Lincoln University
Te Whare Wānaka o Aoraki
CHRISTCHURCH • NEW ZEALAND

Lincoln University Digital Thesis

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- you will use the copy only for the purposes of research or private study
- you will recognise the author's right to be identified as the author of the thesis and due acknowledgement will be made to the author where appropriate
- you will obtain the author's permission before publishing any material from the thesis.

THE FEASIBILITY OF SUBMERGED MACROPHYTE RE-ESTABLISHMENT IN KAITUNA LAGOON, LAKE ELLESMERE (TE WAIHORA).

A thesis

submitted in partial fulfilment

of the requirements for the Degree of

Master of Applied Science

in Resource Management / Ecology

at

Lincoln University

by

W. W. Coffey

Lincoln University

2001

Abstract of a thesis submitted in partial fulfilment of the

requirements for the Degree of M.Appl.Sc.

THE FEASIBILITY OF SUBMERGED MACROPHYTE RE-ESTABLISHMENT IN KAITUNA LAGOON, LAKE ELLESMERE (TE WAIHORA).

by W.W. Coffey

Submerged macrophytes play an important role in the ecology of many lakes, especially shallow wind-swept lakes such as Lake Ellesmere (Te Waihora) in the South Island of New Zealand. Since their destruction in the 1968 Wahine storm, the submerged macrophyte beds of Lake Ellesmere have not recovered to their past distribution, due to unfavourable within-lake conditions. This study addressed the feasibility of re-establishing the submerged macrophytes in Kaituna Lagoon, a part of the lake, using *P. pectinatus* as a facilitating plant. The effects of light and salinity on *P. pectinatus* growth were investigated in a 20 week growth experiment, along with salinity exposure experiments. Habitat surveys were carried out to determine growth conditions within Kaituna Lagoon.

Salinity and light limitation were important stress factors for the submerged macrophytes in this study. The lagoon experiences wide salinity and depth fluctuations, and has very low water clarity, hence low light penetration. It was concluded that Kaituna Lagoon was not a favourable site for submerged macrophyte re-establishment in Lake Ellesmere (Te Waihora) under current conditions.

Key Words: *Potamogeton pectinatus*, *Ruppia megacarpa*, salinity, light penetration, desiccation, lake openings, fluctuation.

Acknowledgments

I would like to thank the following for without whom this thesis would not have been complete:

Jonet Ward, my main supervisor, for having faith in me to research and complete this work, for ideas, employment assistance while studying and photos. Jonet and Eric Scott for reviewing the drafts of the thesis and making valuable corrections. The staff and students of the Natural Resource Engineering and resource Management Departments for input into the study design and progress, notably Ken Hughey and James Lambie. Kelvin Nicolle for technical assistance, and use of laboratory and equipment - apologies for damage sustained whilst in the lake and lab. Human error on my part. Merv Sperway for use of greenhouse. Graham Hickling and Chris Frampton for invaluable research design and statistical assistance. James Griffiths for field assistance.

The helpful staff at NIWA, Christchurch, notably Ian Hawes for providing me with the opportunity to study Lake Ellesmere (Te Waihora), ideas, employment assistance while studying, technical assistance, and use of equipment; Anne-Marie Schwarz for technical assistance; Brian Sorrell for external supervision, ideas and salinity exposure guidance and use of equipment; and others for friendship and assistance.

Maurice Nutira and Don Brown of Ngai Tahu Iwi for allowing me access to Te Waihora, its spiritual and physical realms. The Kaitiaki of the lake - Tuterakihanaunoa - for guiding me whilst in the lake.

Zack, Keith and the "Lincoln whanau" for meditations at Kaitorete Spit and tramping expeditions for maintaining sanity in the abstract world of University.

Mum, Dad, Grandparents and Ilka for support.

CONTENTS

		PAGE
Abstract		ii
Acknowledgments		iii
Contents		iv
List of Tables and Figures		vi
List of Appendices		vii
Chapter	1.0 INTRODUCTION	1
	1.1 Physical Description	1
	1.2 Historical Background and Significance	3
	1.2.1 Cultural significance	3
	1.2.2 Ecological significance	5
	1.2.3 Economic and recreational significance	6
	1.3 Submerged Macrophytes and Lake Openings	6
	1.4 Aim of Study	9
	1.5 Outline	10
Chapter	2.0 LITERATURE REVIEW	11
	2.1 Lake Management	11
	2.2 The Submerged Macrophytes of Lake Ellesmere	14
	2.3 Submerged Macrophyte Growth and Environmental Response	14
	2.3.1 Light	15
	2.3.2 Salinity	17
	2.4 Management Implications for Macrophyte Re-establishment	20
Chapter	3.0 SITE DESCRIPTION AND METHODS	23
	3.1 Site Description	23
	3.2 Aims and Objectives	24
	3.3 Determination of Optimum Light and Salinity	24
	3.3.1 Relative growth trial	25
	3.3.2 Physiological salinity exposure experiment	29
	3.4 Habitat Survey	32
	3.5 Feasibility of re-establishment	34

Chapter 4.0 RESULTS 35
4.1 Growth Experiments 35
4.2 Salinity Exposure Experiment 40
4.3 Habitat survey 41
Chapter 5.0 DISCUSSION AND CONCLUSIONS 48
5.1 Salinity and Light Requirements 48
5.2 Kaituna Lagoon Habitat 52
5.3 Feasibility of Submerged Macrophytes Re-establishment in Kaituna Lagoon 53
5.4 Conclusions and Recommendations 56
5.5 Further Research 58
References Cited 60

LIST OF TABLES, FIGURES AND PLATES

TABLE		PAGE
4.1	Residual mean growth, for light and salinity	38
4.2	Habitat survey data	41
4.3	Salinity and weather data from salinity investigations	45

FIGURE		
1.1	Map of Lake Ellesmere (Te Waihora)	2
1.2	Map of macrophyte beds in 1960	2
3.1	Transect location within Kaituna Lagoon	33
4.1	Salinity and light effects on *P. pectinatus* above-ground growth	36
4.2	Salinity and light effects on *P. pectinatus* below-ground growth	37
4.3	Photosynthesis and respiration rates from exposure experiment	39
4.4	Correlation between water depth and mean plant length	42
4.5	Correlation between water depth and % available light (PAR)	46

PLATE		
1.	*P. pectinatus* growing in aquaria	28
2.	Growth experiment in progress	28
3.	Transect site 3 dry	44
4.	Transect site 3 when not dry and very turbid	44

LIST OF APPENDICES

APPENDIX		PAGE
Appendix I	The National Water Conservation (Lake Ellesmere) Order 1990.	65
Appendix II	Table showing mean standing crops of macrophyte species growing in Overtons Bay and Taumutu.	67
Appendix III	Table of Growth experiments data per container	68
Appendix IV	Raw data from salinity exposure experiments	68
Appendix V	Habitat survey raw data	70
Appendix VI	Lake physio-chemical data from 5/7/1997- 11/5/1998	73
Appendix VII	Lake depth and opening data from 9/6/1996-19/11/1999	74
Appendix VIII	Weather data for May, September - December 1998	75
Appendix IX	ANOVA tables for salinity and light growth trials	78

1.0 Introduction

1.1 Physical Description

Lake Ellesmere (Te Waihora) is a large, shallow, and wind-swept brackish lake, situated south of Christchurch on the east coast of the South Island, New Zealand (Figure 1.1). It is so shallow, (maximum depth 3 m) that it lacks a profundal zone, and could easily be referred to as a large pond (R. Scott, pers. comm). Its approximate area of between 16 000 and 20 000 ha, depending on the water depth, makes it the fifth largest lake in New Zealand (Palmer, 1982). The lake's catchment comprises 2 072 km^2, 777 km^2 of hills and 1,295 km^2 of plains (Gerbeaux, 1989). High concentrations of nutrients and algal-biomass, and low water clarity have led to the highly eutrophic classification of the lake (Palmer, 1982; Lineham, 1983; Gerbeaux & Ward, 1991; Ward *et al.*, 1996).

However, detrimental features associated with eutrophication, such as toxic algal blooms and deoxygenated bottom waters and sediments, are not regular features of the lake (Lineham, 1983). The shallow and wind-swept nature of the lake creates a well mixed and oxygenated water body, and causes a high rate of sediment re-suspension, reducing water clarity (Gerbeaux, 1989). Sediment re-suspension causes light limitation for photosynthesis, hence limiting algal productivity (Ward *et al.,* 1996) and growth and re-establishment of aquatic macrophytes (Gerbeaux, 1989; Ward *et al.,* 1996).

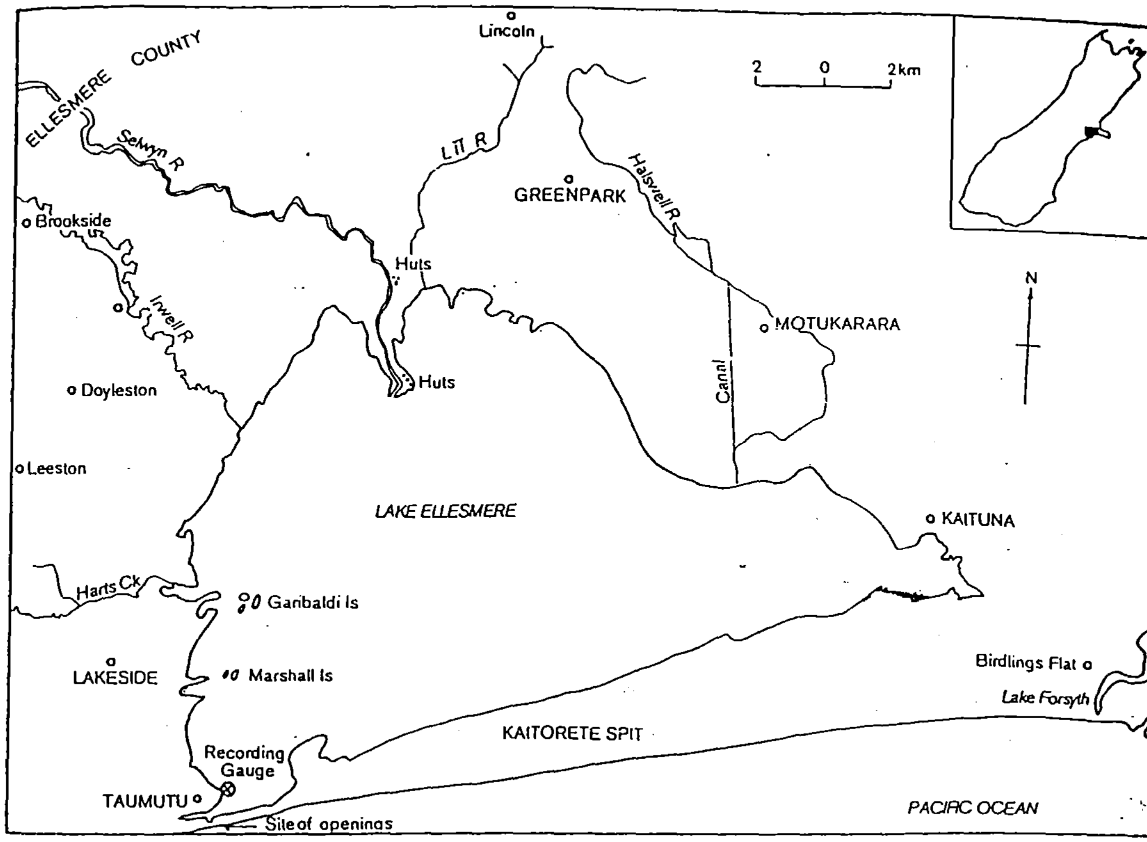


Figure 1.1: Map showing location of Lake Ellesmere (Te Waihora) and environs. (Slightly modified). Source: Gerbeaux, 1989.

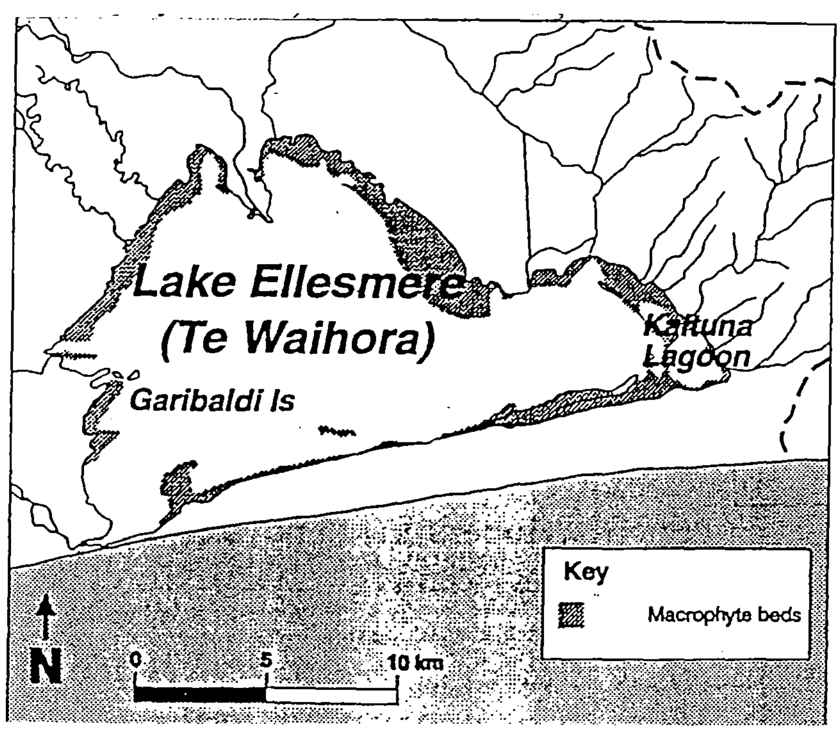


Figure 1.2: Submerged macrophyte beds in 1960. Source: Miers and Williams (1969: in Ward and Taylor, 1996).

Submerged macrophytes formed dense canopies, or "weed beds", in many areas around the lake margins before 1950 (Ward & Taylor, 1996). Figure 1.2 shows the extent of the beds in 1960. Virtual disappearance of the submerged macrophyte beds followed their destruction during the 1968 "Wahine storm". There is now a much-reduced biomass, and the beds have never recovered to their earlier extent (Gerbeaux, 1989; Ward & Taylor, 1996).

Tangata whenua (Ngai Tahu) have expressed concern that eutrophication has had detrimental effects on the fish resources, and lowered their perception of the lake's overall water quality (Ward *et al.,* 1996). Water quality is affected by agricultural practices, such as fertiliser and animal-waste run-off, and effluent discharge, industrial and residential stormwater disposal, and community sewage disposal from Lincoln and Leeston, via the LII and Tramway Reserve Drain tributaries respectively (Ward *et al,* 1996). The result of such agricultural demands and economic development has made the lake's mahinga kai (food resource) negligible (Evison, 1988).

1.2 Historical Background and Significance

1.2.1 Cultural significance

Te Waihora "was probably the richest food basket of the country..... Teeming with millions of eels, flounders, herrings, cockles, pipis and waterfowl, it was measurably the greatest mahinga kai guaranteed to Ngai Tahu under Kemp's Deed" (Evison, 1988: 43). This quotation shows the importance of the lake to tangata whenua for its abundant food supply. Eels, flounder, yellow-eyed mullet, and waterfowl - paradise and grey duck, grey teal, and pukeko - were all taken from the lake (Goodall, 1996).

Food was not only taken from the lake, but the tributaries were important sources as well, and the following quotation demonstrates the importance of the lake's role in the food chain:

> "The well-being of this lake is of paramount importance to the tribe as it is from this lake that the upper lakes in the high country are stocked with fish" (Tau *et al.*, 1990: 5-49).

Traditionally, Ngai Tahu used a broad set of values to monitor and manage the use of the lake and its tributaries (Jull, 1989). Maintaining the spiritual and physical well-being of living things depends on protection of the *mauri* or "life force" (Jull, 1989). To preserve the mauri of a resource, tikanga (protocols and management practices) were developed based on values pertaining to sustainable management, collection of food, observation of spiritual and physical realms, and the protection of the *wairua* or "spirit" of the lake. The mana of the people (mana tangata) depends upon their ability to provide food both for themselves and for visitors (mana kai), and upon their links to their land (mana whenua), which is the source of food, identity, history and knowledge (Gray *et al.*, 1988).

Te Waihora is no exception, and after long association with the lake "Maori feelings are still strong for the area" (Palmer, 1982: p.8). European settlement and agricultural development began in the 1840s and spurred a "long and continuing conflict over Te Waihora and its resources" (Goodall, 1996). In the past, management by government agencies has not recognised or consulted Ngai Tahu, and was in direct breach of the Treaty of Waitangi (ibid). The basis of the concern could be summarised as one of alienation. Ngai Tahu has been denied the ability to manage one of their most prized and valuable resources, has not been able to exercise their customary relationship with their resources, and has seen the decline of a major economic base. Ngai Tahu sought representation in both management and planning functions, protection of customary rights in any management plan for the lake, and mahinga kai restoration as far as practicable (ibid). The decline of the submerged macrophytes has been linked to the decline of the mahinga kai of the lake, especially the fisheries, as fish were seen to have left the lake upon destruction of the beds (M. Nutira, per. comm., 1998).

Current legislation under the Resource Management Act 1991 (RMA) requires regional councils to consult and include tangata whenua values into planning, such as mahinga kai and Taonga (treasures). The Canterbury Regional Council (CRC), currently responsible for the lake's management, has promoted Ngai Tahu's participation, through consultation and input into plans and policy documents.

1.2.2 Ecological significance

Te Waihora has many significant features that contribute great value to the Canterbury and Banks Peninsula regions. The lake is one of New Zealand's most important wetland systems, and was recognised by the International Union for the Conservation of Nature (IUCN) in 1981 as internationally important (Glennie and Taylor, 1996). Its wildlife values are of international importance, due to the number of migrating species, and are the basis of a National Water Conservation (Lake

Ellesmere) Order gazetting of the lake (NWASCA 1990: see Appendix 1). This move was mainly to shift the focus from agricultural values to ecological values of the lake (Taylor, 1996).

1.2.3 Economic and recreational significance

The proximity of the wetland to Christchurch allows many recreational activities to occur, including fishing, waterfowl shooting, bird-watching, boating, wind-surfing and water-skiing on the lake, and picnicking and walking around the lake. The lake is certainly New Zealand's largest eel fishery, and one of the world's largest (Palmer, 1982), and together with its tributaries, used to be considered one of the country's best trout fisheries (Glennie & Taylor, 1996).

1.3 Submerged Macrophytes and Lake Openings

The submerged macrophyte beds play an important ecological role, providing bio-diversity, stabilising wave and sediment movements, habitat diversity for fish and invertebrates, food source for waterfowl, nutrient uptake, nutrient cycle buffers, and maintaining clear water, and are especially important in shallow lakes such as Lake Ellesmere as primary producers and sediment trappers (Gerbeaux, 1989; Ward & Taylor, 1996). Submerged macrophytes in the lake have been widespread around the margins, especially at Taumutu and Greenpark, and have gone through stages of luxuriant growth, decline, and recovery. However, since destruction of the beds during the 1968 'Wahine storm', their non-regeneration has been seen as a problem (Gerbeaux, 1989).

The failure of the submerged macrophytes to recover has been related to climatic factors, lake openings, lake level salinity fluctuations, bird grazing, sediment accretion and nutrient loading (Gerbeaux, 1989; Ward & Taylor, 1996).

Drainage of the lake and surrounding land was notably one of the most devastating impacts of agricultural development and European management. Drainage drastically reduced the original wetland (known as 'wastelands' [by Europeans] in late 1800s) by 81%, reducing the food supply and habitat for fish, plant and bird populations (Jull, 1989; Goodall, 1996). Early settlers opened the lake and, in 1876, the first of several Acts began reclaiming the wetlands proper by establishment of a high flood level (Jull, 1989). Lake openings were controlled initially by the Ellesmere Drainage Board, and then the North Canterbury Catchment Board (NCCB), and conducted by mechanically gouging an opening in the gravel at the southern-most (Taumutu) end of Kaitorete Spit. The lake was opened when it reached a level ranging from 0.67 m - 1.89 m amsl (above mean sea level; from records of 1945-1993: Reid & Holmes, 1996). Ngai Tahu people of Taumutu used to drain the lake to protect their settlement, but this was done at a much higher level (> 2.7m amsl) than it has been by the various Government agencies (Palmer, 1982). Maori openings were most probably timed in conjunction with fish migrations (Love, 1987; Hardy, 1989) producing a multi-valued approach to management.

