The Plant Ecology of Miranda Wetland: Restoration Options

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Abstract

Wetlands are increasingly recognised and valued. Communities are accepting the challenges of restoring these severely degraded ecosystems. This study discusses the problems and opportunities associated with restoring Miranda wetland, that forms part of the Firth of Thames, and is an internationally recognised wetland area.

A review of wetland restoration emphasises the unique characteristics and interacting factors operating in wetland ecosystems. Sound planning including specific objective setting and

Vegetation communities were surveyed for composition, distribution and structure. Basic environmental factors were measured monthly to form community type characteristics and assist in delineating habitat boundaries.

Impacts affecting native vegetation types are assessed and specific attention is given to the control of *Carex divisa* including tests on salinity tolerance to identify potential competitor species. Restoration options include revegetation, continued grazing, and returning the original hydrology.

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Chapter One

General Introduction

Coastal Wetlands

1.1 Coastal Wetland Values

The term wetland includes a diverse range of landforms. A wetland can be a coastal estuary or lagoon, a freshwater lagoon, braided river, a swamp or marsh, a high mountain bog or a large stock water dam (Buxton 1991). Wetlands are normally located in areas where dry land and open water meet. Variations in habitat and seasonal variations make these complex, diverse and productive areas. Large wetlands may comprise several types of wetland as saline plant communities grade into brackish and freshwater ones. Coastal wetlands include estuaries and lagoons; estuaries are partially enclosed by land but are open to the sea and its tidal influence. Estuaries are perhaps the most productive of all wetlands with particularly abundant animal life (Buxton 1991).

Until recently wetlands were seen as unproductive wastelands, places where reclamation achieved a higher economic return profitable in the short term with tangible benefits (Williams 1994). An estimated 10% remnant of wetlands remain in New Zealand (Cromarty and Scott 1995). The main factors contributing to the loss of coastal wetland areas include eutrophication, invasion by weed species, grazing damage, landfilling, drainage, vegetation clearance and extraction of sands and gravels (De Jong 1997, Cromarty and Scott 1995). The rate of wetland drainage, reclamation and use as fill sites and transport routes is continuing to increase with technological improvements in pumps and earth moving machinery (Williams 1994). The loss of wetland functions and resulting adverse impacts, including flooding, loss of biotic diversity and fisheries, coupled with increasing knowledge, experience and use of wetlands are causing a paradigm transformation (Jones et al 1995, Williams 1994).

The diverse values of wetlands in New Zealand have been described by Buxton (1991), and the following selected points relate particularly to coastal wetland values.

- Wetlands as ecotones support diverse and specialised plant species, and are nurseries for fisheries and a food source for adult fish. In New Zealand wetland habitat supports the greatest concentration of bird species (Buxton 1991) and form part of an international network called the East Asian Flyway used by migratory birds (Anonymous 1996).
- Wetlands are increasingly utilised as buffers to non point source pollution and specifically constructed for waste water treatment, absorbing and altering chemical inputs and settling out suspended sediments (Buisson and Bradley 1994). The application of wetland functions is especially valuable for reducing the adverse effects of agricultural runoff on surface water quality (Tanner and Kloosterman 1997).
- Wetlands especially mangroves, control coastal erosion by dampening the wave environment and enhancing sediment deposition (Hackwell 1989).
- Recreation opportunities offered by wetlands include duck shooting, fishing, walking, swimming, boating and observation of wildlife.
- The natural landscape values of wetlands are important to visitors and locals alike; but they are also coveted for future housing development (Walsby 1997).
- Maori hold significant cultural, historical and spiritual values associated with wetlands. Traditional activities such as gathering *kaimoana* (food from the sea) and harvesting wetland plants for fibres and dyes remain important. wetlands are also held to be *taonga*, treasured natural resources to be passed on to future generations (Environment Waikato 1994).
- There are archaeological values in many wetlands that include evidence of past environmental conditions over thousands of years and geological features of interest. Wetlands also hold cultural evidence of past human activities as they preserve artefacts and human and animal remains under optimum conditions (Coles 1994).
- Wetland ecosystems have potential for education and scientific experimentation (Schilser 1991).

1.2 Site Description

The Miranda-Kaiaua coastal wetland is located on the south western coast of the Firth of Thames in the Waikato Ecological Region, and Hauraki Ecological District. It forms a linear strip of approximately 150 ha in area stretching from Miranda Stream in the south to just below Kaiaua township in the north. Its width ranging from 30 to approximately 500m from Mean High Water Mark (MHWM) is restricted by the East Coast Road. To the west, the Hunua Ranges provide limited protection from prevailing westerly winds. In the East lie the Coromandel Ranges which together with the Hunua Ranges, border the Hauraki Depression in which lies the Firth of Thames Estuary. The usually low energy wave climate is susceptible to occasional northeasterly tropical cyclones producing storm surges (Woodroffe 1983). Miranda is significant in that it lies on a unique natural feature, a chenier plain. Chenier plains are rare around the world and are composed of shell or gravel forming one or more shell ridges (Augustinus 1989). Miranda also contains a number of freshwater and brackish temporary pools. A wide variety of wading birds nest and roost on the shell banks and feed in the Firth of Thames Estuary. Miranda forms part of the East-Asian Australasian Flyway, an agreement between Japan, Australia and New Zealand allowing the safe passage of migratory birds (Anonymous 1996). The East Coast Road is now part of a tourism route called the Pacific Coast Highway that connects Auckland, Thames and Tauranga and is often used by touring cyclists. Regionally the Miranda-Kaiaua coastal wetland is important as it links with the larger southern area of coastal wetland vegetation of the Firth of Thames Estuary which has been declared a Ramsar site (Cromarty and Scott 1995).

1.2.1 Surrounding landuse

Adjacent landuse include stock grazing, scattered housing, a campervan site and quarry. Part of the reserve is under the protection of a QEII conservation covenant in which the owner has retained the grazing right. The remainder is the jurisdiction of the Department of Conservation (DoC), which also leases part of the land for grazing. The Ornithological Society of New Zealand established the Miranda Naturalist's Trust which operates an information and meeting centre on a section of land across the road from the wetland. The coastal wetland itself is made up of three separate reserves: Taramaire Wildlife Reserve, Miranda Wildlife Reserve and the Robert Findlay Wildlife Area under QEII covenant (see Fig. 1.1). The general area will be referred to as Miranda salt marsh in this study.

Fig. 1.1. Location map of the Kaiaua-Miranda coastline taken from NZMS 260 S12 topographic map, scale 1:50 000. Inset: location of map section in relation to the Firth of Thames and New Zealand (after Woodroffe 1983).

1.2.2 History of Human Impact

The Miranda coastal region has historical significance for the tangata whenua, Ngati Paoa, who lived in the area. It was also an important eastern access route for families of the Tainui tribe to their land in the south (Galbraith 1992). The Miranda region is named after the redoubt located on the hill above Miranda Hall that was built in 1863 during the Maori land wars. The redoubt itself was named after the gun boat Miranda that was involved in transporting troops to the area. European settlement followed in 1869 along with the clearing and drainage of land for pasture.

A lime-works operated in the area between 1932 and 1945 at the southern end of the QEII reserve (see figure 1.2). Little remains but the concrete foundations and rusting furnace pieces (DuFeu 1996). Shell was at first manually then mechanically extracted from the surrounding farmland which was then levelled and drained. After grinding and drying, powdered shell was bagged and barged to Thames for sale as a cheap source of lime fertiliser. The Miranda bridge is adjacent an old port possibly used in the operation. When the shell resource diminished the operation ceased. A shed has been placed there as a hide for bird watchers and a picnic area is in place of where the managers house was located (DuFeu 1996).

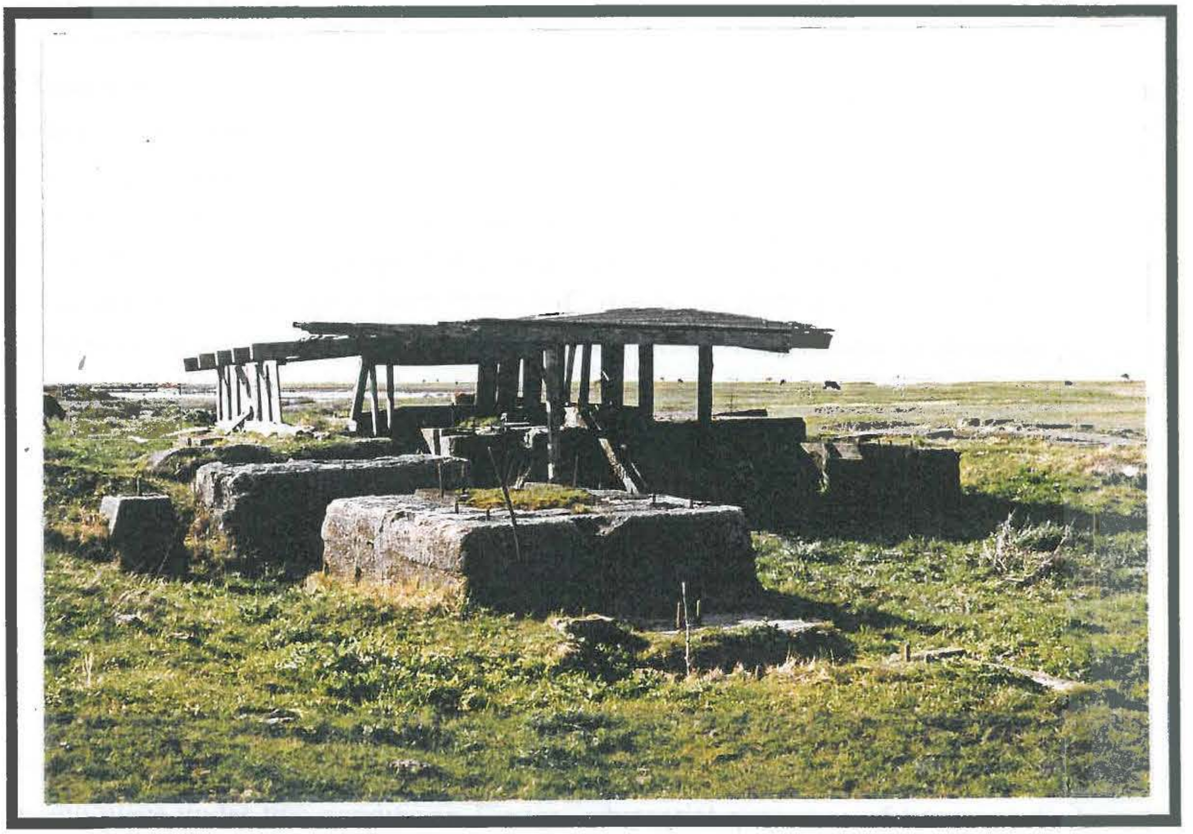

Fig. 1.2 Limeworks foundation on the Robert Findlay Wildlife Area property. The roofing was put in place by the Miranda Naturalist' Trust for a hide in the 1970's.

1.3 Study Objectives

The primary study objectives were:

1. To survey the vegetation of the Miranda reserve.

2. To relate the vegetation patterns and individual species distributions to ecological forcing functions such as salinity, hydrology, substrate characteristics, nutrient status and waterlogging.

3. To predict future vegetation development under selected management scenarios, and to develop recommendations for vegetation rehabilitation programs.

4. To establish a sound experimental basis for monitoring ecological changes at Miranda in future years.

1.4 Chenier Description

1.4.1 Chenier Definition

Miranda wetland is physiographically rare throughout the world in that it is part of a chenier plain, other occurrences are found principally scattered along the Northern Australian coastline and the coastlines of China, South America and isolated occurrences in other countries (Augustinus 1989). Chenier plains are defined by Woodroffe (1983) as a prograded coastal plain in which narrow ridges (cheniers) of sand, gravel or shell have been "stranded" overlying finer grained marine or littoral sediments. The term "chenier" originated in southwest Louisiana to describe parallel sand and shell ridges surrounded by marshland on which grew a species of oak (French: chêne) hence the term chenier (Otvos and Price 1979). The shell ridges at Miranda are predominantly made up of the valves of the cockle *Chione stutchburyi, mactra ovata*, *Paphies australis*, *Tellina liliana* and *Ostrea lutaria*, sourced from beds in the Firth of Thames estuary, although further north from Kaiaua the ridges are composed of gravel (Woodroffe 1983).

1.4.2 Chenier development

Classic chenier development processes are described by Otvos and Price (1979) as taking place under two conditions. Firstly, substantial quantities of river supplied mud must be available for near shore marine transport and coastal mudflat deposition. Secondly, a certain balance of longshore drift, deposition and sand-winnowing must operate to allow beach ridge formation. However, in a review of the literature by Augustinus (1989) a wider variety of possible development conditions are described.
Woodroffe (1983) describes the formation of cheniers at Miranda as beginning with the wave winnowing of muddy sediments that concentrate coarser particles into an offshore

bar. Wave movement causes the bar to migrate shoreward at a decelerating rate. As it slows nearer the shore it forms a base for the deposition of shell material that eventually builds up above the high spring tide level by the swash action of storm events (Woodroffe 1983). Further landward migration proceeds slowly as shells are swept over the ridge into the embayed tidal flat until the ridge has reached a height sufficient to resist washover during spring tides and storm events see Fig 1.3 (Augustinus 1989). Landward movement will also cease when another ridge forms to seaward turning the foreshore of the past shell ridge into an embayed tidal flat (Woodroffe1983).

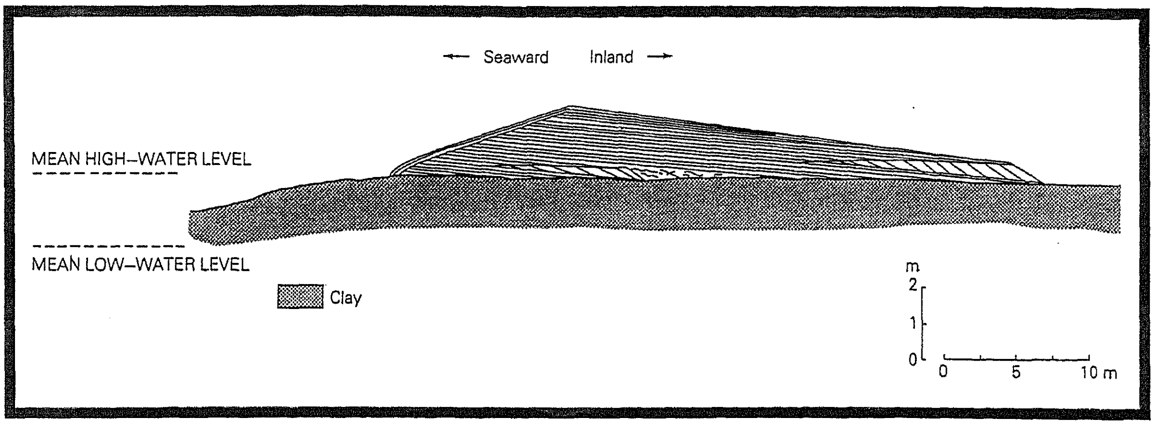

Fig 1.3. A chenier ridge after landward movement has ceased (from Augustinus 1989).

A littoral current operates along the coast moving north to south causing elongation of the shell ridges which results in the formation of large embayed tidal flats. These embayed mudflats are at differing elevations to one another, sediment is greatest at the northern ends as they have been embayed the longest and water movement is more restricted there (Woodroffe 1983). Landward migration is greatest at the distal ends of the cheniers much of this movement occurs during storm events, Woodroffe (1983) recorded as much as 95m of movement over a 7 month period. A study by Schofield (1959) suggested a fluctuating sea level with an overall drop, Woodroffe (1983) described a simpler scheme without oscillations of a gradual drop resulting in a steady progadation out to sea.

1.4.3 Chenier vegetation interaction.

Chapman and Ronaldson (1958) and Ward (1967a,1967b) studied barrier islands in Manukau Harbour which share many characteristics of cheniers. Beach ridges and small barrier islands can be differentiated from cheniers by using bore-hole data as cheniers form a sharp contrast to the silty or clayey lower shoreface deposits which they overly (Augustinus 1989). Formation of shell barriers off shore created shelter for the establishment of mangroves which eventually became partially buried as the shell barrier advanced, halting further establishment and leaving a mature more open canopy of mangrove stems emerging from the shell bank (Ward 1967b). Although their pneumatophores were buried the mangroves continued to grow. Further landward migration exposed the mangoves to the seaward side on a ledge of mud made up of the previously sheltered salt marsh substrate now compressed after the shell ridges advance.

The ledge is resistant to erosion and forms a step down to the mudflats below. The canopy of the mangroves growing on this ledge are more highly placed due to the removal of lower branches by the cheniers advance (Ward 1967b). As wave action exposed the mangrove roots the absorption by the rootlets were reduced causing the trees to starve although they were well anchored by their anchoring roots, eventually only mature stumps remained before being completely washed away (Chapman and Ronaldson 1958). An almost identical situation exists at Miranda (see Fig. 1.4).

Figure 1.4. Raised canopy of remnant mature mangroves on the seaward side of the Chenier ridge system and the step following the coast north to Kaiaua.

Woodroffe (1983) found sediment build up behind the most recent chenier to be greatest at the northern end which has been embayed the longest and where water movement is more restricted. Mangrove density, size and age increased to the north following this pattern of increasing sediment and related elevation. Thus a normal salt marsh zonation is present but occurs at right angles to the main shoreline and chenier. Formation of a new chenier ridge will cause the previous ridge to stabilise and permanent vegetation will establish between the two as the salt marsh infill with sediment, wash over fans diversify the ridge habitat (Ward 1967a).

