Waituna Lagoon - review of existing information relating to opening regime

Prepared for the Department of Conservation, Southland Conservancy

by

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Introduction

Waituna Lagoon (the Lagoon) is a largely unmodified, shallow coastal lagoon that lies within the Awarua/Waituna wetland complex on the southern coast of the South Island, near Invercargill (Figure 1). The Lagoon and the associated coastal wetland system represents one of the last remaining lowland wetland systems in New Zealand and is recognized for its wide range of ecological, cultural and recreational values both nationally and internationally.

In 1971 Waituna Lagoon and a section of the surrounding wetland was protected as a Wetlands Management Reserve. In 1976 the wetland was designated under the RAMSAR convention to be of international significance, and the area was given Scientific Reserve status in 1983. In January 2008, an extension to the Awarua-Waituna wetland RAMSAR designation was approved and a total of 19500 ha of wetlands and estuarine areas is now protected.

The 1976 Awarua-Waituna wetland designation was based on the area meeting three of the four RAMSAR significance criteria (for plants and animals) in that it 'supports an appreciable assemblage of endemic and threatened species and communities, has special value for maintaining the genetic and ecological diversity of the region and provides a habitat for plants and animals at critical stages of their biological cycles'. In particular, the wetland complex provides important habitat for resident and migratory birds including nationally critical and endangered species. The Lagoon (and its catchment) provide habitat for at least 12 native fish species, including several threatened species, and also supports a recreational trout fishery. In addition, the *Ruppia* dominated macrophyte community of the Lagoon is not well represented elsewhere in New Zealand. The terrestrial vegetation of the wetland is noted for its cushion-bog and sand-ridge plant associations and the presence of several alpine and sub-alpine species at sea level.

In 2003 the Department of Conservation (DOC) sponsored an ecological and water quality review of existing information relevant to the Lagoon and its catchment (Thompson and Ryder 2003a). The Thompson & Ryder report provided a number of recommendations regarding further studies and investigations, and, given the ecological vulnerability of the Lagoon, DOC has recently sought to update information on its ecological status as a first step to establish a targeted ecological management plan.

Ultimately, the focus of future work is likely to revolve primarily around the inter-relationship between factors affecting the Lagoon's wider ecology, including water quality issues associated with run-off from the surrounding catchment, and processes associated with the opening and closing of its outlet to the sea.

The Lagoon is a dynamic system, being artificially opened to the sea by excavation of the gravel barrier beach on an almost annual basis, which then closes through natural coastal sedimentation processes. The openings are undertaken under the provisions of a resource consent (Consent Number A0784, granted for 15 years), which is managed by the Lake Waituna Control Association. The only purpose of Lagoon opening is to ensure drainage of the land area around the Lagoon, which is farmed intensively (sheep, beef and diary). Agricultural development is ongoing within the Waituna catchment and, as the associated pressures on and modifications to the Lagoon environment increase, concern for the long term and sustainable ecological future of the Lagoon grows.

The specific objectives of this report are to compile existing information (research and data) on the lagoon relevant to the existing opening regime. This information may be Waituna specific or specific to other areas that have similar issues (e.g., Lake Ellesmere).

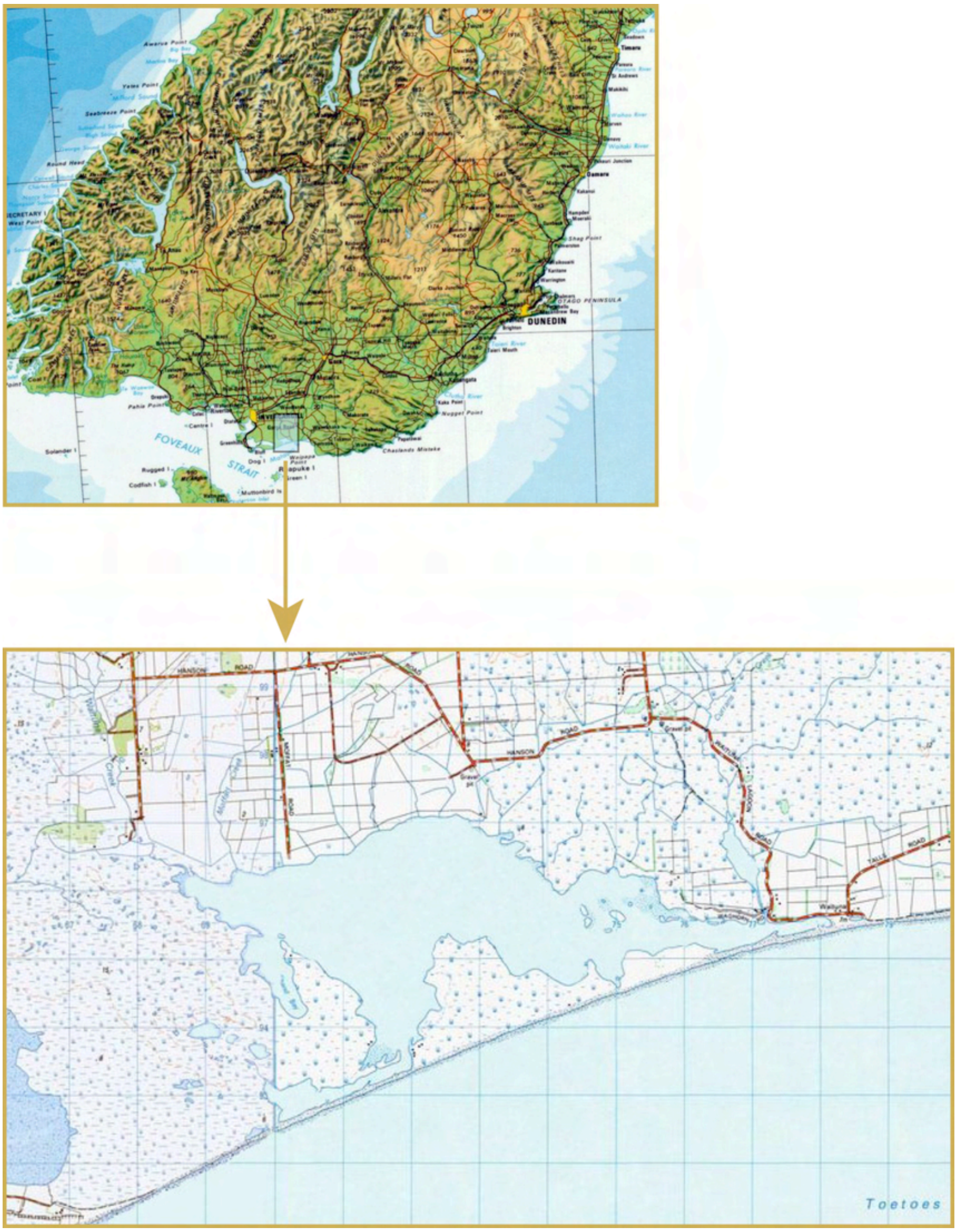


Figure 1 *General location of Waituna Lagoon catchment and accompanying wetlands.*

Review of existing information

General

Since the initial review of information in 2003 (Thompson and Ryder 2003a), and following on from the recommendations made in that review, there have been several significant studies of Waituna Lagoon. Three studies in particular have contributed considerably to existing knowledge of Lagoon ecology; Schallenberg and Tyrrell (2006), Stevens and Robertson (2007a) and Stevens and Robertson (2007b). The findings of each of these and other studies are summarized in the current review, along with relevant information from other lagoons comparable to Waituna Lagoon. Each of the major components of the lagoon ecosystem is discussed in turn.

In broad terms, the likely important linkages between the various ecological and physical components of the Lagoon are portrayed in Figure 2. The linkages diagram presents a simplified outline of the Lagoon ecosystem and should not be considered as a complete summary of all ecosystem linkages. The diagram has a particular focus on the features of the Lagoon environment that influence the *Ruppia* species dominated macrophyte community, which has been identified as a key driver of ecosystem health. Lagoon and wetland ecosystems are complex, with many interacting components, which are not necessarily connected directly. Development of a Waituna Lagoon specific model is required to best understand how the Lagoon functions and how it will respond to various management options. The physical and water chemistry attributes of the Lagoon play important roles in the associated ecosystem. Some of the ecosystem relationships are better understood than others (for example, there is a lack of knowledge of the zooplankton community), and this report attempts to identify known relationships as well as important information gaps that may require filling in order to develop an appropriate ecological management regime.

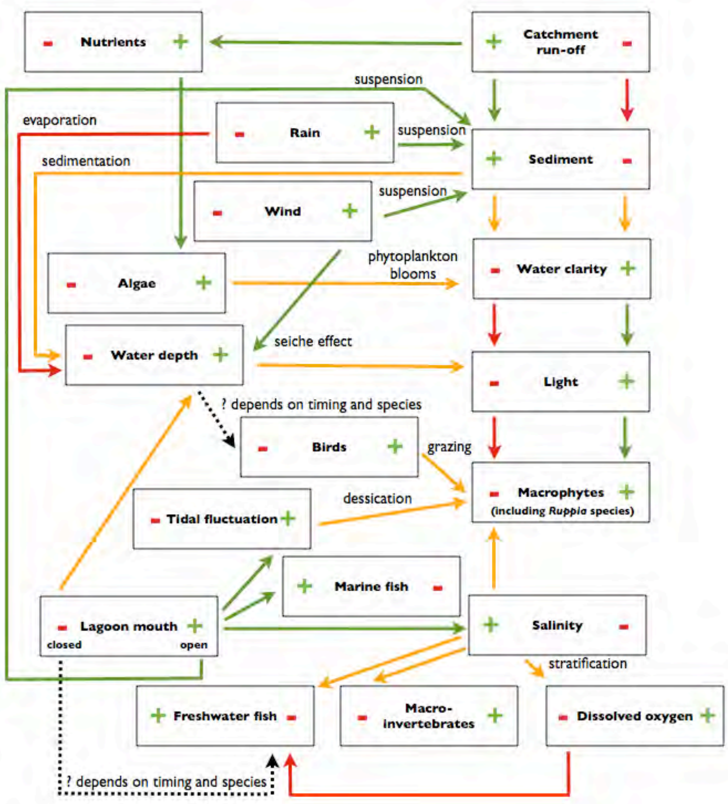


Figure 2 *Likely important ecosystem linkages for Waituna Lagoon.*

Physical setting

Waituna Lagoon (approximate area 14 km²) is termed a 'coastal lake' (Kirk and Lauder 2000). Coastal water bodies are classified based on their method of formation and physical structure. The distinguishing feature of coastal lakes are that they are established by the pooling of water behind a barrier beach. The barrier beach restricts the connection of the lagoon with the sea, while in contrast, estuaries (e.g. Jacobs River Estuary, New River Estuary), which are formed by the sea flooding a river valley, have an open connection with the sea. The Waituna Lagoon was formed by the development of a gravel barrier beach that restricted the connection between the outlets of three major streams (Waituna Creek, Moffat Creek, and Currans Creek) and the sea. Other examples of coastal lake lagoons in New Zealand are Lake Grassmere (Marlborough, approximate area 18 km²), Lake Ellesmere/Te Waihora (central Canterbury, approximate area 200 km²) and Wainono Lagoon (South Canterbury, approximate area 4 km²).

Hydrology and water depth

Water depth is an important physical characteristic influencing lake and lagoon ecology (James *et al.* 2002). In the case of Waituna Lagoon, it is likely to strongly influence the macrophyte[1] community through light limitation and degree of wave action.

[1] aquatic plants visible with the naked eye.

Historically, the Lagoon's three inlet streams increased the water depth until it flowed over the barrier beach, eventually causing it to breach and resulting in the Lagoon emptying (Johnson and Partridge 1998).

> Artificial breaching of the barrier beach began in 1908, initially to improve fishing and later to improve drainage of surrounding farmland. Water depth in the Lagoon has varied significantly in the past, as has the length of time that the Lagoon is open to the sea. Currently artificial opening of the Lagoon occurs when the water level on the Waghorns Road bridge staff gauge reaches 2.2m, corresponding to approximately annual opening.

Under the current regime the water depth in Waituna Lagoon is mostly less than 1.5m, with a maximum depth of about 3m (Stevens and Robertson 2007b). This is similar to the depths of Lake Ellesmere and Wainono Lagoon, which have maximum depths of approximately 2m and 3m respectively (Ministry for the Environment 2007). Stevens and Robertson (2007b) used a combination of techniques (i.e. field measurements, local knowledge, aerial photography) to prepare a map of Waituna Lagoon's depth contours in March 2007 (Figure 3). The map shows that narrow channels of deeper water (greater than 1m deep) were present near the stream inlets and in the southwest corner near where the Lagoon opens to the sea (Stevens and Robertson 2007b). The deepest area of the Lagoon was in the eastern arm where Currans Creek enters (Stevens and Robertson 2007b).

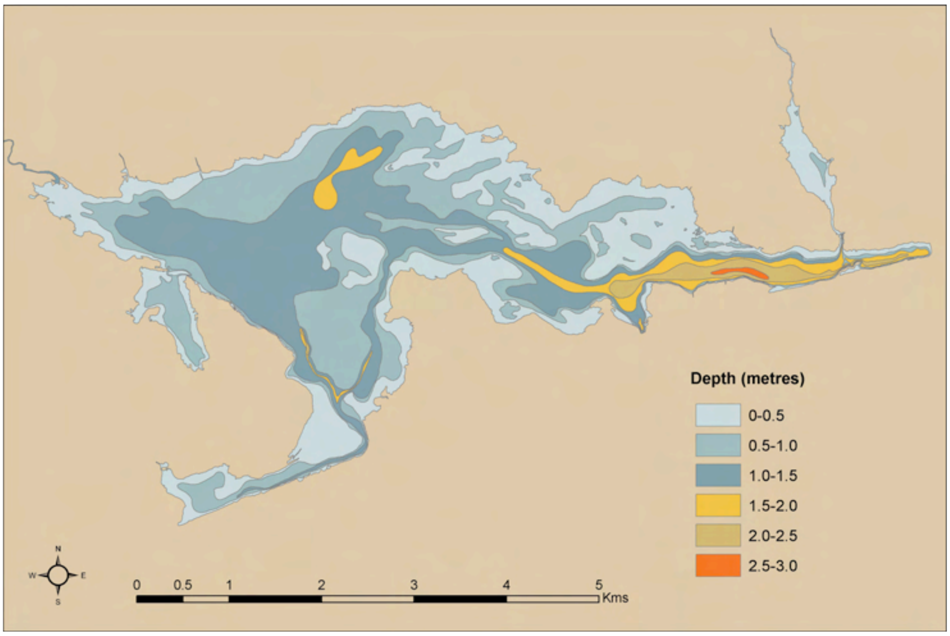


Figure 3 *Map of water depth – Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Analysis of historical records of the Waituna Lagoon opening regime indicates that since 1975 the amount of time that the Lagoon is open to the sea has increased (on average) by 5 days a year (Schallenberg and Tyrrell 2006) (Figure 4). Related to this is a decrease in the frequency of opening. The opening frequency has halved since 1992, due to a suggested change in the artificial opening management that aimed to maximise the time that the Lagoon is open (Schallenberg and Tyrrell 2006). This was achieved by timing Lagoon opening for early spring. In contrast, in Lake Ellesmere the duration of openings has decreased and the frequency of openings has increased (Schallenberg and Tyrrell 2006).