Current opening policy, developed by the National Water And Soil Conservation Order 1990 (NWASCA) determines the opening level at 1.05 m amsl from August to March, and at 1.13 m amsl from April to July (Reid and Holmes, 1996). The Canterbury Regional Council (CRC) effects the openings, with 80% of the cost levied on beneficiaries (primarily farmers), the remainder sourced from CRC's general rate (R. Duneen, pers. comm., 1998). The opening set by the Water Conservation Order (WCO) could potentially benefit the wildlife of the lake. However, Davis *et al.* (1996) suggest that a higher mean lake level and implementation of the lake closure provisions of the WCO would be necessary to increase the abundance of communities present in the lake. This would be disadvantageous to agricultural interests around the lake, and flood diversion measures would have to be implemented as part of a range of management options and implications on the ecosystem considered in the chapter by Davis *et al.*(1996).

Lake Ellesmere has high nutrient levels, and nutrient loading contributes to the prolific growth of phytoplankton. The dense algal growth, coupled with high sediment loading from the catchment, and strong wind mixing, create a very turbid water body with low light penetration, especially at high water-levels.

Low light and salinity are important stress factors for *Ruppia megacarpa* and *R. polycarpa* (Gerbeaux, 1989). Low light levels reduce seedling growth, especially rhizome elongation, reducing anchoring ability.

The lake levels and opening regime mean that the lake receives salt-water via intrusion through the gravel of Kaitorete Spit, which separates the lake from the sea, and via the outlet during long artificial openings, causing the lake to be brackish, with mean salinity around 8 parts per thousand (ppt) (Ward *et al.,* 1996). Germination of the *Ruppia* species seed required near freshwater conditions, although seedlings could tolerate higher salinity (Gerbeaux, 1989).

The impacts of drainage on submerged macrophytes include salinity fluctuation, desiccation, and reduced depth that allows increased waterfowl grazing. These factors combined with low light penetration mean the submerged macrophytes face high stress and re-establishment has been limited. The beds have never recovered their past distribution. Gerbeaux (1989) investigated the conditions required for optimum growth of *R. megacarpa* and *R. polycarpa*. *Potamogeton pectinatus*, the other major species in the lake, has not been investigated. *Potamogeton pectinatus* tolerates low light and wind turbulence (van Wijk, 1986, cited in Ward & Taylor, 1996) and has been suggested as a possible re-establishment plant, stabilising surrounding waters and sediment and thereby allowing *Ruppia* to become established.

1.4 Aim of Study

This thesis investigates the failure of submerged macrophytes to recover in Lake Ellesmere. The overall aim is to assess feasibility of re-establishing the submerged macrophyte beds within the lake. The conditions in Kaituna Lagoon at the Eastern end of Lake Ellesmere have never been investigated as a potential area for macrophyte re-establishment. It was decided to focus on this area and on *P. pectinatus* as a re-establishment plant.

The study was divided up into three specific objectives:

1) determine the optimum salinity and light conditions for *P. pectinatus* growth;
2) assess the habitat conditions within Kaituna Lagoon;

3) determine the feasibility of submerged macrophyte re-establishment within Kaituna Lagoon.

The study area had to be limited, due to time and resource availability, and the time limits of a masters thesis. It was decided to limit the study to one area, to allow time to measure the physio-chemical and biological parameters required to complete the habitat and submerged macrophyte analyses for the study.

1.5 Outline

The outline of the thesis is as follows. Chapter 2 is a literature review, outlining the factors affecting submerged macrophyte decline and lake-management practices. Chapter 3 identifies the study area, submerged macrophytes, and discusses the three approaches used to assess feasibility of submerged macrophyte re-establishment. Chapter 4 outlines the results of the experimental and field work. Chapter 5 discusses the overall feasibility of submerged macrophyte re-establishment, and management implications. Finally Chapter 6 summarises the findings, recommends strategies to improve submerged macrophyte re-establishment and identifies areas of further research needed.

Throughout this thesis, Lake Ellesmere (Te Waihora) may sometimes be referred to as Lake Ellesmere rather than its full title Lake Ellesmere (Te Waihora), to save space, and it is in no way meant in a disrespectful manner to anyone.

2.0 Literature Review

This chapter reviews the historic significance of the lake, the respective management regimes, past and present, and the growth habits of the lake's submerged macrophytes, focusing on environmental responses, particularly salinity and light. The chapter concludes by describing the resulting impacts of management strategies on the ecology of the lake, primarily on submerged macrophyte re-establishment and growth. This review relies heavily on the book produced by Canterbury Regional Council, (Taylor, 1996), titled *"The natural resources of Lake Ellesmere (Te Waihora) and its catchment"*. It is a historic and informative report on the lake's ecology, management, and cultural significance.

2.1 Lake Management

As discussed in Chapter 1, Lake Ellesmere (Te Waihora) has many significant aspects, cultural, agricultural, economic and ecological. Historically, the lake and its surrounds were "... measurably the greatest mahinga kai guaranteed to Ngai Tahu under Kemp's Deed" (Evison, 1988: 43). Access to and control of mahinga kai was also guaranteed to Kai Tahu under Article II of the Treaty of Waitangi. Aside from these guarantees, Te Waihora is mahinga kai to Ngai Tahu through their whakapapa relationship with the land and its relatives.

Before European arrival, Ngai Tahu managed the lake using traditional practices (tikanga), under consultation with the lake's kaitiaki Tuterakihanaunoa (Jull, 1989). The lake's ability to provide food for the tribe is important for the mauri of the lake, as this ability was installed in the lake by Io Matua as its ultimate potential. The ability of a tribe to manage its resources sustainably was in itself a goal essential in the drive to emphasise the tribe's mana (Gray *et al.,* 1988).

Traditional management of Lake Ellesmere was controlled by "a number of whanau and hapu, each working with their own section of the lake" (Tau *et al.,* 1990). Currently five runanga have interests in the lake: Rapaki, Port Levy, Kai Tuahuriri, Wairewa, and Taumutu (Tau *et al.,* 1990). Tikanga, such as temporarily preventing access (rahui) when a resource was in poor physical or spiritual state, and preventing access (tapu) when it was deemed unsuitable for human use, were imperative for maintaining the mauri of a resource, since Maori had a direct dependence on the natural environment, and monitoring signs relating to the physical state were immediate and imperative (Jull, 1989). Other practices included following strict ritual and kawa (protocol) aimed at protecting the important wairua of the lake's water quality and that of its tributaries.

Although access has been maintained post 1840, European arrival and agricultural development created changes to the management of the lake, as drainage for agricultural and economic viability changed the whole ecosystem and its functioning (Jull, 1989). Pollution by point source and non-point source effluent disposal, irrigation depletion of inflows, and management for agricultural development and settlement, have degraded the physical and spiritual properties of the lake. The result of these agricultural demands and economic reclamation have made the lake's mahinga kai negligible (Evison, 1988).

The continued drainage of the lake for agricultural values has not only seriously affected the ecology of fish, plant and bird populations, but has reduced the original size of the lake, reducing the size of the wetland (known as 'wastelands' in late 1800s) by 81%, and thereby reducing the food supply and habitat for fish, plant and bird populations (Jull, 1989; Goodall, 1996).

The focus for lake management up until the 1960s was solely "balancing the needs of agricultural development against the practical considerations of opening the lake" (Palmer, 1982). However, investigations and monitoring of the impacts of lake drainage have proceeded, following new objectives of the Water and Soil Conservation Act 1967, and more recently the Resource Management Act 1991, coupled with an increased understanding of wetland values and recognition of the international importance of Lake Ellesmere as a valuable wetland.

The Canterbury Regional Council is responsible for managing the lake, lake openings, and the lake's catchment. Currently lake openings are controlled by the CRC under the WCO on the lake, and vary from time of year, as described in Chapter 1 (see Appendix I). The openings occur at the Southern end of Kaitorete Spit, adjacent to Taumutu fishing settlement by machinery cutting.

The effects of these policies and practices on submerged macrophytes are discussed in section 2.4.

2.2 The Submerged Macrophytes of Lake Ellesmere

The main species of submerged macrophytes in the lake recorded by Mason in 1946 and 1951 were *R. megacarpa, R. polycarpa,* and some *P. pectinatus*, with single records of *Lepelaena bilocularis*, and *Zannichellia palustris* (Ward & Taylor, 1996). A survey of Overtons Bay and the bay at Taumutu during 1986 - 1987 found similar results, adding 6 other species, but no *Zannichellia* (Gerbeaux, 1989; see Appendix II).

Ruppia. megacarpa and *R. polycarpa* were the main species of submerged macrophytes around the margins of Lake Ellesmere (Figure 1.2) pre-1950, with plants reaching 2 metres high between Timber Yard Point and Coes Bay, west of the Selwyn River mouth (Ward & Taylor, 1996). They grew extensively here and around Taumutu, Garibaldi Island, and Grays bank (near Motukarara), and less extensively along Kaitorete Spit.

2.3 Submerged Macrophyte Growth and Environmental Response

The productivity of lakes depends on many abiotic and biotic environmental and community factors both within and external to the lake ecosystem (Burgis & Morris, 1987). The abiotic factors such as light and nutrient availability, temperature, oxygen and salinity concentrations, lake depth and basin morphology, interact with biotic factors to control community structure and successional processes (ibid). For example, light penetration affects visibility for predatory fish, which if reduced affects prey numbers that may be grazing on plant material causing an increase in grazing. Light penetration in Lake Ellesmere is affected by algal concentrations and sediment concentration. The whole system comprises a complex set of interactions, and processes; their effects on submerged macrophyte growth are discussed below.

2.3.1 Light

Light availability affects primary production of aquatic ecosystems by limiting photosynthetic capacity of aquatic flora, and affects secondary production by limiting visibility of aquatic fauna (Kirk, 1986), therefore affecting their feeding capacity. The optical properties of aquatic ecosystems, which affect light availability within the water column, are discussed below.

Some light striking a lake is reflected back into the atmosphere from the water surface. The exact percentage is influenced by the suns angle and lake waves (Kirk, 1983) and unless it is backscattered by the atmosphere or surrounding topography, this reflected proportion is lost (Wetzel, 1975). In lakes, wind action affects the amount of light that is reflected by the water surface: light reflectance decreases as wind speed increases (increasing wind-swell), more significantly as sun angle lowers (Kirk, 1983).

Light is either scattered or absorbed after it has entered water (ibid), depending on the optical properties of the water body. The relative effect of these phenomena depends on the substances contained in the water (ibid), such as the water itself, algal pigment, non-organic suspensoids, and yellow substances, which affect water clarity. The optical effects of water constituents are additive (Vant & Davies-Colley, 1984) and therefore contributions towards attenuation are relative to their concentrations.

Wind driven turbulence in shallow lakes erodes the lake floor, resuspending sediments (Weisser, 1978, cited in Gerbeaux, 1989), consisting of inorganic and organic particles. Suspended solids have been reported as the major absorber of light (~ 80% of absorbed light) in Lake Ellesmere; phytoplankton the second highest (~ 19% of absorbed light) (Ward *et al.,* 1996).

Water clarity has important implications for light availability to submerged macrophytes (Ward *et al.*, 1996). Low light and high salinity (discussed below) are important stress factors for *R. megacarpa* and *R. polycarpa* (Gerbeaux, 1989). Low light levels reduced seedling growth, especially rhizome elongation, reducing anchoring ability. Greenhouse experiments measured the growth of *Ruppia* spp. seedlings under different light and salinity regimes. Growth was similar at medium light intensity (18% of photosynthetically active radiation (PAR)) and high light (38% of PAR), and lowest at low light (9% PAR) for both species of *Ruppia.* High light encouraged rhizome growth (horizontal growth) while low light encouraged vertical growth. Gerbeaux suggested that *Ruppia* seedling growth requires low salinity concentrations in spring to encourage germination, and low lake levels are also required in spring to increase light penetration (Ward & Taylor, 1996; Gerbeaux, 1993).

Potamogeton pectinatus, on the other hand, has less requirement for high light for tuber germination (van Wijk, 1986, cited in Ward & Taylor, 1996). The effects of temperature and light on tuber germination and early growth of *P. pectinatus* were studied by Madsen & Adams (1988). They found that temperature affected germination, and that light stimulates germination, but concluded that light intensity was not important. Their experiment ran for only four weeks from the placing of ungerminated tubers in treatments. Although this study showed the importance of temperature for germination, the effects of light intensity on growth were inconclusive because of the short period allowed for growth to differentiate between treatments. Gerbeaux's (1989) *Ruppia* experiments showed there were differences in growth after long term exposure to low light intensity that were not evident after short term measurement. In another study, van Wijk (1983: cited in Madsen & Adams, 1988) found that absence of light reduced germination by 50% at 10°C, but found no difference between dark and light treatment on germination between temperatures of 15 and 25°C.

There is no evidence of a long term study on the effects of light limitation on *P. pectinatus'* growth. This was suggested as an area for further research by Gerbeaux (1989). In his study, he found a high standing crop of *R. megacarpa* in Taumutu (high water clarity) in 1986, and no *P. pectinatus* was present. In Overtons Bay (low water clarity) in the same year, there was no *R. megacarpa,* but a medium standing crop of *P. pectinatus* was found (see Appendix II). Further work is required to justify the claims of low light tolerance by *P. pectinatus.*

2.3.2 Salinity

Aquatic organisms are affected by and cope with salinity using a range of physiological mechanisms and adaptations to maintain the necessary balance of water and dissolved ions within their cells. Salinity becomes toxic to aquatic plants and animals as a lack of water and / or ionic concentrations within the cells occur. There are two broad categories of aquatic plants in relation to salinity: halophytes are salt tolerant species, and non-halophytes (glycophytes), which do not tolerate salt; growth of the latter is reduced by increasing salinities (Centre for Stream Ecology, 1989).

Production in brackish (salinised) inland waters by adapted species can be exceedingly high (Wetzel, 1975). The salinity gradient within lakes, and their associated ionic properties, influence biotic distribution, along with the physiological capability of species to tolerate and adapt to changing salinities (Wetzel, 1975).

There are two mechanisms by which aquatic organisms cope with salinity: osmoregulation and osmoconformity. Animals practise osmoregulation in saline habitats and osmoconformity is found in all aquatic plants and in some animals (Williams, 1987). Osmoconformers maintain high internal pressures by accumulating organic or inorganic ion osmolytes in cells and tissues. In many halophytic macrophytes, the osmolyte is the organic substance proline, found in *Ruppia spp.* (Hammer, 1979; Williams, 1987).

Many studies discuss the effects of increasing salinity on submerged macrophyte growth, but few discuss the physiological mechanisms that enable survival in fluctuating salinities. Brock (1981) found that fluctuations in salinity "have at least as great an effect on submerged macrophyte flora as the maximum level of salinity", and although it was a study on halophytes, it obviously has implications for non-halophytic species.

Lake Ellesmere is a hyposaline lake (3-20 ppt) according to Hammer's (1986) classification system. Saline water enters the lake when it is opened to the sea and to a lesser extent via seepage through Kaitorete Spit. Due to this sea water influence, the ionic distribution of the major cations and anions within the lake is in near reverse order to that of normal freshwater: Na>Mg>Ca>K and $Cl>So_4>CO_3$ respectively (Ward *et al.*, 1996). The concentration of salinity within the lake depends on the volume of sea water present relative to the volume of freshwater, and ranges between very low and 14 ppt in both spatial and temporal distribution (Hughes *et al.,* 1974, cited in Ward *et al.,* 1996). The distribution of ions in the lake is a function of distance from the opening, the length of openings, distance from freshwater inputs, and wind mixing. A general gradient occurs, decreasing from the opening to freshwater inflows (Lineham, 1983). Salinities fluctuate seasonally and, more regularly, around the margins than in the middle.

The effects of salinity on submerged macrophyte decline and re-establishment in Lake Ellesmere were investigated by Gerbeaux (1989). High salinity was shown to be a major stress factor for *Ruppia* spp. in the lake, affecting the plants' morphology, germination and life cycle. Gerbeaux found that for germination, salinities needed to be close to freshwater in spring, and between 0 and 8 ppt for optimum growth, and minimum growth occurred at 16 ppt. However, Brock (1981) has found *R. megacarpa* and *R. polycarpa* growing in salinities of 5-46 and 2-66 ppt respectively. The upper limit of salinity concentration for optimum growth of *P. pectinatus* is 4 ppt salinity, although it can tolerate 13 ppt (Brock, 1981; Brock, 1982).

Further work is required on *P. pectinatus*, to determine its optimum salinity range, combined with light tolerance, to aid lake management.

2.4 Management Implications for Submerged Macrophyte Re-establishment

Drainage of Lake Ellesmere has not only affected the size of the wetland, it has also limited submerged macrophyte re-establishment through increasing salinity, exposure of the submerged macrophyte beds to air causing desiccation, and reducing depth, which increases wind turbulence within the submerged macrophyte zone and increases grazing by waterfowl (Gerbeaux, 1989).

Wetlands play a large role in nutrient filtration but drainage along with agricultural development of the catchment have increased the nutrients flowing into Lake Ellesmere, from point source (effluent discharge, sewage) and non-point source (fertiliser and effluent run-off) (Ward, *et al.,* 1996). Algal growth has proliferated as a result of high nutrient levels; and algal biovolume and nutrient concentrations have well exceeded the limits for classification as a 'highly eutrophic' lake. However, the lake is not in a true eutrophic state, as the associated undesirable features, (such as regular toxic algal blooms and deoxygenation of bottom waters) do not apply to Lake Ellesmere (Lineham, 1983; Gerbeaux, 1989; Ward *et al.,* 1996).

During the development stage of this research, Maurice Nutira, Kaumatua from the Taumutu Runanga (Ngai Tahu iwi) and Lincoln University's Maori and Indigenous Peoples Research and Development group, was interviewed, and he spoke of deleterious effects on the fish populations of the disappearance of the macrophyte beds. Fish were seen migrating from the lake, and appeared elsewhere in southern tributaries following destruction of the beds in the 1968 storm. The macrophytes were valued by Ngai Tahu and their restoration is an issue for current management (Goodall, 1996; M. Nutira pers. comm).

The effects of the 1968 'Wahine Storm' have been very damaging to the ecology of the lake's margins and food chain, by destroying the much valued submerged macrophyte beds. Agriculturally focussed drainage and catchment 'development' have prevented re-establishment, through drainage practices, and increased nutrient and sediment loading, indirectly enhancing the reduction of light penetration.

Gerbeaux (1989) suggested that for *Ruppia* spp. seedlings to germinate, spring conditions need to be low salinity, and shallow water level, to increase light penetration for growth of seedlings. However, this is a complex arrangement for management, and poses several problems, discussed in chapter five. Young submerged macrophytes have to be able to tolerate low light and moderate salinities. Kaituna Lagoon has been postulated as a suitable site because it is the furthermost bay from salt water intrusions through the outlet at Taumutu, and receives no salt-water seepage through Kaitorete Spit, as it is very wide at Kaituna (R. Duneen, pers. comm).

Further research is required to determine if Kaituna Lagoon is a suitable site. Problems may occur during low lake levels, because high populations of black swan (*Cygnus atratus*) settle in the lagoon. This may be due to presence of submerged macrophytes and/or shelter from the prominent easterly wind. *P. pectinatus* has been postulated as a suitable re-establishment facilitation plant, because of its low light requirement and its ability to colonise turbulent environments (van Wijk, 1986). It has a long rhizomatic growth form that helps stabilise the plant, and may prove advantageous against grazing, which often uproots young submerged macrophytes.