1.5 Wetland Management in New Zealand

1.5.1 International Agreements

New Zealand is one of 101 signatory countries to the Convention on Wetlands of International Importance known as the Ramsar Convention held in Ramsar, Iran in 1971 (Frazier 1996). Ramsar is administrated by the United Nations Educational, Scientific and Cultural Organisation (UNESCO). Technical assistance is provided by International Union for the Conservation of Nature and Natural Resources (IUCN) and by Wetlands International. Wetlands International was formed in 1995 after a conglomeration of the Waterfowl and Wetlands Research Bureau (IWRB) and Wetlands for America. Other international partners include BirdLife International and the World Wide Fund for Nature (Frazier 1996). Ducks Unlimited, Nature Conservancy and other nongovernmental organisations are involved in protecting wetlands, INTECOL, the International Association of Ecology, sponsors a major international wetland conference every four years (Mitsch and Gosselink 1993). Ramsar is the only global treaty to focus entirely on one type of ecosystem. Each country on signing the convention are obligated to designate at least one wetland to the "List of wetlands of International Importance". The criteria of such wetlands come under three groups, 1) representative of unique wetlands, 2) support rare or endemic plants or animals or provides their habitat at critical life stages, 3) supports substantial numbers of waterfowl or 1% of one species population (Davis 1994). New Zealand has five wetlands that meet the Ramsar requirements these are: Firth of Thames Estuary, Whangamarino Wetland, Kopuatai Peat Dome, Farewell Spit and Waituna Wetlands Scenic Reserve (Saunders *et al* 1997).

The Convention defines wetlands as:

"*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh or brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres* (and) *may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands*" (Frazier 1996).

A centralised database for information exchange has long been requested by researchers and managers (Atkinson 1994, Lewis 1990a, Ogle 1981). In an effort to conserve the world's wetlands, an international directory is being compiled by the Specialist Group on Wetland Restoration, a working group set up by Wetlands International. Information is being gathered from 13 regions one of which is Australasia. Information is gathered on a standard data sheet that contains certain adaptations for each region's unique characteristics (De Jong 1997). Migratory birds are an important feature in most wetlands, the East Asian Australasian Flyway describes a geographic region that migratory shore birds from breeding sites in Siberia, Canada and China travel across into South-east Asia and Australasia (Anonymous 1996). Currently a tidal flat critical to this route in Japan called Fujimae is under threat from infilling with domestic waste, a petition to declare the wetland area a Ramsar site is being petitioned (Save Fugimae 1997).

1.5.2 National Level

Under Ramsar only wetlands of international significance are protected, therefore protection of the remaining 8% of wetlands in New Zealand require national and regional planning strategies (Jones *et al* 1995). Restructuring in New Zealand during the 1980's saw the introduction of the Conservation Act 1987 establishing the Department of Conservation, an agency responsible for promoting the conservation of natural resources and heritage sites (Jones et al 1995). Most importantly however was the enactment of the Resource Management Act 1991 (RMA) which helped unify management and planning of New Zealand's natural and physical resources (Saunders *et al* 1997). Over 30 separate statutes had relevance to wetlands before the RMA was enacted. At times government bodies overlapped in their functions and had potentially conflicting responsibilities (Jones et al 1995). The Department of Lands and Survey for example had the duties to both protect and develop wetlands, and development priorities typically outweighed those of protection (Jones et al 1995).

1.5.3 Legislation Governing Wetland Management

The purpose of the RMA is: "*to promote the sustainable management of natural and physical resources*". Sustainable management means "*managing the use, development and protection of natural and physical resources...*". A key component of sustainable management is protection which is not defined in the RMA. Protection is defined in the Conservation Act 1987 as follows:

"Protection", in relation to a resource, means its maintenance, so far as is practicable in its current state; but includes-
(a) its restoration to some former state; and
(b) its augmentation, enhancement, or expansion after Froude (1997).

Thus the concept of protection includes restoration and enhancement and is not limited to maintenance of a present situation (Froude 1997).

Section 6 of the RMA makes it a matter of national importance to preserve the natural character of the coastal environment, outstanding natural features and significant areas of indigenous vegetation and habitat to indigenous fauna. Section 7 requires particular regard to be for the efficient use of resources, heritage values and the finite characteristics of resources. Section 12 restricts reclamation, drainage, excavation, dumping and introduction of exotic species in the coastal marine area unless allowed by a rule in a regional coastal plan or resource consent.

1.5.4 Division of Responsibilities.

Under the RMA the Minister of Conservation is required to prepare a national coastal policy statement. It is also mandatory for there to be at least one regional coastal policy statement, regional coastal plan and district plan (Rosier and Hastie 1996). The New Zealand Coastal Policy Statement 1994 implements the principle of sustainable management of the coastal marine area and identifies restricted coastal activities that have significant adverse effects on the coastal marine area, for which the Minister of Conservation is the consent authority (Rosier and Hastie 1996).

Plans prepared by Regional Councils must be consistent with the New Zealand Coastal Policy Statement. They provide an overview of the management issues of a region and set out policies and methods to achieve the integrated management of the region's natural resources (Froude 1997). District and regional plans contain objectives, policies, rules, and other methods of implementation to control activities and avoid, remedy and mitigate adverse environmental effects (Froude 1997). District plans and regional coastal plans are separated in their jurisdiction to above Mean High Water Spring (MHWS) and below it respectively (see Fig. 1.5, Rosier and Hastie 1996). Any development spanning this mark requires integrated planning and communication.

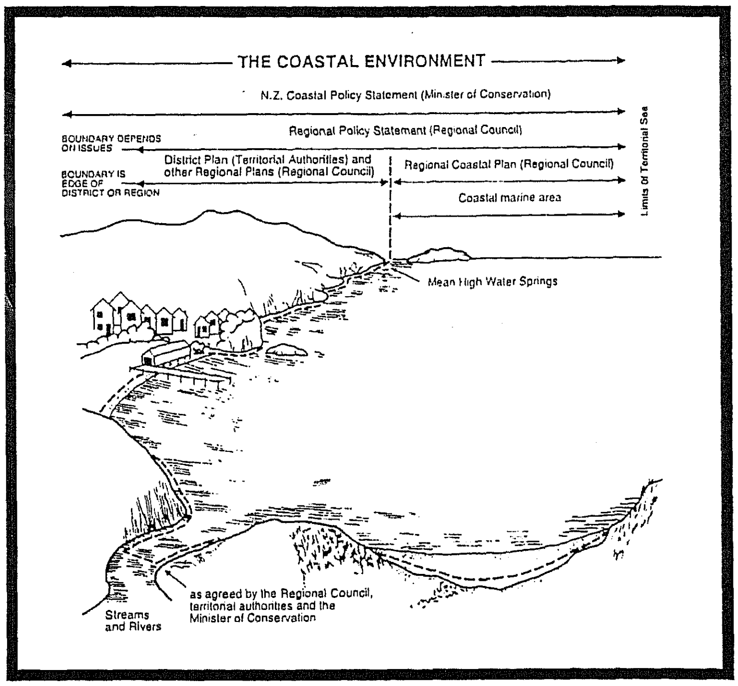

Figure 1.5. The distribution of responsibility in the coastal zone, (Rosier and Hastie 1996).

The RMA sets minimum standards for activities in the coastal marine area restricting or prohibiting activities unless they are facilitated by a rule in a regional coastal plan or resource consent (Rosier and Hastie 1996). The New Zealand Coastal Policy Statement provides more control to DoC over the coastal marine area as all Regional Coastal Plans must be approved by DoC who also have the power to provide or deny consent for any activity.

1.5.5 Monitoring

Section 35 of the RMA requires every local authority to monitor the state of the environment, the effectiveness of policies and statements, the outcomes of delegations and transfers of responsibilities to other organisations and effects of resource consents issued. Of these, state of the environment monitoring is of primary importance and must be carried out to an appropriate level to enable a local authority to effectively carry out its functions (Hutchings 1995). Hutchings suggests that indicators used in monitoring the environment need to:

(a)be representative of the system and based on the critical attributes of that system;
(b)enable spatial and temporal trends to be assessed; 5 yearly sampling is recommended so normal variations do not produce erroneous trends;
(c)be easily carried out and cost effective;
(d)provide a clear message of the environments state.

Applicants of resource consents may be fully or partially liable to monitor the impact of their activities usually this is done in partnership with the local authority. The restriction and costs related to adverse affects places greater incentive for industry and individual in the community to improve environmental management in order to avoid costly regulation of their activities (Rosier and Hastie 1996).

1.5.6 Other New Zealand Legislation Relating to Wetlands

Earlier legislation placed the major responsibility for protecting and managing our natural heritage in the hands of central government. Other than the Resource Management Act the following legislation affects wetlands:

- The Reserves Act 1977 aims to ensure survival of indigenous species and preservation of representative samples of natural ecosystems (Froude 1997).

- The Conservation Act 1987 established the Department of Conservation and sets out its functions. It gives the Minister of Conservation the power to declare land held under the Conservation Act, to be used for particular conservation purposes, restrictions can be placed on access and construction (Froude 1997).

- The National Parks Act 1980 provides for the creation and management of National Parks to ensure nationally important areas are protected, there are special areas within National Parks where a permit to enter is required (Cromarty and Scott 1995).

- The Marine Reserves Act 1977 is administered by DoC to protect coastal marine habitat including estuarine areas; over 13 reserves are in place (Cromarty and Scott 1995).

- The Wildlife Act 1953 provides for the protection of most indigenous animal species through creation of wildlife refuges which may carry restrictions on some activities that affect fauna and habitat (Froude 1997).

- The Freshwater Fisheries Regulations 1983 and the Whitebait Fishing Regulations 1993 are managed by DoC and contain provisions for the passage of fish and catch limits (Cromarty and Scott 1995).

- A New Zealand Wetlands Management Policy was accepted by the New Zealand government in 1986 and contains objectives for the preservation and protection of wetlands particularly internationally and nationally important representative samples (Cromarty and Scott 1995).

1.6 District Plan Provisions

The Proposed Franklin District Plan (Franklin District Council 1995) lists Miranda Chenier Plain as an outstanding natural feature and identifies the Firth of Thames as a Site of Special Wildlife Interest. Any activity that would modify, damage or destroy such an area including disturbance by earthworks, requires a resource consent (Franklin District Council 1995). Setbacks of 6om from MHWS and 30m for lakes, rivers and streams, are imposed on activities classed as discretionary or which are under a conditional resource consent. Any activity that reduces visual values or restricts accessibility requires a resource consent.

Incentives in the Proposed Plan for conservation include:

- Allowing the creation of rural residential lots where an important natural feature is physically and legally protected.

- Up to 100% rates remission under the Rating Powers Act 1988 for voluntary physical and legal protection of natural features, usually unrelated to subdivision.

Other methods include liaison with landowners, informing and educating the public, providing conservation kits to schools and interest groups and holding public meetings. The aim is to encourage voluntary conservation of significant natural resources held in private ownership and promote the principles and use of conservation areas. Establishment of a Conservation Information data base is planned for the district incorporating data from the Protected Natural Areas Programme (PNAP), Sites of Special Wildlife Interest (SSWI) and New Zealand Geological Society's Geopreservation Inventory. A joint monitoring programme is to be implemented in partnership with DoC, Regional Councils, Auckland\Waikato Fish and Game Council, Royal Forest and Bird Society and other relevant agencies and interest groups to assess the ongoing condition of the natural features within the District. The Council's incentives encourage voluntary conservation measures Landowners prefer these methods over land purchase and land-use regulations (Cruikshank and Peukert 1989, Jones *et al* 1995).

1.6.1 Difficulties in Implementing Regional and District Plans in the Coastal Zone

Councils are struggling to deal with parts of the RMA particulary the terms "outstanding" and "significant" in relation to the environment. There is little case law on what is for example 'significant' in the environment. There is a lack of knowledge and experience of ecological processes, diversity and effective planning techniques for protecting the environment (Froude 1997). Their are gaps in databases of WERI and PNAP's compiled by DoC that need updating. Riparian and estuarine margins are particularly susceptible and difficult to develop consistent and comprehensive planning approaches as they overlap District and Regional council boundaries. Rosier and Hastie (1996) suggested this would enable better integration between Regional and District councils but Froude (1997) found relatively few District and Regional councils take the opportunity to work closely together to achieve the best mix of policies and methods for these areas. Landowner consultation which is crucial to co-operative environmental action has been poorly carried out as it is costly, time consuming, and often a threat to the landowner which councils do not want to make (Froude 1997). Froude (1997) suggests councils need to develop criteria and thresholds that can be applied to a range of places and habitat types. Further baseline information needs to be gathered, this can be done using resource consent permits which place the responsibility on the applicant to gather information and monitor their activities impacts.

Chapter Two

Restoration of Salt Marsh Wetlands: a Literature Reveiw

2.1 Introduction

The following literature review provides a definition of coastal wetland restoration, and the distinction is drawn between restoration and other forms of improvement such as enhancement, creation and conservation of wetlands. Review of available literature reveals seven key factors that are critical to wetland restoration due to their controlling influence of plant species. the relative importance of these factors is discussed, and experience is illustrated using new Zealand case studies where possible. Finally, due regard is given to the importance of properly planning and managing any restoration project. A "best practice" planning framework is discussed.

It is interesting to note that, despite the fact that wetlands are one of the most important severely degraded of ecosystems (Jones et al 1995) and the growing legislation of wetland benefits and values discusses in Chapter 1, there is relatively little wetland restoration experience to draw on in the literature. However, a growing body of material is being published on wetland restoration, including coastal wetlands. Most work has been conducted overseas, particularly in the U.S.A, where the Environmental Protection agencies (EPA) policy of 'no net loss' has increased the number of wetland sites restored as part of mitigating or offsetting the adverse effects of development (Josselyn *et al* 1990). Much of the research has focussed on *Spartina* swards which form an important component of Northern hemisphere coastal wetland systems and have been damaged by stock grazing (Broome *et al* 1988, Bakker 1978, Jensen 1985). Future U.S research will focus on the autecology of species and the main factors that make restoration projects successful in varying situations (Kusler and Kentula 1990). From a total of 11 wetlands described as restored in New Zealand three were estuarine, among those listed as being least restored are coastal lagoons, intertidal mudflats and salt marsh ecosystems (De Jong 1997).

2.2 Definition of Coastal Wetland Restoration

There are a number of terms applied in the field of restoration that require interpretation. After peer review and comments a definition of restoration related to wetlands was formulated and presented by Lewis (1990b).

Restoration - *'returned from a disturbed or totally altered condition to a previously existing natural, or altered condition by some human action'.*

The definition includes all aspects of an ecosystem, and implies the return of biotic and abiotic components (including their interactions and processes) to a previous condition. Lewis's definition requires the identification of a previous state to return to. However, in many cases there is little knowlege of the past state of an ecosystem. Moss (1997) poses the question of what past state to restore to: before human settlement; before industrialisation or to before the acceleration of agriculture? He encourages a realistic view of restoration that acknowledges present landuse impacts in the catchment of most restoration projects. Almost all authors are in agreement that restoration (in its purest sense) to exact prexisting conditions is seldom, if ever, possible (Jackson *et al* 1995, Zedler 1988, Schaller and Sutton 1978). Atkinson (1988), following Simberloff (1990), believes that partial restorations are acceptable if they enable specific goals to be met. It is not neccessary to re-establish "exactly the same species and processes in the same proportions as the original system". Lewis (1990) agrees that restoration may not re-establish a past state or return the wetland to a pristine condition. Importantly, he defines restoration success as "achieving established goals". Thus it is critical to set well defined goals in any wetland restoration project.

Wetland "restoration" should not be confused with wetland "conservation", "enhancement", or "creation". Wetland creation describes " *the conversion of a persistent non wetland area into a wetland through some human activity*" (Lewis 1990b). "Enhancement", of wetlands encompasses "*the increase in one or more values of all or a portion of an existing wetland by human activities, often with the accompanying decline in other wetland values*" (Lewis 1990b).

Other forms of enhancement terminology have been used, such as "rehabilitation" which is normally associated with revegetation, "species recovery plans" that centre on a specific species and "ecological engineering" such as the use of pine forests for kiwi habitat. However, none of these terms address an entire ecosystem or have a primary objective of returning to as close as possible the past state (Atkinson 1988). Restoration is differentiated from "protection" as the latter does not involve active intervention to reinstate lost species or physical conditions (Atkinson 1988).

2.3 Physical Factors Important for Coastal Wetland Restoration

The physical factors contributing to the ecosystems in a salt marsh are numerous and interelated and delineation of any one factor's effects is nearly impossible. Single factor effects are more easily isolated in laboratory conditions but often do not correlate well to field studies (Partridge and Wilson 1988). Broome *et al* (1988), dealing primarily with *Spartina* swards, suggested coastal wetland restoration normally translates into replacing the dominant native angiosperm with the assumption that the animal component and other plants will reinvade. Atkinson (1988) also notes revegetation by planting to be the primary method of restoration in New Zealand projects. Therefore, the key factors controlling plant species are the main parameters taken into account in most restoration planning and are the focus of this literature review. Controlling factors include hydrology, salinity, topography and substrate characteristics. The relative importance of each factor is determined by each wetland project's unique characteristics (Broome 1990, Lewis 1990).

2.3.1 Hydrology

The most important factor controlling coastal wetland species composition is the hydrologic regime. Levels of inundation, circulation and salinity are all critical to the plants and animals of coastal ecosystems (Zedler 1988, Erwin 1990a). Hydrology affects primary productivity, decomposition, the export of particulate organic matter and nutrient cycling (Mitsch and Gosselink 1993). Coastal wetlands are considered more readily restored due to the ease of returning tides to provide the correct environmental conditions (Kusler and Kentula 1990). Most damage to wetlands occurs when the hydrology has been altered through roading, stopbanking, ditches and channelisation (Knox and Kilner 1973, De Jong 1997). A result of restricting tidal flow is increased oxidation causing accelerated decomposition of organic matter which may lower dissolved oxygen levels in the water column. Decomposition and compaction result in soil shrinkage, especially in coastal wetlands accreting organic matter. Sulphides accumulated in anaerobic conditions can be oxidised to sulphates forming sulphuric acid and result in acidification (Anisfeld and Benoit 1997). For example the rediversion of the Kaituna River at Maketu Estuary resulted in drying of the substrate over much of the estuary, reducing organic matter and increasing pH which affected root growth and contributed to vegetation decline (Bergin 1991).