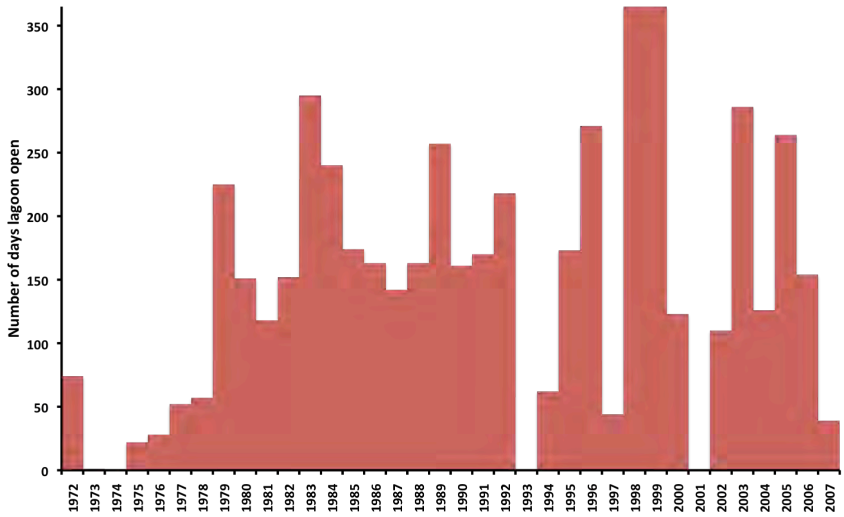


Figure 4 *Lagoon openings (source: ES).*

The primary motivation currently for Lagoon opening is to improve drainage of surrounding farmland. The land around the Lagoon has several features that result in poor drainage (i.e., high water table, low hydraulic gradient, poor soil permeability) and flooding occurs quickly during periods of high rainfall (Jackson *et. al.* 2001).

Analysis has indicated though that Lagoon level may not be the cause of flooding at distances of greater than 60m from the Lagoon or its major tributaries, (i.e. if the Lagoon was empty there would still be flooding) (Jackson *et al.* 2001). More work is required to map the areas that are affected by high Lagoon levels (Schallenberg and Tyrrell 2006). The hydrological model that Jackson *et al.* (2001) developed could be modified and contribute to the development of a decision making tool to guide management of the Lagoon (Thompson and Ryder 2003a).

The weather conditions that result in high rainfall and flooding also appear to be associated with the Lagoon mouth closing. Schallenberg and Tyrrell (2006) calculated that after closure it takes approximately 16 days for the Lagoon level to reach 1m, 1 month (34 days) to reach 1.5m, and two months (59 d) to reach 2m. Artificial opening of the Lagoon is undertaken when the water level on the Waghorns Road bridge staff gauge reaches 2.2m (note that this staff gauge is not calibrated to mean sea level, see discussion in Schallenberg and Tyrrell (2006)). Analysis of gauge water level and rainfall records indicates that short-term fluctuations in water level occur in the absence of rainfall. These are caused by wind induced waves and therefore should not be used to trigger artificial opening (Schallenberg and Tyrrell 2006). Although water levels in the Lagoon have reached at least 3.45m during stormy weather in the past (September 1994) the last natural breach of the barrier beach occurred in 1972 (Thompson and Ryder 2003a, Schallenberg and Tyrrell 2006).

> The water level required for natural breaching of the Lagoon is likely to be substantially higher than the current trigger level of 2.2m (Schallenberg and Tyrrell 2006).

Lagoon-bed substrate

Stevens and Robertson (2007b) also undertook extensive broad scale mapping of the Lagoon bottom substrate (sediments) in March 2007 (Table 1, Figure 5). Prior to this Johnson and Partridge (1998) and Cadmus and Schallenberg (2007) had made general and localized descriptions of the substrate, identifying that the basement substrate of the Lagoon consisted of compact, water-worn quartz gravel and sand with new areas of fine sediment deposition over this. Substrate was grouped into four dominant types; gravel, firm sand, soft mud and very soft mud (Table 1). Soft mud/sand was found to cover the largest area of the Lagoon (40%), although it frequently occurred with gravel (28%) and was often only present as a thin layer. Firm sand was almost equally common as soft mud, covering 38% of the Lagoon's bottom, mainly in the central basin towards the outlet (Table 1, Figure 5). Around the shore of the Lagoon (except the western end) gravel was the dominant substrate, and in the sheltered western bay very soft mud dominated. (Table 1, Figure 5). Narrow plumes of fine sediment were also present near the mouth of the steams.

> The makeup of the Lagoon bed is important in that it can influence the structure of the flora and fauna (e.g., weed beds and benthic or bottom-dwelling invertebrates) community. For example, fine sediment deposition and shelf building around macrophyte beds can potentially provide new sediment environments for flora and fauna, possibly increasing the likelihood of new and unwanted macrophytes establishing within the lagoon (Schallenbery Tyrrell 2006).

Table 1 Summary of broad scale mapping of substrate type, March 2007. Sourced from Stevens and Robertson (2007b).

Dominant Substrate Type	Area (ha)	%	Comments
Gravel	73	5	Common around shorelines, except western end
Gravel (plus Firm Sand)	204	15	Common around shorelines, except western end
Firm Sand (plus Gravel)	179	13	Common in western central basin near lagoon outlet
Firm Sand	317	23	Common in western central basin near lagoon outlet
Firm Mud/Sand	23	2	Uncommon
Soft Mud/Sand (plus Gravel)	381	28	Common in central basin towards eastern end
Soft Mud/Sand	160	12	Waituna Creek plume, Currans Creek plume
Very Soft Mud/Sand	28	2	In sheltered western embayment
Total	1365	100	

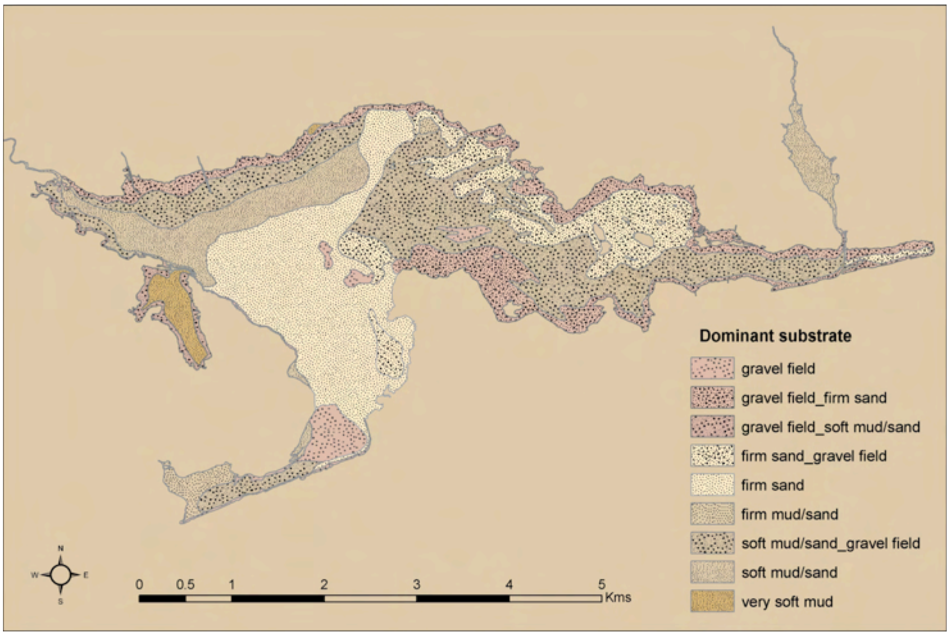


Figure 5 *Map of sediment type – Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Water chemistry

Information on water chemistry of the Lagoon and its catchment inflows is important for understanding the biological, chemical and physical interactions of the ecosystem, and for determining what sources within the catchment may be influencing lagoon ecology. Such information is crucial in order to formulate and evaluate ecological management plans.

Lagoon

Prior to 2001 information on the water chemistry of the Lagoon was scarce, with the only regular monitoring in the catchment occurring at a site in Waituna Creek (monthly monitoring, beginning in July 1995). It was apparent even from the limited information available then that landuse was affecting water quality in the Waituna Lagoon catchment (Thompson and Ryder 2003a). High levels of nitrate and ammonia (the latter sometimes at levels toxic to fish) had been recorded in Waituna Creek (1995-2001), and ammonia levels increased over the monitoring period. Thompson and Ryder (2003a) suggested that this was probably as a result of increasing agricultural effluent inputs. This assessment was supported by the high abundance of indicator bacteria (enterococci and faecal coliforms) in Waituna Creek, comparable to levels recorded in meat works' effluent in the Mataura River (Ryder 1998). However, the lack of information on the water chemistry of Waituna Lagoon at the time meant it was not possible to determine whether the high nutrient levels in Waituna Creek were also present in the Lagoon.

In 2001 the Waituna Landcare Group in association with Environment Southland began monthly measurement of a variety of water quality variables in Waituna Lagoon and all three major tributaries. Stevens and Robertson (2007a) summarized the monitoring as follows:

- Monthly sampling at four sites in Waituna Lagoon.
- Monitoring parameters include: dissolved oxygen (DO), temperature, pH, chlorophyll *a* (an indicator of algal/phytoplankton abundance), conductivity (a useful indicator of nutrient enrichment), dissolved reactive phosphorus (DRP), ammoniacal nitrogen, total nitrogen (TN), total phosphorus (TP), turbidity (an indicator of water clarity and suspended sediment inputs), *Escherichia coli* (E. coli), and salinity. Lagoon level is also monitored.
- Monthly sampling at Currans Creek (at Waituna Lagoon Road and tributary at Waituna Lagoon Road), Moffat Creek (at Moffat Road), and Waituna Creek (at Marshall Road and at Mokotua)
- Monitoring parameters include: nitrate-nitrite nitrogen, TN, TP, DRP, ammoniacal nitrogen, faecal coliforms, E. coli, DO, temperature, turbidity, black disk clarity, conductivity, and biochemical oxygen demand (BOD, only at Waituna Creek). In addition, benthic macroinvertebrates and periphyton (benthic algae) are monitored annually at Waituna Creek (at Marshall Road and at Gorge Road).

The initiation of this regular monitoring has contributed immensely to knowledge of the water chemistry of the Lagoon and its three major tributaries. However, there are limitations to the data, which restrict interpretation and should be borne in mind when reading the following discussion of the water chemistry monitoring results. One-off measurements of water chemistry are made at sites in the Lagoon and its inflows approximately monthly. The measurements are made at different times of day on each month, and the time of sampling varies among sites within a day. This introduces potential sources of variation that make the data less comparable among sites and times. For example, when the Lagoon is open, tidal fluctuations may therefore mean that sites are sampled at different times of the day are also sampled at different parts of the tidal cycle, which may effect the water chemistry (e.g. salinity). Also, some water chemistry parameters vary naturally according to the time of day (e.g. water temperatures tend to be higher in the afternoon, dissolved oxygen levels tend to be lower at night and early morning). Monitoring of water chemistry in the inflows is carried out on different days to that in the Lagoon (sometimes up to weeks apart), making it difficult to understand how changes in water chemistry in the inflows effects water chemistry in the Lagoon. However, the data does allow the identification of patterns of interest, which can then be targeted with more detailed monitoring.

Latest monitoring data (2001-2008) indicates that nutrient levels (nitrogen and phosphorus) and chlorophyll *a* concentrations are both elevated in the Lagoon relative to the appropriate guideline levels (Stevens and Robertson 2007b). The estimated input of faecal coliforms (2 x 10^{15} per year) into the Lagoon from the surrounding catchment is also elevated, however current monitoring indicates that faecal bacteria levels in the Lagoon are moderate (Stevens and Robertson 2007b). Sheep, beef and dairy operations are intensive in the catchment (e.g. 20,400 cows on 5,600ha or 3.6 cows per ha) and are primarily responsible for the elevated faecal bacteria inputs to the Lagoon (Stevens and Robertson 2007b). Dairy farming has increased gradually over the past 13 years (Figure 6).

Although nutrient levels are elevated in Waituna Lagoon (Table 2) relative to guideline levels, they are generally lower than those recorded in Wainono Lagoon and Lake Ellesmere. Total nitrogen concentration in Wainono Lagoon (2000-2006) ranges from 0.56 to 4.7 mg/l and total phosphorus concentration averages 0.27 mg/l (maximum 1.7 mg/l) (URS 2006). In Lake Ellesmere during the July 2003 to May 2004 period, total nitrogen concentrations ranged from 0.2 to 3.5 mg/l (median 1.7 mg/l) and total phosphorus concentrations ranged from 0.15 to 0.84 mg/l (median 0.16 mg/l) (Kelly and Jellyman 2007).

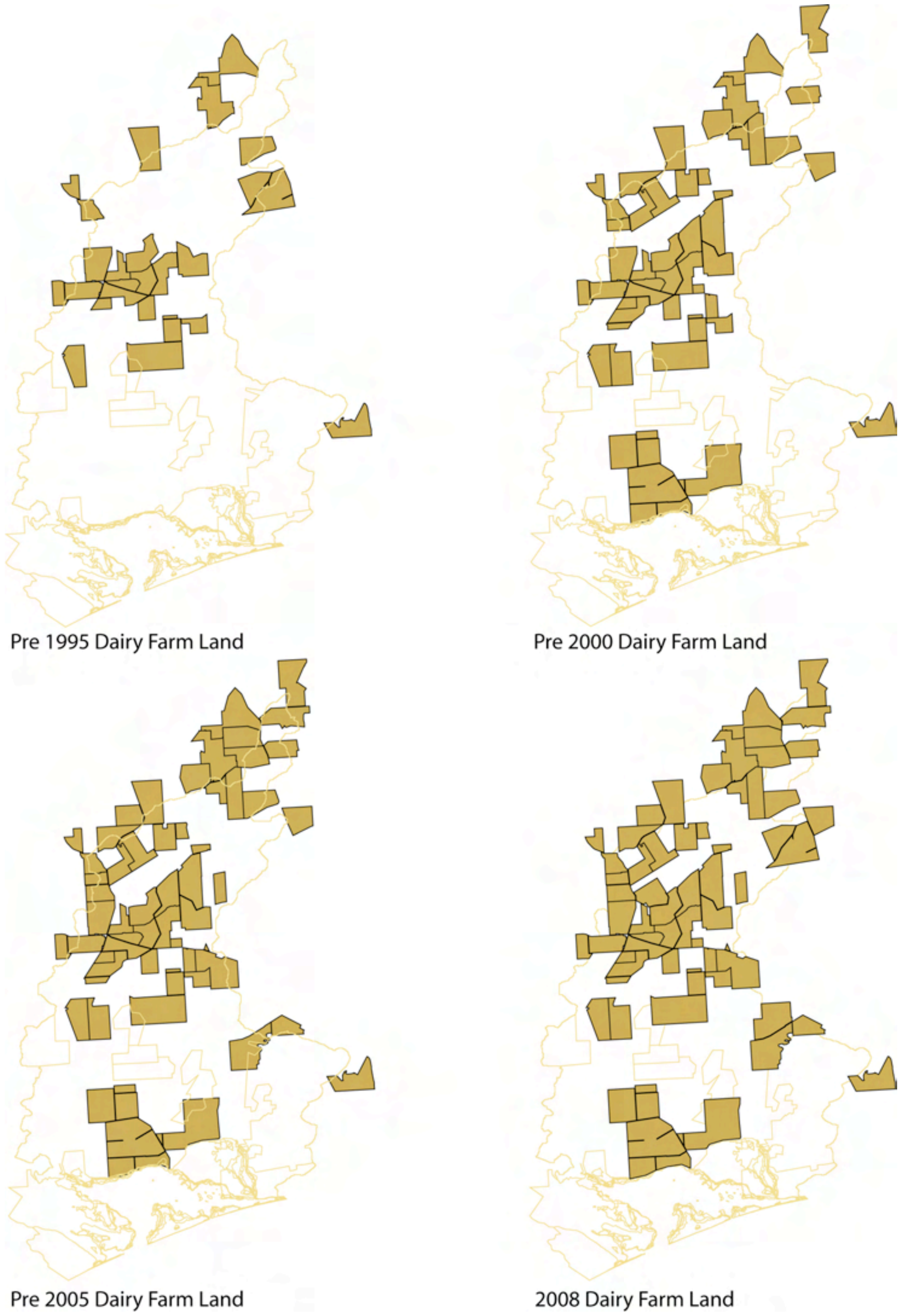


Figure 6 *Waituna Lagoon catchment consented dairy farm land (data source: Environment Southland).*

Dissolved reactive phosphorus concentrations in Lake Ellesmere were slightly lower than that in Waituna Lagoon, ranging from 0.003 to 0.016 mg/l (median 0.004 mg/l) (Kelly and Jellyman 2007), however in Wainono Lagoon the mean dissolved reactive phosphorus concentration of 0.05 mg/l (URS 2006) exceeded the maximum recorded in Waituna Lagoon (Table 2).