The following sections describe the practical studies involved to determine whether Kaituna Lagoon is a suitable site for re-establishment of submerged macrophytes, using *P. pectinatus* as an appropriate establishment plant.

3.0 SITE DESCRIPTION AND METHODS

3.1 Site Description

Lake Ellesmere, before 1950, contained large dense stands of submerged macrophytes that were prolific around much of its lake-margin area. It is these lake margins that are of concern in this study, primarily because of re-establishment of the submerged macrophyte beds.

Lake Ellesmere has an extensive lake-margin and the study area was confined to Kaituna Lagoon, on the Eastern side of the lake, adjacent to Banks Peninsula (see Figure 1.2). Kaituna Lagoon is semi-detached from the lake, especially during low lake levels, because of the long narrow sandbar extending northward from Kaitorete Spit. It is not a lagoon as such, because during average lake levels, and in south and southwest winds, there is no physical distinction between the lake and the lagoon.

Gerbeaux (1989) concluded that successful re-establishment sites need low salinities, high light, warm water temperature and calm conditions with no risk from air exposure in spring. Such sites have been identified as: the bay near Taumutu, around the Marshall and Garibaldi Islands, Overtons Bay, around the mouths of the Selwyn and Halswell rivers and Kaituna Lagoon (Ward &Taylor, 1996; Gerbeaux, 1989). Kaituna Lagoon was chosen due to access reasons (distance from Lincoln and road access to the site) coupled with the physical - chemical suitability discussed.

3.2 Aims and Objectives

The aim of this study was to assess the feasibility of submerged macrophyte re-establishment within Lake Ellesmere, using the submerged macrophyte *Potamogeton pectinatus* as a facilitating plant. To investigate the feasibility of re-establishment using *P. pectinatus* three objectives were: (1) To carry out experiments to determine the factors required for optimum growth of the submerged macrophyte *P. pectinatus*, primarily determining the optimum salinity and light conditions; (2) To assess the habitat of the study area, Kaituna Lagoon, in order to determine the present distribution of submerged macrophytes within the lagoon, and several physio-chemical parameters which may affect submerged macrophyte growth; and (3) To analyse the findings and literature to determine the feasibility of submerged macrophyte re-establishment within Kaituna Lagoon.

These are discussed separately below.

3.3 Determination of Optimum Light and Salinity

Determining the optimum light and salinity conditions for *P. pectinatus* growth was done in two ways. First, a relative growth trial was carried out with different salinity and light combinations and second a physiological response trial to different salinities was conducted.

3.3.1 Relative growth trial

During the summer of 1996-97, *P. pectinatus* plants were sought and collected from a number of sources, because there was initial difficulty finding plant material from within the lake[1] due to the highly turbid waters. Eventually after a succession of two calm days, *P. pectinatus* plants were found in Kaituna Lagoon, near habitat site 2 (see Figure 3.1). The water was only 15-20 mm deep but, during the 1997-1998 summer, there was prolific algal growth[2] making visibility poor.

The plant material was stored in a cool room at 4°C until enough was collected for the experiment. Cuttings with 10 mm of root material (rhizome and root) were placed in washed river sand[3] in 2 L plastic containers,[4] and grown in glass fish-tanks in a greenhouse at Lincoln University (see Plate 1). The tanks were filled with a solution of tap-water and sea-water mixed to give 4 ppt salinity. Salinity was calculated after measuring conductivity using a Solomat 4007 instrument and a 1.0 K probe, and multiplying the measurement in mS/cm by 0.8, following advice from A-M. Schwarz (NIWA, pers. comm.).

When sufficient material was collected and grown for the experiment, further cuttings were taken, similar to above, with 10 mm of root material, and an equal amount of above ground growth. Four cuttings were placed in the four corners of the plastic containers, filled with washed river sand. The containers were then placed in the plastic opaque fish cases, filled with a 4 ppt salinity concentrated solution as above. These were grown for

[1] Submerged macrophyte material from within the lake was preferred for experiments, to provide local genetic material.
[2] Mean Chlorophyll content within the lake at 10/12/1997 = 101.7 mg $m^{3\ -1}$ (*n*=4) (CRC lake monitoring data: see Appendix VI).
[3] Commercially available, sterilised fine-medium grade sand.
[4] 120 x 120 x 80 mm opaque plastic icecream containers.

approximately one week, to assess them for propagation success and signs of growth.

The relative growth experiment was then carried out, beginning in the second and third weeks of January 1998 (mid-summer). A four by three matrix design was used, with four salinities, 0, 4, 8, and 12 ppt, and three light intensities, low (20% PAR entering the greenhouse), medium (40% PAR), and high (56% PAR). This was similar to similar to Gerbeaux's (1989) trials with *R. megacarpa* and *R. polycarpa*. Salinity concentrations were obtained by mixing sea water with tap water, and measured as above. The different light intensities were obtained by placing different grade shade-cloth on top of the fish cases above the water by attaching string and weights at each end (see Plate 2).

Light was measured with a Li-Cor underwater sensor and meter. PAR was calculated by measuring actual light intensity above the containers and 50 mm under the water surface, with respective shadecloth in place, close to midday.

There were 24 fish cases, raised to 60 mm above the ground on concrete blocks to avoid shading from the lower concrete section of the greenhouse wall. Twelve fish cases were placed down each side of the glasshouse, oriented in a north-south direction. Each fish case was assigned a treatment by random block selection, with each of the 12 treatments being duplicated on each side of the greenhouse, to allow for differences attributable to greenhouse effects. The fish cases were filled with the appropriate salinity concentration almost to the top, and aerated using conventional fish-tank pumps and rubber hosing 24 hours per day. Salinity was monitored weekly, and adjusted as necessary, due to evaporation.

Three containers of four plants were placed in each fish case, to provide opportunity for three separate harvests without disturbing growth. Plants were individually coded (for re-measurement at harvest), and above ground growth was measured at the beginning of the experiment (immediately before placement in treatments). Length of plants, rather than each leaf, was measured. There was one shoot per plant at time of measurement. Below ground length was recorded as 10 mm.

Harvests were conducted at 5, 12 and 20 weeks, to provide opportunity to assess short and long term exposure to treatments. At harvest, one container of plants was removed and each plant was removed carefully from the sand, and above and below ground length were measured. If there was more than one shoot per plant, each shoot was measured separately and the lengths were combined to provide one total length per plant. Root length was measured as the length of rhizome and feeding root material combined. Again if there were two separate rhizomes per plant, downward length was measured per rhizome and combined. Other observations, such as presence of tubers or flowers were recorded. The mean values of the four plants per container were used during statistical analyses.

Plates 1 (top) and 2 (below): 1: *P. pectinatus* growing in the plastic containers of washed river sand in aquaria pre treatment stage; 2: Growth experiment in progress.

Plants were placed on a paper towel to remove excess water, and weighed as wet-weight, then dried in an 80°C oven for 8 hours and re-weighed to give a dry weight. A dry weight: wet weight ratio was calculated.

Statistical analyses were carried out using SYSTAT computer program. A multivariate analysis of variance was used to compare mean length (above and below) per treatment. Analyses between treatments were conducted for the following parameters: salinity; light; and light and salinity combined (see appendix IX for ANOVA tables)

3.3.2 Physiological salinity exposure experiment

Salinity-exposure experiments were carried out during summer 1997-98 to test the physiological (photosynthesis and respiration) response of the plants to salinity. The experiment aimed to analyse the effects of stress imposed by one week exposure to different salinity concentrations.

P. pectinatus material was again sourced from Kaituna Lagoon. At the time of collection, the salinity, measured just offshore from habitat site 2, was 12 PPT. Immediately following collection and return to the lab at NIWA Christchurch, pieces of healthy plant material were selected, with root material attached, and placed in containers containing an approximate depth of 50-70 mm washed river-sand. The roots were firmed into the sand. Sea water and tap water were mixed into salinity concentrations of 0, 4, 8, and 12 PPT. This was the same range of salinities used in the growth trial, to provide comparability. The salinity solution was then slowly poured into the containers containing the plants. There were two containers of each salinity for replication. The containers were then placed into a controlled temp, 15°C, under fluorescent lights. Containers were 150 mm diameter, 250 mm tall, and made of clear plastic to allow light to reach plants.

After 24 hours exposure to treatments, respiration and photosynthesis were measured using a Hansatech DW 3 Oxygen Monitoring System, following methodology used by Delieu and Walker (1981) [5]. Random plants were selected from each treatment (from both replicates done separately) and several leaf segments were cut from plants, measured for length, and quickly placed into a measuring chamber containing 5 ml of the associated salinity solution. Temperature was regulated by water-bath flow around the chamber at 18°C. The chamber was initially subject to complete darkness, as oxygen readings were taken for approximately 10 minutes denoting respiration, and then 10 minutes exposure to light (197 μmol photons cm^{-1} s^{-1}) as the plants transferred into photosynthetic activity. The rate of oxygen flux within the chamber denotes the rate of either photosynthesis (O_2 produced) or respiration (O_2 removed) activity.

These first measurements were carried out as a time-0 reference point to base calculations from further measurements after one week exposure to treatments. The 24 hour exposure was carried out to allow plants to adjust to the new salinity, and to record response at this initial stage. Following this 24 hour exposure period and time-0 measurement, containers of untouched plants were returned to the growing room and monitored for one week.

---

[5] Uses a Clark (1956) oxygen electrode. Hansatech model by Delieu and Walker (1981): both not seen, cited in Anon (1995).

Respiration and photosynthesis rates were derived from oxygen readings from within the chamber containing leaves, converted to µmol O_2 cm^{-1} h^{-1}, using the leaf area of the *P. pectinatus* as its length times 1 mm as a constant.[6]

The activity rates were used to determine the impact of salinity exposure on physiological metabolism within the plant. A low relative activity rate indicated a high impact of the associated treatment, and a high relative activity rate indicates a low impact. This conclusion is inferred, because a high activity rate indicates that exposure to the salinity treatment has caused a low level of physiological damage to the plants' internal structure and production/respiration metabolism was relatively undamaged; opposed to that, a low activity rate that indicates a large amount of detrimental damage to the internal structures of the plant has occurred due to the treatment.[7]

After one week exposure, measurements were repeated as above, taking two samples from each replicate for statistical purposes. For this second set of measurements, respiration was allowed to continue for 10 minutes, and then five minutes exposure to increasing light intensity of 55, 111, 174, and 197 µmol photons cm^{-1} s^{-1}, the latter being high enough to produce maximum rates of photosynthesis.

---

[6] Variation in width was deemed too minimal to quantify; use of a constant reduced time and error.
[7] Assuming all other factors were controlled favourably; plant health was monitored and maintained.

3.4 Habitat Survey

The objectives of the habitat surveys were first to collect data on size and relative abundance of submerged macrophyte species within the lagoon, and the range of certain physio-chemical parameters within the water-body of the lagoon. Secondly, it was aimed at determining whether there were any geographical or temporal patterns to the data, and if there were any links between the physio-chemical data and submerged macrophyte growth or distribution.

Four surveys were undertaken, once during late summer (28/02/1998), autumn (25/05/1998), winter (23/07/1998), and again in early summer (09/12/1998). Four line transects within the lagoon were specifically selected to ensure they were accessible, retraceable, and to provide useful coverage of the lagoon (see Figure 3.1). A 1 m2 quadrat was placed on the lake bed at four random sampling points along the 100 m long line-transect. Approximately 50 mm depth of substrate was removed over the whole area of the quadrat to remove all submerged macrophytes. The whole sample was washed through a fine sieve (1.4 mm) to remove mud. Then submerged macrophytes were identified (following keys and pictures in Johnson and Brooke, 1998), separated into species and laid on a paper towel to air-dry. Maximum, minimum, and mean plant length were measured. Macrophyte biomass was measured in each quadrat site as dry weight per square metre multiplied by mean plant height.

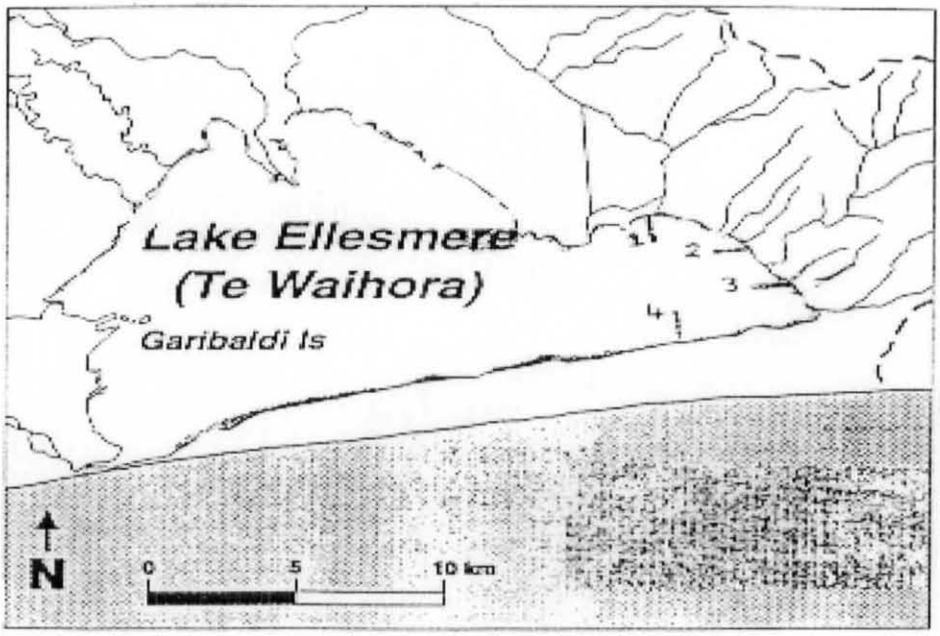


Figure 3.1: Transect location within Kaituna lagoon.

At each site along the transect, measurements were taken of salinity, depth, and light (just below surface and at lake bottom[8]). Water samples were taken for suspended solids analysis. This was done by filtration using GF/C 47 mm ∅ glass-fibre filters of known weight, drying them at 80°C, and reweighing them on a balance The increase in weight represented the total suspended solids of the water sample. Volatile suspended solids were measured by firing the filter at 500°C for 5 hours and weighing the residue. The proportion lost through ignition is considered the organic content, considered to be mainly algae.

Correlation analyses was carried out using Minitab, and Microsoft Exel.

[8] Light measurements were taken using a Li-Cor underwater sensor and meter; Not taken at every site or date, due to time, flat battery, or lack of suitable depth.

A separate salinity survey was undertaken during the spring - summer period of late 1997, to determine the range of salinities over time within Kaituna lagoon. Measurements were taken at the same site as transect 3 (see Figure 3.1) by walking out to a depth of 0.6-0.8m. Salinity was measured using a conductivity meter, following the method discussed above.

3.5 Feasibility of Re-establishment

The objective of the above data collection and experiments was to provide information for analysing the feasibility of submerged macrophyte re-establishment within Kaituna Lagoon using *P. pectinatus* as a facilitating plant. Results from the growth and physiological response trials and the habitat surveys were collated and compared to determine any patterns or correlations between conditions found in the lagoon, and the optimum growth conditions for *P. pectinatus*. Other factors such as management regimes, economic (i.e., agricultural, fisheries, and recreational) and cultural values (i.e., tangata whenua), were briefly considered in the feasibility analyses where appropriate.

4.0 RESULTS

4.1 Growth Experiments

The results from the relative growth experiments of growth above and below ground are shown in Figure 4.1 & 4.2. The effect of light intensity on *P. pectinatus'* growth was as expected. Less growth occurred at 20 % PAR compared with the 40 and 56 % treatments after 5 and 10 weeks, but there was little difference between 40 and 56 % PAR. After 20 weeks (Figure 4.1 & 4.2 (c)), growth was lowest at 20 % PAR and highest at 56%. By this time, the long term (20 weeks) exposure to low light had had a marked affect, experienced by loss of growth and death. Nine of the 32 plants in the 20% PAR treatment had died by 20 weeks, compared with two and three deaths at 40 and 56% PAR respectively.

After 5 weeks growth (Figure 4.1 & 4.2 (a)), there were no statistically significant differences between the four salinity concentrations tested. However, highest above ground growth occurred at 4 ppt salinity across all three light regimes. After 10 weeks (Figure 4.1 & 4.2 (b)), differences were more clear. Highest growth occurred between 4 and 8 ppt in medium and high light. At 20 weeks, growth at 12 ppt was lowest under all light intensities However, growth was higher towards the 0, 4, and 8 ppt at the middle and high light intensities. Above-ground growth favoured a 40% PAR intensity, whereas below-ground growth favoured a 56% intensity Figure 4.1 & 4.2; Table 4.1).

The marginal means, the total mean for each light intensity and each salinity concentration are shown in Table 4.1. These show total mean growth per individual

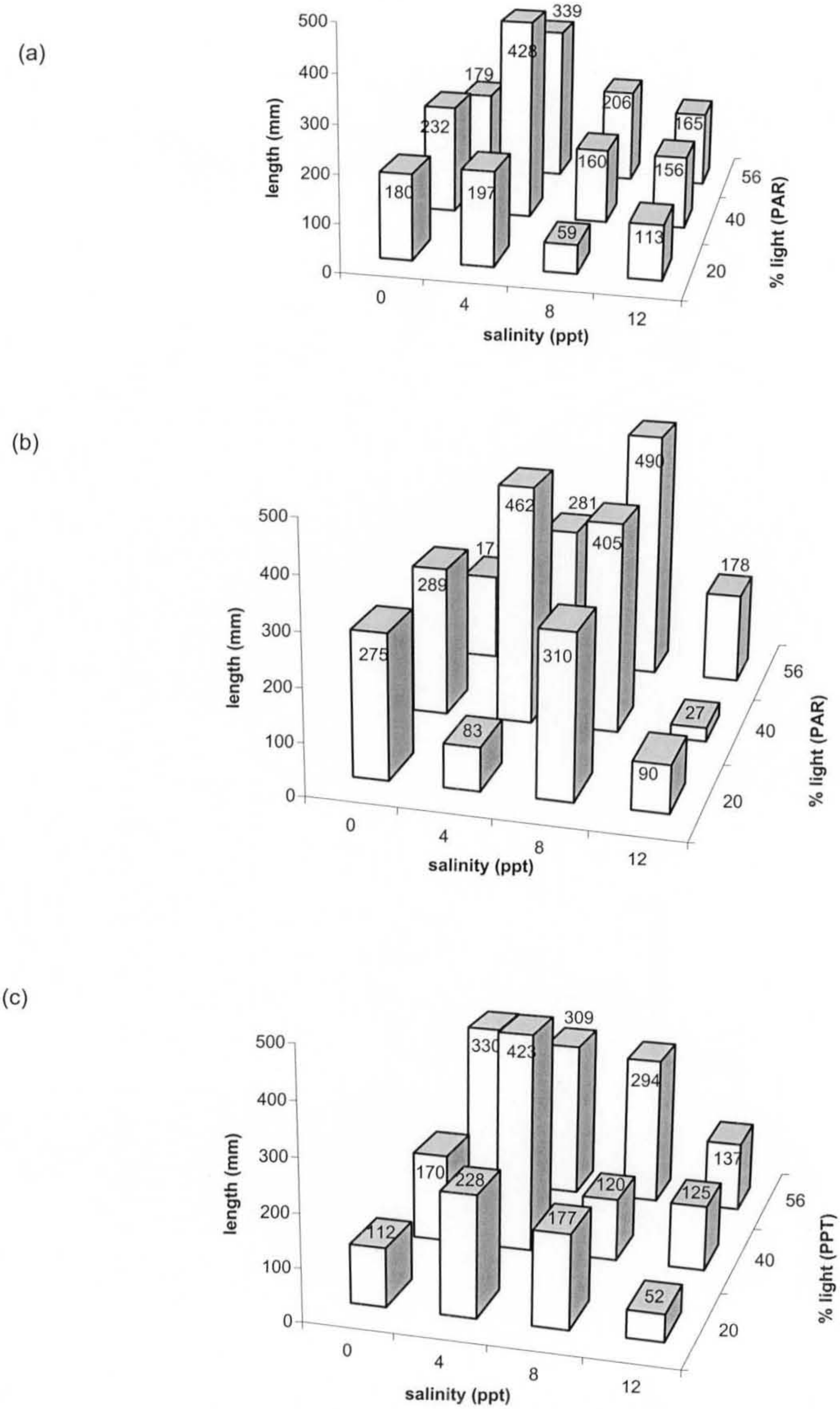
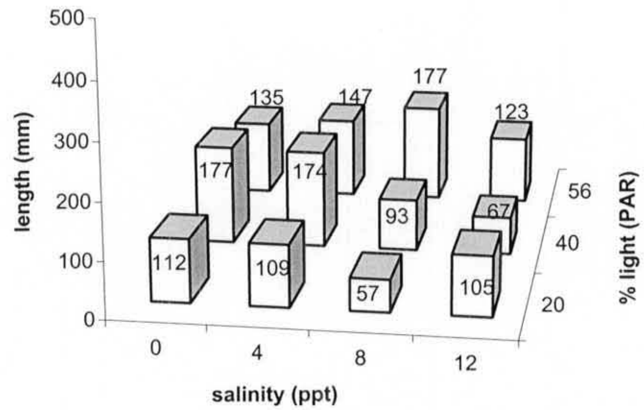
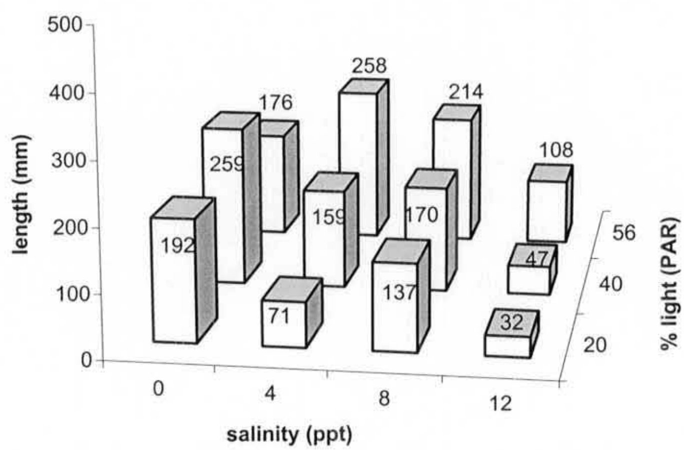


Figure 4.1 Effect of salinity and light on above ground length o *P. pectinatus*.
Values represent mean per treatment: (a) at 5 weeks ($p=>0.05$); (b) at 10 weeks ($p<0.05$); (c) at 20 weeks ($p>0.05$); $n=8$ plants per treatment; (see appendix IX for ANNOVA tables); (see appendix III for raw data per container and variance).