The simplest restoration often involves directly breeching a stopbank and allowing natural processes to take over. However, the implications can be complex when flood risk, subsidence, sedimentation, water quality and erosion concerns are involved (Coats *et al* 1989). Where possible, natural fluctuations should be maintained and extreme periods of salinity or freshwater impacts avoided as both situations can result in a shift of vegetation composition (Zedler 1988). Inundation duration can be critical to species distribution. The intertidal area is determined by elevation, slope and tidal range (Broome 1990). A 0.1m error in predicted tide elevation can result in habitat boundaries varying by over 10m due to the low elevation of coastal wetlands (Goodwin 1994). If the site is excavated then a slight slope should be introduced to provide for drainage and prevent hypersaline 'evaporation' pools forming that restrict vegetation establishment (Lewis 1990a).

In a hydrologic restoration project in California Coats *et al* (1989) utilised aerial photography and ground surveys to construct topographic maps at a scale of 1:1200. It was considered a minimum to include 30cm elevation intervals and spot elevations to the nearest 10cm. The map was linked to tidal information including the tidal prism. Tidal prism is the volume of water exchanged between high and low tide which has an equilibrium relationship to the channel's cross sectional area and can be used to determine channel excavation limits. A channel is better constructed slightly larger than required as deposition and bank slumping will eventually correct it (Coats *et al* 1989).

Hydrologic models have developed in complexity and design, and Coats *et al* (1989) describe a model of tidal influence through channelled networks which has been widely used in salt marsh restorations. Other hydrologic modelling couples nutrient cycles with primary and secondary productivity and may help to fine tune tidal action and freshwater inputs to maximise biotic gain (Coats *et al* 1989). One problem in restoring hydrology is the effect on surrounding land uses. Hence, adjoining areas held in private ownership or mixed private and state ownership can be a stumbling block in restoration projects (Turner and Lewis 1997). Included in the options proposed for the Whakaki Lagoon restoration project (Parlimentary Commissioner for the Environment 1993) was re-establishment of the original water course. However, it was acknowledged that this would reduce the rate of drainage during flood conditions and would adversely affect surrounding agricultural landuse.

2.3.2 Salinity

Salinity is a key factor in the distribution of plant species. Salinity of tide water and pore water are important especially in areas of poor drainage where evaporation can increase salinity halting plant growth and seedling establishment (Chapman 1974, Lewis 1990a). Displacement of lower-marsh plants takes place by more competitive, but less salt tolerant, higher-marsh species when there is a reduction in salinity (Snow and Vince 1984). Salinity is related to the tidal influence and is less variable where the water table is high and freshwater inputs are reliable (Mitsch and Gosselink 1993). Partridge and Wilson (1987) investigated salt tolerance of Otago salt marsh species and suggested species salinity tolerance was most sensitive during establishment as a seedling and is the most important factor determining vegetation zonation. Salinity isobars were constructed across the Maketu Estuary vegetation and tidal flat over a tidal cycle to assess inflow dilutions that would affect the distribution of the vegetation and shell fish (McIntosh and Park 1997).

2.3.3 Wave climate

Wave climate is an important factor in the establishment of vegetation and in sediment transport processes. Bergin (1994) had less success in establishing transplants of *Juncus kraussii* (*maritimus*) in stronger wave environments and suggests temporary shelters for establishment. In re-establishing vegetation on dredged sand spoil islands Broome (1990) suggests fetch and grain size as useful indicators of wave climate to ensure long term stability of proposed plantings.

2.3.4 Substrate

Substrate particle size influences invertebrate species composition with smaller particles increasing the surface area for colonisation by bacterial and algal populations (Raffaelli and Hawkins 1996). In the study of Avon Heathcote Estuary Knox and Kilner (1973) observed increased densities of algal growth on areas of finer sediments. Larger particles increase drainage which reduces soil salinity and water content and increases leaching of nutrients (Walmsley and Davy 1997). Measurements of pH and sediment redox potential help to predict oxygen status in waterlogged soils (Raffaelli and Hawkins 1996).

2.3.5 Nutrients

Nitrogen is often a limiting factor in salt marshes and most is in the form of ammonia, because of the predominance of anaerobic substrate conditions. Plant biomass and nutrient relationships are recommended by Keeney (1993) as best achieved by measuring soil nutrient concentration on a volume basis (g/cm^3). Phosphorus accumulates in high concentrations in salt marshes and does not appear to limit plant growth (Mitsch and Gosselink 1993). Iron also is normally in high concentrations due to the reducing conditions (Mitsch and Gosselink 1993). Sea water contains high levels of sulphur which in anoxic conditions is reduced to sulphide. Hydrogen sulphide is toxic to plants. When exposed to air sulphides are reoxidized to sulphates, which can hydrate to sulphuric acid. Acid sulphate soils are common in coastal marshes.

2.3.6 Ground water levels

Ground water levels fluctuate with the tide, and if close to the surface help regulate soil salinity by reducing extremes (Mitsch and Gosselink 1993). Also, because tidal effects keep the water table high, salt marsh plants are less susceptible to drought periods, depending on the groundwater salinity (Ward 1967a). Drainage and stopbanking of saline areas causes an immediate reduction in soil salinity in the short term. Daly and Rijkse (1976) measured salinity and groundwater fluctuation in the reclaimed Ahuriri Lagoon. Their studies reveal the salinity of the soil is stable after an initial drop, but remains high because of a high, saline water table which is influenced by the tide. During summer periods cappillary rise of the water table deposits salt crystals near the soil surface. Winter salinity levels are lower due to preciptation leaching the salt down the soil profile.

2.3.7 Climate

Climate may determine species presence or absence. For example, low temperatures limit *Avicennia marina* ssp. *australasica* distributions to the upper North Island. *Juncus kraussii* var. *australiensis* then dominates in abundance down to 44° latitude before diminishing in abundance and *Sarcocornia quinqueflora* dominates south of this (Thannheiser and Holland 1994). The South Island salt marshes have more glygophytic species of lower salt tolerance than North Island marshes due to higher precipitation from coastal fog (Thannheiser and Holland 1994). *Leptocarpus similis* is distributed thoughout both the North and South Islands and Stewart Island (Johnson and Brooke 1989).

2.4 Restoration Methods with a Focus on Revegetation

Most restorations have a primary aim of restoring vegetation (Atkinson 1988, Broome *et al* 1988) as this concurrently creates habitat for animals and influences environmental conditions causing successional processes to stablise and diversify the plant and animal communities. It is important in revegetation to use remnant or locally available plant material as this will be better adapted to the local conditions and will conserve the genetic characteristics of the coastal wetland (Hull and Beovich 1996).

2.4.1 Transplanting

Transplanting whole plants or parts of plants works well with rhizomatous species which can be commercially grown or obtained in the field. When using transplants from the field, source sites must be utilised sustainably and donor species preferably selected without parasites or disease (Hull and Beovich 1996). Transplanting has been trialed in small areas at Maketu Estuary (Bergin 1994) on *Juncus kruassii*, *Leptocarpus similis and Avicennia marina* var *australasica*. Establishment and canopy closure was most rapid in sheltered sites using medium to large clumps (10cm x 10cm and 15cm depth) and spaced 0.5m apart. Source sites recovered in less than a year although it was acknowledged that large scale sourcing would be damaging (Bergin 1994). Large transplants of individual mangroves were found to be time consuming and unsuccessful. Small seedlings were more promising, 80% of small seedlings 5-10cm with roots less than 3cm long grew strongly. Only 25% of seedlings with a root length greater than 3cm survived over the same 5 month period (Bergin 1991). Careful assessment of a planting site's physical characteristics is required to ensure species are planted as close as possible to their natural vegetation zone, otherwise in the long term plantings may fail (Zedler 1988). Mangrove propagules and seedlings can be successfully transplanted but until well established require low wave energy and good drainage to prevent saline pools forming by evaporation (Lewis 1990a).

A widespread exotic species in New Zealand is *Spartina* of which three species have been introduced. In New River estuaries *Spartina* dominates from the low tide up to where it meets dense *Leptocarpus similis*, thereby displacing salt meadow communities and part of the *Zostera* beds (Wardle 1991). Spray trials at Maketu were carried out on *Spartina* swards with Gallant and Roundup for their water resistance and quick drying times to mitigate tidal influence. Once *Spartina* is killed the root mass decomposes slowly aiding establishment of transplants by providing a stable substrate (Bergin 1994). Transplants can be deposited in plugs with extra organic matter and NPK fertiliser tablets to aid in establishment, particularly in sandy substrates that experience heavy leaching (Broome *et al* 1988).

2.4.2 Direct Seeding

Direct seeding is most successful on bare, moist substrates or in shallow water in a low energy wave environment (Hull and Beovich 1996). In a freshwater wetland restoration project carried out by Erwin (1990a) on mine tailings, the use of mulched vegetation and top soil stripped from a nearby donor wetland helped to re-establish vegetation. The mulch contained viable seed and roots and provided a germination medium. Generally, seeding is most effective in the upper intertidal zone, with transplants more suited to the lower intertidal zone because of higher salinity and wave action (Broome *et al* 1988).

2.4.3 Seedbanks

Seed bank analysis to identify possible species recruitment is an important part of many restoration projects. Seedbank composition does not always correspond to vegetation present as some seed represents earlier successional species. However, frequently disturbed environments correlate more closely as they are continually reset (Warr *et al* 1993). Atkinson (1988) mentions the preference of many restoration project managers for the process of natural succession to produce a more compatible community. This "wait and see" approach is a low cost method (Hull and Beovich 1996) but can often be upset by invading exotic plant species. However the 'exotic' phase may be temporary if proper hydrologic conditions are imposed. Presenting as many opportunities as possible via seeds and plantings for natural processes to select from will provide a more stable wetland requiring less intervention. Initially, intervention such as weeding may be needed until a high canopy has developed (Mitsch and Gosselink 1993). Even drained and stopbanked soils still have the potential for regeneration from seedbanks once tidal flooding is reinstated. The regeneration rate is dependant on duration and extent of drainage, degree of soil moisture, temperature and chemical conditions (Hull and Beovich 1996).

2.4.4 Timing

Plant establishment and germination is more successful when carried out in Spring and early Summer when higher rainfall lowers surface salinities and temperatures are warmer (Shumway and Bertness 1992). Halophyte seeds are able to remain dormant in high salinities until a window of lower saline conditions occurs (Ungar 1978). Seedlings are more sensitive to hypersaline conditions than adult plants and summer maxima appear to be most important in determining vegetation zonation (Partridge and Wilson 1989). Vegetation can be collected in late winter to early spring and stored in moist sand before planting out in the spring. *Triglochin* and *Juncus* species have been successfully transplanted in late autumn-winter plantings in Australian salt marshes (Hull and Beovich 1996).

2.5 Aerial Photography

Barrett and Niering (1993) describe a study using aerial photographs in which the past altered state and also of partially restored states were compared for cover and distribution of selected plant communities so that revegetation efforts could be evaluated. Coats *et al* (1989) also utilised aerial photography to calculate the intertidal surface area and topography of the Hayward Area Recreation District for accurate inlet channel parameters affecting tidal flushing. Chapman and Ronaldson (1958) compared successive aerials to determine shell bank movement in Auckland harbour. Aerial photography was used to illustrate the historical trend of drainage and channelisation of the catchments for Whakaki Lagoon and Maketu Estuary (Parlimentary Commission 1993, McIntosh and Park 1997).

2.6 Future Research Trends

Mesocosms or small controlled field sites have been proposed by Callaway *et al* (1997) for trialing restoration techniques before embarking on large scale projects. Callaway *et al* (1997) used excavations adjoining a tidal channel with tidal gates at each end to determine hydrologic responses of *Sarcocornia* to differing hydrologic regimes. Tests such as these provide greater autecological understanding of individual plant species.

Microcosm experiments carried out in the laboratory allow more intensive and controlled experiments. Transplant experiments have been used to identify the fundamental niche species and competitive interactions of plant species (Partridge and Wilson 1988), and are recommended for determining species response under different conditions in revegetation projects (Bergin 1994, Lewis 1990a). Schisler (1990) lists future research requirements such as tidal impacts on vegetation associations, transplanting methods, individual species autecology, endangered species habitat requirements, toxic material impact and wetlands as stormwater management facilities.

The literature contains little about the restoration of bird and fish populations which are often assumed to replace themselves once the vegetation is replaced. Another area that needs more research is the development of sound biological indicators linked to other than standard water quality mesures.

2.7 Restoration Planning

Effective planning is critical for restoration projects; Coats *et al* (1989) discovered most projects did not have clear biological objectives and failures were due mainly to poor implementation and lack of follow through. Planning must take into account biological and hydrological variables and proceed in the face of uncertainty. Restoration plans need to be monitored and there needs to be sufficient flexibility to revise the project paramenters (Coats *et al* 1989). There are five stages in restoration planning:
1. setting objectives,
2. design,
3. implementation,
4. monitoring and,
5. evaluation.

A comprehensive planning framework has ben developed for restoration projects by Pastorok *et al* (see Fig 2.1). If more than one possible restoration site exists consideration must be given to the area, linkage with surrounding habitat, species importance, habitat type, long term catchment impacts, human impacts and the available budget (Pastorok *et al* 1997). The representativeness of a proposed conservation area must be evaluated at the regional and national scale and take into account programs already in place. Normally however, site selection is restricted to less favourable areas through landownership issues, surrounding landuse impacts, potential for further development and budget constraints (Atkinson 1994).

2.7.1 Objectives

Initially, a restoration project requires broad based, long term goals. Goals can then be reduced to shorter term, specific, measurable objectives (Reynolds and Brooke 1994). For example, a goal to restore water quality may result in a specific objective such as a 20% increase in water clarity within a set time frame (Pastorok *et al* 1997). Objectives provide a 'road map' for the project and are required to evaluate the success of a project Objectives cannot be defined without an understanding of the ecosystem involved and are often difficult to define due to the highly dynamic state of most coastal salt marsh processes (Zedler 1988). Often it is not known what elements have been lost and decisions need to be made as to what past state is to be restored (Moss 1997). This will involve baseline studies and a professional scientific judgement by a scientist experienced in similar habitats (Pastorok *et al* 1997). The more information and related case studies available the more appropriate and achievable the objectives will be. Pastorok *et al* (1997) also includes planning for failure, by setting objectives that incorporate the variability of the wetland and by 'bet hedging'; creating a range of diferent habitats so that at least one is more likely to succeed.

After objectives have been set a conceptual model can then be built up identifing the main relationships between wetland species and their key controlling factors and suggesting performance indicators (see Fig 2.1). This model can be represented diagrammatically, illustrating for example key abiotic processes, food webs, successional sequences and habitat characteristics (Pastorak *et al* 1997). Hypotheses concerning the expected changes in selected indicator performances in relation to the controlling factors can then be formed and tested prior to the design stage. Small scale field experiments are useful to identify key controlling factors. Quantitative ecological models can be used to refine restoration hypotheses and rank key controlling factors (Pastorok *et al* 1997).

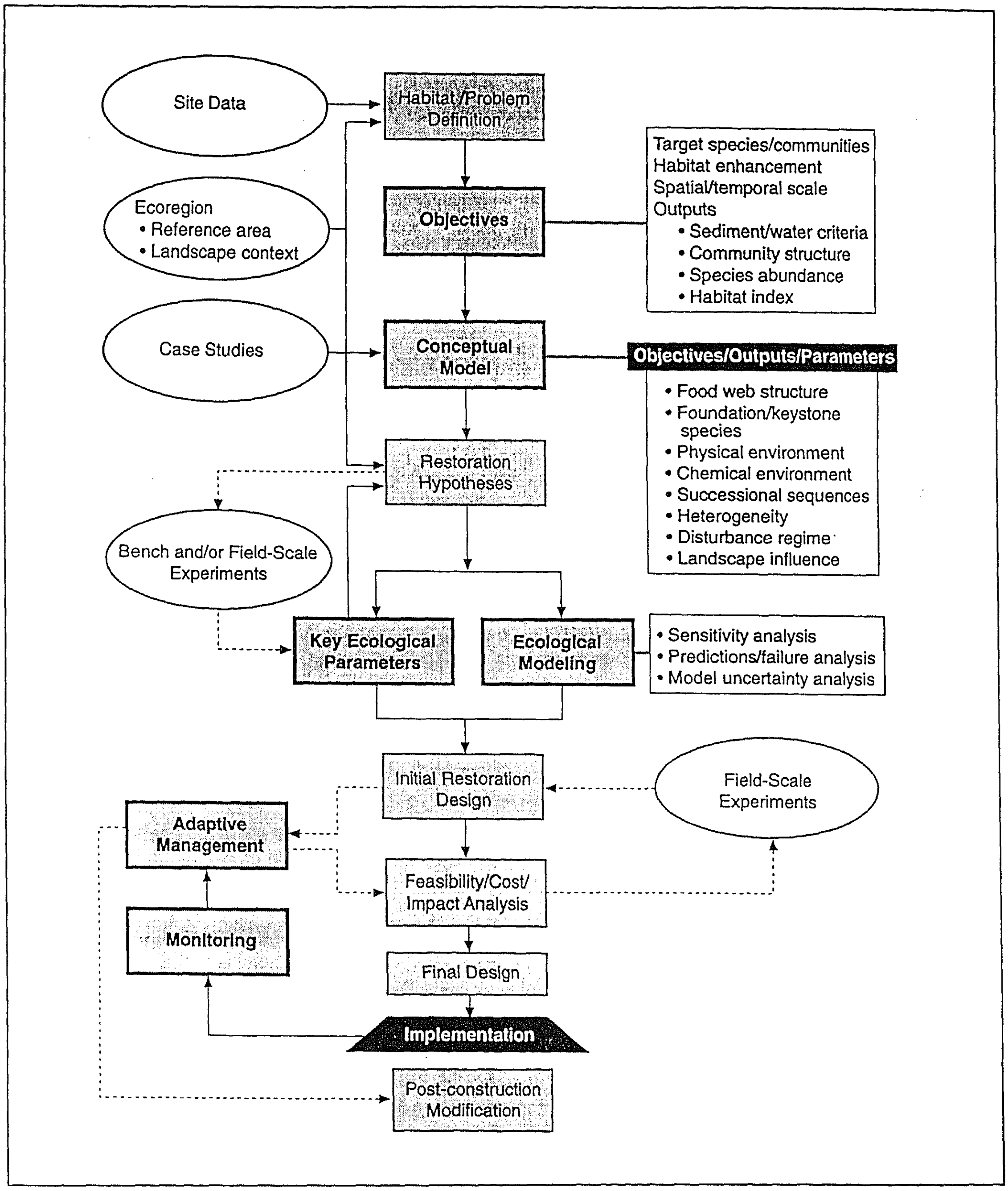

Fig. 2.1. A flow diagram developed by Pastorok *et al* (1997) containing all the main stages of restoration planning.