Schallenberg and Tyrrell (2006) analyzed water quality data collected from four sites in the Lagoon over the 2001 to 2005 monitoring period. This information has now been updated to 2008 (Table 2, Figures 7, 8 and 9).

Table 2 *Minimum, median, mean and maximum water quality variables analysed from four sites in Waituna Lagoon between October 2001 and June 2008 (date source: ES).*

Variable	Minimum	Median	Mean	Maximum	n
Temperature (°C)	3.5	11	11.5	21.5	189
Total nitrogen (mg/l)	0.1	0.7	0.85	3.5	224
Total phosphorus (mg/l)	0.005	0.033	0.039	0.19	225
Nitrate + nitrite nitrogen (mg/l)	0.005	0.06	0.31	2.68	225
Dissolved reactive phosphorus (mg/l)	0.003	0.007	0.011	0.15	224
Ammoniacal nitrogen (mg/l)	0.005	0.015	0.033	0.6	225
Turbidity (NTU)	1.9	5.8	7.6	65	226
Chlorophyll *a* (mg/m3)	0.05	3.4	6.26	65.7	224
Dissolved oxygen (mg/l)	5.8	9.3	9.4	14.1	221
pH	6.8	7.9	7.8	8.7	226
Conductivity (µS/cm)	224	10800	21402	53000	227
Salinity (ppt)	0.2	5.3	13	34.2	203
Escherichia coli (MPN/100ml)	0.5	10	28	340	215

Schallenberg and Tyrrell (2006) identified major patterns in the Lagoon's water quality, and how they relate to Lagoon hydrology (i.e. water level, days elapsed since opening or closing) and phytoplankton biomass/ecology[2].

Nitrogen levels in the Lagoon appear to be related to closures, with higher concentrations of total nitrogen observed when the water level in the Lagoon rises (Schallenberg and Tyrrell 2006, Stevens and Robertson 2007b). This pattern relates well to the high level of nitrate previously observed in Waituna Creek (Thompson and Ryder 2003a), although nitrogen levels in the Lagoon may also increase due to the flooding of sediments on the Lagoon margins as the water level rises (Schallenberg and Tyrrell 2006). In contrast, analysis shows no relationship between

[2] Phytoplankton are microscopic free-floating plants (e.g. algae). They are useful indicators of nutrient enrichment, which can result in 'blooms' (excessive proliferations) and may favour species that are toxic to livestock and humans (e.g. some species of cyanobacteria). There have been anecdotal reports in the past of blooms of cyanobacteria around the margins of the Lagoon (Thompson and Ryder 2003a).

Lagoon hydrology and phosphorus and ammonia concentrations. Water temperatures are generally highest during summer (maximum 21.5°C recorded on 31 January 2008 when the Lagoon was closed), and monitoring indicates that the magnitude of temperature peaks are unrelated to lagoon opening and closing (Figure 10). However, as water temperature fluctuates daily continuous measurements are needed to confirm whether water temperature varies depending on the Lagoon opening regime.

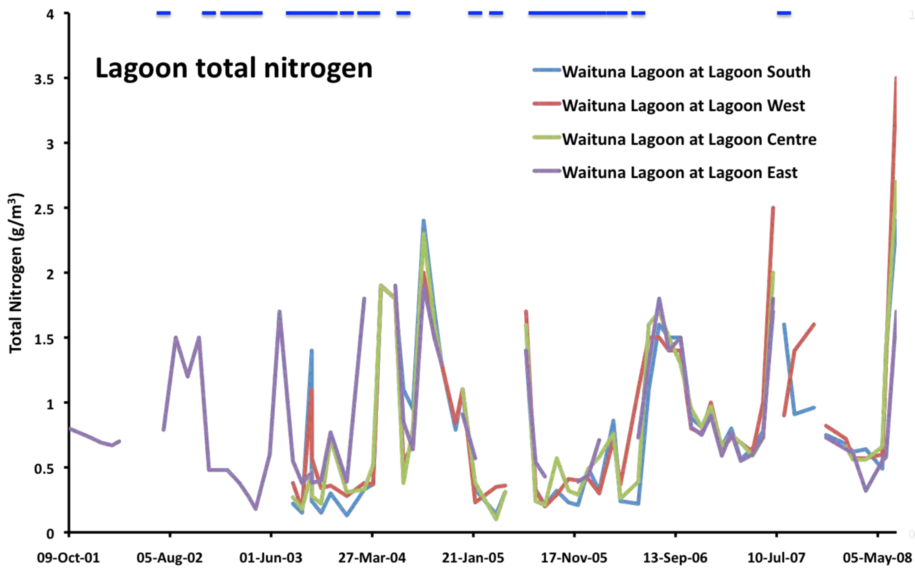


Figure 7 *Waituna Lagoon total nitrogen data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

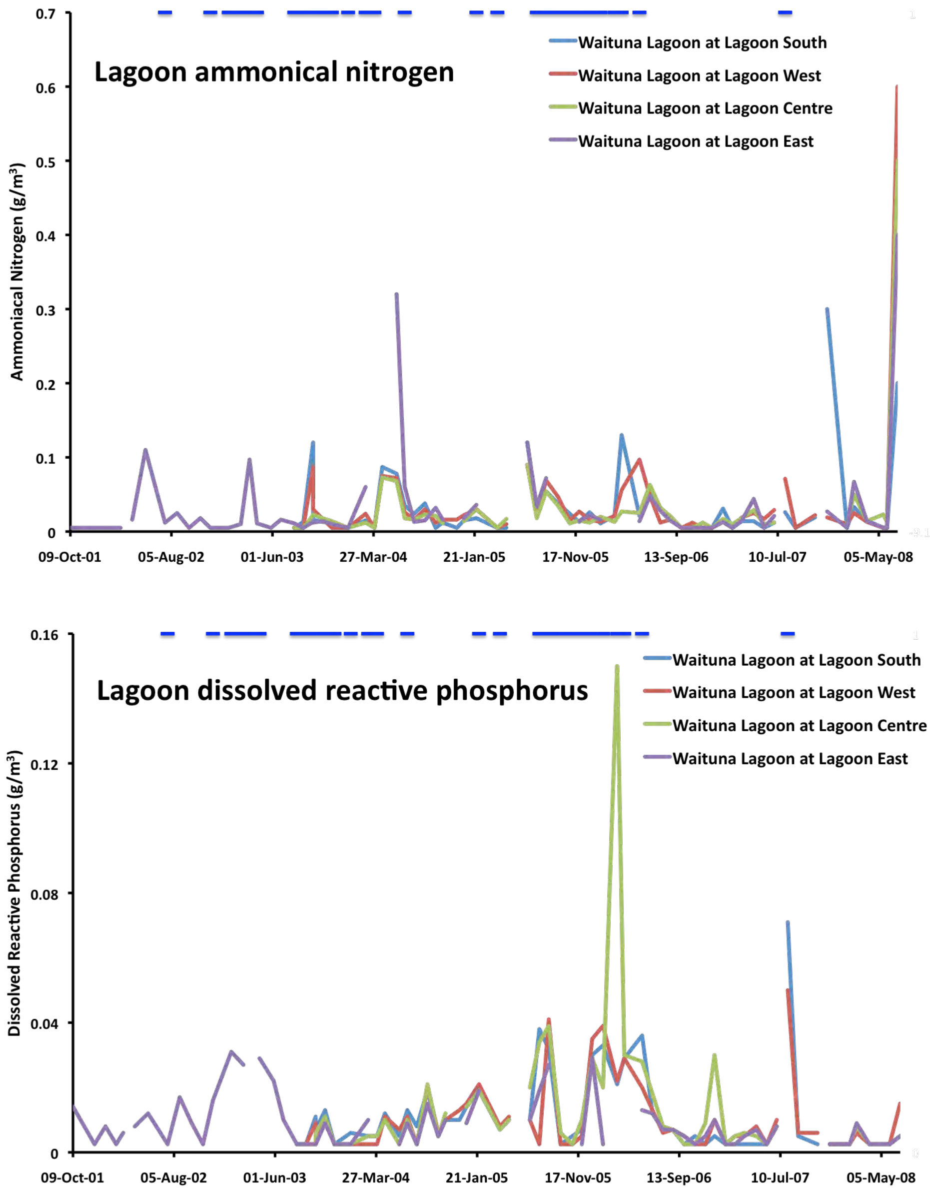


Figure 8 Waituna Lagoon ammonical nitrogen and dissolved reactive phosphorus data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.

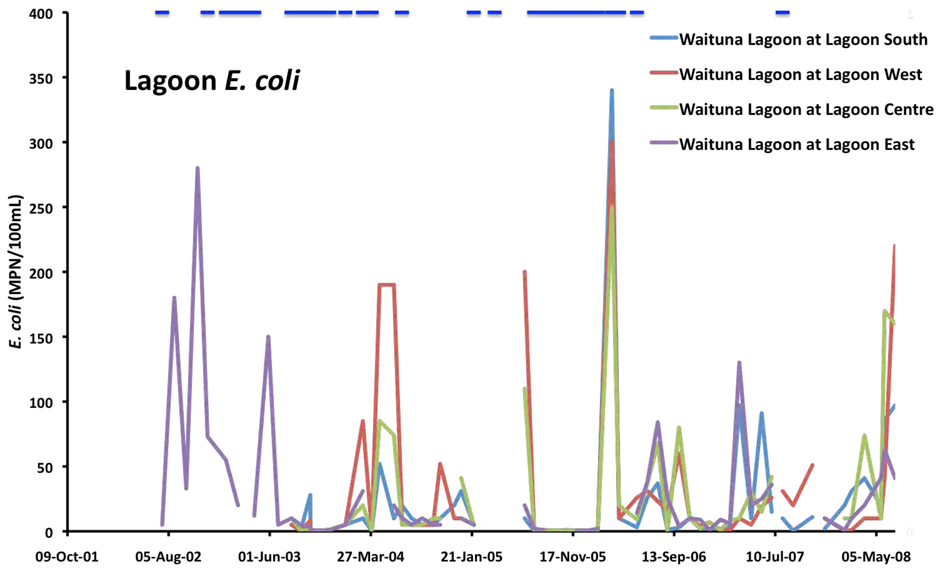


Figure 9 *Waituna Lagoon E. coli data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

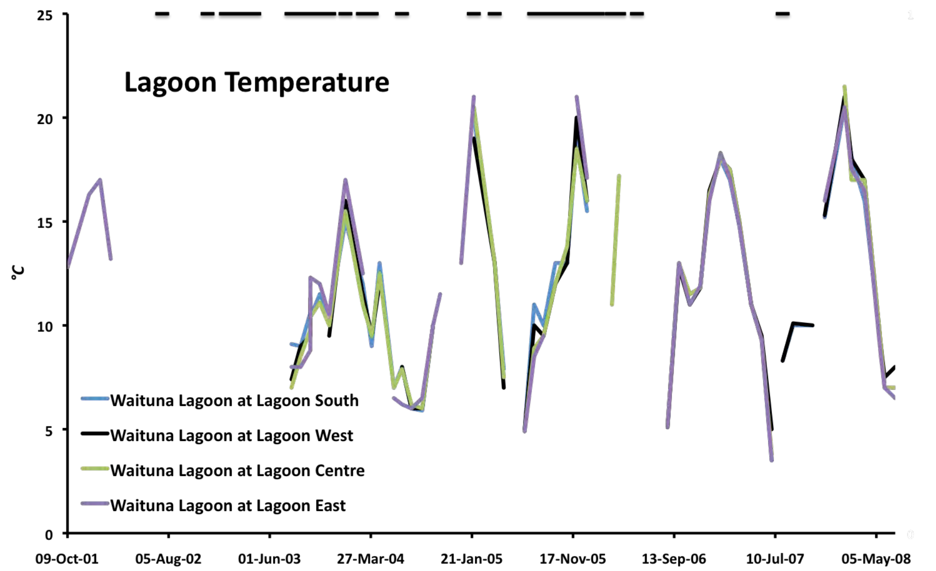


Figure 10 *Waituna Lagoon temperature data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

Nutrient levels do not appear to differ markedly among the four lagoon sites, indicating that there is little relationship between the proximity of a site to the three major inflow streams and the nutrient level at the site. The 'Lagoon West' site is located closest to the mouth of Waituna Creek and Moffatt Creek and nutrient levels may therefore be expected to be higher at this site, however this theory is not supported by the available data.

Schallenberg and Tyrrell also found phytoplankton biomass (chlorophyll *a*) was related to Lagoon hydrology, increasing with Lagoon closure and water level rise (Figure 11). Phytoplankton biomass also increases with increasing nitrogen levels (total nitrogen, dissolved inorganic nitrogen and nitrate+nitrite), the strongest co-relationship being with total nitrogen. This suggests that nitrogen levels in the Lagoon are sufficiently high such that phytoplankton growth may not be nitrogen limited.

