-not			2,4
Myriophyllum pedunculatum	milfoil			2,4
Myriophyllum propinquum	milfoil			1,2,4
Myriophyllum triphyllum	milfoil	F	R	1
Myriophyllum votschii	mini-milfoil	F	R	1,4
Nertera balfouriana		F	R	1,2,4
Nertera depressa		D	R	1,4
Nertera scapanioides		D	R	2,4
Nertera setulosa		D	R	1,4
Oreostylidium subulatum				2,4
Parentucellia viscosa	tarweed			1
Pentachondra pumila†				2,4
Pimelea lyalii	sand daphne			2,4
Pimelea prostrata				4

GROUP	COMMON NAME	HABITAT	TYPE	SOURCE
***Pinus* sp.**				4
Plagianthus divaricatus	saltmarsh ribbonwood	B	R	1,4
Plantago australis	swamp plantain	B	R	1,4
Plantago lanceolata	narrow-leaf plantain			1
Plantago major	broad-leaf plantain			1
Plantago raoulii	tukorehu			2,4
Plantago triandra	starweed			1,2,4
Potentilla anserinoides	silverweed	BF	R	1,2,4
Pratia angulata	panakenake	F	R	1,2,4
Prunella vulgaris	selfheal			1
Ranunculus acaulis	sand buttercup			1,2,4
Ranunculus glabrifolius				1,4
Ranunculus trichophyllus	water buttercup			1
Raoulia glabra	mat daisy			2,4
Raoulia hookeri	alpine mat daisy			2,4
Rorippa palustris	marsh yellow cress	F	C	1
Rubus idaeus	blackberry			4
Rumex acetosella	sheep's sorrel			1,4
Rumex crispus	curled dock	F	C	1,4
Sagina procumbens	pearlwort	D	C	1,4
Salicornia australis	glasswort	B		2,4
Samolus repens		BB	R	1,2,4
Schizeilema cockaynei				1,2,4
Sedum acre	stonecrop	D	C	1,4
Selliera radicans	selliera	BF	R	1,2,4
Senecio bisseratus	firewood			2,4
Senecio jacobaea	ragwort			1,4
Senecio lautus	shore groundsel			4
Senecio minimus				4
Sonchus asper	prickly sow thistle	D	C	1
Sonchus kirkii	shore puha			4
Spergularia rubra	sand spurrey			1
Taraxacum officinale	dandelion			4
Trifolium repens	white clover	D	R	1
Ulex europaeus	gorse	D	R	1,4
Utricularia sp.	yellow bladder wort			3
Viola cunninghamii	native violet	F	R	1,2
Viola filicaulis				3
MONOCOTYLEDONS				
Agropyron repens	couch	BF	R	1
Agrostis pallescens				4
Agrostis stolonifera	creeping bent	BF	R	1
Agrostis tenuis	browntop			4
Ammophila arenaria	marram grass			1,4
Anthoxanthum odoratum	sweet vernal	D	R	1,4
Astelia nervosa†				3
Baumea huttonii				2,4
Baumea rubiginosa				2,4
Baumea tenax				2,4
Carex appressa	sedge			4
Carex buchananii		F	C	1
Carex comans	maurea			2,4
Carex coriacea	rautahi	F	R	1,2,4