2.7.2 Design

Design success is greater with more detailed information and related case studies. The chosen design must be one that provides the maximum benefit over the greatest range of attributes. If possible, experimentation should be carried out at this stage to test design feasibility (Pastorok *et al* 1997). Every opportunity to include experimentation needs to be followed as the results of these are the principal source of new understanding (Zedler 1988, Atkinson 1994). This may mean putting aside areas for mesocosm scale experiments or leaving an unrestored reference area as a control. Restorations should not rely on complex technology and intensive management as in the long term this becomes expensive and prone to failure, Mitsch and Gosselink (1993) quote **Boulê** (1988) "*simple systems tend to be self regulating and self maintaining.*"

2.7.3 Implementation

Restoration projects may not be fully implemented as planned because of unforseen circumstances or impracticalities in the field. To ensure that objectives and design criteria are met careful supervision is required and any design changes should be discussed by everyone involved (Coats *et al* 1989). Implementation should be carried out in stages so that new information about effects of each stage can shape future decisions. This process is known as adaptive management and requires flexible objectives and designs (Pastorok *et al* 1997).

2.7.4 Monitoring

Restoration is a long term venture and short term success may not represent long term sustainability of the system. Monitoring is required as design faults may go unnoticed resulting in a permanently substandard ecosystem. Monitoring allows minor improvements to fine tune the system and provide future information (Coats *et al* 1989). A restoration plan should contain at least a 5 year monitoring phase that includes who will be responsible to carry it out, the parameters requiring measurement and the frequency of the measurements (Atkinson 1994). Monitoring will enable evaluation of success for each objective and reveal the future trajectory of the system whether it is part of a mitigation site or conservation area (Josselyn *et al* 1990).

2.7.5 Evaluation

Indicators used in assessing the ecological state of a coastal wetland need to be connected to environmental values and sensitive to change, but should not overestimate impacts resulting from normal variation. Evaluation must take account of cumulative effects and require limited sampling effort and be cost effective (Pastorok *et al* 1997). Experience has shown that, like monitoring, evaluation procedures that become too complex and therefore too demanding will not be done. Resources and knowledge are limited and simple procedures that can be continued by new staff need to be used (Atkinson 1994). An example of a cost effective and simple method for evaluation are photographic points that also provide plant cover value estimates (Atikinson 1994).

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Chapter Three

Methodology

3.1 Vegetation survey

A plant survey was carried out during the months of November and December 1997 to coincide with the highest species diversity due to the many annuals present. Scott's (1965) height-frequency method was used to survey the vegetation. This method involves the measurement of a plant species frequency in successive layers within the vegetation. A transect is set up consisting of a line held taut between two posts and marked at 0.5m spacing. At each mark a graduated pole is positioned vertically with the aid of a spirit level to one side of the line. Every 5cm interval up the pole a set volume of space is estimated using a sampling frame. Scott (1965) accomplished this with two 5cm diameter metal rings stacked to define a column. Any species present within the sampling frame at each height interval is recorded. The results can be displayed on a histogram illustrating the various proportions of a species occurrence at each height interval. A single summed height frequency value of each species at each site, corresponding to its total frequency in all the height intervals, provides a simple measure of a species importance at a site (Dickenson *et al* 1992).

The method was first developed by Scott (ibid) to measure vertical structure in native tussock grassland and shrubland communities of Otago. These communities were later surveyed by McIntosh *et al* (1983) and Dickenson *et al* (1992) using the same method. Other methods such as the point intercept method do not give vertical species distribution, although Jonasson (1988) describes a point intercept method that includes vertical 5cm height measurements to provide a biomass index. Disadvantages of the point intercept method are the difficulty in measuring vegetation above 1m height and working in windy conditions (Scott 1965). The coastal locality of the Miranda study site is exposed, and consequently windy conditions prevail. Under these conditions the fine stems and leaves of species such as *Stipa stipoides*, *Juncus kraussii* and *Carex divisa* are impossible to measure using the point intercept technique. Scotts height frequency method has the advantage of being easily used to heights of 2m and was therefore useful in measuring *Plagianthus divaricatus* and *Avicennia marina* plants. The height of the vegetation is easily noted by the set movements of the sampling frame up the pole, and information can be gathered on shading influences and plant-plant interactions. Less detailed cover information can also be collected using this method. The Miranda study required only general compositions to enable site comparisons. Structural and compositional information is readily presented diagrammatically for comparison with other sites and to reveal trends in long term investigations (Dickenson *et al* 1992).

The height frequency method has been suggested as a useful tool in providing information for nature conservation purposes in that it is easily carried out, consistent with different users, and inexpensive (Dickenson et al 1992). The summed height frequency value has the potential to be used as an above ground biomass index (McIntosh *et al* 1983).

In this study uniform communities exist in discrete bands parrallel to the shore and abrupt changes in vegetation and abiotic factors occur over short distances. The use of line transects to measure the vegetation types would cross adjoining zones, and resulting vegetation compositions would not correlate to specific site conditions. For this reason sampling was undertaken with plots spaced along three line transects. Environmental factors measured at each plot are then able to be related directly to the vegetation present. Plots were placed randomly at set distances along the transect in order to identify communities without bias. Each plot has a unique identifier based on the Trasect line number (1 to 3) followed by a Plot number (1 to 24). These are abbreviated in the text, for example, 1.2 refers to Trasect line 1, plot 2. Six plots were selected to enable comparison of an exclosure site and to ensure coverage of important communities not represented in the line transects but identified in the literature (Chapman and Ronaldson 1958, Ward 1967b). The selected sites are abbreviated as S.1 to S.6 in the text. The number of plots was limited due to the time required in measuring the environmental factors at each plot and in carrying out the plant survey. Plot transects and select plots are displayed in maps 1-4.

In this study sampling was carried out in 24 plots measuring 2 metres by 2 metres. A square framed sampling frame of $5cm^3$ was used to measure a set volume of space at 5cm height intervals along a 2m aluminium pole. The pole was placed at each sampling point and kept vertical with the aid of a circular level. At each height interval any plant species present within the square framed cup was recorded. The values were entered into a spreadsheet and for each plot a single summed height-frequency value was obtained for each species present. A tape measure was held between two posts above the vegetation in the plot and sampled at 10 points spaced at 20cm intervals. It was then moved 20cm across the plot and a further 10 sampling points were taken spaced at 20cm intervals until 11 lines totalling 110 points were sampled. Thus points were distributed as a grid pattern inside each 2x2m plot. A disadvantage of this particular approach was the trampling of vegetation beside each sampling line in the plot because of the density of sample points. Summed height-frequency data for each species at each plot was entered into a spreadsheet and analyzed using the PATN computer software package (Belbin 1995). Cluster analysis of plots was used to produce a dendrogram and ordered table for identification of communities (see Table 4.1). An ordination was carried out using PATN on summed height frequency data for each species at each plot and also on averaged environmental variables at each plot (see Fig. 4.9a-b). Structural analysis was determined by graphing the height frequencies of each species in each plot to provide a visual comparison (see Fig. 4.2a-d)

Dickenson *et al* (1992) used 100 points per line transect but found 60 points was sufficient to record an average 89% of species present in a tussock community. In this study the 110 point survey for each plot covered most of the species present except for isolated, widely spread species. Due to the small sample size of 24 plots not all the vegetation types and species present between Kaiaua and Miranda could be sampled. Less frequent and widely spaced species have been missed as well as those not present during the summer sampling. The small quadrat area of each plot may not be representative of the overall community composition and structure being sampled. However, previous surveys have comprehensively listed most species that occur along the foreshore of the study area, as well as the general distribution and cover values of the communities present (Merrett and Clarkson 1997, Ogle 1981). The main species at each plot characterising the vegetation were linked into the communities found in the wider survey of 88 plots by Merrett and Clarkson (1997).

3.2 Measurement of environmental factors

3.2.1 Introduction

The following factors were measured to aid the characterisation of differing vegetation types and to provide information on the main controlling factors at each plot. Most factors were measured monthly to determine the variability at each site and seasonal variations. Single measurements of some factors were also made for comparison between plots.

3.2.2 Elevation

The elevation of each plot was determined using a Wild NK 01 dumpy level. The highest and lowest observable points at each plot were measured and averaged to obtain a single value. In addition, elevations were determined along two transects protected from the tide by stopbanks. Readings were taken back to bench marks along the East Coast Road which are related to the Auckland 1946 datum, Mean Sea Level (MSL). This datum corresponds to mean sea level at Queens Wharf, Auckland Harbour for the period 1909-1946 (Woodroffe 1983). Elevations were taken to the nearest centimetre, the accuracy of each benchmark was last checked in 1981 (Geodetic database 1997).

3.2.3 Ground water levels

At each plot above the high tide a 1m PVC pipe with 1mm vertically cut slots around the side to admit soil water was inserted into the ground. A 20cm diameter hole was excavated with a hand operated soil borer. The depth to which the pipes could be sunk was limited on the shell banks to 80cm as the substrate continued to collapse any deeper than this. Plots inundated by the tide on the salt marsh were not measured because of sediment infilling the pipes and surface flows entering the pipes in the deeper plots. Groundwater was measured with a graduated pole, and a taped paper marker produced a water mark to gauge the water level in relation to the soil surface. On 19 October 1997 water levels were measured over a half tidal cycle to determine the extent they were raised due to a Spring tide. In addition, ground water was tested when present in the pipe for conductivity with a portable Oakton conductivity meter.

3.2.4 Soil analysis

Soil samples were obtained monthly by taking two random cores outside each plot with a hand operated auger, retaining the 5-7cm portion. Samples were transported back to the laboratory for analysis within 24hrs in plastic screw top containers. Samples used for the estimation of ammonium nitrogen or for commercial analysis for total nitrogen and organic matter were collected the same day and kept in ice during collection and transport from the feild.

3.2.5 Water content

Soil water content was determined following the method laid out in Blakemore *et al* (1987). A 20g sample of field moist soil from a 5-7cm depth was weighed before and after oven drying at 105°C to a constant weight. The difference was then converted to a percentage value by weight. Soil was sieved to <2mm to remove root matter and shell fragments that would give higher and lower values respectively. Plots 2.1, S.3, S.4 and S.5 were not easily sieved to <2mm because of a high clay content. In this instance larger shell fragments were picked out manually before oven drying. Similarly, sites on clay substrate without shell fragments were not sieved. For the months September to November water content was measured using the results obtained from bulk density samples that were placed into the soil at a depth of 5-10cm. Moisture factor, the water content of air dry soil, was also measured by oven drying at 105 °C after it was dried at room temperature.

3.2.6 Bulk density

Bulk density samples were taken using a 5cm long by 5cm diameter steel ring to obtain a 5-10cm depth sample. One steel ring was driven into the substrate by another ring above it to obtain samples at a constant depth for all the plots. Samples were wrapped in plastic wrap in the field to conserve moisture and keep the less stable shell material together. In the laboratory samples were cut to size and weighed within 24hrs before oven drying at 105°C to a constant weight following the method described by Rowell (1994). Bulk densities were taken once a month for three months, and values were averaged and presented as g/cm^3.

3.2.7 Particle size

Soil particle size was measured for each of the plots using a Mastersizer S laser particle sizer. Approximately 2g of soil was taken off the top of one set of bulk density samples, representing a depth of 5cm. Plots S.3, S.4, S.5, S.6 and 3.1, 3.8 and 3.9 contained a shell component and were collected separately in the field with a spade approximately $20cm^3$ was collected. A 0.5kg sample was sifted to <1mm for these plots and given as a percentage by weight of the total sample. These were sieved to <2mm before a representative subsample of <5g was wet sieved at <1mm. The extract was shaken with approximately 5ml dilute clay dispersant and placed in an ultrasound bath to separate the clay colloids. The lazer was set to measure the size range 0.05-878.7um. Particles were grouped using the Wentworth size classes. Various divisions of silt and sand were omitted leaving three groups of clay, silt and sand as follows:

1. Clay - 0.05um to 3.9 um
2. Silt - 4um to 62.5um
3. Sand - 63um to 878um

3.2.8 Conductivity

Salinity of soil and standing water was measured with an Oakton hand held electrical conductivity meter with automatic temperature compensation providing readings in millisiemens (ms) corrected to 25°C. *Insitu* measurements were made in open water and down pipes to the water table. Soil salinity was obtained using a 1:5 soil to water solution following the methodology of Rayment and Higginson (1992). A 10g sample of air dry <2mm sieved soil and 50ml distilled water was mechanically shaken for 1 hour then left to settle for 30 minutes before measurement. Conductivity was measured by gently raising and lowering the conductivity cell in the supernatant without disturbing the soil. Electrical conductivity at 25°C ms multiplied by 0.34 gives an approximation of soluble salt within a solution (Rayment and Higginson 1992).

3.2.9 pH

Measurements of pH were taken at the same time as conductivity in the 1:5 mixture of soil to water using a Hamilton flushtrode pH meter. The methodology in Rayment and Higginson (1992) was followed using a 1:5 soil to water suspension at 25°C. After shaking for one hour the solution was measured ensuring the pH probe was well immersed.

3.2.10 Climate

Daily precipitation and temperature readings for 1993 to 1997 were obtained from Ardmore Airport which is situated approximately 30km north of Miranda. This is the closest climate station to Miranda and Kaiaua, and is located in a similar coastal environment. The distance from Ardmore airport and the orographic effect of the Hunua ranges may have prevented closely correlated daily readings, however, overall climate trends are well correlated.

3.2.11 Soil nitrogen

Soil samples were tested in October for ammonium, nitrate and mineralizable nitrogen. In addition each plot was analysed for organic matter and four were tested for total nitrogen. The latter two tests were carried out by R.J. Hill Laboratories Ltd. in December 1997.

Available nitrogen in soils is that present in forms, concentrations and spatial position that allows utilisation by plants growing in the soil. Most plant species can effectively use either ammonium or nitrate but some species use ammonium preferentially (Bundy and Meisinger 1994). Nitrogen availability indices attempt to estimate the amount of available N released from the soil under specific conditions and can be divided into biological and chemical tests (Keeney 1982). Biological tests generally involve short term incubation under either aerobic or anaerobic conditions. Highly significant relationships have been reported for incubations that provide a relative measure of the soils ability to release nitrogen for plant growth (Keeney 1982). Anaerobic incubation tests have advantages over aerobic tests in that (i) only ammonium need be measured (ii) problems with optimal water content during incubation is omitted (iii) more mineralizable nitrogen is produced in a given time period, and (iv) higher temperatures can be used speeding up mineralization (Keeney 1982). Mineralizable nitrogen availability is normally closely related to total soil nitrogen and soil organic matter. The following biological index technique is simple, requiring basic chemicals and equipment, and has been proven to give a good prediction of soil nitrogen availability (Keeney 1982).

Ammonium-Nitrogen Production Under Waterlogged Conditions.

This technique involves the estimation of available nitrogen from ammonium produced under waterlogged conditions. The technique was developed by Waring and Bremmer (1964) and procedures were elaborated by Bundy and Meisinger (1994). A 10g subsample of field moist soil was shaken on an orbital shaker for one hour in 25ml of 4M KCL. The solution was then filtered through Whatman number 42 filter paper and the extract frozen until analysis through an autoanalyzer. A further 10g subsample of field moist soil was placed into a 16x150mm test tube with 12.5 ± 0.1ml of distilled water, stoppered and incubated at 40°C for 7 days. The solution was then briefly shaken and washed into an Erlenmeyer flask facilitated with 12 ± 0.1ml of 4 M KCL and mechanically shaken for 1hr. The solution was then filtered through Whatman number 42 filter paper. The extract at this stage was frozen until analysis through an autoanalyzer for ammonium and nitrate. Available nitrogen was calculated as the difference between the concentrations of NH4 in the incubated and unincubated sample. Results obtained were corrected for soil water content. Using bulk density data allowed results to be calculated to a volume basis of ug/cm^3 better representing that which is available to plants (Rowell 1994).