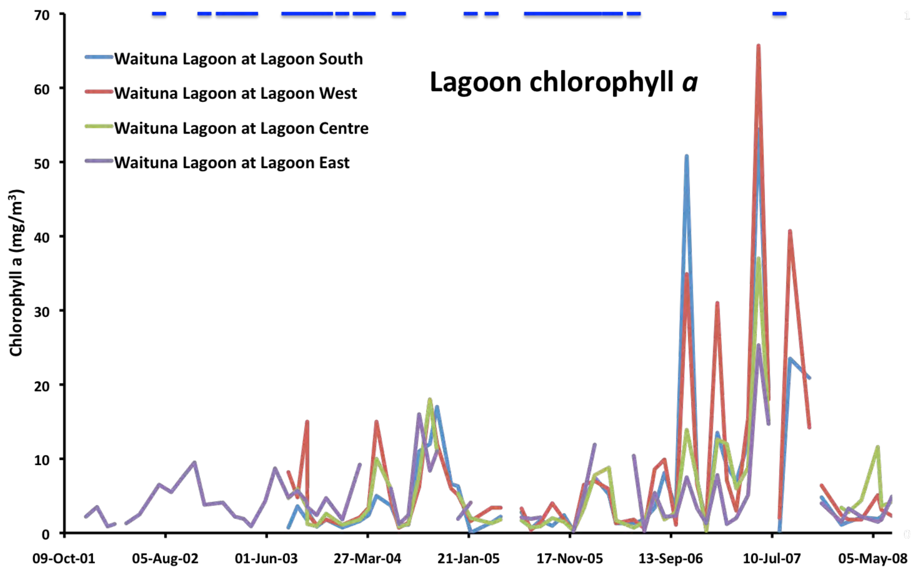


Figure 11 *Waituna Lagoon chlorophyll a data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

Phytoplankton biomass and phosphorus levels (dissolved reactive phosphorus) were not found to be related (Schallenberg and Tyrrell 2006). This suggests that phytoplankton growth may be restricted when phosphorus levels in the Lagoon are low, and that under the right conditions (i.e. sufficient light and temperature) an increase in phosphorus levels may lead to rapid phytoplankton growth. This theory appears to be supported by the high concentrations of chlorophyll *a* that were recorded in October 2006 when the lagoon was closed (Figure 11). This peak in chlorophyll *a* followed a peak in dissolved reactive phosphorus that occurred from December 2005 to May 2006 (Figure 8). The same relationship was again apparent in 2007, when peaks in chlorophyll a concentration in September and October 2007 (Figure 11) followed a peak in dissolved reactive phosphorus in August 2007 (Figure 8). This is an important finding of Schallenberg and Tyrrell's analysis as it indicates that reducing phosphorus inputs to the Lagoon could be the most effective way to prevent nuisance phytoplankton growths. Limiting nitrogen inputs may also control phytoplankton growth, although consideration of the nitrogen:phosphorus ratio would be necessary to avoid (undesirable) cyanobacteria growth (Schallenberg and Tyrrell 2006). In contrast, recent research in Wainono Lagoon suggests that phytoplankton growth is limited by nitrogen availability rather than phosphorus (Norton *et al.* 2007).

More research (particularly on Lagoon light levels and zooplankton abundance) would be needed to confirm which is the most effective way to avoid phytoplankton blooms. It should also be noted that Stevens and Robertson (2007a) identified that an error was made by the analytical laboratory in the reporting of chlorophyll *a* concentrations in the Lagoon, which may have (unbeknown to them) influenced the results of Schallenberg and Tyrell's (2006) analysis. Stevens and Robertson (2007a) reported that the corrected chlorophyll *a* range were 2 to 7mg/m^3 when the Lagoon was open and 1 to 35mg/m^3 when closed, although they also expressed some doubt over these high values. Further analysis of chlorophyll *a* concentrations is therefore required.

Based on Schallenberg and Tyrell's (2006) data and more recent data up to 2008 (Table 2), phytoplankton productivity in Lake Ellesmere appears to be higher than in Waituna Lagoon, with chlorophyll *a* levels ranging from 60.7 to 141.5mg/m^3 in Lake Ellesmere over the 2003 to 2004 monitoring period (median 61.4mg/m^3) (Kelly and Jellyman 2007). The phytoplankton community in Lake Ellesmere is comprised mainly of cyanobacteria, however cyanobacteria blooms have not been recorded from the lake because of its high turbidity and limited light (Kelly and Jellyman 2007). It is possible that high turbidity also limits phytoplankton growth in Wainono Lagoon, as there appears to be no indication that the two major nutrients (nitrogen and phosphorus) are limiting phytoplankton biomass (URS 2006). Analysis of turbidity data for Waituna Lagoon indicates that turbidity is not related to chlorophyll *a* levels, or Lagoon opening and closing (Figure 11) (Schallenberg and Tyrell 2006). However, as water quality sampling is generally conducted during calm weather it may not be a true representation of the full range of turbidity levels that occur in the Lagoon (Schallenberg and Tyrell 2006).

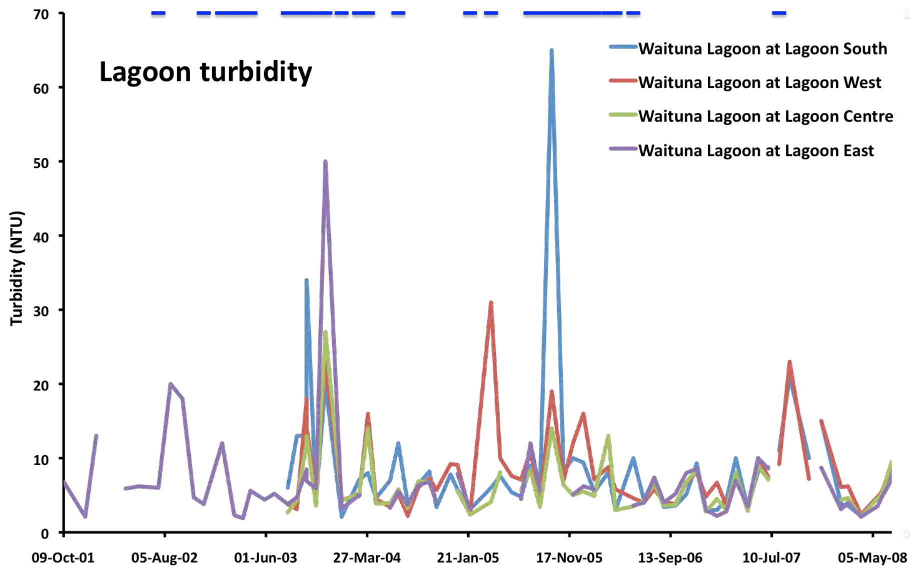


Figure 12 *Waituna Lagoon turbidity data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

The salinity level in the Waituna Lagoon has been identified by several authors (Johnson and Partridge 1998, Schallenberg and Tyrrell 2006, Stevens and Robertson 2007a) as an important water quality parameter because of it ability to influence several components of the Lagoon's ecology (e.g. macroinvertebrate and macrophyte communities). Salinity levels in the Lagoon have been measured on occasions in the past (Johnson and Partridge 1998, Schallenberg and Tyrrell 2006), however since 2003 Environment Southland has included salinity measurements in their regular monthly monitoring (Figure 13). Stevens and Robertson (2007a) summarized the results of this monitoring and reported that salinity levels in the Lagoon averaged 28.9 parts per thousand[3] (ppt) when the Lagoon was open (December 2005 to June 2006) and 2.6ppt when the Lagoon was closed (June 2006 to July 2007).

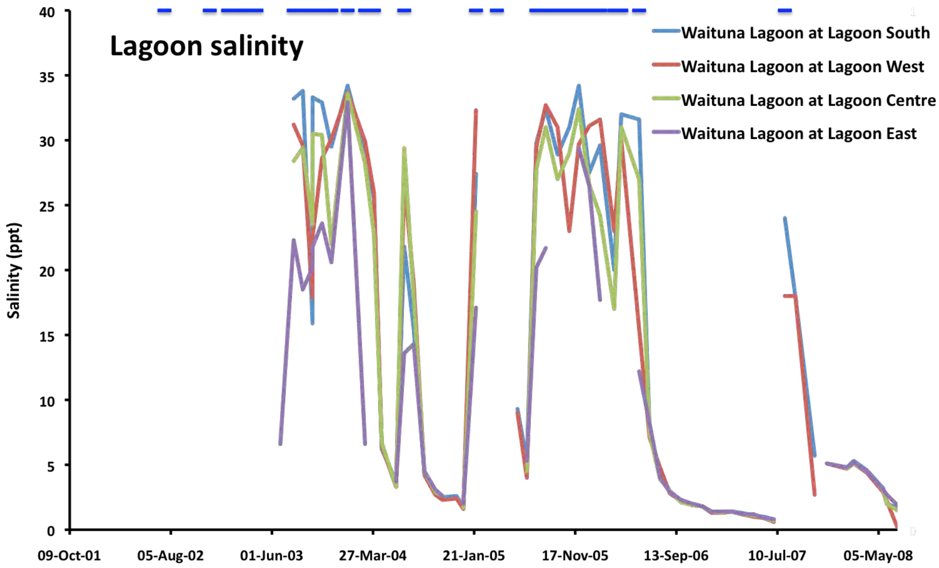


Figure 13 *Waituna Lagoon salinity data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

Schallenberg and Tyrrell (2006) identified that vertical stratification of salinity occurs on occasions in the Lagoon and if this was persistent it could lead to oxygen depletion of bottom waters (e.g., making it inhospitable for fish). Stevens and Robertson (2007b) noted that there were localized areas of oxygen depleted sediments in the Lagoon near the stream mouths and in places on the margins where there was decaying vegetation. Dissolved oxygen monitoring at four sites in the Lagoon by Environment Southland since 2003 (Figure 14), however indicates that oxygen levels in the water column are good (generally above 8 mg/l) and that oxygenation depletion is currently not a problem (Stevens and Robertson 2007b). Dissolved oxygen levels in Waituna Creek are also currently good (mean 9.4). More frequent monitoring of dissolved oxygen concentrations at a range of water depths is necessary to determine if oxygen depletion does occur.

3 Salinity levels of less than 5ppt are equivalent to freshwaters, while the range of salinity for most of the ocean's water is from 34.6 to 34.8ppt.

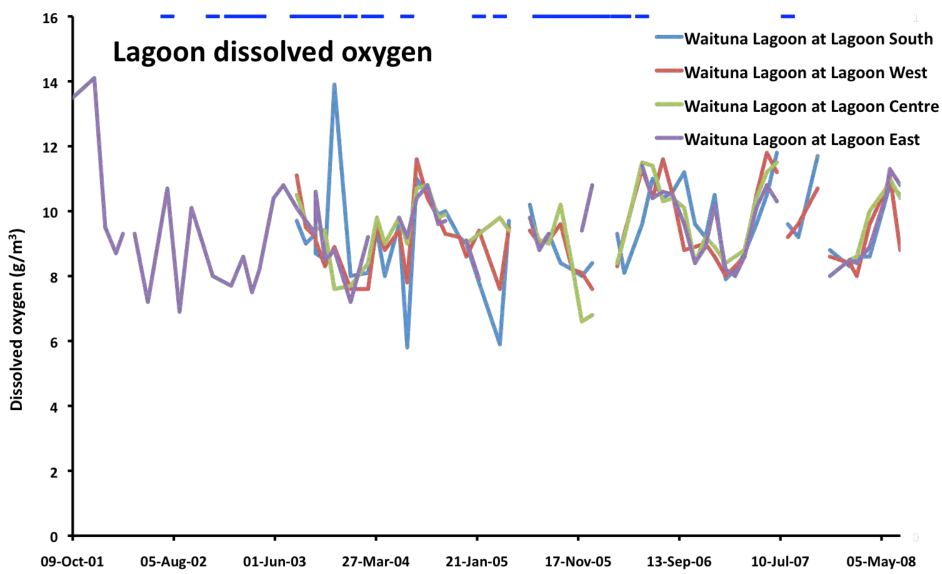


Figure 14 *Waituna Lagoon dissolved oxygen data, 2001-2008 (data source: ES). Intermittent blue line at top of graphs represent periods when Lagoon mouth is open.*

Thompson and Ryder (2003a) identified that more information was needed on sediment inputs to Waituna Lagoon. At the time there was some evidence that sedimentation rates were high (Johnson and Partridge 1998, Environment Southland unpublished data June-July 2001, Thompson and Ryder 2003a), but there was little information on where sediments were accumulating and/or if the rate of sediment accumulation was increasing. In order to understand historical sedimentation rates a sediment core was collected from the western end of the Lagoon in March 2007 (Stevens and Robertson 2007b). Analysis of this core indicated that the sedimentation rate over the 1960 to 2007 period was 2.5 to 3.0mm/year (Steven and Robertson 2007b). Cadmus and Schallenberg (2007) calculated a similar rate of sedimentation (2.8mm/year, 1960-2007) from cores collected at two other locations in the Lagoon (near Currans Creek and in the northwest of Waituna Lagoon east of Moffats Creek). This rate is low to moderate compared with most other New Zealand estuaries with developed catchments (Steven and Robertson 2007b). Higher rates of sedimentation are likely in some parts of the Lagoon (i.e. stream outlets, sheltered bays). Although low to moderate relative to other lagoons, Cadmus and Schallenberg (2007) calculated that the current sedimentation rate at the Currans Creek mouth is 44 times that of the rate pre-European settlement (pre 1860s, 0.005 to 0.006cm/year). Ongoing measurement of the sedimentation rate in the Lagoon was initiated in 2007 by the establishment of a monitoring site near the mouth of Waituna Creek, the area where sedimentation rates are likely to be the highest (Stevens and Robertson 2007a). Four plates (20cm square concrete blocks) have been buried along a transect line deep in the sediments. The position of each plate has been marked and the depth of sediment over the plate recorded. Annual measurements (monitoring undertaken by Environment Southland) will be made of the sediment depth on each plate and, over the long term, this will provide a measure of rates of sedimentation in the Lagoon (Stevens and Robertson 2007a).

Inflows

Water quality of the Lagoon inflows has also been updated to 2008. Virtual flows in each of the three inflows at the time of sampling, which has been recorded since July 2005, is also presented (Figure 15). Concentrations of total nitrogen continue to be high with annual winter peaks increasing in magnitude since 2003 (Figure 16). Nitrogen concentrations are generally higher in the inflows than in the Lagoon itself (Figures 7 and 16). When the Lagoon is closed peaks in nitrogen concentration in the inflows correspond approximately with peaks in nitrogen concentration in the Lagoon (Figures 7 and 16). However, when the Lagoon is closed the relationship is not as apparent (Figures 7 and 16).