GROUP	COMMON NAME	HABITAT	TYPE	SOURCE
Carex dipsacea				1
Carex dissita		D	R	1
Carex flaeillifera				1,4
Carex flaviformis		F	R	1
Carex gaudichaudiana		F	R	1
Carex pumila	sand sedge			1,2,4
Carex secta	purei, niggerhead			2,4
Carex sinclairii				1
Carex virgata		BF	R	1
Carpha alpina†				2,4
Centrolepis ciliata				4
Chionochloa rubra	red tussock			1,2,4
Cordyline australis	cabbage tree	F	R	1
Cortaderia richardii	toetoe	F	R	1,2,4
Dactylis glomerata	cocksfoot	D	R	1
Deschampsia cespitosa var. *macrantha*	tufted hairgrass	BF	R	1
Desmochoenus spiralis	pingao			2,4
Dianella nigra	inkberry			4
Eleocharis acuta	sharp spike-sedge	BF	R	1
Eleocharis gracilis	slender spike-sedge	F	R	1,2,4
Eleocharis sphacelata	giant spike-rush	F		2,4
Empodisma minus	tangle-foot	F		2,3,4
Erica lusitanica	Spanish heath			4
Festuca arundinacea	tall fescue	BF	R	1
Festuca rubra	red fescue			1
Gaimardia ciliata		F		2,3
Herpolirion novae-zelandiae†				2,4
Hierochloe redolens	holy grass			1,2,4
Holcus lanatus	Yorkshire fog	BF	R	1,4
Isolepis aucklandica				1,2,4
Isolepis basilaris				1,2,4
Isolepis cernua	slender clubrush	B	R	1,2,4
Isolepis distigmatosa				1,2,4
Isolepis nodosa	knobby clubrush	B	R	1,2,4
Juncus antarcticus				2,4
Juncus articulatus	jointed rush			1,4
Juncus bufonius	toad rush			1
Juncus gregiflorus				1,4
Juncus pallidus				1,2,4
Juncus pauciflorus				2,4
Juncus planifolius		F	C	1,2,4
Lachnagrostis striata	wind grass	BF	C	1,2,4
Lepidosperma australe	square sedge	F	R	1,2,4
Leptocarpus similis	leptocarpus	BF	R	1,2,4
Libertia peregrinans	native iris, tukauki	D		2,4
Luzula picta	wood rush			1,4
Microlaena thomsonii				3
Microtis oligantha	onion orchid			1
Microtis unifolia	onion orchid			1
Montia fontana	blinks			3
Oreobolus pectinatus†	comb sedge			2,4
Oreobolus strictus†				2,4
Oreomyrrhis colensoi	mountain myrrh			2,4

GROUP	COMMON NAME	HABITAT	TYPE	SOURCE
Phormium tenax	flax	F	R	1,2,4
Poa annua				1
Poa cita	silver tussock	D	R	1,4
Poa triodioides	coastal/sand tussock			4
Potamogeton ochreatus	blunt pondweed	F		1
Prasophyllum colensoi	leek orchid			1,2,4
Puccinellia sp.				4
Ruppia megacarpa	horse's mane weed	B	R	1,2,4
Ruppia polycarpa	horse's mane weed	BF	R	1
Rytidosperma gracile	danthonia	D	R	1,3
Schoenoplectus pungens	three-square	BF	R	1
Schoenus concinnus		F		1
Schoenus maschalinus	dwarf bog-rush	F		1
Schoenus nitens		F		2,4
Schoenus pauciflorus	bog-rush	F		2,4
Thelymitra longifolia	common sun-orchid			2,4
Thelymitra pachyphylla	southern sun-orchid			2,5
Thelymitra pulchella	bog sun-orchid			2,4
Thelymitra venosa	veined sun orchid	F		2,4
Triglochin striata	arrow-grass	BF	R	1,2,4
Uncinia rubra	hook sedge			2,4
Uncinia silvestris var. *squamata*				4
Urtica linearifolia	swamp nettle			See text
FERNS				
Blechnum minus	swamp kiokio	F	R	1,2,4
Blechnum penna-marina	little hard fern			2,4
Gleichenia dicarpa	tangle fern	F	R	1,2,4
Histiopteris incisa	water-fern			4
Hypolepis tenuifolia				4
Lindsaea linearis				1
Lycopodium ramulosum		F		2
Ophioglossum sp.	adder's tongue			2,4
Pteridium esculentum	bracken	F	R	1,2,4
Schizaea fistulosa	comb fern	F		2,4
BRYOPHYTES				
Fissidens asplenioides				1
Hypnum cupressiforme				1
Lycopodium ramulosum	carpet clubmoss			4
Riccardia sp.				1
Thuidium fufurosum				1
ALGAE				
Bachelotia antillarum		B		1
Enteromorpha sp.		B		1

Appendix 2

Bird species found at Waituna Lagoon (Department of Lands and Survey 1984; Rance & Cooper 1997). Naturalised species are shown in bold. Birds are identified as either occasional (O), migratory (M), or resident (R) based on Department of Lands and Survey (1984), W. Cooper (DOC, Southland Conservancy, pers. comm.) and Southland Ornithological Society records (unpublished). National threat status (Molloy et al. 2001) is shown.