3.2.12 Salinity

Carex divisa (Divided sedge) is the most abundant plant species at Miranda second only to *Sarcocornia quinqueflora* (Merrett and Clarkson 1997). It is found growing in waterlogged areas of low salinity, but also extends down amongst *Selliera* and *Samolus* in isolated areas and occurs less often on dry shell banks. At present *C. divisa* is controlled by grazing to prevent pure swards developing and overtopping other species. In order to predict more closely its invasive potential and possible range into the salt marsh communities its salinity tolerance was studied *in vitro*. Included in this experiment were species assessed as potential competitors of *C. divisa* that could permanently displace it once they have been established. The species selected included *Bolboschoenus caldwellii* which grows in pure stands amongst *C. divisa* swards in waterlogged freshwater sites, *Leptocarpus similis* grows in two isolated clumps at Miranda and possibly its range has been reduced by *C. divisa* invasion or trampling as it is normally abundant in salt marshes (Wardle 1991). Some seedlings of *Leptospernum scoparium* were also tested as a potential competitor as it grows in waterlogged substrates and can tolerate relatively high salinities (Johnson and Brooke 1989).

Salinity Tolerance Methodology

The salinity experiment described closely follows the methodology used by Partridge and Wilson (1987) of Otago salt marsh species salinity tolerances. The main difference apparent is the lack of a replicate test in the following season to confirm and enlarge on the first salinity values obtained and to provide a statistical comparison. Three plant species, *C. divisa, B. caldwellii* and *L. similis* were collected from Miranda. Seedlings of *L. scoparium* were obtained from a commercial garden centre as no specimens were found in the field. Plants were washed to remove soil, divided into individual stems each with a root segment of 3-4cm and grown in quarter strength Hewitts nutrient solution (Hewitt 1966) until the plants developed water roots and appeared healthy.

Each species was divided into four class sizes by weight and height and half were randomly chosen to be oven dried; this was the first harvest. The remaining plants were grown in plastic 4L containers at differing salinity concentrations. One plant of each class size was grown in each container. Concentrations of salinity were set in order to identify the upper limit of tolerance for each species. Plants were held around their stems by rubber washers and protruded through holes in the lids of the containers. The stems of *L. similis* were too thin and had to be supported by their rhizomes with smaller pots held within the 4L containers. To a full strength Hewitt's nutrient solution of 2L was added differing quantities of sodium chloride in solution. The remaining volume was made up to 4L with distilled water to obtain a half strength solution at the correct salinity concentration in each container. Containers were aerated and held in a glasshouse with a regulated air temperature (see Fig. 3.1).

Solutions were changed every 10 days or less as the plants grew larger. The second harvest took place after 11 weeks of growth except for *B. caldwellii* which was harvested at 10 weeks due to the size it had attained which began to restrict its root growth. Plant survival was recorded and the plants washed in distilled water to remove excreted salt before being oven dried at 80°C to a constant weight.

Plant dry weights were calculated and totalled for the four plants in each container including dead plant material. Some decay took place but as Partridge and Wilson (1987) noticed in their study this was reduced in the more saline solutions. Relative growth rates were calculated following Wilson *et al* (1996) using the standard formula:

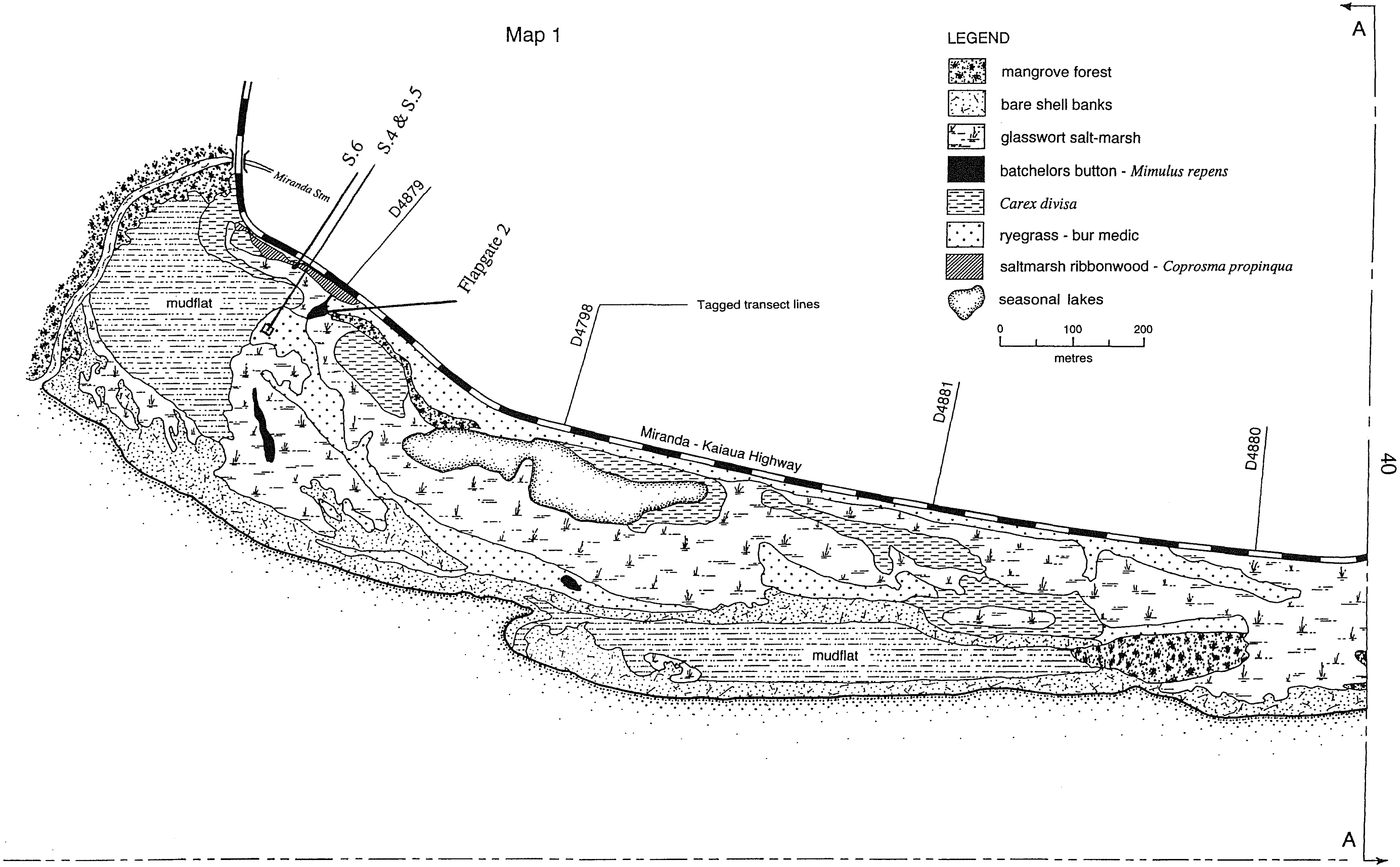
$$\frac{\text{Log e(weight harvest 2)-Log e(weight harvest 1)}}{\text{time}}$$

Final weights were used to determine optimal, half and zero growth parameters and to compare salt tolerances following Partridge and Wilson (1987). Relative growth rates were used by Wilson *et al* (1996) to determine their half and zero salinity tolerances.

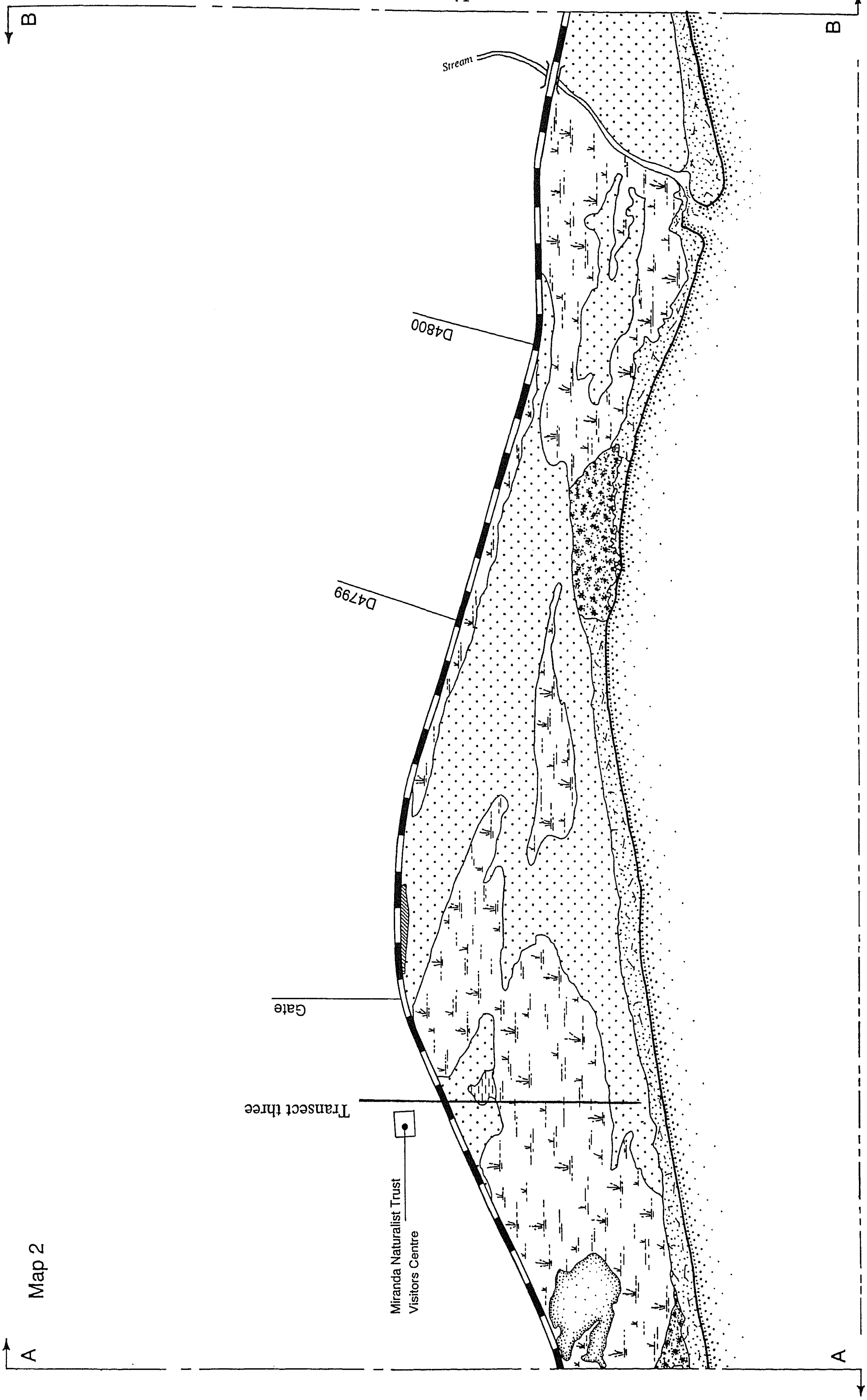
Fig. 3.1. Glasshouse set up with containers of differing salinity. Chlorosis in the leaves of *B. caldwellii* can be seen in two containers of lower salinity.

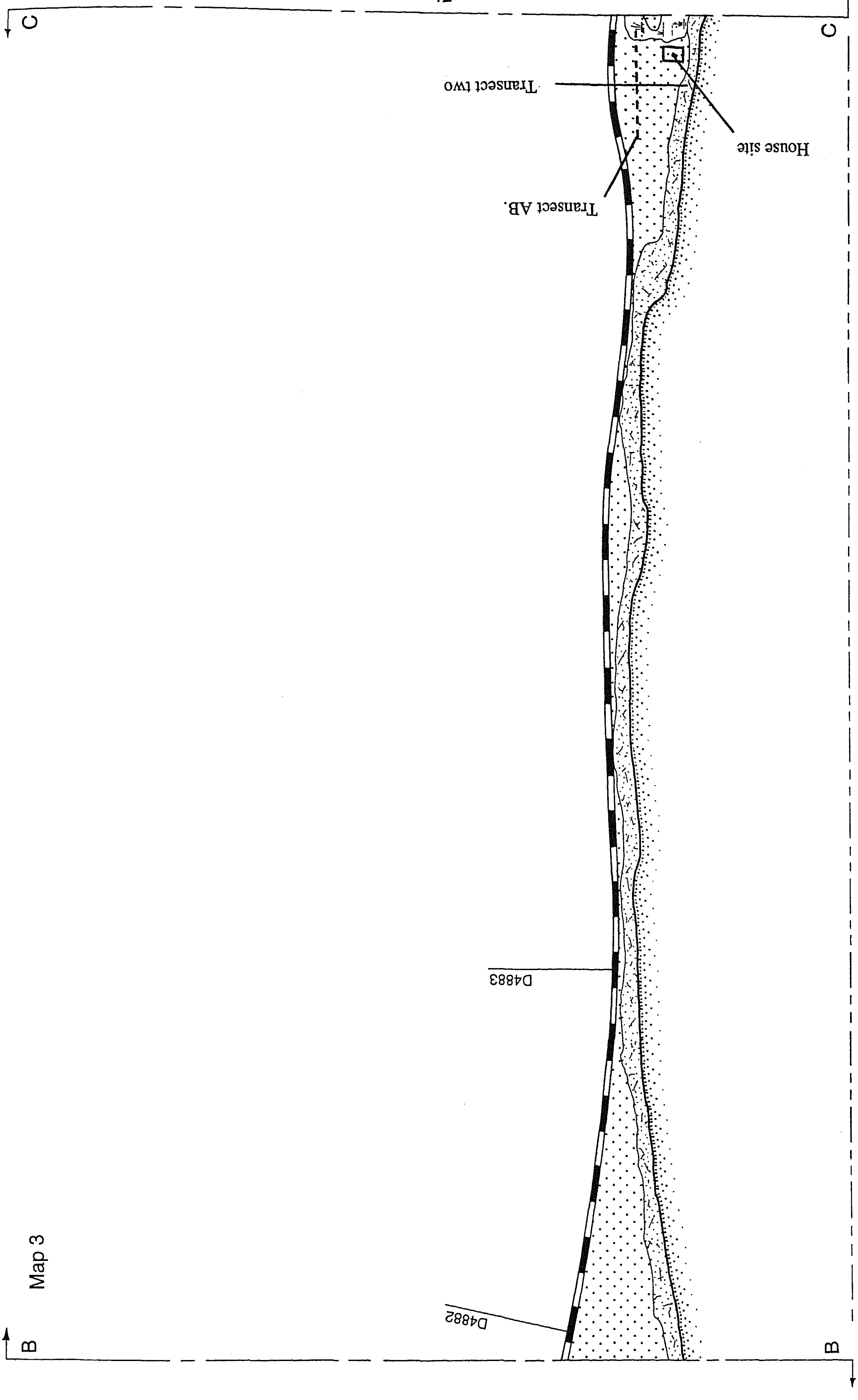
3.2.13 Conclusion

The above discussion describes the methodology of measuring eleven critical factors for establishing, maintaining or restoring wetlands. The next chapter presents the results of a vegetation survey at Miranda wetland, the subject of this study.



Vegetation Communities at Miranda Wetland
Map showing locations of transect lines, select plots, flap gates and house site


Map 2
A
B
Stream
D4800
D4799
Gate
Transect three
Miranda Naturalist Trust
Visitors Centre
A
B


Map 3
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House site
Transect AB.
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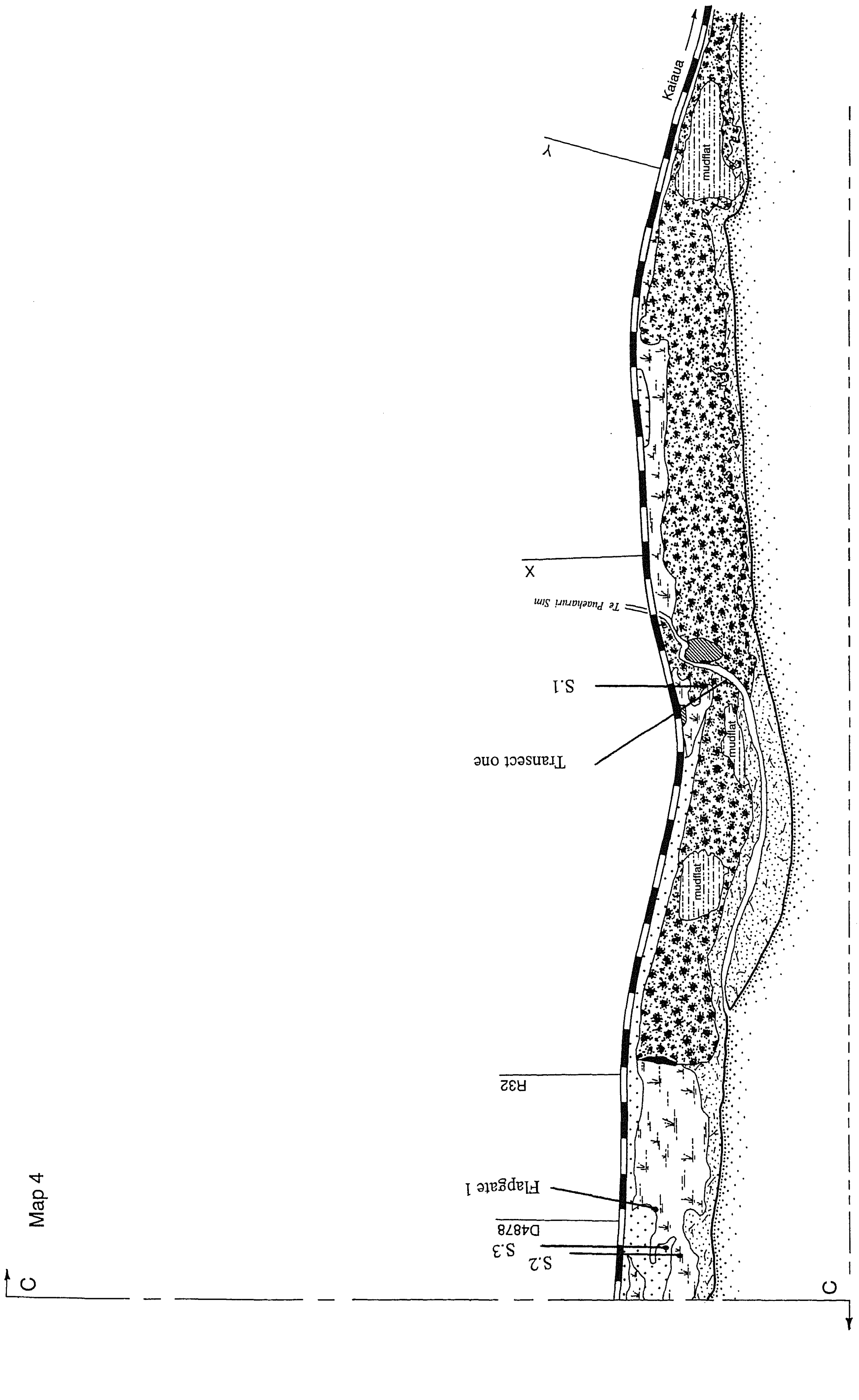
Map 4
Kaiaua
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mudflat
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Flapgate I
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Chapter Four

Results.