(a)



(b)



(c)

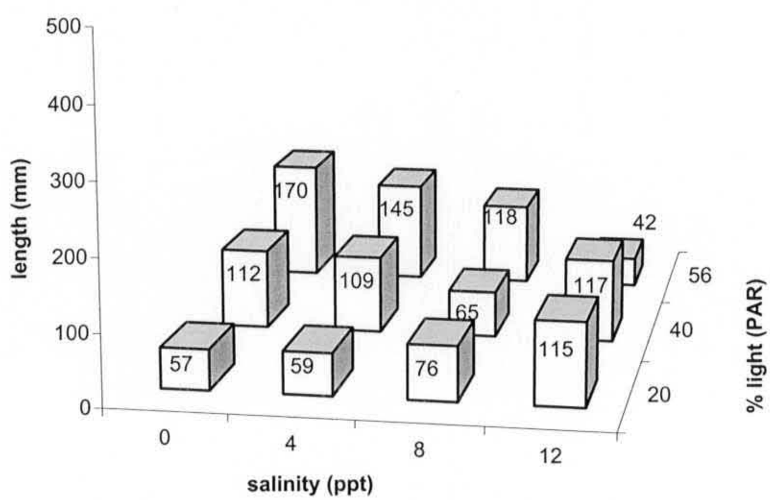


Figure 4.2: Effect of salinity and light on below ground length of *P. pectinatus*.
Values represent mean per treatment: (a) at 5 weeks ($p=>0.05$); (b) at 10 weeks ($p < 0.05$); (c) at 20 weeks ($p > 0.05$); $n = 8$ plants; (see appendix IX for ANNOVA tables); (see appendix III for raw data per container and variance).

light intensity and salinity concentration separately, but still represent the combined effect of both salinity and light. Mean growth increased as light intensity increased, almost twice as much growth at 56 % PAR as at 20 %. Salinities 4 and 8 ppt showed higher total growth than 0, and 12. Below and above-ground growth differed slightly in pattern, below-ground favouring 0 ppt salinity and above-ground growth favouring 4 and 8 ppt salinities.

Table 4.1 Marginal height means (mm) per individual light and salinity levels of *P. pectinatus*:

(a) above ground growth, and **(b)** below ground growth; (raw data see Appendix III).

(a) salinity (ppt)	5 wks	10 wks	20 wks	total of means	**(b)** salinity (ppt)	5 wks	10 wks	20 wks	total of mean s
0	197	245	204	646	0	141	209	113	463
4	321	275	320	916	4	143	162	104	409
8	141	544	197	882	8	109	174	86	369
12	144	98	104	346	12	98	62	91	251
light (%PAR)					light (%PAR)				
20	137	189	142	486	20	96	108	76	280
40	244	295	209	748	40	128	159	100	387
56	222	386	267	875	56	145	62	91	298

Optimum growth in this trial occurred within medium and high light intensities, at 4 and 8 ppt salinity. The only significant result was the effect of salinity at ten weeks on both above and below-ground growth ($P < 0.05$).[1]

[1] Transformed (+1) data used for statistical analyses; untransformed data was used in graphs (Figures 4.1 & 4.2).

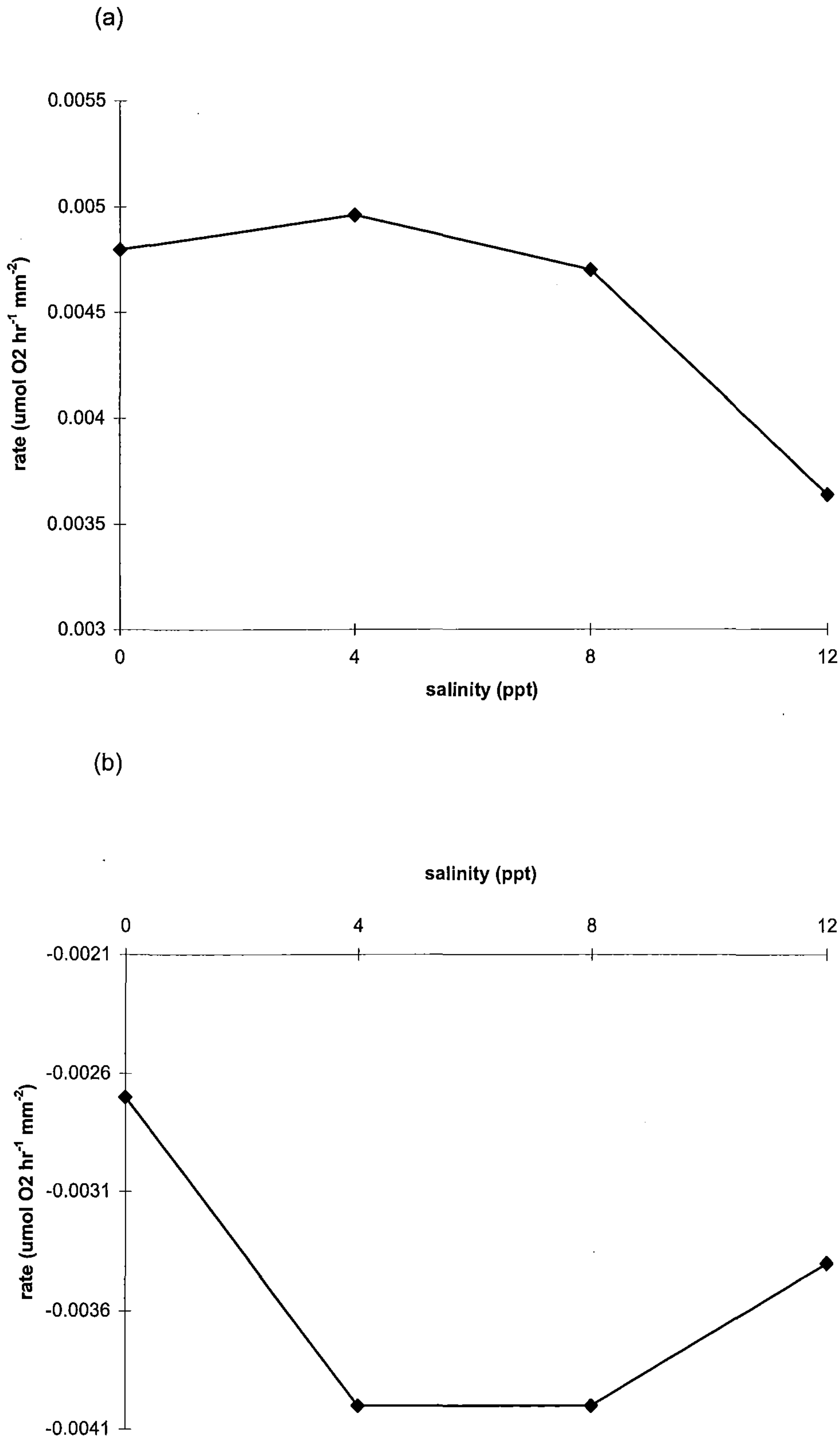


Figure 4.3. (a) Mean photosynthesis and (b) respiration rates of *P. pectinatus* after 1 week exposure to 4 different salinity concentrations; see appendix IV for light concentrations and raw data

4.2 Salinity Exposure Experiment

The effects of the salinity exposure experiments confirmed the effects of salinity on *P. pectinatus*[2] growth (S. 4.1). Exposure to 12 ppt salinity detrimentally affected the photosynthetic rate of *P. pectinatus*, (Figure 4.3)[3] and photosynthesis was highest at 0, 4 and 8 ppt salinities. Respiration was highest at 4 and 8 ppt salinity, less at 12 ppt, and lowest at 0 ppt.

4.3 Habitat Survey

The results from the four seasonal habitat surveys in Kaituna Lagoon during 1998 have been presented separately due to a number of differences in the methodology. Refinements were made following the discovery that identification problems occurred between *R. megacarpa* and *P. pectinatus.* The macrophytes were very small due, in part, to water depth, and associated light penetration, and further reduction by grazing by waterfowl, primarily black swan. Maximum length was 51 mm, although very few plants reached that length; the mean length for the macrophytes was 19 mm (Table 4.2). Figure 4.4 shows that there is an 80% correlation between lagoon depth and macrophyte height, macrophyte height increasing with depth. This could be related to grazing, or growth towards light. However, observation would support the former, because most plants showed signs of grazing damage, and plants would not stop growing once they had reached the light, they would grow on further, therefore skewing the correlation results.

---

[2] Identification problems reduce certainty of all plants being *P. pectinatus.* This was not noticed until later during final habitat survey, well after these experiments. Microscope identification was necessary to distinguish *P. pectinatus* from *R. megacarpa* due to swan grazing damage, and size of plants < 10mm.

[3] Raw data see appendix IV.

Table 4.2 Habitat survey data: Summer, Autumn, and Summer (2): mean physio-chemical and plant data per site transect (1-4).

site transect	depth cm	salinity ppt	suspended solids mgL^{-1}	rganic % of SS	plant sp.	dry plant biomass $g\ m^{-3}$	mean plant length mm	range mm + *n*
Summer (28/02/1998)								
1	6	12.8	26	48	*P. p / R.m*	0.001	15	7-21 *n=10*
1					*S. quinqueflora*	0.000	24	26-41 *n*=11
1					*Characean*	0.0002	nm	
2	31	18.0	37	43	*P. p / R.m*	0.0020	29	15-41 *n*=36
3	27	17.1	49	38	*P. p / R.m*	0.000	26	19-44 *n*=25
4	22	15.6	48	42	*P. p / R.m*	0.000	24	18-41 *n*=25
Autumn (25/05/1998)								
1	22	9.5	16	50	*P. p / R.m*	0.000	19	15-35 *n*=11
1					*J. articulatus*	0.000	34	26-43 *n*=22
1					*Characean*	0.000	nm	
2	39	9.5	20	41	*P. p / R.m*	0.001	23	14-33 *n*=32
2					*J. articulatus*	0.000	nm	
3	40	9.5	21	36	*P. p / R.m*	0.000	18	14-26 *n*=16
4	29	9.3	29	31	*P. p / R.m*	0.000	16	11-26 *n*=24
4					*Characean*	nm	nm	
Winter (23/07/1998)								
1	10	nm	67	25	*Characean*	0.000	nm	
1					*R. megacarpa*	nm	14	12-17 *n*=24
2	40	nm	67	20	*R. megacarpa*	0.000	20	8-38 *n*=113
2					*J. articulatus*	nm	32	18-51 *n*=10
2					dead mac 's	0.001	nm	
3	44	nm	66	20	*R. megacarpa*	0.001	19	12-33 *n*=73
3					*P. pectinatus*		2 tubers only	
4	30	9.5	92	16	*R. megacarpa*	0.000	18	1-25 *n*=10
4					*P. pectinatus*	nm	nm	*n*=8
4					dead mac 's	0.000	nm	
Summer (2) (9/12/1998)								
2	5	9.7	11	43	unid. mac 's	0.000	29	14-52 *n=10*
2					*R. megacarpa*	nm	20	12-29 *n*=10
3	8	nm	11	25	*P. p / R.m*	nm	15	12-19 *n*=3
					Mean length =		19	

(Key: nm= not measurable; *P. p* = *P. pectinatus* and *R.m* = *R. megacarpa;* and inid. = unidentified; mac's = macrophytes; mean depth salinity, suspended solids and organic % - *n*=4;
For Summer and Autumn, plant data *n* = only those plants that were measured, whereas for the Winter and Summer (2) data *n* = total plants. See Appendix V for raw data; Summer 2 sites 1 and 4 were dry at sampling time, so no data exists - above ground plant material was obviously dessicated.

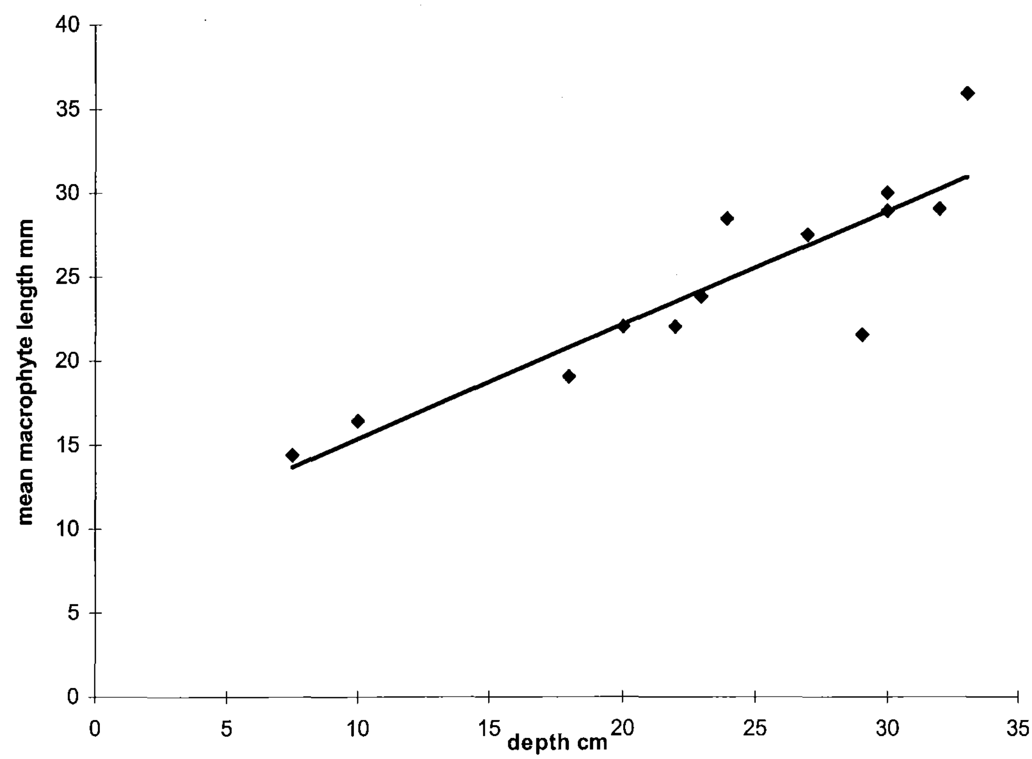


Figure 4.4: Correlation between water depth in Kaituna Lagoon, and mean macrophyte length during summer 1998 (28/02/1998); ($R^2 = 0.8$).

Water depth, wind direction and strength, and bathymetry all varied spatially and seasonally in Kaituna Lagoon. Depth at most transects increased with distance from the shore, except site 3, which decreased from shore site 3a to 3c, (see Figure 3.1 for site location) then increased to site 3d (appendix V). Mean depth (Table 4.2) varied between transect sites, sites 2 and 3 predominantly being the deepest. During December 1998, sites 1 and 4 were completely dry and desiccated beyond the 4th quadrat (100 m from shore), (summer (2) survey: Table 4.2) as lake levels were very low (~ 0.6 m depth at the Taumutu gauge) following opening of the lake at 30

October 1998 (see Plates 3 and 4; Appendix VII). There were signs of macrophyte material, but it was desiccated.

The biomass of submerged macrophytes was very low (Table 4.2) compared with Gerbeaux and Ward's (1991) results (see appendix II) from Overtons Bay and Taumutu in 1986-87[4]. Percent cover could not be obtained, as visibility was impossible.

R. megacarpa was the highest density species. Small quantities of *Juncus articulatus* (jointed rush) and *Sarcocornia quinqueflora* (glasswort) and an unidentified *Chara* sp. was present in very small quantities, during all four 1998 surveys (Table 4.2). Dead macrophyte material was observed during the winter (1998) survey, and the cold water temperature (6° C) could have accounted for the low *P. pectinatus* density. Problems with identification between *P. pectinatus* and *R. megacarpa* prevented analyses of *P. pectinatus* density from the 1st summer and Autumn (1998) surveys, and overall macrophyte density was low in the 2nd summer survey.

Salinity within the lagoon varied both temporally and spatially during the four surveys. The range of variability depended on weather conditions on the day of sampling. Salinity concentrations varied more under calm conditions. Windy, rough- swell conditions mixed the water body well, providing a similar range of salinities

[4] It was noted by fisherman that macrophyte growth was exceptionally higher than previous years.

Plates 3 (top) and 4 (below): 3: view of transect site 4 with no water (December 1998); 4: almost the same location in May 1998 covered in water, note turbidity in mild strength wind conditions.

across the lagoon. The 1st summer (1998) survey provided the only opportunity to compare results on a very calm day. Transect 1, (see Figure 3.1) the northern-most, near the Halswell Canal mouth, displayed the lowest salinity (mean 12.8 ppt). The eastern-most transects (2 and 3) were the highest mean salinities (17 and 18 ppt respectively), and transect 4 extending from Kaitorete Spit showed a 15.6 ppt mean salinity. Transect 2 is furthest from any fresh water inflows, 3 and 4 are closer to the Kaituna River mouth and may be affected by freshwater influx. There was no relationship between plant data and salinity, as the latter changes frequently, as shown in table 4.3.

Table 4.3: Results showing the variability of salinity over two months investigations at Site 3 (see Figure 3.2) within Kaituna Lagoon.