	COMMON NAME	TYPE	STATUS
Alauda arvensis arvensis	skylark	R	
Anarhynchus frontalis	wrybill	M	
Anas chlorotis	brown teal	O	Critical
Anas gracilis	grey teal	M	
Anas platyrhynchos	mallard	R	
Anas rhynchotis	New Zealand shoveler	R	Vulnerable
Anas superciliosa	grey duck	R	Serious decline
Anthus novaeseelandiae	New Zealand pipit	R	
Ardea novaehollandiae	white-faced heron	R	
Arenaria interpres	turnstone	M	
Botaurus poiciloptilus	Australasian bittern	R	Endangered
Bowdleria punctata punctata	South Island fernbird	R	Sparse
Branta canadensis	Canada goose	R	
Bubulcus ibis	cattle egret	O	
Calidris acuminata	sharp-tailed sandpiper	M	
Calidris alba	sanderling	M	
Calidris cauntus	knot	O	
Calidris ferruginea	curlew sandpiper	M	
Calidris melanotos	pectoral sandpiper	M	
Calidris ruficollis	red-necked stint	M	
Carduelis carduelis britannica	goldfinch	R	
Carduelis chloris chloris	greenfinch	R	
Carduelis flammea cabaret	redpoll	R	
Charadrius bicinctus bicinctus	banded dotterel	M	Gradual decline
Charadrius mongolus	Mongolian dotterel	M	
Charadrius obscurus obscurus	New Zealand dotterel	M	Critical
Charadrius veredus	oriental dotterel	M	
Circus approximans gouldi	Australasian harrier	R	
Cygnus atratus	black swan	R	
Egretta alba modesta	white heron	O	Critical
Egretta garzetta immaculata	little egret	O	
Emberiza citrinella caliginosa	yellowhammer	R	
Finschia novaeseelandiae	brown creeper	R	
Fringa brevipes	Siberian tattler	M	
Fringilla coelebs gengleri	chaffinch	R	
Gerygone igata	grey warbler	R	
Haemotopus ostralegus finschi	pied oystercatcher	R	
Haemotopus unicolor	variable oystercatcher	R	
Himantopus leucocephalus	pied stilt	R	
Hirundo tahitica neoxena	welcome swallow	R	

	COMMON NAME	TYPE	STATUS
Larus bulleri	black-billed gull	R	Serious decline
Larus dominicanus	southern black-backed gull	R	
Larus novaehollandiae scopulinus	red-billed gull	R	
Leucocarbo chalconotus	Stewart Is. shag	R	Vulnerable
Limosa lapponica baueri	eastern bar-tailed godwit	M	
Numenius madagascariensis	far-eastern curlew	M	
Numenius phaeopus hudsonicus	American whimbrel	M	
Numenicus phaeopus variegatus	asiatic whimbrel	M	
Phalacrocorax carbo novaehollandiae	black shag	R	Sparse
Phalacrocorax varius varius	pied shag	R	Sparse
Phalacrocorax melanoleucos brevirostris	little shag	R	
Phalacrocorax sulcirostris	little black shag	R	
Platalea leucorodia regia	royal spoonbill	O	
Plegadis falcinellus peregrinus	glossy ibis	O	
Pluvialis fulva	Pacific golden plover	M	
Pluvialis squantarola	grey plover	M	
Porphyrio melanotus	pukeko	R	
Porzana pusilla affinis	marsh crake	R	Sparse
Porzana tabuensis plumbea	spotless crake	R	Sparse
Prunella modularis occidentalis	hedgesparrow	R	
Stercorarius pomarinus	Pomarine skua	O	
Sterna albifrons sinensis	eastern little tern	M	
Sterna albostriata	black-fronted tern	M	Serious decline
Sterna striata	white-fronted tern	R	Gradual decline
Sturnus vulgaris vulgaris	starling	R	
Tadorna tadornoides	chestnut-breasted shelduck	M	
Tadorna variegata	paradise shelduck	R	
Todiramphus sanctus	sacred kingfisher	R	
Tringa stagnatilis	marsh sandpiper		
Turdus merula merula	blackbird	R	
Turdus philomelos clarkei	song thrush	R	
Vanellus miles novaehollandiae	spur-winged plover	R	
Xenus cinereus	Terek sandpiper	M	