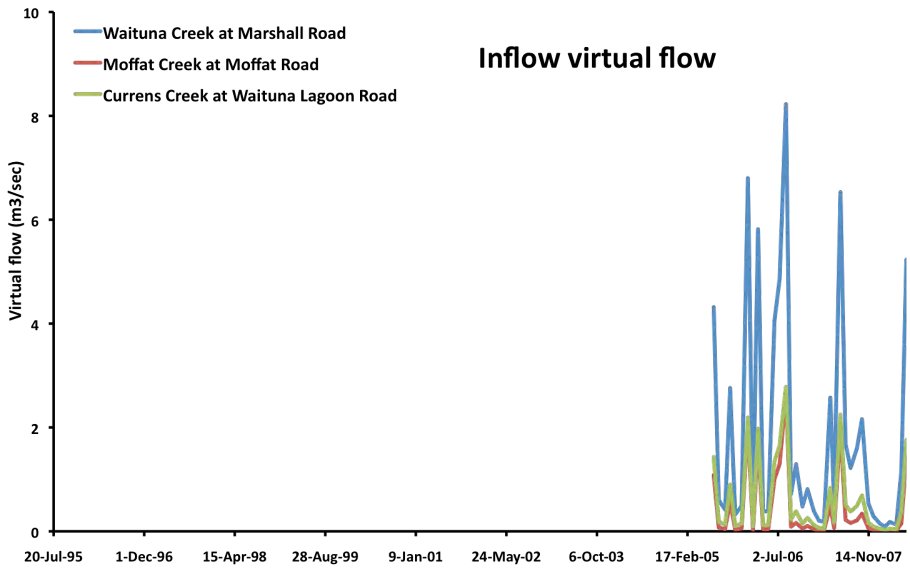


Figure 15 *Waituna Lagoon inflow virtual flow data, 1995-2008 (data source: ES).*

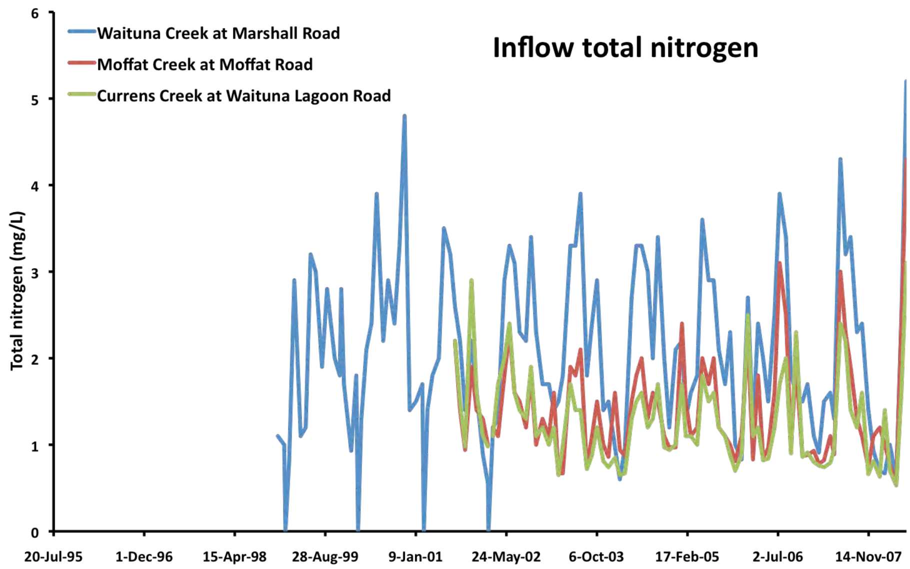
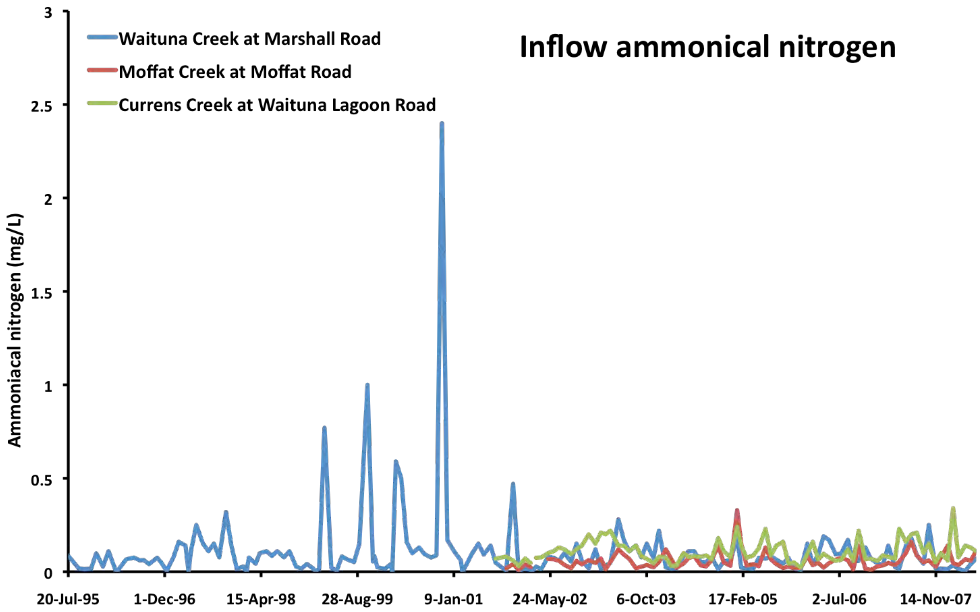


Figure 16 *Waituna Lagoon inflow total nitrogen data, 1995-2008 (data source: ES).*

Monitoring indicates that ammonia and dissolved reactive phosphorus levels are not increasing with time, as they are for total nitrogen. It is possible that a lack of an increasing trend in ammonia and phosphorus is due to greater emphasis on the (on-site) disposal of farm effluent, while a continuing increase in total nitrogen is due to increases in non-point source runoff via overland flow and tile drain discharges, which has come about through a progressive increase in stocking throughout the catchment (particularly dairy cows). The observation that the highest peaks in total nitrogen concentration are also associated with relatively high flows supports this (Figures 15 and 16).

As for total nitrogen, ammonia and dissolved reactive phosphorus levels are generally lower in the Lagoon than in the inflows (Figures 8 and 17).In contrast to total nitrogen though, peaks in inflow levels of ammonia and dissolved reactive phosphorus in the Lagoon do not appear to be strongly related to peaks in the levels of these nutrients in the inflows (Figures 8 and 17). However, nutrient levels in the inflows and Lagoon are not measured on the same day, so short term effects of the inflows on Lagoon water quality may not be detected.



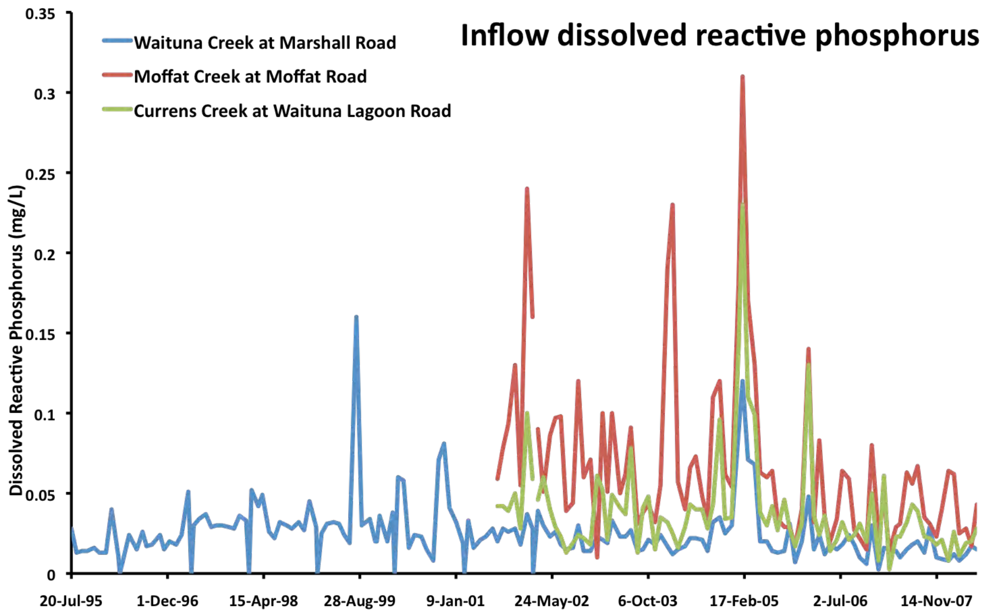
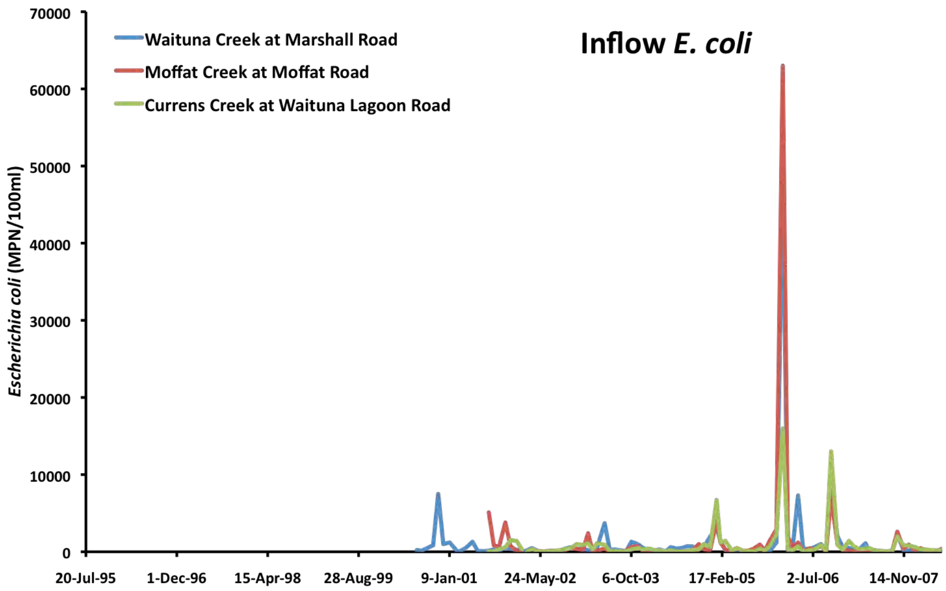


Figure 17 *Waituna Lagoon inflow ammonical nitrogen and dissolved reactive phosphorus data, 1995-2008 (data source: ES).*

E. coli concentrations remains variable in the inflows, but the the high peaks observed around early 2006 have not been recorded since (Figure 18) and there is some indication of relatively consistent low readings over the past summer. As with total nitrogen, there appears to be some evidence of a relationship between high water flows in the inflow streams and peaks in *E. coli* concentrations in the inflows (Figure 15 and 18). *E. coli* concentrations in the Lagoon are generally lower than those observed in the inflows (Figures 9 and 18). Peaks in *E. coli* concentrations in the Lagoon do not appear to correspond well with peaks in the Lagoon (Figures 9 and 18). However, it should be noted that the *E. coli* concentrations in the inflows have not been measured on the same day as those in the Lagoon, and this may obscure a relationship between the two.

Also on a positive note is that water clarity in the inflows, most notably in Waituna Creek, has steadily increased since about the middle of winter 2006 (Figure 18). Reasons for this have not been examined as yet, but it could be related to lack of significant rain events and/or improved landuse practices.



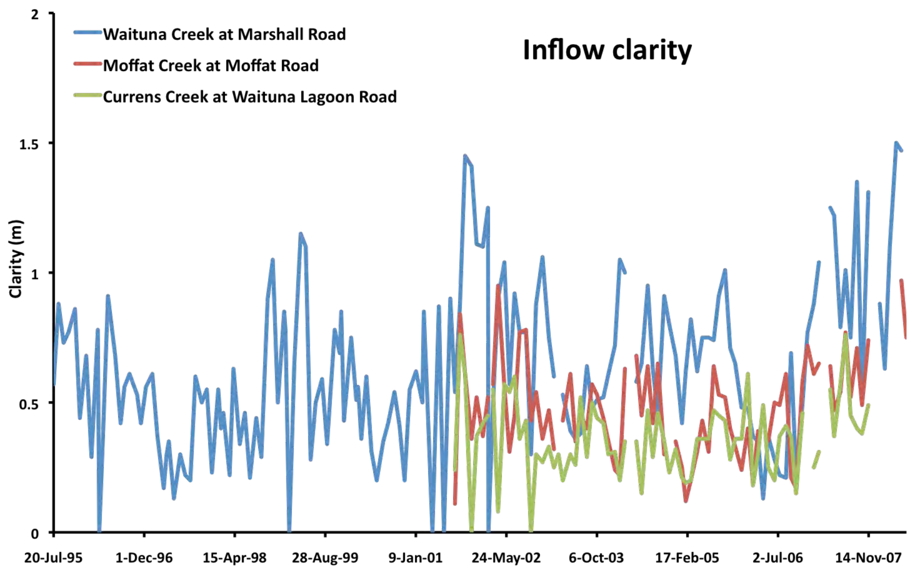


Figure 18 *Waituna Lagoon inflow E. coli and clarity data, 1995-2008 (data source: ES).*

Botany

Aquatic growths - Macrophytes

The *Ruppia megacarpa* (horse's mane weed) dominated macrophyte community of Waituna Lagoon was first described in detail by Johnson and Partridge (1998). At the time of their study (April and July 1995) deeper areas of the Lagoon (greater than 0.5m depth) were dominated by *Ruppia megacarpa* with *Myriophyllum triphyllum* (water milfoil) also abundant. Shallower, silty bays were dominated by a more diverse community, including *Glossostigma elatinoides*, *Lilaeopsis novae-zelandiae*, *Myriophyllum triphyllum* and *Ruppia polycarpa*.

In 1971 Waituna Lagoon and a section of the surrounding wetland was protected as a Wetlands Management Reserve and in 1976 the wetland was designated under the RAMSAR convention to be of international significance. In 1983 the area was given Scientific Reserve status.

Thompson and Ryder (2003a) noted that at the time of Johnson and Partridge's study the Lagoon had mostly been closed to the sea, however there was a period of prolonged opening (1997-2000) following this and at the time of Thompson and Ryder's (2003a) review it was unknown what effect, if any, this had had on the freshwater species dominated macrophyte community.

Schallenberg and Tyrrell (2006) surveyed the macrophyte community of the Lagoon again in June 2006, at which time it was closed (closed for 23 days, after being open for 330 days). Schallenberg and Tyrrell (2006) found that the distribution of aquatic macrophytes in the Lagoon was very restricted; with only one of the four sites they sampled having abundant and healthy *Ruppia* species cover. They found less plant species, and in lower abundance than that observed by Johnson and Partridge (1998). Although the Lagoon was closed at the time of sampling in both studies, the length of time that it had been closed was shorter prior to Schallenberg and Tyrrell's (2006) survey and therefore the conditions in the Lagoon were very different between the two surveys.

In March 2007 Stevens and Robertson (2007b) undertook extensive broad scale mapping of macrophyte cover in the Lagoon (Figure 18). The Lagoon had been closed for approximately 270 days at the time of sampling, a similar period of closure to that preceding Johnson and Partridge's (1998) survey. As with previous surveys *Ruppia* species dominated, two species were identified *Ruppia polycarpa* and *Ruppia megacarpa* (Table 3, Figure 19). Each species was restricted to certain preferred locations in the Lagoon. *Ruppia polycarpa* dominated shallower areas (particularly the north-eastern shoreline), while larger *Ruppia megacarpa* dominated deeper parts of the Lagoon to the south and east. Johnson and Partridge (1998) reported a similar pattern in the depth distribution of the two species. Stevens and Robertson (2007b) found that sheltered areas throughout the Lagoon had the highest *Ruppia* cover (80-100%). Johnson and Partridge (1998) recorded 25% cover of *Ruppia megacarpa* in sheltered sites.