Date 1998	salinity ppt
16-Sept.	3.7
18-Sept.	3.4
19-Sept.	3.3
25-Sept.	5.1
26-Sept.	9.1
29-Sept.	6.9
2-Oct.	7.2
3-Oct.	7.6
6-Oct.	7.3
8-Oct.	7.8
9-Oct.	7.9

Salinity increased during spring and summer (1998) (Table 4.2 & 4.3). However, readings were not regular enough, or for long enough duration to draw any strong conclusions. Analyses of Canterbury Regional Council readings taken monthly in

Lake Ellesmere show that salinity is higher in summer and autumn (see Appendix VII). Weather data from the Lincoln region (Appendix VIII) show no correlation between rain or wind speed and salinity at site 3 during September and October.

Analyses of the light reading results (Figure 4.5) show that, as depth increased, the percentage of light reaching the bottom decreased. Suspended solid (SS) measurement revealed that Kaituna Lagoon is a water body with very high light limiting properties (see Plate 4). SS measurements ranged from 100 mg l^{-1} on the 2nd Summer survey, to 900 mg l^{-1} during the winter survey, which was in very windy and choppy conditions, and the water was very turbid. The organic content

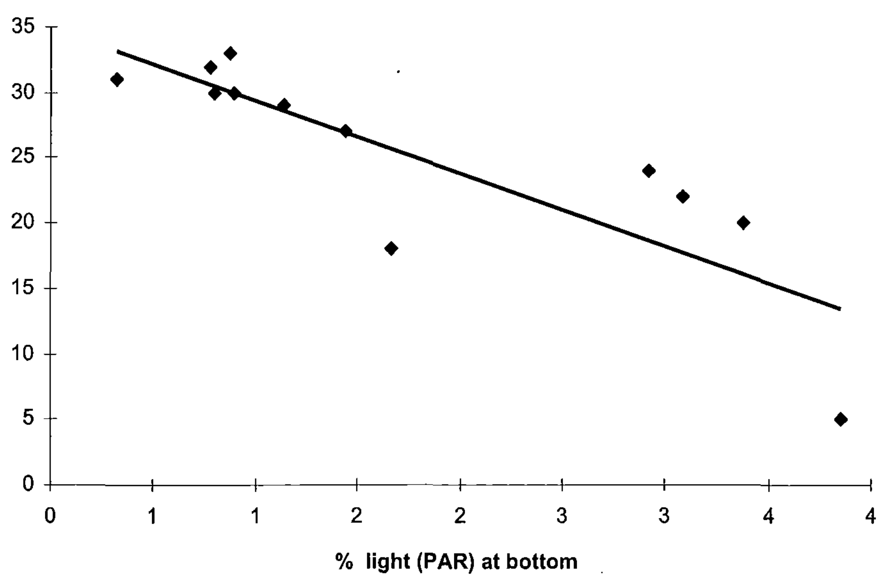


Figure 4.5. Correlation between lagoon depth and % light (PAR) reaching the bottom of the lake bed at Kaituna Lagoon. See Appendix V for data, range and n; $R^2 = 0.7$; Readings taken summer (28/02/1998) on a bright sunny day.

(presumed to be mostly phytoplankton) ranged between 41 and 50 % of SS during summer and autumn, and decreased to between 16 and 25 % during winter, denoting the seasonal changes in phytoplankton abundance, which may affect the light absorption properties of the water.

These results will now be discussed, with a focus on the feasibility of macrophyte re-establishment in the following discussion and conclusion chapters.

5.0 Discussion

This chapter discusses the results in relation to the literature and the implications for the re-establishment of submerged macrophytes, and is divided into the following four sections: salinity and light requirements; habitat conditions within Kaituna Lagoon; the feasibility of submerged-macrophyte re-establishment; and, finally, conclusions from the study and recommendations for re-establishment of submerged macrophytes within Kaituna Lagoon.

5.1 Salinity and Light Requirements

The results from both the relative growth and salinity exposure experiments show that *P. pectinatus* prefers a salinity concentration in the range of 4 or 8 ppt. Both respiration and photosynthetic activity were less at 12 ppt than the other salinities, (Figure 4.3) suggesting this salinity damages physiological processes of *P. pectinatus*. *Potamogeton* plants that were growing at 12 ppt salinity in the relative growth experiment were stunted, lost leaves, and many died, suggesting that long term exposure to 12 ppt was damaging to plant health. Brock (1981; 1982) found that *P. pectinatus* reached its tolerance limit at 4 ppt, although it can tolerate 13 ppt.

Brock (1981) found *Ruppia megacarpa* and *R. polycarpa,* the two *Ruppia* species found in Lake Ellesmere, growing in salinities of 5-46 and 2-66 ppt respectively. Gerbeaux (1989) found that optimum growth of *R. megacarpa* occurred between 0-8 ppt salinity. Both of the *Ruppia* species and *P. pectinatus* tolerate a wide range of salinities, but optimum growth occurs within a narrow range.

Brock (1981), found that fluctuations in salinity, and depth, "have at least as great an effect on submerged macrophyte flora as the maximum level of salinity", and although her study was on halophytes, it obviously has implications for non-halophytic species such as *P. pectinatus.* Perhaps the low respiration rate at 0 ppt (Figure 4.3), could be explained by this effect of fluctuating salinities, as they were taken from the lagoon at 12 ppt salinity, and the fact that *P. pectinatus* is not a freshwater plant, and prefers slightly brackish water. Fluctuations should be minimised to maximise plant production, and remain with the optimum range of 4-8 ppt.

High salinity is a stress factor that damages *P. pectinatus* growth, and lake management must incorporate this consideration if submerged-macrophyte re-establishment is a goal. Current lake openings are not controlled to limit salinity fluctuations, and lake depth reaches low levels around the margins in summer (Table 4.2). Low lake levels have implications for both desiccation and salinity fluctuation around the lake margins, as evaporation and wind movement of water exposes the plants to wide fluctuations in salinity and water depth.

P. pectinatus tolerates low light (van Wijk, 1986, cited in Ward & Taylor, 1996). However the growth experiments showed that long term exposure to 20 % PAR damaged growth. Perhaps in high salinities the plants' tolerance of low light is limited and in low light conditions *P. pectinatus* has less tolerance to high salinity. This possibility was not clearly shown by the results.

Light measurements taken during the first summer (February 1998) habitat survey in Kaituna Lagoon showed a very low proportion of incident light was reaching the lake bottom (Figure 4.5). At 0.3 m water-depth, only 1% PAR reached the bottom of the lagoon. This is not enough to sustain growth of the submerged macrophytes. At 0.05 m water-depth, only 4% PAR was reached the bed of the lagoon. Suspended solids were high during this summer survey, but not as high as the winter readings. Wind re-suspension of lake bed sediments is the most important factor leading to low water clarity (Gerbeaux, 1989). Suspended solids and phytoplankton both affect light penetration, via absorption and reflection respectively. The values recorded during this study are among the highest for New Zealand lakes, and indicate very low water clarity.

The difficulty in managing the lake for increased light penetration is very complex. Lowering suspended solids would be the most beneficial factor for increasing light penetration. Sediment loading in the lake is high, due to the nature of the agricultural and mountainous catchment (see Ward *et al.,* 1996). It may be possible to lower sediment inputs, through catchment and tributary management. A second method of stabilising lake-bed sediments is by re-establishment of the submerged macrophytes. But light penetration has to be improved first, before submerged macrophytes can become established. Another problem with improving water clarity is that of the phytoplankton. If non-organic sediments are reduced, thus increasing light penetration, the question "Will phytoplankton productivity increase as a result?" needs to be addressed (Ward *et al.*, 1996). This may be counteracted by a reduction of sediment-bound nutrients, and reductions in run-off entering the lake as a result of reducing sediment loading.

The other way of increasing light penetration is through lowering lake depth. This, however, exposes the plants to higher risk of grazing, and to exposure as the lake margin shifts in windy conditions and during prolonged dry periods. Controlling depth around the margins is a difficult task, and fluctuations in depth, and salinity harmed submerged macrophyte growth (Brock 1981). Further study into means of increasing light penetration without the risk of increased grazing or desiccation is necessary. The benefits of improved water clarity include the improved perception of recreational users of the lake, improved traditional eel catching (Ward *et al.*, 1996), as well as the possibility of submerged macrophyte re-establishment.

A limitation of this study has been time, which did not allow an investigation into the conditions needed for maximising "germination" of *P. pectinatus* tubers. The literature was unclear about the conditions needed for early success of *P. pectinatus* plants. Madsen and Adams (1988) found that temperature needed to be between 15 and 25 °C for tuber germination after winter stratification. Light stimulated germination, and dark significantly reduced germination success (65 % vs. 13 % respectively), but light intensity did not make a difference. They concluded that the light intensities they studied were not a limiting factor on early growth. Spencer (1986), however, suggested that the light and temperature conditions that exist during early growth are critical to the success of establishing *P. pectinatus* plants in a particular location. The importance of tuber depth is also found important (Spencer, 1987). *P. pectinatus* relies more heavily on tubers than seeds for germination (*ibid*). It is by these tubers that plants are able to withstand desiccation (Madsen and Adams, 1988). The effects of substrate type, sedimentation, and swan grazing on tuber germination and distribution needs further research.

5.2 Kaituna Lagoon Habitat

From the results of the four habitat surveys in 1998, present conditions in Kaituna Lagoon are unlikely to favour submerged macrophyte re-establishment. The depth and salinity fluctuation experienced during 1998 would cause difficulties and much stress for any submerged macrophytes germinating in late spring when the water reaches the required temperatures for germination. During December 1998, there was no water at transects 1 and 4 up to 100 m out from the shoreline. This low depth in Kaituna Lagoon followed a lake opening (1/11/1998) and low precipitation that left the depth at Taumutu around 0.5 m (above sea level) for 6 weeks (see Appendix VII and VIII). This represents the lowest depth recorded since November 1996, and the longest duration low period at the Taumutu station in 3 years. Desiccated macrophytes were observed on the muddy lake bed.

As mentioned above, fluctuations in depth and salinity are harmful to macrophyte growth (Brock, 1981), and minimising fluctuations are as important as keeping the maximum levels of salinity below a harmful level. In achieving submerged macrophyte re-establishment shallow lake depths increase the likelihood of depth fluctuations around the margins so perhaps the summer lake opening level needs to be increased to reduce long periods of shallow depth that may occur following an opening.

The height of the submerged macrophytes in Kaituna Lagoon was very low (Table 4.2) with a mean length of 19 mm; the plants are capable of growing to a height of 3 metres (Johnson and Brooke, 1998). Grazing by waterfowl was obvious from the chewed appearance of the leaf tips, the high black swan numbers within the lagoon, and the many footprints and faeces on the surrounding mudflat. Figure 4.4 shows an 80 % correlation between water depth and plant height. This is possibly due to waterfowl grazing, so that when the plants reach a certain height, they become grazed. This factor results from a combination of depth and reach of the swans necks. Measurements indicate that black swan feeding reach is about 1 m (Mitchell *et al.* 1988). This reach is greater than the depths recorded in the lagoon surveys.

The biomass of submerged macrophytes within the lagoon was low in comparison to past records for other areas of the lake (Appendix II). The shaded area in Figure 1.2 shows that there were prolific submerged macrophyte beds in Kaituna lagoon pre 1960, that were destroyed in the 1968 "Wahine Storm". Re-establishment of the submerged macrophytes has not been successful to date, and conditions will have to change to facilitate re-establishment. "It is one form of insanity to do the same thing and expect different results" (unknown source). This quote sounds the need for a change in management focus for the lake, and to focus on the within-lake conditions needed for the re-establishment of submerged macrophytes before any progress towards re-establishment may begin.

5.3 Feasibility of Submerged Macrophyte Re-establishment in Kaituna Lagoon

The aim of this study was to determine the feasibility of re-establishing the submerged macrophytes in Kaituna Lagoon, using *P. pectinatus* as a facilitation plant. The study found that *P. pectinatus* tolerates relatively low light conditions, as found by van Wijk (1986, cited in Ward & Taylor, 1996). This is an advantageous characteristic under the current water clarity conditions. However, light penetration to the lake bed is very low at any considerable depth, 1 % PAR at 0.3 m, well below the light in the 20 % PAR treatment which caused damage to growth and death, and is unlikely to support re-establishment.

The salinity range within the lagoon was wider and reached higher levels than the 4-8 ppt required for optimum *P. pectinatus* growth, and the 0-8 ppt range preferred by *R. megacarpa* (Gerbeaux 1989). Salinity concentration fluctuates when wind velocity changes from calm and settled to windy, resulting in choppy and mixed waters. These changes cause diurnal, day to day and seasonal fluctuations in salinity.

Given these two light and salinity conclusions alone, it would seem impossible to re-establish submerged macrophytes in Kaituna Lagoon using *P. pectinatus* or *R. megacarpa*. In addition, the depth fluctuated widely during the study, especially at transects 1 and 4. Desiccation, alteration of light penetration, and exposure to increased grazing by black swan are known stress factors caused by depth fluctuations. Given the density properties of salt water[1], possibly also salinity fluctuations, although they were not quantified in this study.

The low biomass of submerged macrophytes found in this study reflects the difficult growing conditions in the lagoon. The present light, salinity, and depth conditions in the lagoon are unsuitable for re-establishment. More research is required into the links between these factors and causal events such as lake openings, weather conditions, inflow levels and their sediment, nutrient loadings and swan grazing.

In 1997-1998, the Canterbury Regional Council discussed the possibility of implementing a monitoring station within the lagoon to measure physio-chemical data such as climate, light, depth, salinity and turbidity. This would provide useful data regarding habitat conditions within the lagoon, and would have helped this current study. Readings from the proposed station would provide possible correlating results with the other monitoring station at Taumutu, and the monthly readings taken manually by the Canterbury Regional Council at Taumutu, the middle of the lake, Greenpark Sands, and Overtons Bay regions. Salinity changes could be linked to openings and light readings to weather data. This would be a useful tool in the designing of a management plan for the lagoon, should it be chosen as a submerged macrophyte re-establishment site in the future.

Other sites within the lake that have been suggested as suitable sites for submerged macrophyte re-establishment are Taumutu, off Garabaldi Island, Overtons Bay and Greenpark Sands (Gerbeaux, 1989). These sites could be assessed for their suitability compared with the optimum conditions required for *P. pectinatus* and *Ruppia* growth proposed by this study and Gerbeaux (1989).

A number of improvements could have been made to this study. Proper differentiation between *P. pectinatus* and *R. megacarpa* should have been made under a microscope from the beginning. With plants are as small as were found in this study, and when swan grazed, a microscope is needed to analyse leaf tip form. Tubers also help identify *P. pectinatus.* There were *P. pectinatus* in Kaituna

---

[1] Salt-water is heavier (more dense) than freshwater, and a salinity gradient can form after calm conditions as the heavier salt laden water settles to the bottom (K. Nicolle Natural Resource Engineering Group, Lincoln University, personal communication).

Lagoon, and most plants in the growth experiment came from plants with tubers attached.

This study has included a range of investigations on the topic including growth and exposure experiments, the four habitat surveys and a literature review. It is suggested that a concentrated growth trial focussing the conditions required for early growth and germination would have given more information needed for re-establishment. The habitat surveys with the associated lab and field analyses were time consuming. Hindsight is a wonderful tool for reflection and learning.

5.4 Conclusions and Recommendations

Submerged macrophytes play an important role in the ecology of many lakes, especially shallow wind swept lakes such as Lake Ellesmere (Te Waihora). They act as nutrient buffers, sediment trappers, provide important food sources for wildlife, and provide habitat diversity for fish and invertebrates. Before their destruction in the 1968 "Wahine Storm", the submerged macrophyte beds were prolific and well established. Since their destruction, they have not recovered to their past distribution or biomass level due to unfavourable lake conditions, mostly caused by agriculturally focussed management of lake levels and catchment inputs such as sediments and nutrients. Salinity, light and possibly waterfowl grazing are important stress factors for the submerged macrophytes.

Following Gerbeaux's (1989) study into *Ruppia* growth, this study focussed on *P. pectinatus* as a suitable plant for facilitating re-establishment in Kaituna Lagoon. Salinity must be maintained at around 4-8 ppt for optimum *P. pectinatus* growth.

Wide fluctuations of salinity and depth must be avoided to maintain optimum growth. The salinity range within the lagoon exceeds levels required for optimum growth and, especially in summer, the growing season, salinity reaches maximum levels tolerated by *P. pectinatus.* Controlling salinity would involve controlling depth by forced lake closures in the event of possible long openings, and low in-flows. The feasibility of managing the lake for salinity control will have to be evaluated.

Low light is tolerated by *P. pectinatus* but light penetration should be improved above present levels to improve early growth of *P. pectinatus*, and especially for *Ruppia* sp. Wind generated re-suspension of sediments is the primary factor in light limitation, followed by phytoplankton density. Re-establishment of submerged macrophyte beds will reduce re-suspension of sediments, and improve light penetration provided phytoplankton density does not increase as a result.

P. pectinatus tolerates low light conditions better than *R. megacarpa*, and therefore may be a suitable plant for facilitating the re-establishment cycle. But since not much *P. pectinatus* was found in Kaituna Lagoon, this may involve planting tubers collected elsewhere, protection from grazing, and possibly controlling re-suspension of sediments.

Installation of the proposed monitoring station at Kaituna Lagoon will help determine the relationships between lake openings and inflows and the conditions within the lagoon, and help assess the feasibility of achieving the above objectives.

Other factors also need to be monitored, including the effects of the summer opening depth on lake margins.

In summary this study recommends:

- Lowering maximum salinity to within a range of 4-8 ppt;
- Reducing salinity and depth fluctuations, especially around the lake margins;
- Improvement of light penetration;
- Controlling sediment re-suspension and inflows
- Control waterfowl grazing
- Monitor relationship between lake openings and lake margin conditions.

The costs of these recommendations may prove unfeasible, and other sites may need to be assessed for submerged macrophyte re-establishment which may not need as much modification to management or as much wind or swan protection as Kaituna Lagoon. Taumutu, Overtons Bay and Greenpark Sands may exhibit better conditions for re-establishment. They may not suffer such damaging depth fluctuations as Kaituna, or the salinity range, although light penetration remains a problem throughout the lake.

5.5 Further Research

Further research is needed into the following areas:

- the effects of sediments and sedimentation on *P. pectinatus* tuber germination;
- the effects of black swan grazing and tuber consumption;
- the links between lake openings and salinity and depth at Kaituna Lagoon
- the links between inflow sediment loading and nutrients and light penetration;

- the costs of management focussed on achieving the optimum growth conditions for submerged macrophyte re-establishment;
- the feasibility of swan exclosures and tyre-wall wind shelters.

References cited

Anon, (1995) Hansatech Oxygen System Operators Manual Hansatech Instruments Ltd. England.

Brock, M., (1981) The ecology of halophytes in the south-east of South Australia, *Hydrobiologia*, 81: 23-32.

Brock, M., (1982) Biology of the salinity tolerant genus *Ruppia* L. in saline lakes in South Australia, *Aquatic Botany,* 13: 219-248.

Burgis, M., and Morris, P., (1987) *The natural history of lakes*, Cambridge University Press, New York.

Centre for Stream Ecology, (1989) *Biological effects of saline discharges to streams and wetlands*, Report prepared for the Australian Salinity Bureau, February, 1989.

Clark, L., (1956) Monitor and control of blood tissue oxygen tension. *Transactions of the American Society for artificial organs* 2: 41.

Davis, S., Blackford, C., Glennie, J., Glova, G., Hughey, K., Partridge, T., Taylor, K., and Ward, J., (1996) Lake Ecosystem: Taylor, K., (ed) *The natural resources of Lake Ellesmere (Te Waihora) and its catchment.* p 161-177, Canterbury Regional Council, Report 96(7), Christchurch.

Delieu , T. and Walker, D., (1981) Polargraphic measurement of photosynthetic oxygen evolution by leaf discs. *New Phytologist,* 89: 165-175.

Duneen, R. Engineer, Canterbury Regional Council.

Evison, H., (ed) (1988) *The Treaty of Waitangi & the Ngai Tahu claim: a summary,* Ngai Tahu Trust Board, Christchurch..

Gerbeaux, P., (1989) *Aquatic macrophyte decline in Lake Ellesmere: a case for macrophyte management in a shallow New Zealand lake.* Unpublished Phd Thesis, Lincoln College, Canterbury.