4.1 Vegetation Survey.

The vegetation survey worked well in the low growing salt marsh vegetation. However, pasture sites took longer to record especially in the ungrazed plots that had a high species diversity. The wide sampling frame of $5cm^3$ recorded several species at a time especially at ground level where intertwined growth of clovers and grasses required painstaking work to carefully identify each species. Vegetation on the shell banks of Transect 3 dried up more rapidly and earlier in the year than expected due to higher than average temperatures. Where possible, dead plants on the shell banks were still measured for their structural and cover values but are not representative of early summer values.

For each plot the total number of recordings at every height for each species was summed, providing the biomass index for each species at that plot. The data was put into a matrix of plots (objects) against species (attributes). Cluster analysis was performed using a PATN computer software package (Belbin 1995). PATN contains a set of programs able to process data containing a high proportion of zeros which occurs, for example, when species are not present at a plot. Species summed height frequency values were standardised using the TRND option as the data values covered the full frequency range in PATN of 0-999. A dendrogram was produced of plots most similar to each other in species composition and summed height frequency value that enabled an ordered table to be constructed of plots (see Fig 4.1). Due to the diverse range of vegetation types sampled eight separate groups were formed, but at least two plots were present in each group.

The table reveals greater species diversity following decreasing salinity and increasing elevation. Each community is categorised after the communities identified in the wider survey of 88 plots carried out by the Waikato Botanical Society and compiled by Merrett and Clarkson (1997).

Their study was used to group plots S.2 and S.3 together as a *Parapholis incurva* and *Plantago coronopifolia* community. Some communities listed by Merrett and Clarkson were not covered in this study, namely, *Sarcocornia-Suaeda*, *Selliera-Samolus*, *Cotula-Mimulus*, and dry *C. divisa*. A community not covered by Merrett and Clarkson but found in this survey is a pure *Sarcocornia* sward. The *Sarcocornia-Samolus* community mentioned by Merret and Clarkson (1997) is quite diverse and the particular representative plots in this survey form subgroup of the possible species able to be present. The diversity of this particular band of vegetation is highlighted by the four subgroups assigned to it by Merrett and Clarkson (1997).

	Mangrove forest			Sarcocornia			Sarcocornia-Juncus				Plagianthus-Stipa				Wet Carex				Rye grass-bur medic		Rye grass-bur medic dry				
Species	1.2	1.3	1.5	1.4	3.4	3.7	3.2	3.5	3.6	3.3	1.1	4.1	4.4	4.6	2.1	4.2	4.3	4.5	2.2	2.3	2.4	3.1	3.8	3.9	**Total sp. freq.**
Agrostis stolonifera										4					10		48		222	6		3			293
Allium vineale											6														6
Anagallis arvensis																			2	3					5
Apium prostratum												44													44
Aster subulatus																	22								22
Atriplex prostrata																	2	42							44
Avena fatua														12											12
Avicennia resinifera	248	400	878									214													1740
Bidens sp.																			1						1
Briza minor														6				5					1		12
Bromus diandrus											4										98			21	123
Bromus hordaceous																					2	150	41	3	196
Calstegia soldanella																							32		32
Carex divisa										4			740		1026	705	49	373							2897
Carduus tenuifolius																			3						3
Catapodium rigidum																					5	71	37	28	141
Cerastium glomeratus																		1							1
Crepis capillaris																						92		1	93
Cynodon dactylon																	8				32				40
Daucus carrota																					1				1
Echium vulgare																							12		12
Erodium cicutarium											6														6
Festuca arundinacea											38	36	181	263			761	6	9	2	7				1303
Foeniculum vulgare																						17			17
Galium divaricatum																								5	5
Geranium molle																								2	2
Helmintia echioides																				16					16
Holcus lanatus																				77					77
Hypochaeris radicata																			1		13			17	31
Isolepis cernua															16		2								18
Juncus maritimus							238	787	190	42															1257
Juncus sp.															16			4	10	84		5			119
Lagarus ovatus																					159		1		160
Linum bienne																							18	5	23
Lolium perrene																		5	576	1185		397	209	2	2374
Lythrum hyssopifolia																		3							3
Medicargo lupulina																		9			390	86	61	14	560
Medicargo nigra														1			22	53	34	33		9	91	82	325
Melilotus indica														3			38							2	43
Parapholis incurva										14						96		9							119
Parmelia sp.			5								19	28													52
Parapholis strigosa										16							76	216	4						312
Picris echoides																							17	21	38
Plantago coronopus										53							522	37					1		613
Plagianthus divaricatus											857	348													1205
Plantago lanceolata																			2	85	2	1	22	17	129
Poa pratensis																	3	31	98	121					253
Polypogon monspliensis															22	20	22	54	83	21					222
Portulaca oleracea																							28		28
Ramalina sp.		31	48								83	186													348
Ranunculus repens																			14	20					34
Rumex crispus													5						73	31					109
Rumex pulcher																			31	157					188
Rumex sp.															8				13						21
Samolus repens								531	424	59		175				34									1223
Sarcocornia quinqueflora				331	154	182	431	341	201	233	239	195	117	97				2							2523
Sedum arce																						8	3	1	12
Selliera radicans										30			2			90	10	1							133
Sonchus asper																		3			73			10	86
Sonchus olearus																		2	2					1	5
Spergularia media																3									3
Sporobolus africanus																						7			7
Stipa stipoides											555	258		764											1577
Suaeda novae zealandiae												31						1							32
Taraxicum officinale																				1					1
Teloschistes sp.		25	24								42	39													130
Trifolium dubium																						3	11		14
Trifolium fragiferum																			1						1
Trifolium repens																			42	189					231
Trifolium resupinatum																		17	1			22			40
Trifolium scabrum																	14		5		76	13	36	12	156
Usnea sp.			140																						140
Veronica arvensis																		1							1
Vulpia bromoides																			1		61	62	13	267	404
Xanthoria sp.		14	7								5														26

Table 4.1. Ordered table of plots grouped into vegetation types by species frequency and type. The community titles are adapted from Merrett and Clarkson (1997).

Plots were displayed using an ordination which grouped plots by degree of similarity, those most similar are closest together (see Fig 4.7b). The ordination correlates well with the groupings produced in the dendrogram and better illustrates the degree of similarity. The pure swards of *Sarcocornia* and two plots of wet ryegrass-bur medic are strongly similar. The associated species are all different from eachother in the *C. divisa* dominated plots, resulting in a looser grouping. The exclusion plot S.4 is grouped into the *Plagianthus-Stipa* community because of to the presence of *Sarcocornia* and *Festuca arundinacea.* Mangrove and *Plagianthus* plots were grouped beside eachother because of their similarity in lichen species. This demonstrates a weakness in the data collected in that the biomass of lichens was over represented. Lichens covered the mangroves and *P. divaricatus,* and the presence and consistent association of the different lichen species pulled *P. divaricatus* and the mangrove plots closer together. Due to abrupt changes in elevation, more than one community was covered by some plots, reducing their compatibility. For example, plot 3.3 had a *Selliera-Parapholis* community and *Sarcocornia-Samolus* community with shell and mud substrates respectively. Similarly, plots 1.1 and S.1 covered raised ridges and mudflat containing *Plagianthus* and *Sarcoconia* respectively. Community composition was complicated through fine scale changes in microtopography, substrate characteristics and freshwater inputs. A vegetation sequence could be truncated or more subtly varied through these differences. Short term establishment of some species occured in areas otherwise out of their range. Cultural impacts also changed the natural composition. Cattle have opened up establishment sites, and increased pugging and stopbanks has allowed glycophytic vegetation to establish.

4.2 Structural Characteristics of Communities.

Height frequency values for each species in each plot were displayed on a separate bar graph. A series of bar graphs were constructed for every plot and selected plots used to represent a certain vegetation type (see Fig. 4.2 a-d). Species with a summed height frequency biomass index of 40 or above were displayed. Other species present in the plot but below this amount were listed beneath with their individual summed height frequency value. All eight vegetation types are displayed. Any single plant whose size could not be covered by one plot did not produce a representative structural pattern for their species and growth form. Two species that fit this category are the mangrove and *P. divaricatus*. In some plots, half of a large plant would be present and consequently the structural pattern produced represents only a side portion of a plant, an example of this occurred in plot S.1 with *P. divaricatus* and a mangrove plant (see Fig 4.2d). Plots containing a whole plant of either mangrove or *P. divaricatus* produced a more realistic height frequency distribution but as only one individual was sampled the result is not representative of the other individuals making up the population in the area, for example plots 1.1 and 1.2 (see Fig. 4.2a).

The time it takes to sample 100 points along a transect line has been estimated by Scott (1965) to be approximately 1 hour in open, low vegetation and 4 hours for dense scrub. However at Miranda for some pasture sites with diverse species assemblages and plots containing dense *Plagianthus divaricatus* and associated lichens up to 8 hours were required for accurate measurement. Difficulties in carrying out the survey included obstructing branches that caused displacement of sampling points. Vegetation above 2m could only be measured approximately by sight against the pole without the sampling cup, this was carried out in the tall mangrove plot.

A limitation of displaying results in a bar graph is that gaps in the foliage are not readily discernible as all values are grouped about the central axis. The $5cm^3$ sampling cup did not pick up gaps smaller than its width, such as were evident around the base of *C. divisa* stems under its dense canopy. Grazed plots, particularly the dry plot 3.8, had little height differences and were only useful for conveying cover values.

Three mangrove height groupings can be made at Miranda: (1) scattered indiviuals on the mudflats with a shorter more rounded appearance of 1-1.5m; (2) those of the mangrove forest with a canopy of 2-3m; and, (3) tall mangroves on the verge of tidal creeks attaining 3-3.5m. The associated lichen distribution is limited in height to older portions of mangove and *P. divaricatus* as new growth is only slowly colonised. The tide height reduces their basal extent to approximately 35cm above the ground.

The bar graphs of *S. quinqueflora* are variable with a widespread low growth in plot 1.4 which contained dry scraggly growth to plot 3.7 that has less cover but more lush, taller vegetation, possibly due to differences in inundation periods. Greater height was obtained by *S. quinqueflora* when it grew in dense pure swards, or where other supporting vegetation was present such as in plots 3.5, S.4 and the *Plagianthus-Stipa* communities. One specimen attained the height of 1m with the support of a nearby fence and *Plagianthus* bush near plot S.6.

In the plots where *C. divisa* attained a closed canopy species, diversity decreased dramatically. When stems of *C. divisa* were fully extended in the lush growth of plot 2.1 they measured up to 1m in height, but wind reduced this particularly in plot S.4. The under growth of closed canopy *C. divisa* generally consisted of species that could penetrate the canopy and included *P. monspliensis* and *Rumex* sp. at plot 2.1 and *F. arundinacea* in plot S.4. *Sarcocornia* was able to reach a greater height in plot S.4 especially over wind thrown areas but was still contained within the canopy. *Selliera* turfs invaded by *C. divisa* were thinned out under its dense canopy and remaining individuals were taller by 5cm which is half again their normal height (see Fig. 4.3d). The main competitive advantage of *C. divisa* is its shade tolerance and ability to shade out halophytes that require high light levels. The grazed plot of S.5 had a far greater species diversity than plot S.4 or other *C. divisa* dominated plots. The survey was taken a few weeks after the cattle had been removed in December and the rapid regrowth of *C. divisa* was already noticable.

An interesting structural pattern exists in the *Plagianthus-Stipa* community types. *Stipa* dominates the canopy and its dead component reduces establishment sites around its base and increases surface shading. *S. quinqueflora* was found around the edge of *Stipa* and was supported to a certain extent by the surrounding vegetation. The canopies of both *Stipa* and *Plagianthus* reduced any growth beneath them. Open patches on sites adjacent to plots S.1 and 1.1 were colonised by *Sarcoconia*, *Samolus*, *Suaeda* and *Selliera*. Shaded sites reduced evaporation and hence salinity and water stress so these sites had more lush growth in the low growing species.

The pasture sites dried up prematurely compared with the same time in December 1996. Plants were stunted and most were dead. Those that continued to flourish were *Calstegia soldanella*, *Foeniculum vulgare* and two succulents *Portulaca oleracea* and *Sedum acre*. Other plants surviving the dry conditions were *Picris echoides*, *Plantago lanceolata* and *Echium vulgare* though many *Echium* dried up. *Echium vulgare* is a striking part of the pasture community in the summer and plants are nearly always situated in a strip along the tops of the shell rises in the field. This may be a reflection of micro-environmental factors such as particle size, organic matter or moisture content. The plot that closest resembles this habitat is 3.8 which had two *E. vulgare* plants in its border. In comparision to the other shellbank plots no factor stands out as different except a slightly higher nitrate and sand content for plot 3.8.

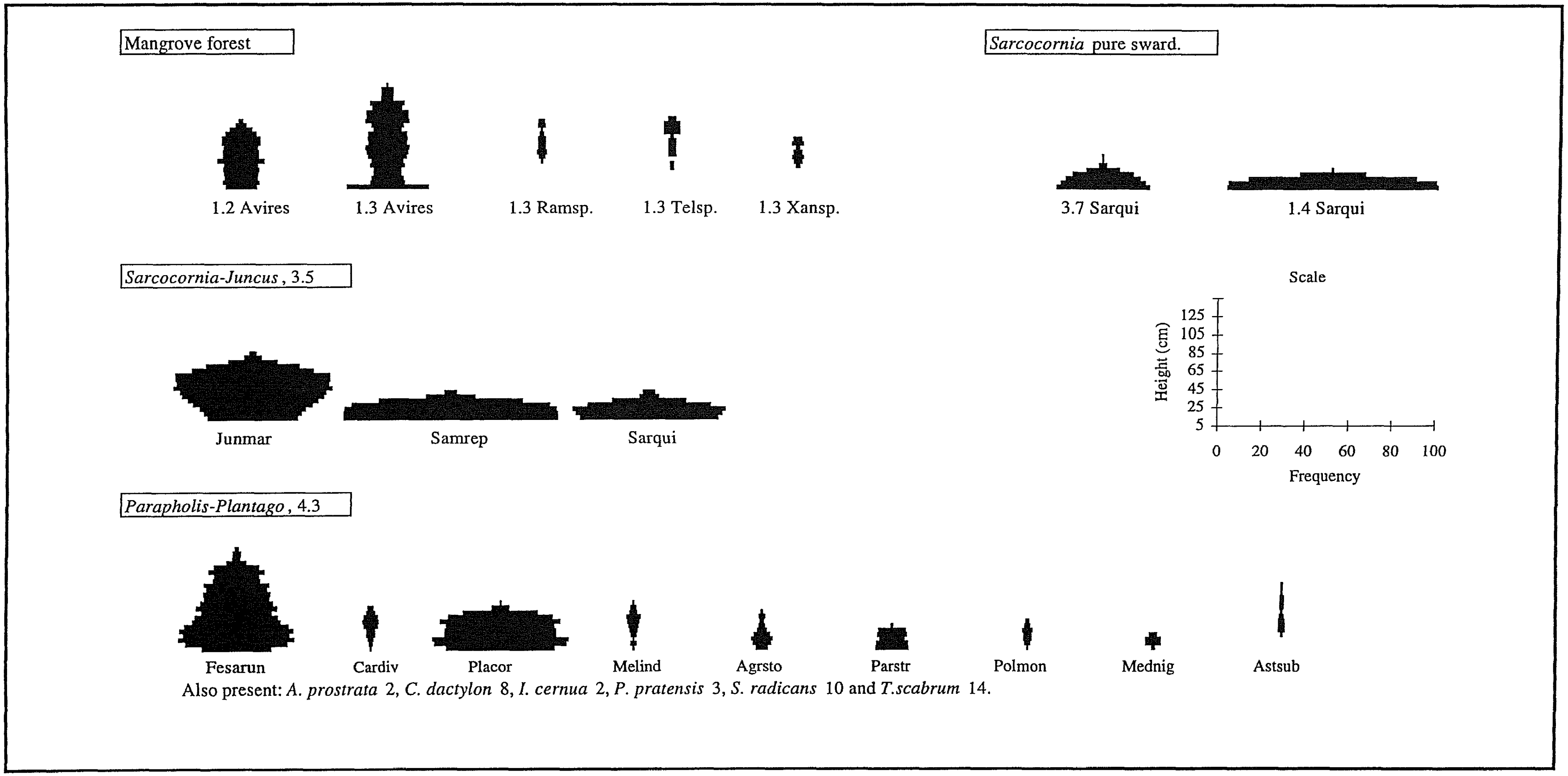

Figure 4.2a. Height frequency histograms of four lower-marsh communities.