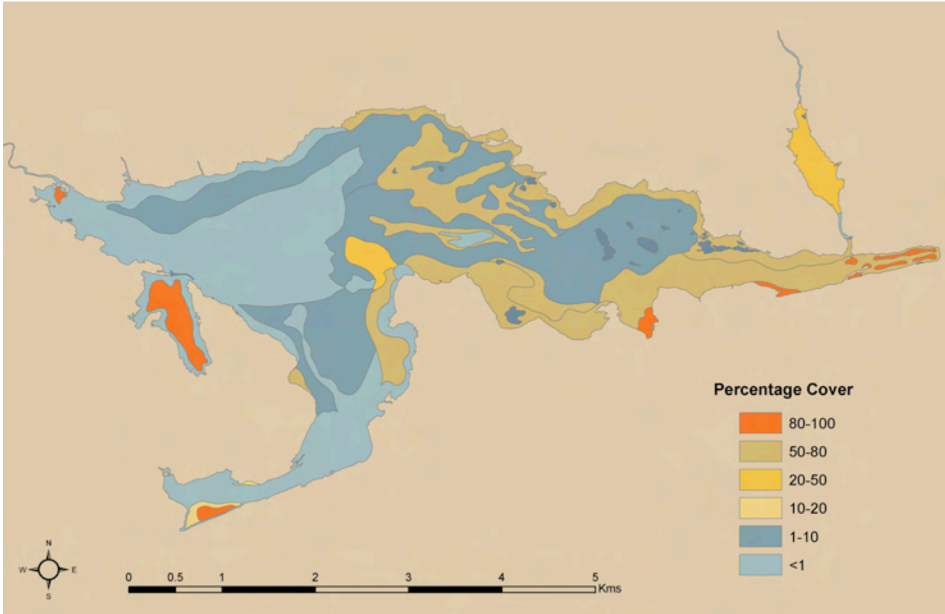


Figure 18 *Map of macrophyte percentage cover – Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Table 3 *Summary of broad scale Ruppia percent cover mapping, March 2007. Sourced from Stevens and Robertson (2007b).*

% Cover Category		Area (ha)		%	
		R. polycarpa	*R. megacarpa*	*R. polycarpa*	*R. megacarpa*
Very Low	<1%	458		33.5	
Low	1-10%	155	306	11.3	22.4
Low-Mod	10-20%	1	4	0.1	0.3
Moderate	20-50%	28	16	2.1	1.2
High	50-80%	231	127	16.9	9.3
Very High	>80%	-	41	-	3

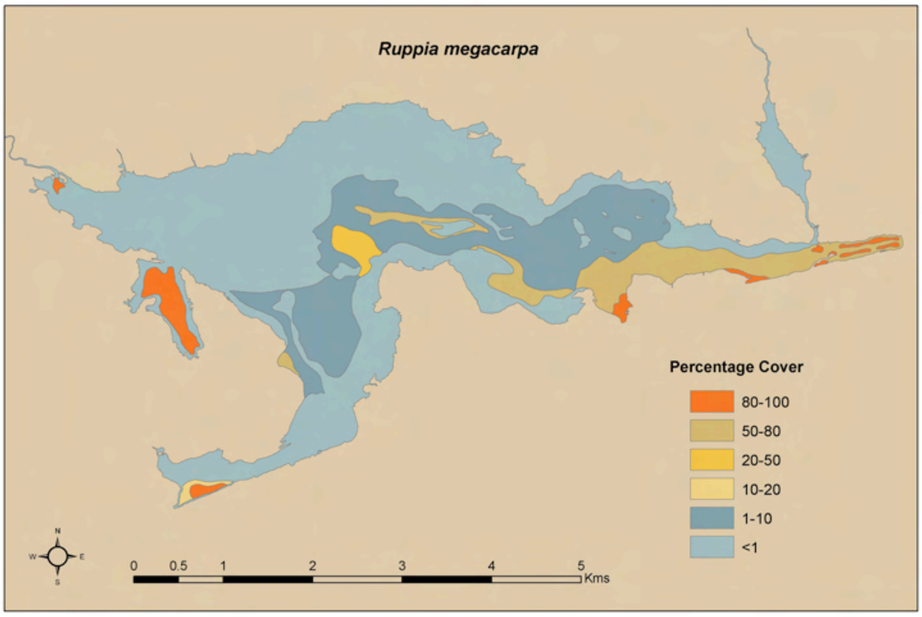


Figure 19 *Map of Ruppia species percentage cover – Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Stevens and Robertson (2007b) reported that the substrate in the areas of most *Ruppia* cover was gravels and sands with relatively little mud. Shallow exposed areas with either muddy or sandy substrate had low percentage cover (<1%) of *Ruppia*. Stevens and Robertson (2007b) concluded that *Ruppia* was still thriving in the Lagoon when conditions were optimal (extended period of Lagoon closure, good clarity). The optimum salinity range for *Ruppia* seed germination, establishment and growth is 4 to 8ppt so extended periods of Lagoon opening may expose *Ruppia* to suboptimal conditions (Schallenberg and Tyrrell 2006). *Ruppia* seedling growth is also reduced under low light levels associated with high turbidity (Schallenberg and Tyrrell 2006).

Ruppia megacarpa is also the dominant macrophyte in Wilson Inlet, a coastal lagoon in Western Australia (Department of Environment 2003). Like Waituna Lagoon, Wilson Inlet has a regular annual cycle of artificial opening, generally being opened in late winter or early spring and staying open for approximately five months (between August to February). *Ruppia* abundance varies seasonally in Wilson Inlet with summer biomass thought to be about twice that in winter (Department of Environment 2003). Studies of *Ruppia* in the Inlet suggest that 40% of the variation in the distribution and abundance between seasons is explained by variations in the turbidity and salinity of the Inlet (Department of Environment 2003). Salinity ranges from 1 to 37ppt (1995-2001 data), varying between seasons, with the lowest salinity occurring in spring (median 17ppt, range 1 to 35ppt) (Department of Environment 2003). Short periods of low salinity provide the required conditions for *Ruppia* germination and six months (January to March) after this *Ruppia* biomass peaks (Department of Environment 2003). Turbidity is high in the Inlet over winter and early spring due to the input of suspended material by inflowing rivers. High turbidity limits the light available for *Ruppia* growth and long periods of high turbidity can significantly reduce *Ruppia* cover. Phytoplankton blooms and storms causing re-suspension of silt from the Inlet bottom can also cause high turbidity (Department of Environment 2003). Storms can also cause direct physical damage by uprooting *Ruppia* (Department of Environment 2003). Research in Wilson Inlet has shown that *Ruppia* growth is limited by the availability of nutrients, phosphorus in particular (Department of Environment 2003). Schallenberg and Tyrrell (2006) have suggested that reducing phosphorus inputs to Waituna Lagoon could be the most effective way to prevent nuisance phytoplankton growths (see Section 2.3), however this may have the unwanted effect of also limiting *Ruppia* growth. *Ruppia* in Wilson Inlet takes up nutrients from the water column (through its leaves) in winter and early spring when nutrient concentrations are high due to catchment runoff, these nutrients are then stored for later use when light conditions are favourable (Department of Environment 2003). In this way *Ruppia* plays an important role in preventing algal blooms (Department of Environment 2003). The high short-term variability observed in the abundance and distribution of *Ruppia* in Wilson Inlet means that one-off measures of *Ruppia* do not provide a good indication of long-term water quality changes in the Inlet, many measures of *Ruppia* are instead necessary over time and at different sites (Department of Environment 2003).

Johnson and Partridge (1998) observed that *Myriophyllum triphyllum* was abundant with *Ruppia* in some locations in the Waituna Lagoon, particularly in sheltered bays, however *Myriophyllum triphyllum* was not recorded in Schallenberg and Tyrrell's (2006) survey and Stevens and Robertson (2007b) did not make any comment on its presence or otherwise. *Myriophyllum triphyllum* is relatively intolerant of salinity and the prolonged opening that occurred from 1997-2000 may therefore have negatively impacted its distribution. Alternatively grazing by birds (e.g. black swans) may have reduced *Myriophyllum triphyllum* abundance. Johnson and Partridge (1998) noted that most of the *Myriophyllum triphyllum* observed during their survey comprised stems, with relatively few leaves remaining attached, and they suggested this may be a result of bird grazing.

Frequent variations in salinity may assist in protecting the Lagoon from invasive aquatic plants (Schallenberg and Tyrrell 2006). Johnson and Partridge (1998) identified two non-native (naturalized) species (*Callitriche stagnalis* and *Ranunculus trichophyllus*), although neither was in sufficient abundance to be problematic. Schallenberg and Tyrrell (2006) noted that no rare or threatened submerged aquatic plant species have been recorded from the Lagoon.

The *Ruppia* dominated macrophyte beds play a key role in the Lagoon ecosystem by stabilizing the bottom sediments, reducing sediment re-suspension and limiting shoreline erosion, and they provide food and/or habitat for macroinvertebrates, fish and birds. *Ruppia* also plays an important part in regulation of the Lagoon's water quality, taking up nutrients from the water column and thereby reducing the potential for high nutrient levels to result in nuisance algal blooms.

Aquatic growths - Algae

In March 2007 Stevens and Robertson (2007b) undertook extensive broad scale mapping of macroalgal[4] cover in the Lagoon (Figure 20). They found that macroalgal cover was relatively low and restricted to certain localities where growth conditions were favourable, mostly shallow waters around the Lagoon margins. *Enteromorpha* species, a brackish-water tolerant green alga, dominated the

[4] Algae are relatively simple plants that live in freshwater or saltwater environments. In the marine environment, they are often called seaweeds. Although they contain chlorophyll, they differ from many other plants by their lack of vascular tissues (roots, stems, and leaves). Many familiar algae fall into three major divisions: Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae). Macroalgae are algae observable without using a microscope. Certain types of macroalgae can grow to nuisance levels in nutrient-enriched estuaries causing sediment deterioration, oxygen depletion, bad odours and adverse impacts to biota (Stevens and Robertson 2007b).

macroalgal community in March 2007, it was also present at most sites surveyed in June 2006 by Schallenberg and Tyrrell (2006). Schallenberg and Tyrrell (2006) noted that the distribution of brackish-water tolerant algae species had changed since the previous survey in 1995 (Johnson and Partridge 1998), with *Enteromorpha* species and other unidentified species of marine algae present in all parts of the Lagoon in 2006, in contrast to 1995 where they were confined to near the Lagoon mouth. Macroalgal cover is expected to vary depending on Lagoon level and season; highest growth is expected when the Lagoon is exposed to the sea, with low water levels and tidal level changes (Stevens and Robertson 2007b). The variation in macroalgal cover among the three studies is probably related to the period of time the Lagoon was open prior to each survey. Macroalgal cover was relatively low at the time of Johnson and Partridge's (1998) and Stevens and Robertson's (2007b) surveys, which were both proceeded by relatively long periods of Lagoon closure (210 and 270 days, respectively). In contrast, macroalgae were present throughout the Lagoon at the time of Schallenberg and Tyrrell's (2006) survey, which was preceded by a relatively short period of Lagoon closure (23 days, following 330 days open).

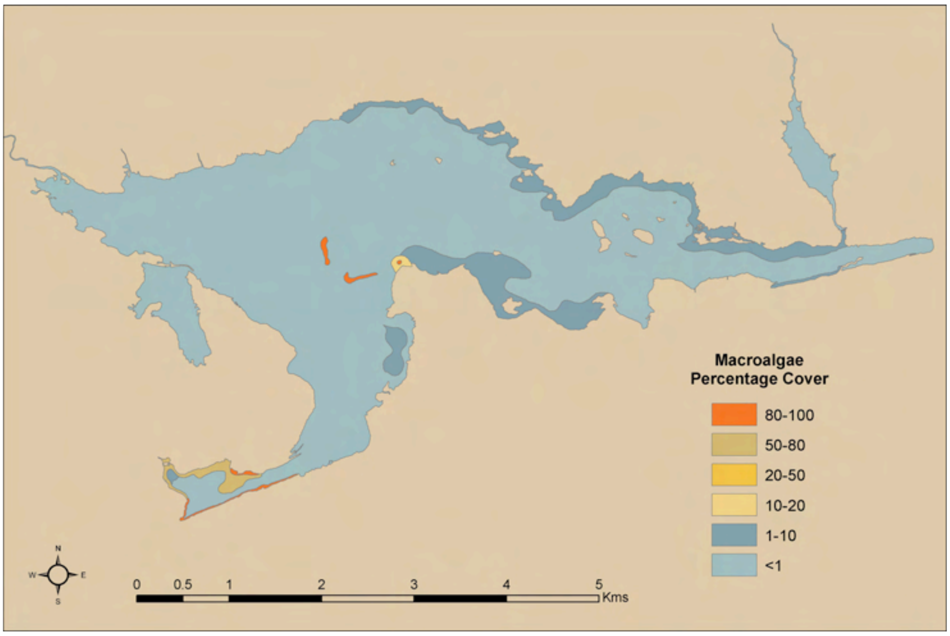


Figure 20 *Map of macroalgal percentage cover - Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Terrestrial vegetation

The distinctive terrestrial vegetation of Waituna Lagoon and the surrounding wetland area has interested botanists for many years and consequently several botanical surveys have been undertaken (Crosby-Smith 1927, Kelly 1968, Department of Lands and Survey 1984, Rance and Cooper 1997, Johnson and Partridge 1998, Stevens and Robertson 2007b). Historically the Waituna catchment was dominated by wetland vegetation, including cushion-bogs, sedges and rushlands, with areas of lowland podocarp forest, manuka (*Leptospermum scoparium*)/ *Dracophyllum* scrubland and sand-ridge tussock/pingao associations (*Chionochloa* species/*Desmoschoenus spiralis*). In drier areas there are, and were, extensive areas of flax (*Phormium* species) and toetoe (*Cortaderia* species), with wire rush (*Empodisma minus*) and tangle fern (*Gleichenia dicarpa*). The area is also notable for the presence of a locally uncommon species of mat-daisy (*Raoulia* species) and several alpine and sub-alpine species at sea level.

The unique vegetation of Waituna Lagoon was recognized by Kelly (1968), who described the vegetation and flora of the Lagoon edges, adjacent peatland, and seashore, and recommended that a representative reserve be established.

A comprehensive survey of the flora and vegetation types within and around the shores of Waituna Lagoon was undertaken by Johnson and Partridge (1998) in 1995. They observed that *Leptocarpus similis* (jointed wire rush) dominated the shore vegetation, however there was also a diverse range of other species present. A total of 136 vascular plant species (98 native, 38 naturalised) were recorded, including three taxa that are considered to be declining (*Isolepis basilaris*, in serious decline; *Deschampsia cespitosa var. macrantha* and *Urtica linearifolia* in gradual decline) (Johnson and Partridge 1998, Hitchmough et al. 2005). Johnson and Partridge (1998) noted a distinctive feature of the community was that it included plants that are otherwise typical of situations that are either saltier or drier. There were not many plants present that are typical of fully tidal estuaries, most species are instead capable of tolerating both fully salty and fully freshwater environments (i.e. dual purpose) or else are typical of a freshwater wetland environment. Johnson and Partridge (1998) described a community that varied as distance from the Lagoon shore increased, influenced mainly by the degree of shelter from, or exposure to, wind and waves (related to patterns of erosion and deposition of sediment). Proceeding up slope the general vegetation pattern observed was small patches of turf plants on the Lagoon's shore, then dense clumps of *Leptocarpus* on hummocky ground, followed by more rushland on flatter ground, and eventually a mixture of sedges and grasses, then flax, bracken and manuka scrub on the more elevated ground (Johnson and Partridge 1998). Johnson and Partridge (1998) identified that the extent of *Leptocarpus* rushland had increased since 1951 (as indicated by aerial photographs and anecdotal reports), they concluded that this was in response to the lowered Lagoon water regime and to increased sedimentation. They observed no corresponding advance in the abundance of gorse (or other woody vegetation e.g. manuka) towards the Lagoon shore.

In March 2007 Stevens and Robertson (2007b) undertook extensive broad scale mapping of vegetation cover in the area surrounding the Lagoon (Table 4, Figure 21). They grouped the dominant vegetation surrounding Waituna Lagoon into four zones:

(a) Wetland Vegetation: areas periodically inundated with fresh or saltwater and dominated by reed, rush, sedge, or tussockland communities.
(b) Terrestrial Margin Vegetation: a strip 200m landward of wetland vegetation.
(c) RAMSAR Site Vegetation: includes most of the wetland and 200m terrestrial margin and part of the terrestrial vegetation outside of the 200m margin.
(d) Terrestrial Vegetation: all plants landward of the wetland margin including those within the Terrestrial Margin.