Gerbeaux, P., and Ward, J., (1991) Factors affecting water clarity in Lake Ellesmere, New Zealand. *New Zealand Journal of marine and freshwater research,* 25: 209-216.

Glennie, J., and Taylor, K., (1996) General Introduction: Taylor, K., (ed), *The natural resources in Lake Ellesmere (Te Waihora) and its catchment,* p.1-5, Canterbury Regional Council, Report 96(7), Christchurch.

Goodall, A., (1996) Te Waihora - Te Kete Ika: Taylor, K., (ed), *The natural resources in Lake Ellesmere (Te Waihora) and its catchment.* p. 145-150, Canterbury Regional Council, Report 96(7), Christchurch.

Grey et al., (1988) in Woods, K., (1989), Rangatiratanga in the context of Lake Ellesmere / Te Waihora: Identifying the conditions necessary for the exercise and expression of tribal authority over trial resources; Unpublished thesis, University of Canterbury and Lincoln College;

Hardy, (1989) in Jull, J., (1989) *Traditional Maori methods for natural resource management in a contemporary world: - options and implications for Te Waihora (Lake Ellesmere),*Unpublished Masters thesis, University of Canterbury and Lincoln College.

Johnson, P., and Brooke, P., (1998) *Wetland plants in New Zealand,* Manaaki Whenua Press, Lincoln, N.Z.

Jull, J., (1989) *Traditional Maori methods for natural resource management in a contemporary world: - options and implications for Te Waihora (Lake Ellesmere),*Unpublished Masters thesis, University of Canterbury and Lincoln College.

Lineham, I., (1983) *Eutrophication of Lake Ellesmere: a study of phytoplankton,* Thesis, University of Canterbury, Christchurch.

Love, (1987) Jull, J., (1989) *Traditional Maori methods for natural resource management in a contemporary world: - options and implications for Te Waihora (Lake Ellesmere),* Unpublished Masters thesis, University of Canterbury and Lincoln College.

Madsen, J., and Adams, S., (1998) The germination of *Potamogeton pectinatus* L. tubers: environmental control by temperature and light. *Canadian Journal of Botany* 66(12) p. 2523-2526.

Mitchell, S., Hamilton, D., MacGibbon, W., Nayar, P., and Reynolds, R., (1988) Interrelationships between phytoplankton, submerged macrophytes black swan (*Cygnus atratus*) and zooplankton in a shallow New Zealand lake. *Hydrobiologia*. 73: 143-170.

Nicolle, K., Tutor, Lincoln Univerity Natural Resource Engineering Group.

NWASCA (National Water and Soil Conservation Authority) (1990) National Water Conservation (Lake Ellesmere) Order, 1990. Order In Council 1990 / 155. National Water and Soil Conservation Authority, Wellington.

Nutira, M. (Lincoln University Maori and Indigenous Planning and Research Group.) Kaumatua, and Taumutu Runanga Kaumatua.

Palmer, J., (1982) *Ellesmere, a critical area,* coastal resource investigation. Dept. of Lands and Survey, Christchurch.

Reid, R., and Holmes, R., (1996) Lake level control, flood hazard management, and drainage: Taylor, K., (ed), *The natural resources in Lake Ellesmere (Te Waihora) and its catchment.* p. 51-65, Canterbury Regional Council, Report 96(7), Christchurch.

Scott, R. Senior Lecturer, Lincoln University Ecology and Entomology Dept.

Spencer, D., (1986) Early growth of *Potamogeton pectinatus* L. in response to temperature: irradiance: morphology and pigment composition. *Aquatic Botany* 26: 1-8.

Spencer, D., (1987) Tuber size and planting depth influence growth of *Potamogeton pectinatus* L. *American midland naturalist.* 118:1.p 77-84.

Taylor, K., (1996) The wildlife community: *The natural resources of Lake Ellesmere (Te Waihora) and its catchment.* p. 189-283, Canterbury Regional Council, Report 96(7), Christchurch.

Tau, Te M., Goodall, A., Palmer, D., Tau, R., (1990) *Te Whakatau Kaupapa: Ngai Tahu resource management strategy for the Canterbury region,* Aoraki Press, Wellington.

Van Wijk (1986) in Ward, J., & Taylor, K., (1996), "Plants of the lake and margins: Taylor, K., (ed), *The natural resources in Lake Ellesmere (Te Waihora) and its catchment.* p.177-188, Canterbury Regional Council, Report 96(7), Christchurch.

Vant, W., and Davies-Colley, R., (1984) Factors affecting clarity of New Zealand lakes, *New Zealand Journal of Marine and Freshwater Research,* Vol. 18: pp 367-377.

Ward, J. And Taylor, K., (1996), "Plants of the lake and margins: Taylor, K., (ed), *The natural resources in Lake Ellesmere (Te Waihora) and its catchment.* p.177-188, Canterbury Regional Council, Report 96(7), Christchurch.

Ward, J., Fietje, L., Freeman, M., Hawes, I., Smith, V., and Taylor, K., (1996) Water quality of the Lake and tributaries: Taylor, K., (ed), *The natural resources in Lake Ellesmere (Te Waihora) and its catchmen.* p. 105-140, Canterbury Regional Council, Report 96(7), Christchurch.

Wetzel, R., (1975) *Limnology,* W.B. Saunders company, London.

Williams, W., (1987) Salinization of rivers and streams: an important biological hazard, *Ambio.* 16 (4): 180-185.

Woods, K., (1989) *Rangatiratanga in the context of Lake Ellesmere / Te Waihora: Identifying the conditions necessary for the exercise and expression of tribal authority over trial resources*; Unpublished thesis, University of Canterbury and Lincoln College.

Appendix I: The National Water Conservation (Lake Ellesmere) Order 1990.

The National Water Conservation (Lake Ellesmere) Order 1990
Paul Reeves, Governor-General
Order in Council
At Wellington this 2nd day of July 1990

Present:

His Excellency the Governor-General in Council

PURSUANT to section 20D of the Water and Soil Conservation Act 1967, His Excellency the Governor-General, acting by and with the advice and consent of the Executive Council, hereby makes the following order.

ORDER

1. **Title and commencement**—(1) This order may be cited as the National Water Conservation (Lake Ellesmere) Order 1990.

(2) This order shall come into force on the 28th day after the date of its notification in the *Gazette*.

2. **Interpretation**—In this order, unless the context otherwise requires,—

"Act" means the Water and Soil Conservation Act 1967;

"Lake Ellesmere" means that variable body of water commonly known as Lake Ellesmere, otherwise known as Waihora, located at and about map reference NZMS 262 13:468714, and having an area of about 20,000 hectares;

"Lake level" means the water level measured in calm conditions by the recorder at Taumutu (map reference NZMS 260 M37:599064) maintained by the Canterbury Regional Council;

provided that the Canterbury Regional Council may, at its discretion and when necessary due to windy conditions, estimate the reading which would have been obtained in calm conditions:

"m.a.s.l." means the elevation in metres above 1988 mean sea level at the Port of Lyttelton.

3. **Outstanding features**— It is hereby declared that Lake Ellesmere provides an outstanding wildlife habitat.

4. **Restriction on lake openings and closings**—(1) Subject to subclause (2) of this clause, because of the outstanding features specified in clause 3 of this order, a water right shall not be granted under section 21 of the Act and a general authorisation shall not be made under section 22 of the Act allowing Lake Ellesmere to be artificially opened to the sea or artificially closed from the sea.

(2) A water right may be so granted—

(a) To allow the lake to be artificially opened to the sea whenever the lake level—

(i) Exceeds 1.05 m.a.s.l. during any period commencing on the 1st day of August and ending with the 31st day of March next following; or

(ii) Exceeds 1.13 m.a.s.l. during any period commencing on the 1st day of April and ending with the 31st day of July next following;

(b) To allow the lake to be artificially opened to the sea at any time during any period commencing on the 15th day of September and ending with the 15th day of October next following;

(c) To allow the lake to be artificially closed from the sea whenever the lake level is below 0.6 m.a.s.l. during any period commencing on the 1st day of October and ending with the 31st day of March next following.

5. Right to dam or to drain land not to be granted—

(1) Subjected to subclauses (2) to (4) of this clause, because of the outstanding features specified in clause 3 of this order, a water right shall not be granted under section 21 of the Act and a general authorisation shall not be made under section 22 of the Act allowing the damming, stopbanking, polderisation, or drainage of any part of Lake Ellesmere where the lake bed is below 1.13 m.a.s.l. in elevation.

(2) A water right to polderise for fish-farming or for research into fisheries may be so granted if there is no significant impact on the outstanding features of Lake Ellesmere specified in clause 3 of this order.

(3) A water right may be so granted for any stopbanks, drains, and other uses of water which existed on the 27th day of June 1986.

(4) A water right may be so granted for works associated with the maintenance of those outlets of rivers, streams, and drains, and of those stopbanks, which existed on the 27th day of June 1986.

6 Restriction on grant of water rights—

(1) A water right shall not be granted under section 21 of the Act and a general authorisation shall not be made under section 22 of the Act in respect of the waters of Lake Ellesmere if the effect of such a right or authorisation would be that the provisions of this order could not be observed without those provisions being changed or varied.

(2) Notwithstanding anything in this order, it shall be lawful for a water right to be so granted for research into, and enhancement of, wildlife habitats.

7. Scope of this order—Nothing in this order shall be construed as limiting the effect of the second proviso to section 21 (1) of the Act relating to the use of water for domestic needs, for the needs of animals, and for or in connection with fire-fighting purposes.

MARIE SHROFF

Clerk of the Executive Council

EXPLANATORY NOTE

This note is not part of the order, but is intended to indicate its general effect.

This order declares that Lake Ellesmere provides an outstanding wildlife habitat.

The order also includes various provisions to preserve and protect the wildlife habitat.

Issued under the authority of the Acts and Regulations Publication Act 1989.

Date of notification in *Gazette*: 5 July 1990.

This order is administered in the Ministry for the Environment.

Appendix II: Mean standing crop of submerged macrophytes growing in 1986-1987 in Lake Ellesmere. All values in g m-3; range in brackets. Overtons Bay with low water clarity; Taumutu with high water clarity. (Source: Gerbeaux & Ward, 1991).

	Overtons Bay 1986	Overtons Bay 1987	Taumutu 1986
Ruppia megacarpa	-	-	364 (200-500)
Ruppia polycarpa	6 (1-14)	8 (<1-30)	61 (8-107)
Lepilaena bilocularis	38 (<1-45)	13 (<1-33)	57 (25-89)
Potamogeton pectinatus	57 (2-176)	44 (28-73)	-
Lilaeopsis spp.	5 (1-12)	-	-
Mimulus repens	3 (<1-6)	5 (2-7)	-
Lamprothamnium papulosum	20 (<1-52)	8 (<1-18)	22 (3-77)
Chara globularis	-	13 (2-39)	-
Enteromorpha spp.	-	-	50 (1-120)
Myriophyllum spp.	-	6 (<1-16)	-

Appendix III: Above length and below length (mm) data per container; (n =4 plants per container); the symbol . = all dead.

light	salinity	5wk above	10wk above	20wk above	5wk below	10wk below	20 wk below
20	0	162	350	161	129	237	53
20	0	197	199	62	94	147	60
20	4	78	30	.	91	33	.
20	4	315	136	228	127	108	117
20	8	118	409	170	57	170	81
20	8	0	210	183	0	104	70
20	12	0	163	82	25	62	84
20	12	225	16	21	185	2	24
40	0	194	294	275	120	261	158
40	0	270	283	64	234	256	66
40	4	628	786	631	238	261	152
40	4	228	137	214	110	57	65
40	8	17	577	68	4	180	37
40	8	302	233	171	181	160	92
40	12	248	10	83	116	80	136
40	12	13	43	166	18	14	97
56	0	239	111	383	102	219	292
56	0	118	231	277	168	132	147
56	4	435	297	328	131	208	179
56	4	242	264	289	162	307	110
56	8	98	521	149	120	615	89
56	8	313	459	438	334	241	146
56	12	22	113	0	102	134	5
56	12	308	242	273	143	82	78
Mean (mm)	6	199	255	205	125	170	102
Variance	4	114	141	112	55	91	45

Appendix IV: raw data from exposure experiments.

light intensity u mol photons cm-2 S-1	salinity (ppt)	u mol O_2 h^{-1} mm^{-2}
dark	12	-0.001543
174	12	0.004095
dark	12	-0.002671
174	12	0.002892
197 (full light)	12	0.00581
dark	12	-0.001614
55	12	0.000553
dark	12	-0.004266
55	12	0.001199
111	12	0.003817
174	12	0.005675
197	12	0.005057
dark	0	-0.003476
55	0	0.003506
111	0	0.004888
174	0	0.006141
197	0	0.0079
dark	0	-0.002906
55	0	0.001961
111	0	0.004071
174	0	0.005391
197	0	0.005789
dark	0	-0.002387
55	0	0.002645
111	0	0.004188
174	0	0.005837
197	0	0.006923
dark	0	-0.002027
55	0	0.001749
111	0	0.003327
174	0	0.004382
197	0	0.008059
drk	0	-0.002338
dark	4	-0.005319
55	4	0.001635
111	4	0.006059
174	4	0.008514
197	4	0.008858
dark	4	-0.003485
55	4	0.001454
111	4	0.002156
174	4	0.005349
197	4	0.006781
dark	4	-0.002822
55	4	0.00183
111	4	0.00325
174	4	0.007083
197	4	0.00714
dark	4	-0.004204
55	4	0.001773

Cont'd

umol photons cm^{-2} S^{-1}	salinity (ppt)	umol O_2 $hour^{-1}$ mm^{-2}
111	4	0.003777
174	4	0.006062
197	4	0.007642
dark	8	-0.004063
55	8	0.000805
111	8	0.004766
174	8	0.005402
197	8	0.006715
dark	8	-0.003869
55	8	0.001139
111	8	0.004586
174	8	0.006481
197	8	0.007703

Appendix V: Mean data per site (quadrat) for habitat surveys 1998.
Key: site = transect No. + site where a = near shore, d = furthermost site.
P.p = *Potamogeton pectinatus* and *R.m* = *Ruppia megacarpa*

site	depth cm	salinity ppt	Susp. solids (mg L^{-1})	organic % of SS	plant sp.	Dry plant biomass (g m^{-3})	mean plant length mm	range mm + *n*
Summer								
1a	2	nm	220	54	*S. quinqueflora*	0.0009	33.50	24-51 n=6
1b	5	13.44	284	44	*Chara sp.*	0.0002	nm	
1b	5	13.44			*S. quinqueflora*	0.0001	32.00	n=1
1c	7.5	12.24	220	48	*P.p / R.m*	0.0005	14.40	7-20 n=5
1d	10	12.8	302	44	*S. quinqueflora*	0.0001	33.60	26-41 n=5
1d	10	12.8			*P.p / R.m*	0.0006	16.40	13-21 n=5
2a	30	19.68	263	52	*P.p / R.m*	0.0021	28.89	23-39 n=9
2b	31	18.24	533	38	*P.p / R.m*	0.0028	28.89	22-35 n=9
2c	30	17.28	353	38	*P.p / R.m*	0.0018	30.00	15-41 n=9
2d	32	16.72	317	45	*P.p / R.m*	0.0031	29.00	29-36 n=9
3a	33	15.44	530	32	*P.p / R.m*	0.0005	36.00	22-44 n=9
3b	23	18.4	420	43	*P.p / R.m*	0.0003	23.86	19-31 n=7
3c	22	17.6	507	39	*P.p / R.m*	0.0002	22.00	21-23 n=4
3d	29	17.12	510	40	*P.p / R.m*	0.0001	21.60	21-23 n=5
4a	18	14.88	573	55	*P.p / R.m*	0.0002	19.00	18-20 n=2
4b	20	15.28	483	30	*P.p / R.m*	0.0001	22.00	20-26 n=5
4c	24	15.92	470	52	*P.p / R.m*	0.0003	28.44	24-41 n=9
4d	27	16.24	400	29	*P.p / R.m*	0.0007	27.44	23-34 n=9
		Autumn						
1a	14	11.2	153	57	*J. articulatus*	0.0001	35.33	34-41 n=6
1a	14	11.2			*Chara sp.*	0.0002	nm	
1b	20	16.0			*Juncus articulat*	0.0001	nm	
1b	20	16.0	203	39	*Chara sp.*	0.0003	nm	
1c	25	20.0			*Chara sp.*	0.0003	nm	
1c	25	20.0	150	52	*J. articulatus*	0.0001	33.63	26-45 n=8
1c	25	20.0			*P.p / R.m*	nm	15.3	15-16 n=3
1d	27	21.6	138	51	*P.p / R.m*	0.0001	22.5	18-35 n=8
1d	27	21.6			*J. articulatus*	0.0001	31.8	26-43 n=8
1d	27	21.6			*Chara sp.*	0.0004	nm	
2a	36	28.8	183	44	*P.p / R.m*	0.0014	22.8	17-26 n=8
2a	36	28.8			*J. articulatus*	0.0001	nm	
2b	37	29.6	203	31	*P.p / R.m*	0.0014	24.4	20-31 n=8
2b	37	29.6			*J. articulatus*	0.0001	nm	
2c	40	32.0	180	49	*P.p / R.m*	0.0006	24.6	18-32 n=8
2d	42	33.6			*P.p / R.m*	0.0006	21.0	14-33 n=8
2d	42	33.6	235	40	*J. articulatus*	0.0000	nm	
2d	42	33.6			*Chara sp.*	nm	nm	
3a	44	35.2	288	25	*P.p / R.m*	nm	nm	
3b	39	31.2	218	34	*P.p / R.m*	0.0001	16.9	14-22 n=8
3c	38	30.4	160	39	*P.p / R.m*	0.0001	18.4	14-26 n=8
3c	38	30.4			*Chara sp.*	nm	nm	
3d	40	32.0	165	44	*P.p / R.m*	0.0001	nm	
4a	23	18.4	290	29	*P.p / R.m*	0.0003	14.6	13-17 n=8
4b	27	21.6	318	25	*P.p / R.m*	0.0001	13.3	11-16 n=8
4b	27	21.6			*Chara sp.*	nm	nm	
4c	31	24.8	343	28	*P.p / R.m*	0.0002	19.8	11-26 n=8
4d	36	28.8	190	43	*P.p / R.m*	0.0006	nm	

Appendix V cont'd.