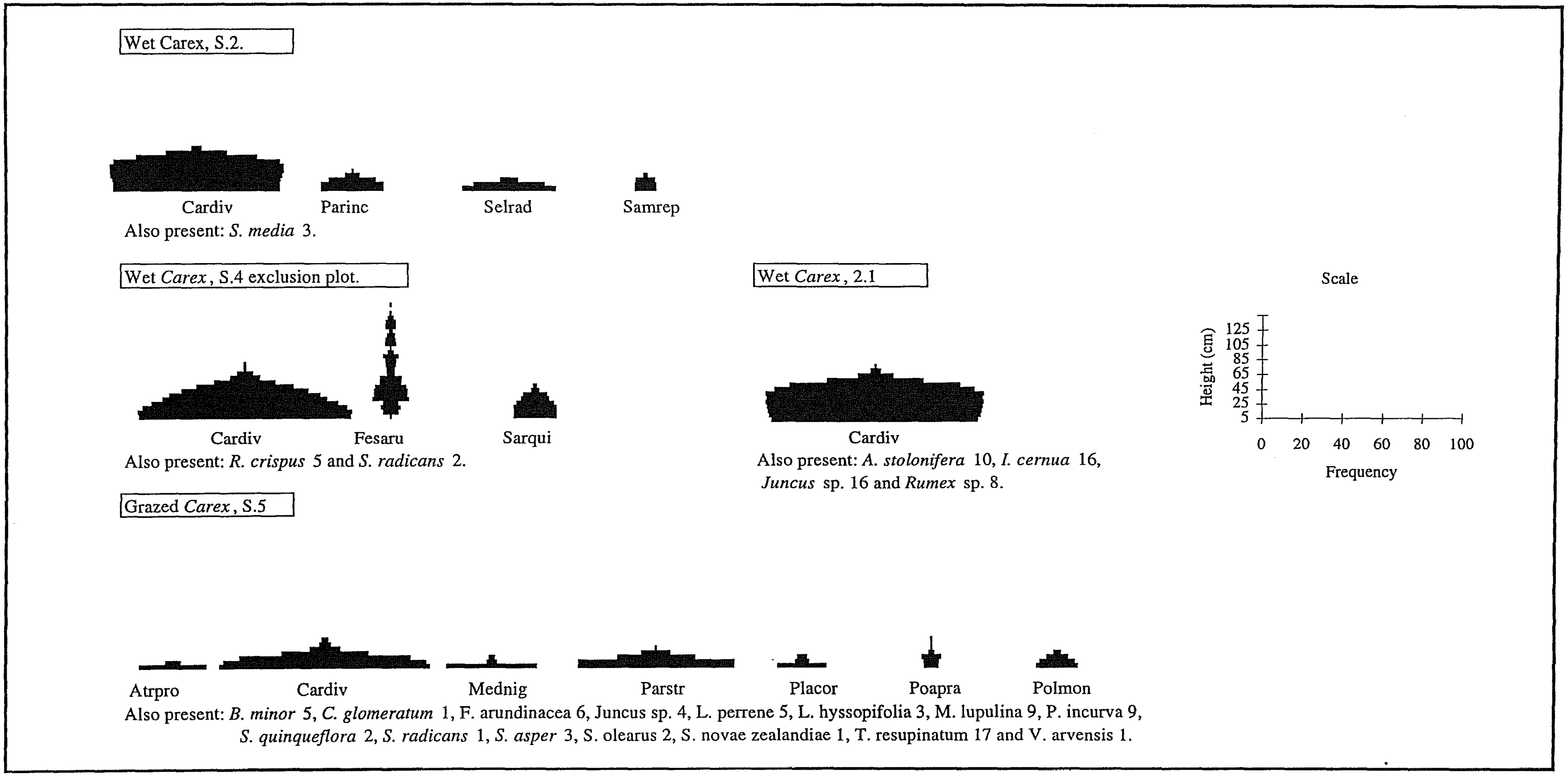

Figure 4.2b. Height frequency histograms of four *C.divsa* plots.

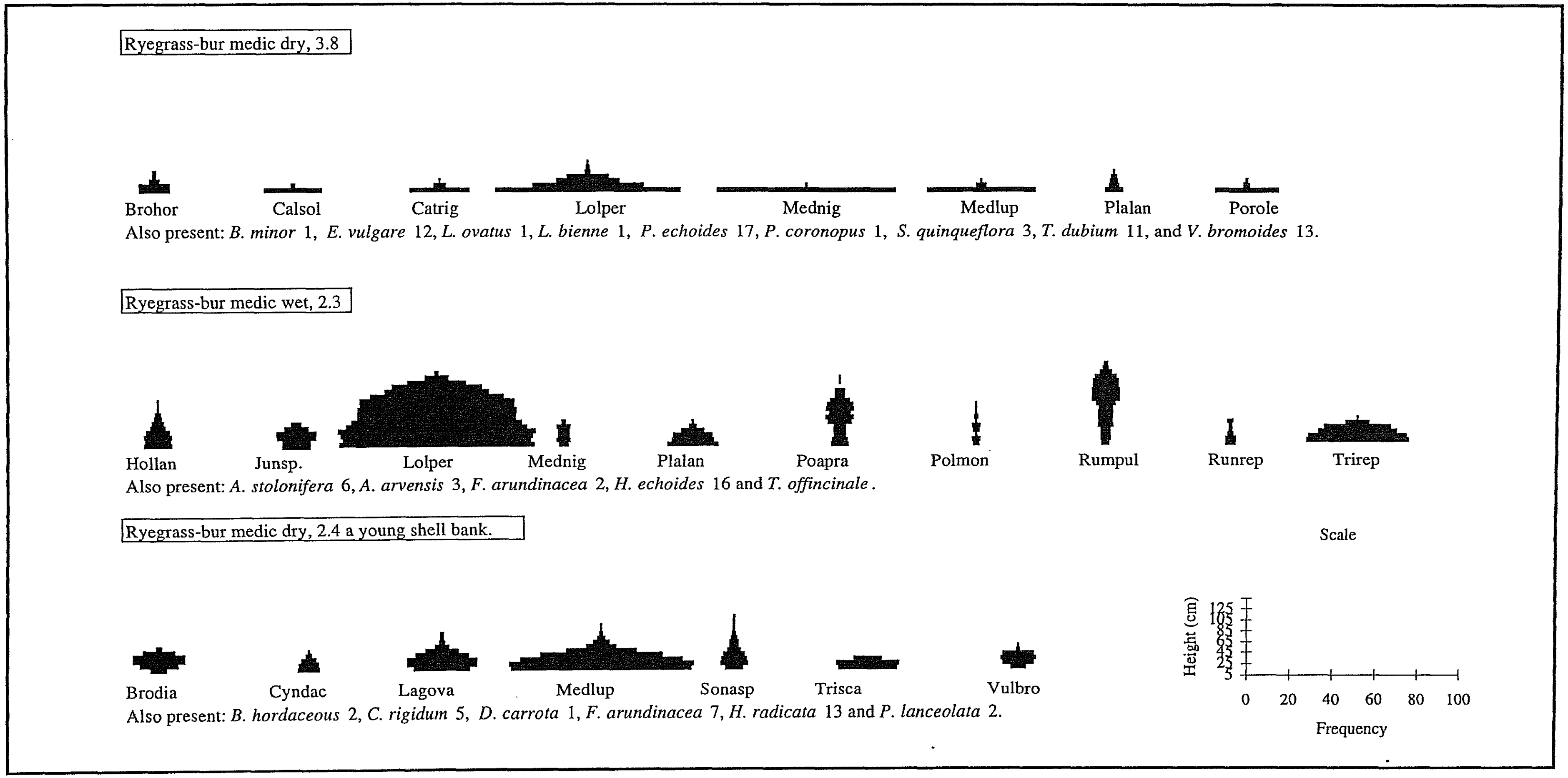

Figure 4.2c. Height frequency histograms of rye-grass-bur medic communities.

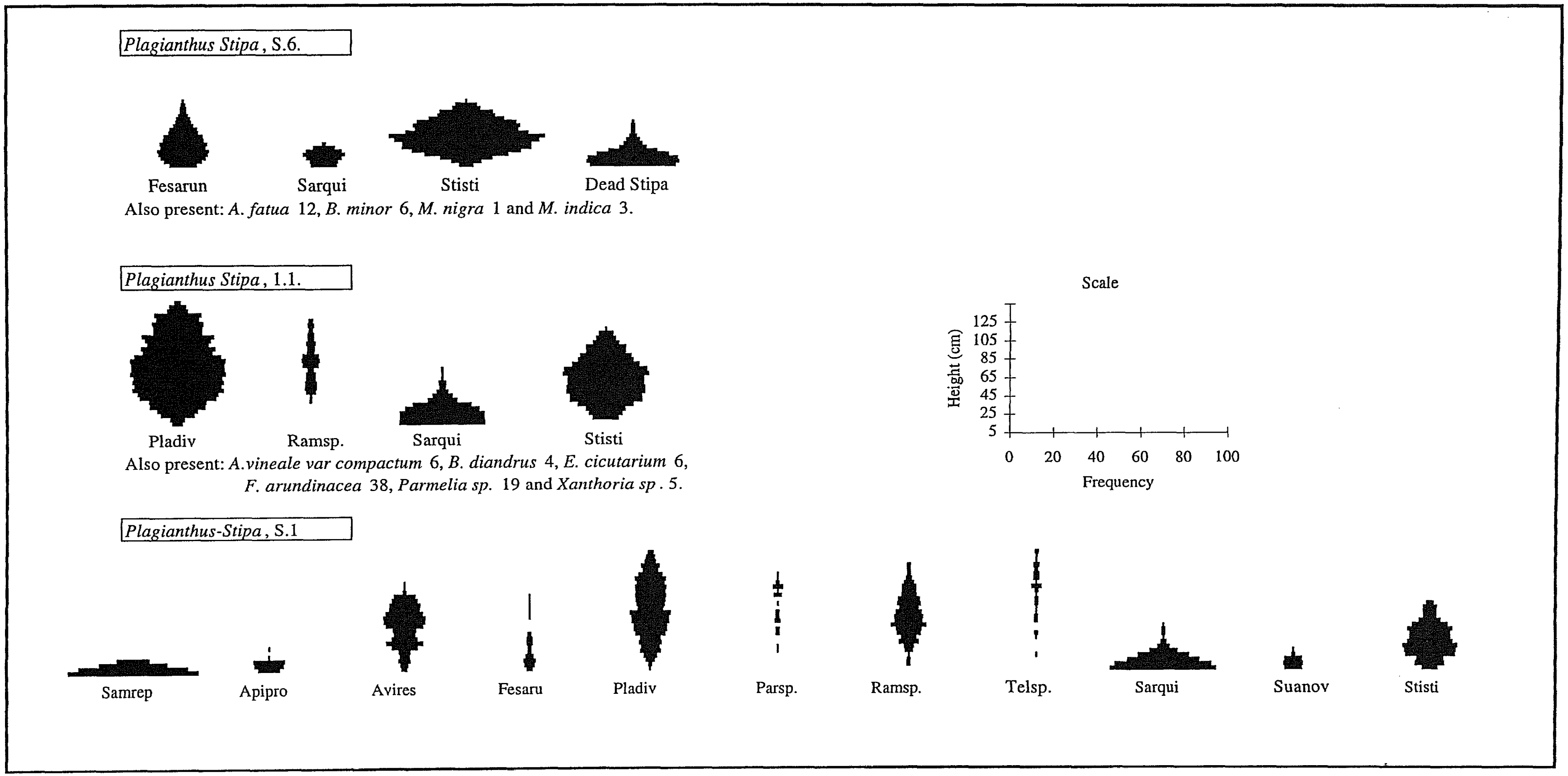

Figure 4.2d. Height frequency histograms of *Plagianthus-Stipa* communities.

4.3 Evironmental Factors.

4.3.1 Sampling Variability.

Measurements in each plot varied considerably due to abrupt changes within plots. For example, plot 3.3 contained shell and clay substrates. The environmental results for the plots, where displayed, are grouped by the vegetation types discovered in the survey described earlier. In this way changes in environmental factor values between different vegetation types can be highlighted. Miranda salt marsh is highly modified by human impacts including stopbanks, grazing, oversowing in grasses and shell mining. Less obvious modifications from the past are the compaction of soils, irrigation, freshwater inputs from water troughs, burning and ploughing. Hence a sample site may not present a natural pattern.

4.3.2 Elevation.

As expected the plot elevations were strongly correlated to vegetation type with a progressive rise from salt flat species to more glycophytic vegetation on the rises. Plot elevations ranged from a *C. divisa* plot at 1.44m above Mean Sea Level (MSL) to a shell bank plot of 2.7m above MSL. Transect data ranged from 0.6m below MSL in a drain to 2.5m above MSL on a shell bank. The plots containing *C. divisa* (2.1, 2.2 and 2.3) were all below the elevations of transect 1 plots that contained lower marsh species. Stopbanks protect these sites from sea water entry. Likewise for transects A-B and C-D which are all below 1.5m MSL. Transect A-B follows an old water course with decreasing elevation to a height of 0.8m above MSL. Transect C-D covers an area of *Sarcocornia*, *Samolus* and *Selliera* impounded from the tide that is 15-20cm lower than the mud flat on the other side of the stopbank. The tidal ranges for the Firth of Thames in metres are 3.3 Mean High Water Springs, 2.9 Mean High Water Neap, 0.9 Mean Low Water Neap, 0.5 Mean Low Water Springs and 1.9 MSL.

4.3.3 Water table.

The average water table of the study area was 1.24m above MSL, which correlates to levels observed by Bryce (in press). Fluctuations were caused by tidal cycles; levels measured on 19 October 1997 during a spring high tide revealed an increase in water table to a maximum of 1.56m above MSL. The winter months of June to September averaged 1.24m above MSL, which dropped to 1.12 over November to January. Winter values may be lower than normal because of the reduced rainfall over July and August. The salinity of the ground water is important to determine if it can be used in the root zone for plant uptake particularly in drier months (Ward 1967b). Conductivity values of groundwater were between 2.8 and 0.8ms for transect 2. The other plots were above 20ms except for S.3 which consistently trailed its neighbouring plot S.2 by at least 10 ms. Water levels fluctuated with the tide and rainfall reaching 1.63m above MSL on a Spring tide. The salinity was still high in the lower salt marsh and even for plot S.1 and 1.1 containing *Plagianthus*. However, S.3 had a conductivity of 24ms, 10ms below its neighbouring plot. Tides fluctuated the water table and its salinity. The highest value measured was 40ms at 1.1 at 50cm depth. S.2 contained the lowest marsh pipe which had values between 30 to 40ms and a water level of approximately 30cm deep falling to 55cm in December. Transect 2 plots had the highest water table at less than 0.5m deep and never higher than 5ms.

4.3.4 Water content.

The percentage water content of each site was highest in the plots regularly inundated by the tide and lower in the well drained sandy substrates and ridges of higher elevation. All plots showed a decrease into the last summer sample to what would have been even lower values over the summer period (see Fig 4.3). Plot 3.3 demonstrates the effect of contrasting substrates on water content values.

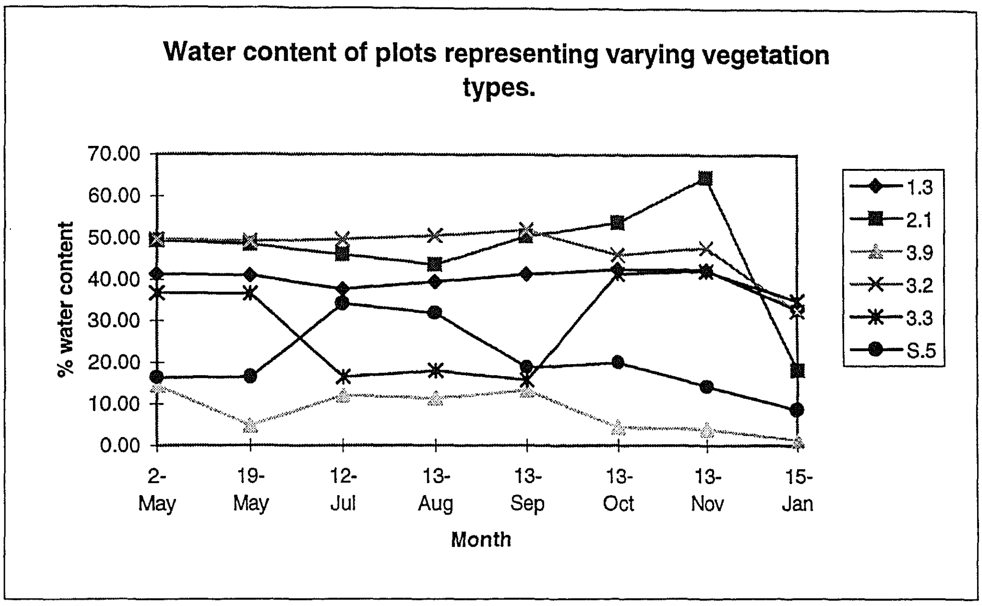

Fig. 4.3. Water content of plots linked with varying vegetation types; 1.3 mangrove, 2.1 wet *C. divisa*, 3.9 shell bank ryegrass-bur medic, 3.2 *Sarcocornia-Juncus*, 3.3 *Sarcocornia* was added to show its variability of shell and clay content and S.5 dry *C. divisa*.

4.3.5 Bulk Density.

Bulk densities were difficult to take as the clays were highly variable depending on water content, and shell material was unconsolidated and difficult to handle. However, there was good agreement between three replicate samples taken a month apart for each site. Clay substrates had the highest bulk densities and shell the lowest; mixtures of these two had intermediate values (see Fig. 4.4).

4.3.6 Particle size.

Plots containing a shell component had a proportion of shell of >1mm diameter of 60-70% by weight. Plot 3.9 had 90% reflecting the recent construction of the shell ridge that it is situated upon. Plot S.6 had finer shell fragments with only a 25% portion greater than 1mm. S.5 had half as much as S.4 with 35%. Plots regularly inundated by the tide where characterised by high clay and silt substrates. Moisture factor was higher in those samples containing a higher clay content.