Wetland vegetation in 2007, as it had been in 1995 (Johnson and Partridge 1998), was dominated by *Leptocarpus* rushland (Table 4, Figure 21). Stevens and Robertson (2007b) noted that the uniform coverage of rushland inland from the Lagoon was unusual, and that it may play an important role in Lagoon functioning by trapping sediment and nutrients. They identified that there were two direct impacts present on the rushland:

- Increased extent of *Leptocarpus* rushland in response to a generally lower Lagoon level, combined with increases in sedimentation and nutrients.
- Encroachment of farmland into the rushland through vegetation clearance and drainage on the western side of Currans Creek (approximately 30ha).

Stevens and Robertson (2007b) also noted that along the north and east of the Lagoon many introduced weeds and grasses were establishing adjacent to farmland.

Table 4 *Summary of broad scale wetland vegetation mapping, March 2007. Sourced from Stevens and Robertson (2007b).*

Class	Dominant vegetation	Area (ha)	%
Estuarine shrubs	*Plagianthus divaricatus* (saltmarsh ribbonwood), *Coprosma propinqua* (mingi mingi)	7.8	1.6
Tussockland	*Phormium tenax* (NZ flax), *Cortaderia richardii* (toetoe)	8.1	1.7
Sedgeland	*Schoenoplectus pungens* (three square)	0.01	0.01
Rushland	*Leptocarpus similis* (jointed wire rush), *Isolepis nodosa* (knobby clubrush), *Juncus gregiflorus*	456	96.6
Total		472	100

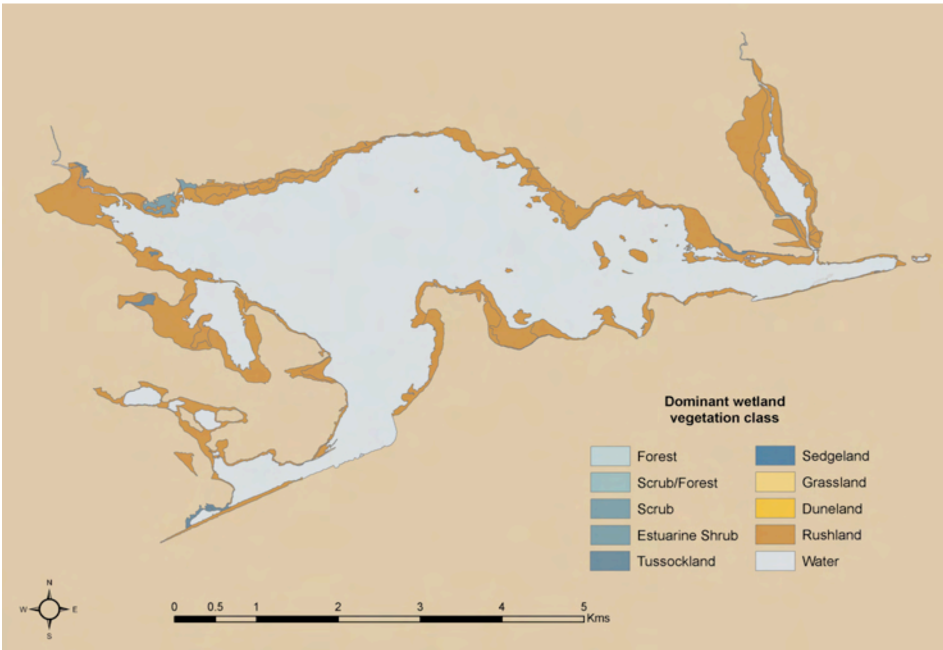


Figure 21 *Map of wetland vegetation - Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Immediately inland from the wetland vegetation zone is a 200m wide buffer strip of terrestrial vegetation (Table 5, Figure 22). Stevens and Robertson (2007b) observed that the composition of this strip contrasted according to location, with thick native scrub and forest dominating to the south and west of the Lagoon and also the central southern headland, while to the north and east grassland (dairy and beef farms) dominated. This area had been modified in the past by draining and channelling with most of the previous cover of forest and scrub removed. Only a narrow strip of scrub (e.g. manuka, gorse, bracken) or tussockland (e.g. flax, toetoe, red tussock) remained separating this area from the wetland. Grassland development was still occurring in several areas, including around Moffats Creek, the Currans Creek embayment, the band of scrub along the middle of the northern shoreline and on the southeastern edge of the Lagoon adjacent to the coast. In the south and west though the buffer of tussockland, scrub, and forest remained wide and stable. Stevens and Robertson (2007b) did not comment on whether the distribution of gorse or other weed or woody species had changed since Johnson and Partridge's (1998) 1995 survey.

Table 5 *Summary of broad scale 200m terrestrial margin mapping, March 2007. Sourced from Stevens and Robertson (2007b).*

Class	Dominant vegetation	Area (ha)	%
Forest	*Leptospermum scoparium* (manuka)	303	29.4
Scrub	*Leptospermum scoparium* (manuka), *Plagianthus divaricatus* (saltmarsh ribbonwood), *Coprosma propinqua* (mingimingi)	310	30.2
Tussockland	*Phormium tenax* (NZ flax), *Cortaderia richardii* (toetoe). *Chionochloa rubra* (red tussock)	51	4.9
Grassland	Unidentified grass, *Festuca arundinacea* (tall fescue)	239	23.3
Duneland	*Ammophila arenaria* (marram grass), *Isolepis cernua* (slender clubrush)	8	0.8
Total		1,029	100

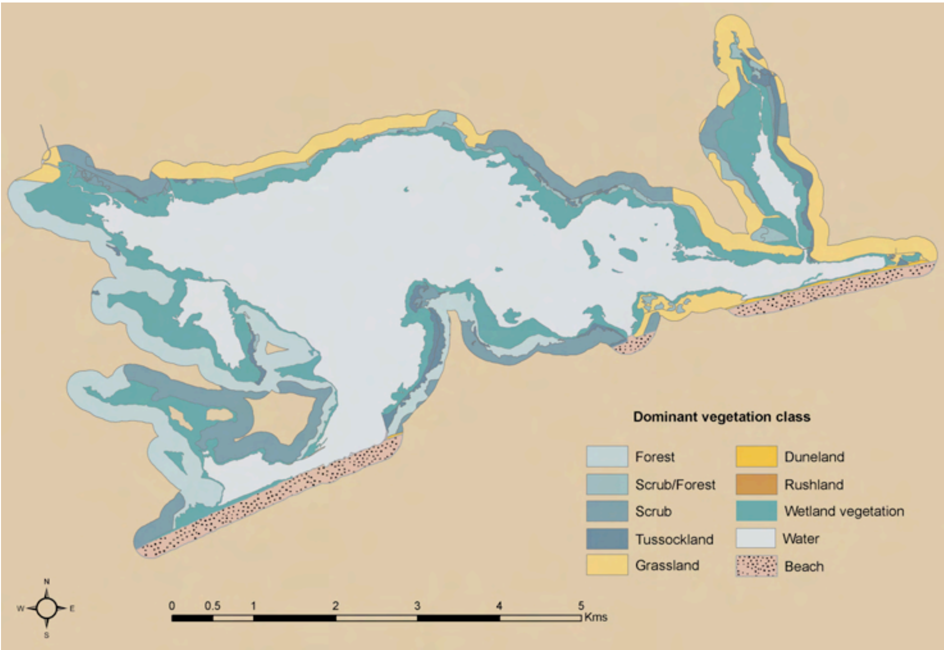


Figure 22 *Map of 200m terrestrial margin vegetation - Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).*

Stevens and Robertson (2007b) also identified the distribution of terrestrial and wetland vegetation within the RAMSAR site boundary (Table 6, Figure 23). The area was dominated by terrestrial native scrub and forest (78%), and wetland rushland (18%), representing a approximately 80% of the total area of these vegetation types remaining within the wider Waituna catchment. Within the scrub and forest habitat are numerous small ponds, each differing in character and together supporting a diverse range of freshwater vegetation. Remaining areas of native scrub and tussockland that buffer the northern margins of the Lagoon and the reclaimed rushland on the western side of the Currans Creek embayment are outside the RAMSAR boundary and therefore unprotected.

Table 6 Summary of broad scale RAMSAR site terrestrial vegetation mapping, March 2007. Sourced from Stevens and Robertson (2007b).

Class	Dominant vegetation	Area (ha)	%
Forest	*Leptospermum scoparium* (manuka)	954	44.1
Scrub	*Leptospermum scoparium* (manuka), *Dracophyllum longifolium* (inaka)	738	34.1
Tussockland	*Phormium tenax* (NZ flax), *Cortaderia richardii* (toetoe). *Chionochloa rubra* (red tussock)	39	2.2
Grassland	Unidentified grass, *Festuca arundinacea* (tall fescue)	25	1.4
Duneland	*Ammophila arenaria* (marram grass), *Isolepis cernua* (slender clubrush)	9	0.5
Rushland	*Leptocarpus similis* (jointed wire rush), *Isolepis nodosa* (knobby clubrush), *Juncus gregiflorus*	389	18
Total		2,161	100

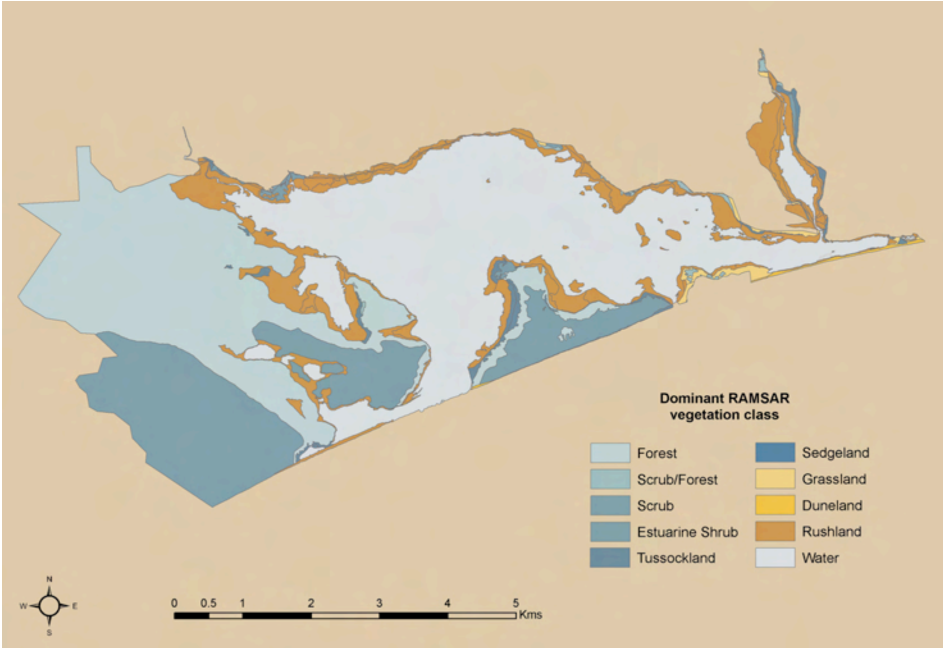


Figure 23 Map of terrestrial vegetation within the RAMSAR site - Waituna Lagoon 2007. Sourced from Stevens and Robertson (2007b).

Terrestrial fauna

In contrast to terrestrial vegetation, there is very little known about the terrestrial fauna of the Waituna Lagoon area. Ryder and Thompson (2003a) reviewed the existing information and to our knowledge there have been no further studies since that review. The invertebrate community is expected to be diverse, with over 80 species of moths alone already identified in the Seaward Moss/Toetoes/Waituna Wetlands complex (Rance and Cooper 1997). The invertebrate community is also expected to be distinctive due to the unique vegetation present. This is supported by the finding of sub-alpine insect species in association with bog vegetation in the wetland area (Department of Lands and Survey 1984). There is no information on the presence of geckos or skinks in the area, however there is suitable habitat available. Hares and possums have been reported from the wetlands and it is likely that other mammal species, including rabbits, ferrets, stoats, rats and mice, are almost certainly present (Department of Lands and Survey 1984).

Avian fauna

The Waituna Lagoon area provides habitat for at least 76 bird species (21 naturalized), including residents and national or international migrants. International migratory species of note include the Mongolian dotterel (*Charadrius mongolus*), grey plover (*Pluvialis squatarola*), marsh sandpiper (*Tringa stagnatilis*), sanderling (*Calidris alba*) and Asiatic whimbrel (*Numenius phaeopus variegatus*) (Rance and Cooper 1997). The Lagoon area also provides habitat for a number of nationally critical species including Southern New Zealand dotterel (*Charadrius obscrurus obscurus*), South Island brown teal (*Anas chlorotis* "South Island"), and white heron (*Egretta alba modesta*), and nationally endangered species including Australasian bittern (*Botaurus poiciloptilus*), black-fronted tern (*Sterna albostriata*) and grey duck (*Anas superciliosa superciliosa*) (Department of Lands and Survey 1984, Hitchmough et al. 2007).

The resident birdlife is comprised of 27 species, 24 of which are endemic or native and three are naturalized (black swan (*Cygnus atratus*), Canada goose (*Branta canadensis*) and mallard (*Anas platyrhynchos*)). These three naturalized species, together with Paradise shelduck (*Tadorna variegata*) and grey duck directly graze aquatic macrophytes (Schallenberg and Tyrrell 2006). Overgrazing of macrophytes by waterfowl can lead to substantial decreases in macrophyte abundance and biomass. In Lake Ellesmere high densities of black swan (25 swans per ha) substantially restricted macrophyte re-growth (Gerbeaux 1993), and it has been estimated that 25% of the *Ruppia* in Wilson Inlet, Western Australia is consumed by herbivorous fish (not present in Waituna Lagoon) and birds (e.g. black swans) (Department of Environment 2003). There is no information available on how waterfowl grazing influences macrophtye abundance and biomass in Waituna Lagoon. Loss of macrophyte beds in the Lagoon would have a negative impact on several wading bird species (Schallenberg and Tyrrell 2006).

Changes in the level of the Lagoon have the potential to significantly effect the availability of breeding and feeding habitat of birds. When the Lagoon is open to the sea there are extensive tidal mudflats, which provide important summer feeding areas for waders (Rance and Cooper 1997). High water levels are more desirable during autumn and winter when waterfowl numbers on lakes are high, however if the Lagoon is closed for a long time water levels may become too deep for wading birds (Schallenberg and Tyrrell 2006). O'Donnell (1985) identified that the optimum opening regime for birds in Lake Ellesmere was a gradual (i.e not sudden) drop of water levels in summer, synchronized with waterfowl breeding. However this conflicts with the suggestion of Gerbeaux (1993) that the lake should be opened in early spring, in order to provide light to *Ruppia* seedlings, and closed in summer to maintain a high water level in the lake to protect *Ruppia* from wave action and waterfowl grazing. This example from Lake Ellesmere illustrates the difficulty of developing a management regime that maximizes the benefit to all ecosystem components.

Aquatic fauna

Existing information on the fish community of the Waituna catchment was reviewed by Thompson and Ryder (2003a and 2003b). Information was sourced from published (Riddell et al. 1998) and unpublished surveys of the catchment and from records contained in the New Zealand Freshwater Fish database (administered by NIWA). A survey of the fish community has recently been undertaken, however the results of this are not yet available. To our knowledge this is the first survey of the fish community undertaken since the 2003 review.