site	depth cm	salinity ppt	Susp. solids (mg L^{-1})	organic % of SS	plant sp.	dry plant biomass (g m^{-3})	mean plant length mm	range mm + *n*
	Winter							
1a	2	nm			*J. articulatus*	nm	nm	
1a			1032	21	*Chara sp.*	nm	nm	
1b	8	nm	564	24	*J. articulatus*	nm	nm	
1b		nm			*Chara sp.*	nm	nm	
1c	12	nm	580	28	*R. megacarpa*	0.0000	14.375	2-17 *n* =24
1d	18	nm	520	27	*Chara sp.*	0.0001	nm	
2a	38	nm	636	21	*R. megacarpa*	0.0001	21.3	2-38 *n* =63
2a					*J. articulatus*	0.0001	28.2	18-35 *n* =5
2a					dead mac's	0.0005		
2b	40	nm	772	16	*R. megacarpa*	0.0000	21.1	1-28 *n=24*
2b					*J. articulatus*	0.0001	36.6	24-51 *n* =5
2b					dead mac's	0.0001		
2c	40	nm	752	19	*R. megacarpa*	0.0000	16.7	8-20 *n* =17
2c					dead mac's	0.0007		
2d	41	nm	500	25	*R. megacarpa*	0.0000	19.1	12-29 *n* =9
2d					dead mac's	0.0008		
3a	50	nm	717	18	*R. megacarpa*	0.0000	19.4	2-30 *n* =21
3a					*P. pectinatus*		1 tuber only	
3b	40	nm	660	21	*R. megacarpa*	0.0000	26.125	1-33 *n* =31
3b					*P. pectinatus*		1 tuber only	
3c	40	nm	570	23	*R. megacarpa*	0.0000	22.4	8-30 *n* =20
3d	45	nm	697	17	*R. megacarpa*	0.0000	7.0	*n*= 1
4a	26	9.5	773	17	*R. megacarpa*	0.0002	17.1	4-24 *n* =38
4a					*P. pectinatus*	0.0000	nm	*n* =4
4a					dead mac's	0.0010	nm	
4b	30	9.5	1060	14	*R. megacarpa*	0.0000	20.4	4-25 *n* =16
4b					*P. pectinatus*	nm	nm	*n* =2
4b					dead mac's	0.0005	nm	
4c	32.5	9.5	910	17	*R. megacarpa*	0.0000	16.8	1-24 *n* =42
4c					*P. pectinatus*	nm	nm	*n* =2
4d	32.5	9.5	940	18	*R. megacarpa*	0.0000	19.1	3-24 *n* =12
4d					unid. mac's	0.0003	nm	
Summer (2)								
2a	3	7.9	80	58	unid. mac's	nm	nm	
2b	4	7.5	81	38	*R. megacarpa*	nm	19.5	12-29 n=4
2b					unid. mac's	0.0003	29.1	14-52 n=10
2c	5	7.4	107	41	*R. megacarpa*	nm	13.5	7-19 n=4
2d	7	8.2	166	35	nm			
3a	7	1.9	78	30	nm			
3b	8	1.8	100	23	*P. pectinatus*	nm	nm	n=1
3c	7	2.0	68	23	*P. pectinatus*	nm	14.7	*12-19 n=3*
3d	9	6.0	200	24	nm	nm	nm	

Appendix V (continued)

Light readings taken summer 1998 (28/02/1998)

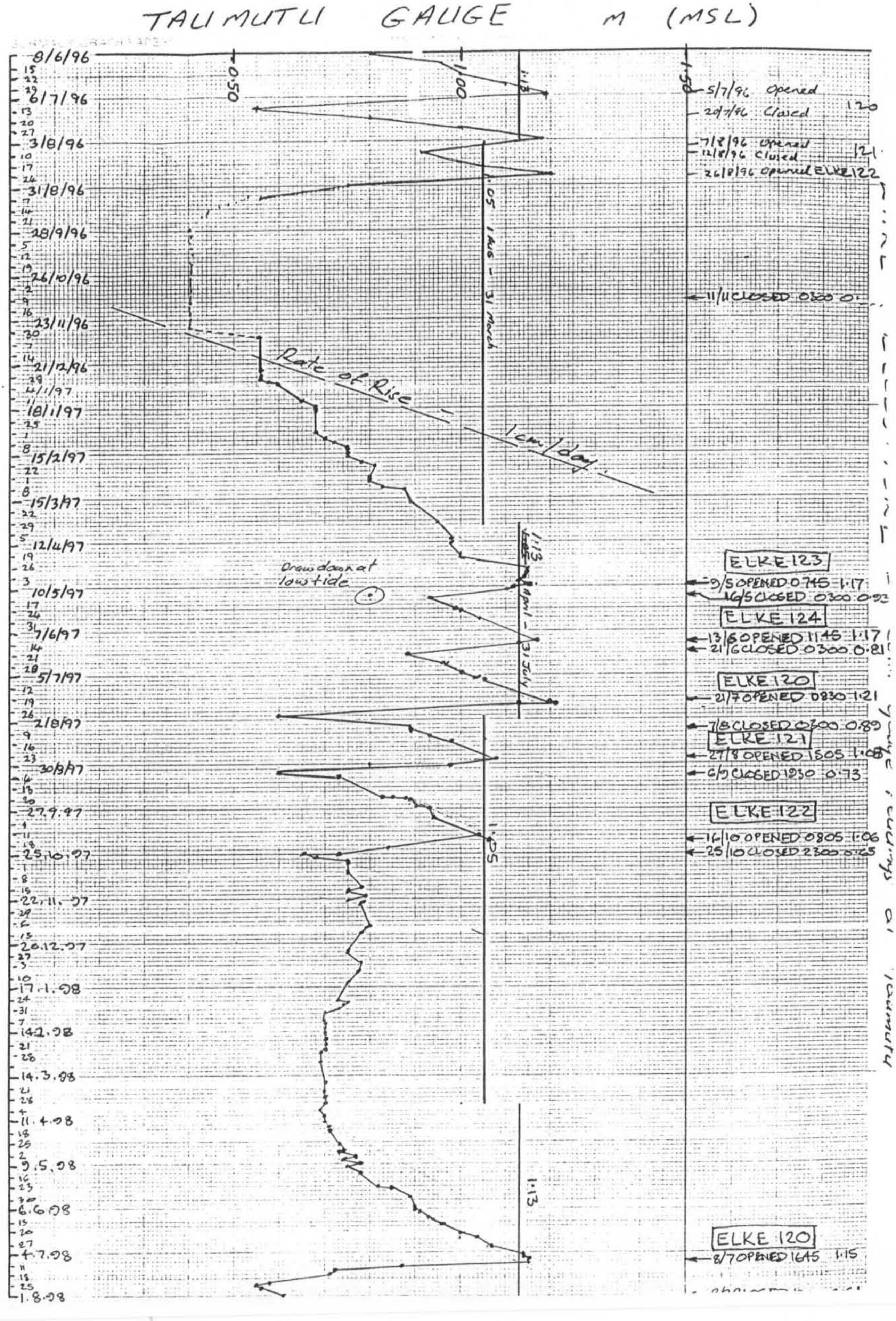
Just above surface	bottom of lake bed	light at bottom of lake bed	depth
u mol photons per cm^2	*u* mol photons per cm^2	as a % of surface	cm
2524	22.6	1	30
2444	7.8	0	31
1674	13.4	1	30
1779	13.9	1	32
2094	18.4	1	33
2210	68.1	3	22
2324	26.4	1	29
2604	43.4	2	18
2458	83	3	20
2351	68.7	3	24
2224	32	1	27

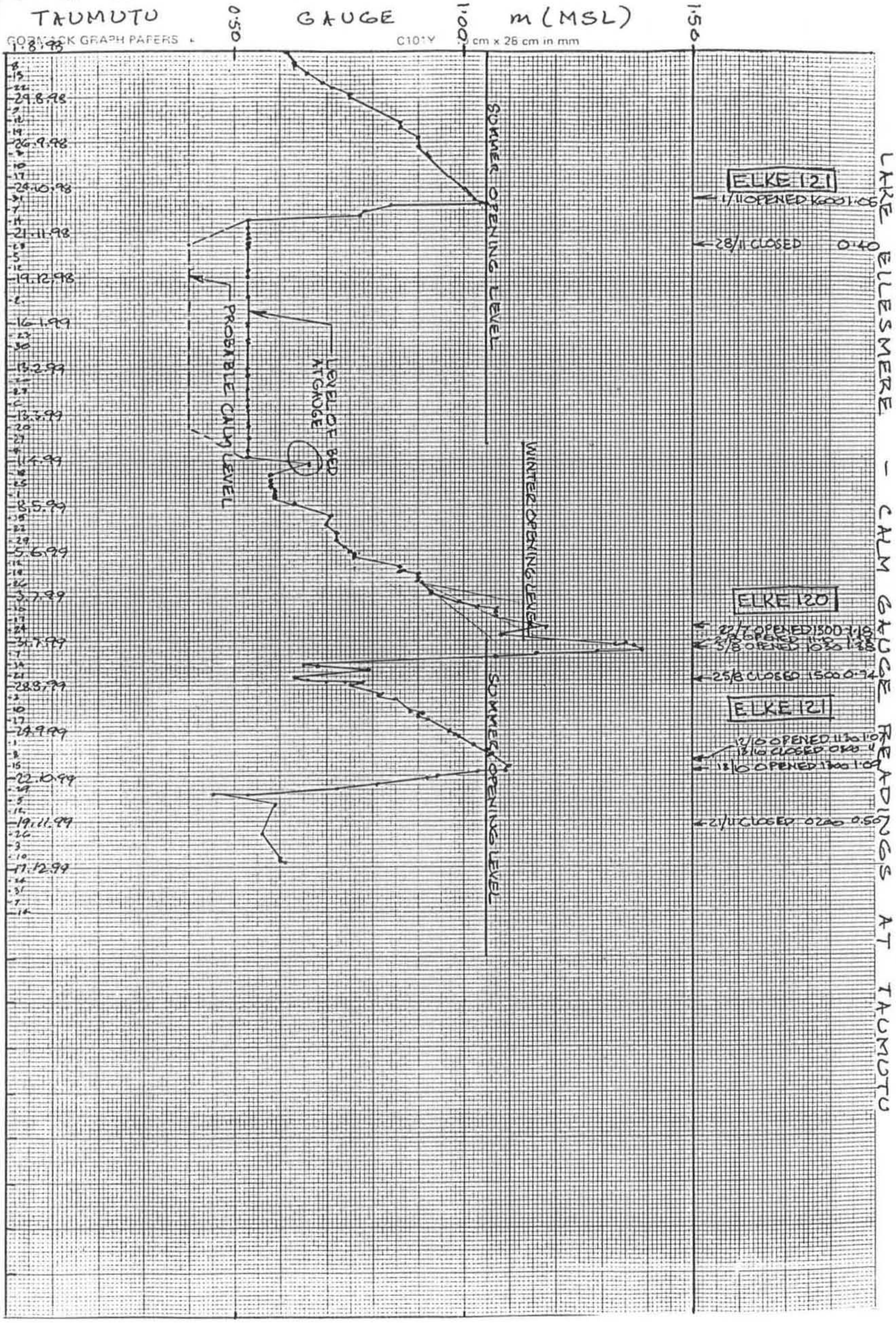
NB: some readings, obviously skewed by wave action, were removed.

Appendix VI: Lake Ellesmere (Te Waihora) Physio-chemical data from August 1997 to September 1998. Source: Canterbury Regional Council.

SITE NO	SAMPLE	DATE	TIME	TEMP 'C	SAL 0/00	CHL mg/m3
Lake Ellesmere			south of Timber Yard Point			
300953	CRC971836	970805	1245	6.5	5.7	121.8
300953	CRC971852	970917	1215	10.3	6.0	129.2
300953	CRC972856	971014	1020	14.5	5.3	95.2
300953	CRC972722	971118	1030	14.0	5.8	51.8
300953	CRC973197	971210	1045	17.3	6.1	108.5
300953	CRC985050	980106	1020	19.2	6.2	88.9
300953	CRC985931	980217	1015	22.6	7	87.1
300953	CRC986258	980316	1000	14	6.5	79.9
300953	CRC986443	980407	1100	12.7	6.2	104.7
300953	CRC986766	980511	1100	11.7	5.2	97.3
300953	CRC987416	980716	1055	6.2	3.9	103.9
300953	CRC987562	980810	1215	6.6	5.2	85.2
300953	CRC987921	980917	1145	12.5	5.0	91.1
Lake Ellesmere			mid lake			
300954	CRC971834	970805	1155	6.2	6.9	125.8
300954	CRC971850	970917	1135	10.9	5.5	132.4
300954	CRC972854	971014	0935	14.4	5.0	90.5
300954	CRC972720	971118	0945	14.4	5.2	61.9
300954	CRC973195	971210	1000	17.1	5.5	93.1
300954	CRC985048	980106	0930	19.3	6.2	99.7
300954	CRC985929	980217	0855	22.1	6	78.8
300954	CRC986256	980316	0905	13.0	5	77.3
300954	CRC986441	980407	1000	12.3	6.0	112.2
300954	CRC986764	980511	1000	11.7	5.2	49.9
300954	CRC986961	980608	1100	6.9	5.0	66.3
300954	CRC987414	980716	1010	6.6	3.2	97.8
300954	CRC987560	980810	1130	6.4	4.4	107.6
300954	CRC987919	980917	1100	12.0	4.4	104.7
Lake Ellesmere			off Selwyn R mouth			
300955	CRC971835	970805	1215	6.1	5.7	96.5
300955	CRC971851	970917	1200	10.6	5.0	59.4
300955	CRC972855	971014	1000	15.0	5.0	72.1
300955	CRC972721	971118	1010	14.3	5.8	51.9
300955	CRC973196	971210	1025	17.0	6.3	98.9
300955	CRC985049	980106	0955	19.2	6.0	96.8
300955	CRC985930	980217	0945	21.9	7	90.1
300955	CRC986257	980316	1015	13.5	6.0	82.2
300955	CRC986442	980407	1030	12.0	6.0	92.7
300955	CRC986765	980511	1030	11.5	5.5	99.6
300955	CRC986962	980608	*	*	*	*
300955	CRC987417	980716	1115	6.5	4.0	120.0
300955	CRC987561	980810	1200	6.7	5.0	118.8
300955	CRC987920	980917	1115	12.5	5.0	111.8
Lake Ellesmere			at Taumutu (at gauge)			
300956	CRC971837	970805	1315	6.2	18.9	137.7
300956	CRC971988	970819	1300	*	*	*
300956	CRC971853	970917	1235	10.6	7.3	125.6
300956	CRC972857	971014	1040	14.0	4.8	94.2
300956	CRC972723	971118	1100	13.8	6.0	57.9
300956	CRC973198	971210	1110	17.6	5.9	105.9
300956	CRC985052	980105	1015	*	*	*
300956	CRC985051	980106	1045	18.7	6.7	68.0
300956	CRC985932	980217	1045	22.5	7.5	94.9
300956	CRC986259	980316	0940	11.5	5.2	91.6

Appendix VII: Lake level and opening data from 9/6/1996-19/11/1999 at the Taumutu monitoring station. Source: Canterbury Regional Council.





TAUMUTU GAUGE m (MSL)
0.50
1.00
1.50
CORMACK GRAPH PAPERS
C101Y
cm x 26 cm in mm
1.8.98
29.8.98
26.9.98
24.10.98
21.11.98
19.12.98
16.1.99
13.2.99
13.3.99
11.4.99
8.5.99
5.6.99
3.7.99
31.7.99
28.8.99
24.9.99
22.10.99
19.11.99
17.12.99
SUMMER OPENING LEVEL
WINTER OPENING LEVEL
PROBABLE CALM LEVEL
LEVEL OF BED AT GAUGE
ELKE 121
1/11 OPENED 1600 1.05
28/11 CLOSED 0.40
ELKE 120
22/7 OPENED 1300 1.18
3/8 OPENED 1030 1.38
25/8 CLOSED 1500 0.94
ELKE 121
18/10 OPENED 1300 1.09
21/11 CLOSED 0200 0.50
LAKE ELLESMERE - CALM GAUGE READINGS AT TAUMUTU

Appendix VIII: weather data at Lincoln - September - November 1998 (note: 2 pages state same date - 10th month, whereas the page with "p12" at the top is 10th and the one with "p13" at the top is actually from the 11th month). Source: Lincoln University Climate Research Unit Publication.

Weather Summary analysis for Lincoln, September 1998

Date	Rain mm	Max °C	Min °C	Mean °C	Grass °C	Sol MJ/m²	Wind km	VP mb	Pen mm	Smoist mm	Therm °C-d	S10 °C	S30 °C	S100 °C
1 9 98	0.0	12.4	0.3	5.9	-2.4	14.3	172.1	8.6	1.8	49.2	5.9	6.5	6.8	8.3
2 9 98	3.5	13.5	3.7	8.2	1.6	12.2	343.6	9.2	2.0	50.7	14.1	8.1	7.5	8.3
3 9 98	8.2	7.5	5.2	6.1	2.1	4.3	469.5	7.8	1.2	57.7	20.2	6.6	7.6	8.3
4 9 98	5.0	8.1	2.7	5.3	1.1	8.7	274.5	7.8	1.3	61.4	25.5	6.3	7.0	8.4
5 9 98	0.0	11.3	1.9	7.4	-0.3	15.7	334.7	8.6	2.5	58.9	32.9	7.7	7.2	8.4
6 9 98	1.5	12.8	5.7	8.9	4.4	13.4	286.7	9.3	2.3	58.1	41.8	8.7	8.0	8.3
7 9 98	0.0	16.8	2.9	9.4	0.4	12.4	326.7	8.3	2.7	55.4	51.2	7.8	8.0	8.4
8 9 98	0.0	16.5	1.8	8.2	-0.8	16.5	342.0	7.8	3.1	52.3	59.4	8.0	8.0	8.5
9 9 98	0.0	11.4	0.2	6.8	-2.1	16.8	284.2	7.5	2.7	49.6	66.2	8.0	8.1	8.6
10 9 98	0.0	18.2	3.4	9.8	1.0	15.4	242.7	8.0	3.0	46.6	76.0	8.3	8.1	8.6
11 9 98	0.0	13.0	0.2	6.5	-1.1	15.8	158.1	8.2	2.2	44.4	82.5	7.8	8.1	8.7
12 9 98	0.0	12.6	0.2	6.3	-1.8	17.3	252.2	8.1	2.5	41.9	88.8	7.9	8.1	8.7
13 9 98	0.0	15.4	0.8	6.8	-2.1	15.5	283.7	8.6	2.2	39.7	95.6	8.3	8.2	8.8
14 9 98	0.0	18.9	3.4	11.6	1.0	18.0	421.7	8.5	4.2	35.5	107.2	9.3	8.6	8.8
15 9 98	0.0	21.7	10.2	16.8	10.3	13.6	512.1	9.7	5.1	30.4	124.0	11.7	9.6	8.8
16 9 98	0.0	22.3	12.0	13.2	9.0	12.1	332.9	10.7	2.9	27.5	137.2	12.0	10.4	8.9
17 9 98	0.0	11.2	4.8	8.1	1.9	10.5	126.9	9.7	1.5	26.0	145.3	10.3	10.1	9.1
18 9 98	0.0	15.4	5.5	9.8	4.2	17.9	341.6	9.5	3.1	22.9	155.1	10.6	10.0	9.3
19 9 98	0.0	22.5	4.4	12.4	1.3	19.3	251.2	10.5	3.6	19.3	167.5	11.3	10.1	9.4
20 9 98	0.8	15.8	4.3	11.3	2.4	18.2	344.9	10.7	3.3	16.8	178.8	11.4	10.6	9.6
21 9 98	0.0	16.0	6.2	10.4	3.4	19.9	213.8	10.1	3.2	13.6	189.2	12.0	10.9	9.7
22 9 98	0.0	17.6	2.0	9.2	-0.2	20.8	169.2	9.0	3.2	10.4	198.4	11.1	10.7	9.8
23 9 98	0.0	14.5	1.7	8.9	-0.9	19.4	422.2	9.8	3.1	7.3	207.3	10.5	10.6	9.9
24 9 98	0.0	16.8	8.3	13.5	5.5	5.6	714.0	9.7	3.5	3.8	220.8	10.4	10.5	10.0
25 9 98	0.3	10.7	8.5	9.6	8.5	6.4	289.5	9.5	1.5	2.6	230.4	10.3	10.4	10.1
26 9 98	0.0	12.7	7.6	9.4	7.4	2.9	296.5	10.5	0.7	1.9	239.8	9.7	10.1	10.2
27 9 98	0.0	13.1	8.7	10.7	9.0	9.5	316.8	10.5	1.9	0.0	250.5	10.8	10.2	10.2
28 9 98	0.0	16.2	5.9	10.5	4.4	20.9	432.9	9.4	3.9	0.0	261.0	11.8	10.6	10.2
29 9 98	0.0	19.5	8.9	12.9	7.2	22.7	318.5	10.1	4.5	0.0	273.9	12.6	11.2	10.2
30 9 98	0.0	24.0	6.7	16.1	2.0	22.9	394.2	7.6	6.4	0.0	290.0	13.1	11.5	10.3
Totals and Means	19.3	15.3	4.6	9.7	2.5	438.9	9669.6	9.1	85.2	0.0	290.0	9.6	9.2	9.2