Thompson and Ryder (2003b) identified that 13 species of fish (12 native) have been recorded from the catchment and Lagoon (Table 7). Several of the species are estuarine fish (yellow-eye mullet, smelt, cockabully and flounder) and subsequently have only been recorded only from the Lagoon and the extreme lower reaches of Waituna Creek. The dominant native fish in all three main stream catchments are longfin eels (shortfin eels are also present), inanga and common bullies, although redfin bullies are also present. Giant kokopu, considered to nationally be in decline (Hitchmough et al. 2007), have been regularly recorded from the catchment (Table 7). Suitable habitat for several other native species occurs in the catchment and based on this it is considered likely that banded kokopu (*Galaxias fasciatus*), giant bullies (*Gobiomorphus gobiodes*) and shortjaw kokopu (*Galaxias postvectis*) may also be present.

A significant population of brown trout is present in the Lagoon, sustained by a mix of sea-run and freshwater fish. Exotic redfin perch (*Perca fluviatilis*) have been suggested to occur in the Lagoon (Riddell et al. 1998), however there are no recent records to indicate their presence. Use of the Lagoon by anglers (angler days ± 1 standard error) during the 2001-2002 fishing season (1220 ± 550) was significantly higher than that of Lake Ellesmere (150 ± 150) and similar to that of South Mavora Lake (1130 ± 300), the Eglinton River (1120 ± 400) and Otapiri Stream (990 ± 260) (all in Southland) (Unwin and Image 2003). Southland Fish and Game undertake annual spawning surveys of the Lagoon and these indicate that the trout population is doing well, recent estimates suggest that the spawning population exceeds 3000 fish with an average length of approximately 550mm and weight of 1.5kg (Moss 2008).

The timing and frequency of Lagoon opening is crucial to the recruitment of native fish in the Waituna catchment as most species (except giant kokopu, common bully) require access to and from the sea at some stage of their life cycle (Table 7). Likewise, Lagoon closure prevents sea-run brown trout from moving into the catchment to spawn. For example, the main period of juvenile inanga (whitebait) upstream migration, from the sea into the Lagoon, occurs during the months of September to November. In 11 of the past 36 years (31% of the time) the Lagoon has been closed for this three month period, preventing whitebait from entering the Lagoon. Similarly, inanga larvae, which migrate to the sea after hatching, predominantly during the months of March to May, would have been preventing from exiting the Lagoon and accessing the sea during this period in 12 of the past 36 years (33% of the time).

Bullies and kokopu are unlikely to be able to tolerate the highly saline water present when the Lagoon is open and probably move upstream into freshwaters. Lagoon opening also allows estuarine/marine fish to enter the lagoon and they may compete with and/or prey on freshwater fish (or vice versa).

Table 7 *Freshwater and estuarine fish species (and freshwater crayfish) described from the Waituna catchment (New Zealand Freshwater Fish Database, 2003). The life history of the freshwater fish species is shown, 'M' indicating that they are migratory and therefore require access to the sea to complete their lifecycle, and 'R & M' indicating that they can also form resident (landlocked) populations that do not require access to the sea. Years indicate the survey occasion[5]. Sourced from Thompson and Ryder (2003b).*

Species	Common name	Life history	Waituna	Moffatt	Currans	Lagoon
Aldrichetta forsteri	Yelloweye mullet					√ 1985
Anguilla australis	Shortfin eel	M	√		√	√ 1985
Anguilla dieffenbachii	Longfin eel	M	√ 1985, 99	√ 1985	√ 1985, 95, 99	
Galaxias argenteus	Giant kokopu	R & M	√ 1985	√ 1985	√ 1985, 95, 99	
Galaxias maculatus	Inanga	M	√	√ 1985	√ 1985, 95	√ 1985
Geotria australis	Lamprey	M	√ 1985			
Gobiomorphus cotidianus	Common bully	R & M	√	√ 1985	√ 1985	√ 1985, 01
Gobiomorphus huttoni	Redfin bully	M	√	√ 1985		
Grahamina nigripenne	Cockabully					√ 1985
Paranephrops zelandicus	F-W crayfish		√ 1985			√ 1985
Retropinna retropinna	Common smelt	M	√			√ 1985
Rhombosolea retiaria	Black flounder	M	√ 1999			√ 1985
Salmo trutta	Brown trout	R & M	√ 1999		√	√ 1985

Macroinvertebrate[6] communities have not been studied extensively in Waituna Lagoon, although they are monitored annually in Waituna Creek (two sites, Environment Southland). Thompson and Ryder (2003b) reviewed existing information on macroinvertebrate communities in streams in the Waituna catchment and concluded that they are typical of those in similar lowland streams elsewhere in Southland. The fauna is dominated by amphipods, snails and chironomids, although a variety of other species are also present in relatively small numbers. Macroinvertebrate indices (MCI and SQMCI scores), which provide an indication of the health of the community, suggest that streams within the catchment have the condition of 'probable moderate' to 'severe' pollution. Thompson and Ryder (2003b) noted that there was possibly a trend of declining

[5] 1985 Southland Fish and Game, 1995 NIWA, 1999 NIWA, 1970 NIWA 5.2001 DoC.

[6] Macroinvertebrates are animals that have no backbone and are larger than 250 microns in size. This broad grouping includes insect larvae (e.g. caddisflies, mayflies, stoneflies), aquatic worms (oligochaetes), aquatic snails, and crustaceans (e.g., amphipods, isopods and freshwater crayfish). Different macroinvertebrate species have different tolerances to environmental factors, such as dissolved oxygen, chemical pollutants and fine sediment, the presence or absence of different species can therefore indicate changes in water quality.

community condition in Waituna Creek with time (although monitoring data was limited), however recent monitoring (2004-2006) indicates that the community condition is reasonably stable.

The macroinvertebrate community in the Lagoon itself is influenced by fluctuation in salinity levels due to Lagoon opening and closing and therefore appears to be limited to relatively few species (which are able to tolerate the variation in salinity) (Schallenberg and Tyrrell 2006). Riddell et al. (1998) sampled three sites in the Lagoon in August 1985 and recorded only nine macroinvertebrate taxa, with amphipods (*Paracorophium excavatum*), snails (*Potamopyrgus antipodarum*) and worms (platyhelminths and annelids) dominant. The low diversity and patchy distribution of macroinvertebrates recorded in Riddell et al.'s (1998) survey may have been partly related to the low abundance of macrophytes in the Lagoon at the time (macrophytes provide important food and habitat resources for macroinvertebrates). In June 2006 Schallenberg and Tyrrell (2006) observed that amphipods, isopods (*Austridotea annectans*) and decapod crabs (*Halicarcinus* species) were abundant in *Ruppia beds*. Outside the macrophyte beds, snails (*Potamopyrgus antipodarum*), small marine bivalves (possibly *Austrovenus stuchburyi*), amphipods, crabs, and empty caddis fly cases were found in lower densities (Schallenberg and Tyrrell 2006). Thompson and Ryder (2003a) assumed that the prolonged opening of the Lagoon in 1997 to 2000 would have had a profound effect on its macroinvertebrates due to the exposure to extended periods of high salinity. Such an effect may have occurred (it is not possible to determine due to a lack of data), however it appears that the macroinvertebrate community subsequently recovered with a similar community observed in August 1985 (Riddell et al. 1998) and June 2006 (Schallenberg and Tyrrell 2006). Schallenberg and Tyrrell (2006) also noted that pipis (*Phaphus australe*) and other crabs (*Helice crassa* and *Macrophthalmus hirtipes*) have been reported from the Lagoon. The presence of marine invertebrate species suggests that relatively high salinity levels are maintained at the Lagoon bottom even when it is closed (probably due to vertical density stratification) (Schallenberg and Tyrrell 2006).

The aquatic invertebrate fauna of Lake Waituna is similar to that of Wainono Lagoon (Schallenberg and Tyrell 2006), but differs from that of Lake Ellesmere in terms of the dominant taxa. Kelly and Jellyman (2007) identified that the macroinvertebrate community of Lake Ellesmere has changed since the 1960's (when macrophyte abundance began to decline) from being dominated by species such as *Potamopyrgus antipodarum* snails, to now being almost entirely comprised of subterranean species such as *Chironomus zealandicus* (midges) and oligochaetes (worms). This shift appears to have had negative consequences for shortfin eel growth (Kelly and Jellyman 2007).

There is little known about the zooplankton community of Waituna Lagoon, however the fauna of the Lagoon is expected to be similar to that of other coastal lakes and estuaries in southern New Zealand (Jeppesen et al. 1997). During their 1985 survey Riddell et al. (1988) identified nine planktonic invertebrate taxa including two species of copepod, amphipods (*Paracalliope fluviatilis*) and mysid shrimps (T*enagomysis* species). The variations in salinity associated with the Lagoon opening and closing regime are expected to influence the zooplankton community, as they do the macroinvertebrate community. However, as some zooplankton species are able to respond to unfavourable salinity conditions by forming resting eggs that hatch when conditions become more suitable, zooplankton abundance and community composition in the Lagoon may be more stable than that of macroinvertebrates (Thompson and Ryder 2003a).

Conclusion

Status of information

Water chemisty data for the Lagoon and its inflows has improved in recent years, following the recommendations of (Thompson and Ryder 2003a),and the use of this by Schallenberg and Tyrrell (2006) provides an indication of the value of regular, long-term monitoring programmes in identifying cause and effect relationships. However monitoring may need to be targeted to address specific issues of the kind outlined by these authors.

Schallenberg and Tyrrell (2006) identified the potential for vertical stratification to occur in the Lagoon (which may negatively affect fish and invertebrates). To determine the temporal and spatial extent of stratification and how this is related to the opening regime a period of continuous and simultaneous monitoring of Lagoon water temperature, dissolved oxygen and salinity at a range of depths is necessary. Adjustments to the current monitoring regime are necessary in order to better understand how tributary water chemistry and flows influence Lagoon water chemistry. Measurements of inflows and Lagoon water chemistry are currently made on different days, which hinders comparisons. Measurements should instead be made on the same day and, to allow comparison among sampling occasions, as close to possible to the same time on each occasion. Additional sampling should also be carried out during and/or immediately following flood or high rainfall events. This would assist in determining the circulation and residence times of nutrients in the Lagoon. Tidal fluctuations occur in the Lagoon when it is open and this introduces an additional source of variation to water chemistry measurements (e.g. salinity), which hinders data interpretation. An attempt should be made to sample all Lagoon sites within the same part of the tide cycle on each sampling occasion (e.g. at high tide). Lagoon water chemistry is also currently mostly undertaken during calm weather conditions. A better understanding of the relationship between Lagoon ecology and water chemistry (e.g. chlorophyll *a* and turbidity levels) could be achieved by measurements of water chemistry (particularly light availability) during and after storm events.

Stevens and Robertson (2007 a and b) recently undertook broad scale mapping of Lagoon water depth, substrate (including initiation of sedimentation rate measurement), macroalgae, wetland and terrestrial vegetation. This provides a baseline against which to compare future surveys and identify any changes in these aspects of the Lagoon environment (e.g. expansion of rush land). A program for initiating regular surveys needs to be prepared, and these surveys should follow the methods of Stevens and Robertson (2007 a and b). It should be noted that high short-term variability has been observed in the abundance and distribution of *Ruppia* in some locations (e.g. Wilson Inlet, Australia), therefore one-off measures of *Ruppia* in the Lagoon do not necessarily provide a good indication of long-term water quality changes and many measures of *Ruppia* are instead necessary over time and at different sites. Regular surveys will also assist in identifying and controlling invasive aquatic and terrestrial plants before they spread.

Significant information gaps remain for an array of ecosystem attributes, in particular there is no information on the zooplankton community. Measurements should also be made of dissolved organic carbon (DOC), fine particulate organic matter (FPOM) and coarse particulate organic matter (CPOM) levels in the Lagoon as they are a important food source for microorganisms (Eric Edwards, DoC Southland, pers. comm.). Little is known about how the distribution, abundance and composition of zooplankton, benthic macroinvertebrate and fish communities in the Lagoon are affected by opening and the resulting changes in salinity.

Importantly, regular monitoring of the likes of bird populations and shore-line plant communities is necessary to correlate patterns in, for example, water level and clarity, with community composition. It is this form of monitoring that ultimately will be required to validate any ecological management plan.

Key issues worthy of future focus for ecological management

The *Ruppia* species dominated macrophyte community of Waituna Lagoon plays a key role in maintaining the health of other components of the Lagoon's ecosystem. *Ruppia* beds stabilise the Lagoon's bottom sediments, reducing sediment re-suspension and limiting shoreline erosion, and they provide food and/or habitat for macroinvertebrates, fish and birds. *Ruppia* also plays an important part in regulation of the Lagoon's water quality, taking up nutrients from the water column and thereby reducing the potential for high nutrient levels to result in nuisance algal blooms (see Figure 2). Maintaining the *Ruppia* community is therefore essential to ensuring the wider, more natural and desirable, ecological features of the Lagoon are preserved. Consequently, we have identified the *Ruppia* dominated macrophyte community for use in an ecological management plan for the Lagoon.

Several key components of the Lagoon environment have been identified as influencing the *Ruppia* dominated macrophyte community, either negatively or positively, depending on the direction of the change:

(a) **Lagoon mouth opening/closing:** Lagoon opening results in major changes to the Lagoon environment, essentially converting it from a freshwater to a brackish water environment. The major impacts of this are an increase in salinity and the exposure of the Lagoon to tidal fluctuations. An increase in salinity (above 8ppt) prevents the germination of *Ruppia* and may allow the establishment of brackish water tolerant species, such as macroalgae (seaweeds), which can smother *Ruppia*. Tidal fluctuations expose *Ruppia* to the risk of desiccation and may also increase turbulence in the Lagoon, resulting in re-suspension of sediments and a reduction in water clarity, which may limit *Ruppia* growth. Conversely, long periods of Lagoon closure may result in an increase in water depth in the Lagoon to the point where *Ruppia* growth is limited by the availability of light.

(b) **Catchment run-off:** Sediment run-off from the surrounding catchment may lead to reductions in water clarity in the Lagoon, limiting light levels and therefore reducing *Ruppia* growth. Catchment run-off could also increase nutrient levels in the Lagoon, upsetting the phosphorus and nitrogen balance and resulting in nuisance algal blooms. Algal blooms can in turn reduce light levels, thereby limiting *Ruppia* growth. Increasing dairy development in the catchment may lead to increases in nutrient inputs to the Lagoon. Alternatively, large reductions in nutrient input (especially phosphorus) from the surrounding catchment could reduce *Ruppia* growth.

(c) **Storm events:** Storm events can directly damage the *Ruppia* community through waves uprooting plants and also indirectly by causing sediment re-suspension and reducing light levels and *Ruppia* growth.

(d) **Overgrazing:** Grazing of herbivorous birds (e.g. black swans) on *Ruppia* reduces it height and therefore its ability to obtain light for growth. High numbers of herbivorous birds could therefore cause a reduction in *Ruppia* abundance.

These components are interlinked, with changes in the level of one influencing the impact of others, although not necessarily directly. Overlying this is the potential impact of climate change on Lagoon ecology, through the effects it will have on the key components of the Lagoon environment (e.g. increased frequency of storm events, sea-level rise and increased salinity).

Where to from here?

A better understanding of the components identified above, and their linkages with the wider Waituna Lagoon ecosystem, is essential if an effective ecological management plan is to be developed. An additional matter that will need to be addressed is the influence of these components on the human use of the Lagoon's catchment, as undoubtedly this will be affected to some degree.

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