Rainfall	19.3 mm	Maximum	15.3 °C	Highest Daily Max.	24.0 °C on 30 Sep
Solar Radiation	438.9 MJ/m²	Mean	9.7 °C	Lowest Daily Mean	5.3 °C on 4 Sep
Wind Run	9669.6 km	Minimum	4.6 °C	Lowest Daily Min.	0.2 °C on 11 & 12 Sep
Penman	85.2 mm	Grass Minimum	2.5 °C	Lowest Grass Min.	-2.4 °C on 1 Sep
Deficit Days	4	Mean Wind Run	322.3 km/dy	No. of Ground Frosts	5
Temperature Sum	290.0 Day °C	Mean VP	9.1 mb	No. of Screen Frosts	0
No. of Rain Days (P>0)	6	No. of Wet Days (P>=1)	4	Highest Daily Rain	8.2 mm on 3 Sep

Wind Direction Summary:

NW	N	NE	E	SE	S	SW	W	Calm
16.3	27.5	12.9	1.7	7.6	12.8	10.8	10.1	0.3

North 56.7% South 31.3%

Weather Summary Analysis for Lincoln, October 1998

Date			Rain mm	Max °C	Min °C	Mean °C	Grass °C	Sol MJ/m²	Wind km	VP mb	Pen mm	Smoist mm	Therm °C-d	S10 °C	S30 °C	S100 °C
1	10	98	2.7	16.8	5.6	12.3	3.1	19.1	335.7	9.1	4.1	0.0	12.3	13.6	12.2	10.4
2	10	98	14.6	10.5	9.3	9.7	7.4	3.5	245.5	9.7	1.0	13.6	22.0	11.5	11.9	10.6
3	10	98	0.2	14.0	5.0	8.6	4.8	22.7	273.4	8.6	3.6	10.2	30.6	11.4	11.2	10.7
4	10	98	0.2	19.2	6.4	11.8	3.9	23.4	348.2	9.2	4.6	5.8	42.4	11.7	11.3	10.7
5	10	98	3.4	18.7	6.9	11.2	3.8	16.9	254.5	9.0	3.4	5.8	53.6	11.6	11.4	10.8
6	10	98	0.0	17.0	3.2	10.5	1.9	22.7	430.8	9.2	4.3	1.5	64.1	11.6	11.3	10.8
7	10	98	0.0	19.1	7.8	14.7	7.6	9.8	539.9	9.9	3.9	0.0	78.8	11.5	11.5	10.9
8	10	98	0.0	25.0	13.8	17.1	12.9	16.8	371.1	13.0	4.2	0.0	95.9	14.1	11.9	10.9
9	10	98	0.0	12.5	9.3	10.9	8.3	9.8	192.4	11.9	1.5	0.0	106.8	13.5	12.7	11.0
10	10	98	0.0	13.6	8.6	10.3	8.0	17.0	250.0	11.4	2.5	0.0	117.1	13.9	12.6	11.1
11	10	98	3.5	12.3	8.3	9.9	8.2	10.5	298.4	10.7	1.8	1.7	127.0	13.0	12.7	11.2
12	10	98	8.6	14.1	9.0	11.5	8.9	9.1	318.9	12.5	1.5	8.8	138.5	12.5	12.4	11.4
13	10	98	0.7	15.5	10.4	12.3	10.1	12.2	179.2	13.0	1.9	7.6	150.8	13.6	12.6	11.4
14	10	98	0.5	20.8	7.6	14.2	4.7	24.6	328.6	10.1	5.2	2.7	165.0	14.3	13.0	11.5
15	10	98	0.3	13.8	8.2	10.7	7.3	9.1	302.3	11.5	1.6	1.4	175.7	13.3	13.1	11.6
16	10	98	12.4	13.7	8.4	9.6	7.8	12.5	169.6	9.8	2.1	12.7	185.3	12.6	12.7	11.7
17	10	98	0.0	16.7	1.9	9.6	0.2	24.3	265.4	9.1	3.9	8.8	194.9	12.0	12.3	11.8
18	10	98	0.0	21.4	4.4	14.1	2.3	26.4	607.3	8.0	7.1	1.7	209.0	13.0	12.4	11.8
19	10	98	0.0	19.1	11.7	15.1	7.5	15.6	505.9	9.8	4.8	0.0	224.1	13.2	12.8	11.9
20	10	98	0.3	16.4	4.6	11.9	1.1	16.8	454.8	8.2	4.3	0.0	236.0	12.1	12.5	11.9
21	10	98	0.0	18.5	4.9	11.0	3.1	27.0	420.3	8.8	5.1	0.0	247.0	13.3	12.5	11.9
22	10	98	1.2	13.3	4.0	8.8	1.5	21.5	307.3	8.1	3.7	0.0	255.8	12.1	12.5	12.0
23	10	98	0.2	17.7	3.0	8.1	1.0	26.9	381.4	7.7	4.5	0.0	263.9	11.8	12.1	12.0
24	10	98	0.0	15.2	2.2	9.3	-0.5	24.8	336.5	7.7	4.5	0.0	273.2	11.6	11.9	12.0
25	10	98	0.0	18.5	6.0	13.8	2.4	10.8	492.3	8.4	4.1	0.0	287.0	11.4	11.9	12.0
26	10	98	0.0	20.5	15.2	17.1	11.7	7.6	405.7	10.4	3.6	0.0	304.1	12.6	12.1	11.9
27	10	98	5.7	27.7	14.8	19.1	12.6	24.2	377.0	12.8	6.1	0.0	323.2	15.9	12.9	11.9
28	10	98	1.7	13.1	11.1	11.8	10.9	6.1	292.1	12.9	1.0	0.7	335.0	14.6	14.0	11.9
29	10	98	0.3	21.2	10.6	14.7	9.8	22.9	222.0	12.4	4.3	0.0	349.7	15.4	13.7	12.0
30	10	98	0.7	16.1	10.0	11.4	9.2	13.7	312.5	11.8	2.3	0.0	361.1	14.5	14.1	12.1
31	10	98	0.0	13.4	8.7	10.1	8.2	15.1	171.0	10.2	2.4	0.0	371.2	13.7	13.5	12.3
Totals and Means			57.2	16.9	7.8	12.0	6.1	523.4	10390.0	10.2	108.9	0.0	371.2	12.9	12.4	11.5

Rainfall	57.2 mm	Maximum	16.9 °C	Highest Daily Max.	27.7 °C on 27 Oct
Solar Radiation	523.4 MJ/m²	Mean	12.0 °C	Lowest Daily Mean	8.1 °C on 23 Oct
Wind Run	10390.0 km	Minimum	7.8 °C	Lowest Daily Min.	1.9 °C on 17 Oct
Penman	108.9 mm	Grass Minimum	6.1 °C	Lowest Grass Min.	-0.5 °C on 24 Oct
Deficit Days	17	Mean Wind Run	335.2 km/dy	No. of Ground Frosts	0
Temperature Sum	371.2 Day °C	Mean VP	10.2 mb	No. of Screen Frosts	0
No. of Rain Days (P>0)	18	No. of Wet Days (P>=1)	9	Highest Daily Rain	14.6 mm on 2 Oct

Wind Direction Summary:

NW	N	NE	E	SE	S	SW	W	Calm
17.1	16.0	14.9	1.7	6.6	18.8	9.9	14.8	0.1

North 48.0% South 35.3%

Weather Summary Analysis for Lincoln, November 1998

Date	Rain mm	Max °C	Min °C	Mean °C	Grass °C	Sol MJ/m²	Wind km	VP mb	Pen mm	Smoist mm	Therm °C-d	S10 °C	S30 °C	S100 °C
1 10 98	0.0	12.0	8.3	9.5	8.1	10.2	187.8	10.1	1.7	0.0	9.5	13.0	13.3	12.3
2 10 98	0.0	12.6	6.3	9.5	3.5	15.8	230.1	9.4	2.6	0.0	19.0	12.5	12.9	12.4
3 10 98	0.3	12.4	6.8	9.7	4.8	7.1	122.4	10.5	1.2	0.0	28.7	12.3	12.8	12.5
4 10 98	0.3	15.0	5.3	10.1	3.4	24.3	137.1	9.8	3.7	0.0	38.8	13.7	12.7	12.5
5 10 98	0.0	19.1	7.8	12.9	5.8	27.3	372.6	11.1	5.0	0.0	51.7	16.0	13.9	12.5
6 10 98	0.8	24.6	11.1	16.4	8.3	13.2	401.3	10.4	4.3	0.0	68.1	14.7	14.4	12.5
7 10 98	0.0	16.7	8.1	12.4	6.0	20.5	316.0	11.5	3.6	0.0	80.5	15.6	14.3	12.7
8 10 98	0.0	16.0	8.1	12.3	5.6	27.1	635.9	11.3	5.1	0.0	92.8	15.2	14.6	12.7
9 10 98	0.2	24.0	10.7	15.8	7.8	14.9	230.9	12.4	3.3	0.0	108.6	15.8	14.7	12.8
10 10 98	0.0	19.2	7.0	12.9	5.3	27.8	261.0	11.6	4.7	0.0	121.5	17.4	15.3	13.0
11 10 98	0.0	16.1	7.2	12.3	3.3	27.9	510.6	11.2	5.0	0.0	133.8	16.4	15.6	13.1
12 10 98	1.2	21.7	6.5	13.6	4.5	17.1	344.2	11.2	3.6	0.0	147.4	16.3	15.5	13.2
13 10 98	0.2	14.0	7.5	10.0	7.0	23.4	171.3	9.4	3.7	0.0	157.4	15.5	15.2	13.4
14 10 98	0.0	16.1	2.3	10.5	0.9	28.7	483.4	9.6	5.0	0.0	167.9	15.8	15.1	13.5
15 10 98	0.0	16.2	9.1	12.6	6.8	28.8	791.0	11.2	5.8	0.0	180.5	15.8	15.3	13.5
16 10 98	0.0	19.3	11.6	14.8	9.9	29.6	363.3	12.8	5.5	0.0	195.3	17.2	15.6	13.6
17 10 98	0.0	22.1	5.0	14.9	3.0	29.5	206.6	11.2	5.5	0.0	210.2	18.5	16.3	13.6
18 10 98	0.0	23.6	8.6	15.5	6.4	26.9	279.2	13.5	5.0	0.0	225.7	20.2	17.3	13.7
19 10 98	5.4	16.6	10.9	12.6	9.8	13.6	394.3	12.4	2.6	1.8	238.3	18.1	17.7	13.9
20 10 98	0.0	13.6	8.5	10.4	8.1	14.1	199.8	10.6	2.3	0.0	248.7	15.1	16.2	14.1
21 10 98	0.0	16.4	8.5	12.2	6.8	24.6	289.2	10.5	4.4	0.0	260.9	15.8	15.5	14.3
22 10 98	0.0	14.8	9.8	11.9	9.5	17.8	401.4	10.7	3.5	0.0	272.8	16.0	15.8	14.2
23 10 98	1.0	20.5	10.7	12.1	9.6	13.7	237.7	11.5	2.5	0.0	284.9	15.2	15.6	14.2
24 10 98	3.0	17.9	2.8	11.3	1.7	29.1	286.9	10.4	4.8	0.0	296.2	15.7	15.1	14.3
25 10 98	5.0	13.7	9.5	10.4	8.3	16.8	245.2	10.6	2.7	2.3	306.6	15.0	15.5	14.2
26 10 98	0.3	11.3	7.5	8.9	6.8	15.6	183.6	8.9	2.5	0.1	315.5	13.2	14.6	14.3
27 10 98	0.0	15.2	6.2	9.7	6.2	21.6	164.8	9.0	3.4	0.0	325.2	14.2	14.1	14.2
28 10 98	0.0	14.5	2.0	9.9	-0.4	31.5	600.2	9.0	5.6	0.0	335.1	14.1	14.3	14.2
29 10 98	2.4	15.7	11.0	13.5	9.5	14.5	730.0	11.8	3.8	0.0	348.6	14.5	14.7	14.1
30 10 98	0.2	20.9	13.1	15.7	12.3	22.1	260.3	15.2	3.9	0.0	364.3	17.1	15.0	14.1
Totals and Means	20.3	17.1	7.9	12.1	6.3	635.1	10038.1	11.0	116.3	0.0	364.3	15.5	15.0	13.5

Rainfall	20.3 mm	Maximum	20.3 °C	Highest Daily Max.	24.6 °C on 6 Nov
Solar Radiation	635.1 MJ/m²	Mean	12.1 °C	Highest Daily Mean	16.4 °C on 6 Nov
Wind Run	10038.1 km	Minimum	7.9 °C	Lowest Daily Min.	2.0 °C on 28 Nov
Penman	116.3 mm	Grass Minimum	6.3 °C	Lowest Grass Min.	-0.4 °C on 28 Nov
Deficit Days	27	Mean Wind Run	334.6 km/dy	No. of Ground Frosts	0
Temperature Sum	364.3 Day °C	Mean VP	11.0 mb	No. of Screen Frosts	0
No. of Rain Days (P>0)	13	No. of Wet Days (P>=1)	5	Highest Daily Rain	5.0 mm on 25 Nov

Wind Direction Summary:

NW	N	NE	E	SE	S	SW	W	Calm
6.9	18.3	35.0	2.6	10.1	15.8	6.4	3.9	0.8

North 60.3% South 32.4%

Appendix IX: ANOVA Tables for salinity and light growth experiment data used in figures 4.2 and 4.3; (LL = length above ground; LB = length below ground; WK = weeks in treatment).

```
LEVELS ENCOUNTERED DURING PROCESSING ARE:

 BLK

        1.000        2.000
 SALINITY
        0.000        4.000        8.000        12.000
 LIGHT
       20.000       40.000       56.000
     1 CASES DELETED DUE TO MISSING DATA.
```

DEP VAR: LL5WK N:23 MULTIPLE R: .583 SQUARED MULTIPLE R: .340

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.313	1	0.313	1.089	0.321
SALINITY	0.202	3	0.067	0.234	0.871
LIGHT	0.590	2	0.295	1.026	0.393
LIGHT *SALINITY	0.462	6	0.077	0.268	0.940
ERROR	2.874	10	0.287		

DEP VAR: LA5WK N:24 MULTIPLE R: .596 SQUARED MULTIPLE R: .355

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.861	1	0.861	0.716	0.415
SALINITY	4.480	3	1.493	1.242	0.341
LIGHT	0.777	2	0.389	0.323	0.730
LIGHT *SALINITY	1.654	6	0.276	0.229	0.958
ERROR	13.221	11	1.202		

DEP VAR: LB5WK N:23 MULTIPLE R: .642 SQUARED MULTIPLE R: .412

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.023	1	0.023	0.024	0.881
SALINITY	2.998	3	0.999	1.006	0.430
LIGHT	0.926	2	0.463	0.466	0.641
LIGHT *SALINITY	1.925	6	0.321	0.323	0.910
ERROR	9.935	10	0.993		

DEP VAR: LL11WK N:23 MULTIPLE R: .882 SQUARED MULTIPLE R: .778

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.011	1	0.011	0.082	0.780
SALINITY	1.809	3	0.603	4.482	0.031
LIGHT	1.099	2	0.549	4.083	0.051
LIGHT *SALINITY	2.008	6	0.335	2.487	0.097
ERROR	1.345	10	0.135		

DEP VAR: LA10WK N:23 MULTIPLE R: .829 SQUARED MULTIPLE R: .687

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.316	1	0.316	0.739	0.410
SALINITY	5.290	3	1.763	4.122	0.038
LIGHT	0.586	2	0.293	0.685	0.526
LIGHT *SALINITY	3.506	6	0.584	1.366	0.316
ERROR	4.278	10	0.428		

DEP VAR: LB11WK N:23 MULTIPLE R: .880 SQUARED MULTIPLE R: .774

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	1.552	1	1.552	5.275	0.045
SALINITY	6.041	3	2.014	6.845	0.009
LIGHT	1.785	2	0.893	3.035	0.093
LIGHT *SALINITY	1.281	6	0.214	0.726	0.639
ERROR	2.942	10	0.294		

DEP VAR: LL20WK N:23 MULTIPLE R: .798 SQUARED MULTIPLE R: .638

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.233	1	0.233	0.982	0.345
SALINITY	1.736	3	0.579	2.443	0.124
LIGHT	0.302	2	0.151	0.637	0.549
LIGHT *SALINITY	1.334	6	0.222	0.938	0.509
ERROR	2.369	10	0.237		

DEP VAR: LA20WK N:23 MULTIPLE R: .705 SQUARED MULTIPLE R: .497

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.262	1	0.262	0.236	0.638
SALINITY	6.335	3	2.112	1.901	0.193
LIGHT	0.129	2	0.065	0.058	0.944
LIGHT *SALINITY	4.207	6	0.701	0.631	0.704
ERROR	11.107	10	1.111		

DEP VAR: LB20WK N:23 MULTIPLE R: .817 SQUARED MULTIPLE R: .667

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
BLK	0.259	1	0.259	1.030	0.334
SALINITY	0.987	3	0.329	1.307	0.326
LIGHT	0.079	2	0.040	0.158	0.856
LIGHT *SALINITY	4.079	6	0.680	2.701	0.080
ERROR	2.517	10	0.252		

DEP VAR: LL5WK N:23 MULTIPLE R: .517 SQUARED MULTIPLE R: .268

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	0.155	3	0.052	0.178	0.909
LIGHT	0.590	2	0.295	1.018	0.393
LIGHT *SALINITY	0.407	6	0.068	0.234	0.956
ERROR	3.187	11	0.290		

DEP VAR: LA5WK N:24 MULTIPLE R: .559 SQUARED MULTIPLE R: .313

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	4.418	3	1.473	1.255	0.333
LIGHT	0.777	2	0.389	0.331	0.724
LIGHT *SALINITY	1.220	6	0.203	0.173	0.979
ERROR	14.082	12	1.173		

DEP VAR: LB5WK N:23 MULTIPLE R: .641 SQUARED MULTIPLE R: .410

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	3.063	3	1.021	1.128	0.380
LIGHT	0.926	2	0.463	0.511	0.613
LIGHT *SALINITY	1.903	6	0.317	0.350	0.895
ERROR	9.958	11	0.905		

DEP VAR: LL11WK N:23 MULTIPLE R: .881 SQUARED MULTIPLE R: .776

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	1.818	3	0.606	4.913	0.021
LIGHT	1.099	2	0.549	4.455	0.038
LIGHT *SALINITY	1.998	6	0.333	2.700	0.073
ERROR	1.357	11	0.123		

DEP VAR: LA11WK N:23 MULTIPLE R: .815 SQUARED MULTIPLE R: .664

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	4.975	3	1.658	3.970	0.038
LIGHT	0.586	2	0.293	0.702	0.517
LIGHT *SALINITY	3.648	6	0.608	1.456	0.279
ERROR	4.595	11	0.418		

DEP VAR: LB10WK N:23 MULTIPLE R: .809 SQUARED MULTIPLE R: .655

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	5.122	3	1.707	4.180	0.033
LIGHT	1.785	2	0.893	2.185	0.159
LIGHT *SALINITY	1.523	6	0.254	0.621	0.711
ERROR	4.493	11	0.408		

DEP VAR: LL20WK N:23 MULTIPLE R: .776 SQUARED MULTIPLE R: .602

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	1.983	3	0.661	2.794	0.090
LIGHT	0.243	2	0.122	0.514	0.612
LIGHT *SALINITY	1.562	6	0.260	1.101	0.420
ERROR	2.602	11	0.237		

DEP VAR: LA20WK N:23 MULTIPLE R: .696 SQUARED MULTIPLE R: .485

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	6.120	3	2.040	1.974	0.176
LIGHT	0.180	2	0.090	0.087	0.917
LIGHT *SALINITY	3.947	6	0.658	0.637	0.700
ERROR	11.369	11	1.034		

DEP VAR: LB20WK N:23 MULTIPLE R: .796 SQUARED MULTIPLE R: .633

ANALYSIS OF VARIANCE

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SALINITY	0.798	3	0.266	1.054	0.408
LIGHT	0.121	2	0.060	0.239	0.791
LIGHT *SALINITY	3.820	6	0.637	2.522	0.087
ERROR	2.776	11	0.252		