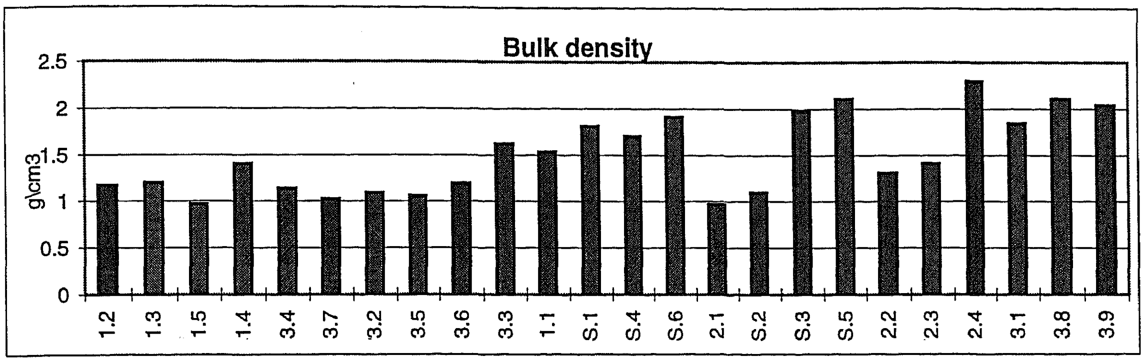

Fig. 4.4. Averaged bulk densities for each plot.

4.3.7 Conductivity.

Conductivity was highest in the plots affected by the tide (Fig 4.5). The well drained shell ridges had very low salinity and variance. Plots that experienced high salinity also had high salinity variance as rainfall abruptly dropped salinity at all the sites. The plots revealed a trend of higher salinity towards tidal channels. Plot 3.2 contrasts strikingly with other plots on Transect 3. Possible reasons for its consistently higher conductivities include ponding and evaporation of seawater. Plot 3.3 has lower values as half of the measurements were taken on its shell substrate.

In field investigations, the smaller pools present at Miranda were found to be between 5-8ms and 20 to 30cm deep. Larger pooled water on mud flats open to the tide were measured at 20 ms rising to 36ms towards the inlet for the sea. Two large pools approximately 50cm deep with 1-30cm soft mud at the bottom are situated adjacent and south of transect three. The one on the road side has a conductivty of 8-9ms and the other is 18-26ms reflecting tidal influence. Both pools dried up completely in the summer, and were recharged over night on 21 February 1998 during heavy rainfall (pers. comm. K. Woodley, Miranda Naturalist Trust Manager). A pool is present at Transect 2 which had a conductivity of 5ms in October that dropped to less than 1ms by November.

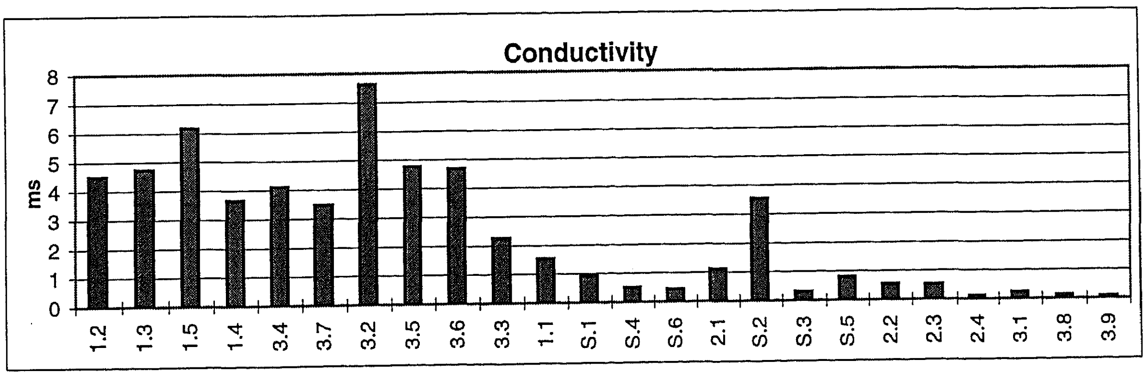

Fig. 4.5 Average conductivity of each plot.

4.3.8 pH.

There was little variation in pH readings. Field tests in ground water during July were just under and above a pH of 7. An exception was plot 3.2 with a pH of 6.4. Soil tests carried out in a 1:5 soil to water solution were more alkaline by half a pH unit compared to results when carried out at a 1:1 ratio. Field tests are almost a pH unit more acidic than laboratory measurements.

4.3.9 Nitrogen.

Shell ridge plots had the lowest nitrogen values and plots with partial shell content were also low. The highest values were connected to the mid-marsh plots of transect three (see Fig 4.6). Mangrove substrates had lower values than the mid-marsh. The last four plots of Transect 1 have very similar ammonium levels, possibly because they are regulated by seawater flooding as are plots 3.2, 3.4 and 3.5. Plot 2.2 is high in ammonium and nitrate values but low in mineralizable nitrogen. Plot 2.1 has very high mineralizable nitrogen but low nitrate and ammonium.

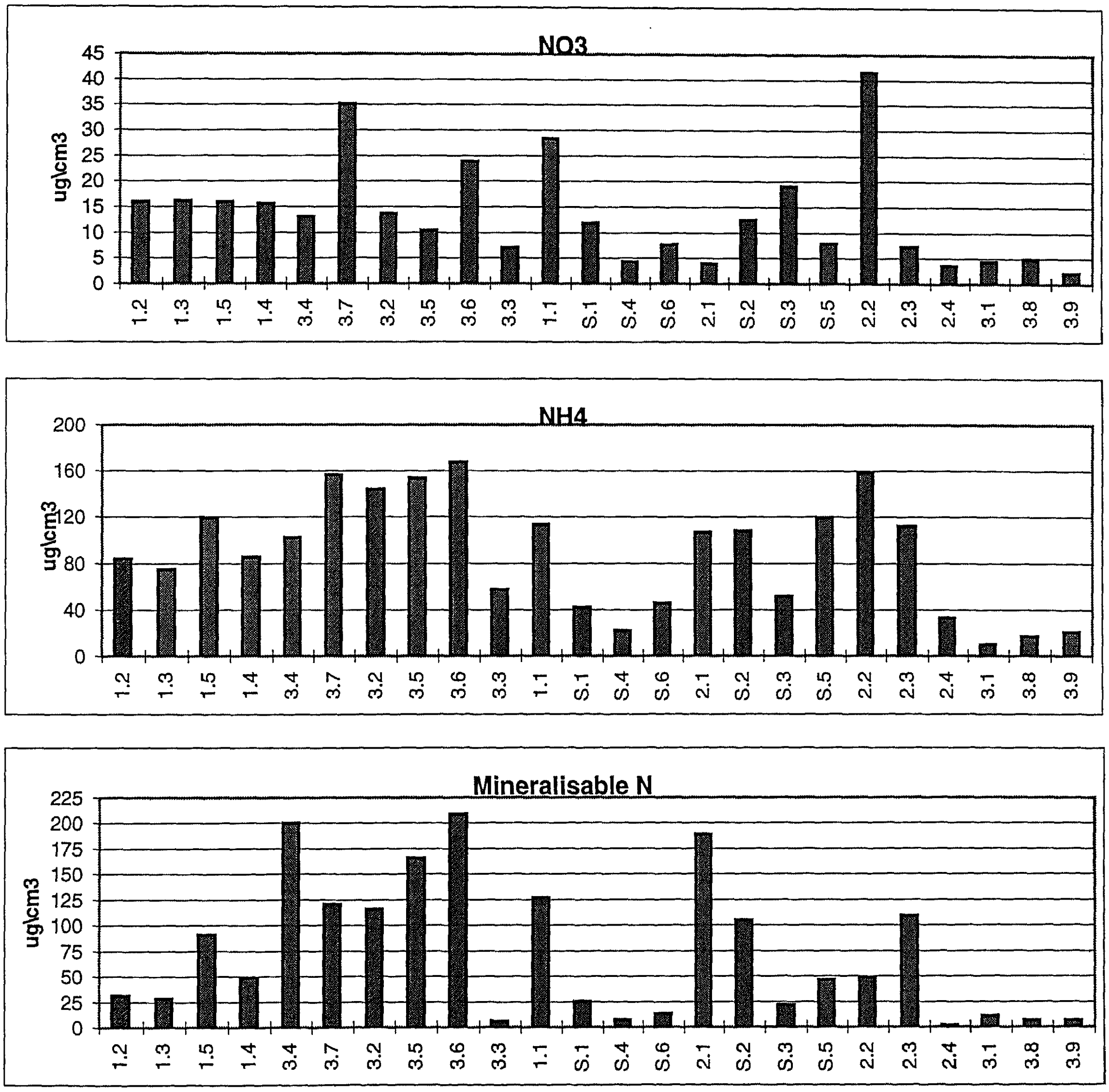

Fig 4.6. Graphs of soil ammonium, nitrate and mineralizable nitrogen results.

4.3.10 Climate.

On 11 January 1997, cyclone Drena combined heavy rainfall and low pressure with a 3.6m Spring high tide causing a storm surge in the southern Firth of Thames (New Zealand Meteorological Service 1997). Seawater crossed the East Coast Road into neighbouring paddocks and past the Miranda Naturalist's Trust. The most recent shell ridge was overtopped and moved inland and fence posts on the lower mud flats were overtopped (pers. comm. David Game, Regional Conservator). The effect on the vegetation was a resetting of the grasses and annuals which dried up and all shell bank species were washed away. The seawater filled the temporary pools, abruptly increasing their salinity.

During the study year El Niño weather conditions predominated in June. El Niño is a term used to describe extensive warming of the central and eastern Pacific ocean leading to a shift in weather conditions for surrounding regions. Generally drier and warmer conditions prevail in Australasia (Bureau of Meteorology 1997). Winter temperatures rose and less rainfall fell particularly in July and August resulting in an "Indian Summer" (see Fig 4.7). Summer temperatures were higher than average and dried out the shell bank vegetation earlier than in the 1996-97 summer period when the Waikato Botanical Society carried out its survey. Hence the structure of the annuals and seasonal values in some environmental variables will not be typical for Miranda wetland.

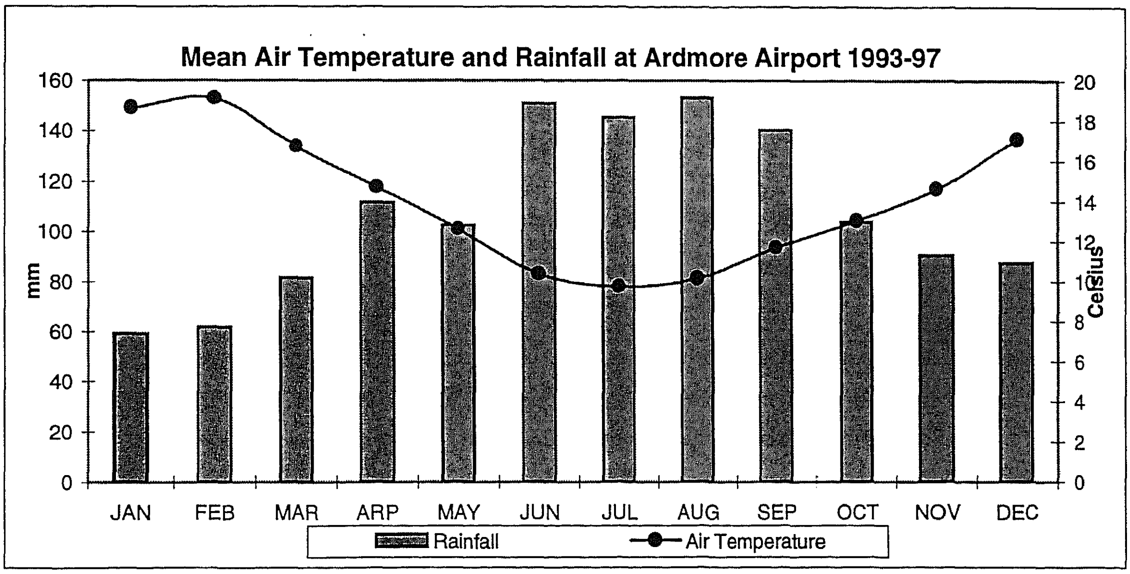

Fig. 4.7. Average rainfall and temperature values at compared to the year 1997.

4.3.11 Salinity Tolerances.

All four species tesyed were able to grow in freshwater, however, *C. divisa* and *B. caldwellii* both showed marked growth reductions in the freshwater solution (see Fig. 4.8). Both species showed chlorosis of the leaves and stem in the two lowest salinity concentrations. *L. scoparium* also had yellowing in its leaves in the weakest salt solution. A possible cause may have been an imbalance in the nutrient solution that was negated in the higher salinity solutions. Elevated iron levels may be competing for uptake sites with other nutrients as there is a large iron component in Hewitt's solution (see Appendix 3). Moog and Janiesch (1989) investigated six *C. divisa* species nutrient requirements in solution culture and suggested Hewitts nutrient solution (1966) as inapproriate as it was developed for high nutrient demanding crop plants. Only very weak nutrient solutions were needed in the *C. divisa* species tested. Species from wetland habitats required more nitrogen, requirements for iron were extremely variable. Moog and Janiesch (1989) also noted that light levels in a greenhouse can be too high for *C. divisa* which can inhabit low light envronments. Alternatively a disease may have been contracted from sap sucking insects which were discovered in large numbers on the roots and stems of *B. caldwellii,* they were sprayed once with insecticide after which the symptoms were somewhat reduced. Therefore maximal growth is expected to occur at 0% salinity and at a higher level than that achieved in the salinities of 0.25 and 0.5% for *C. divisa* and *B. caldwellii* respectively. Such a pattern of a higher salinity requirement for optimum growth is the definition of a 'facultative halophyte' a few of which have been identified (Barbour and Davis 1970). Partridge and Wilson (1987) discovered eight species that required higher salinity for maximum growth one included *Polypogon monspeliensis* that grows alongside *C. divisa* on muddy substrates at Miranda.

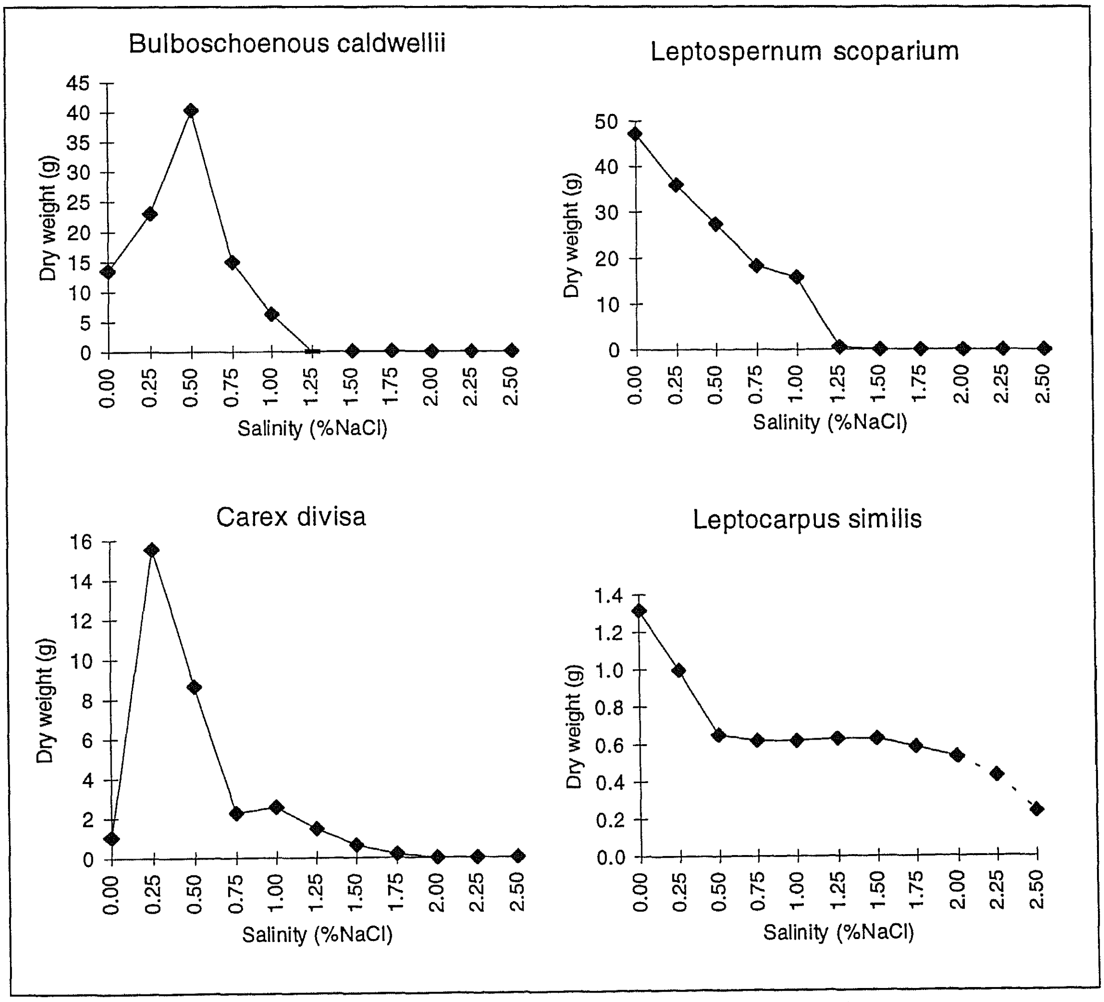

Fig. 4.8. Dry weight increases at each salinity of the four species tested for salinity.

Of the four species *B. caldwellii* had the lowest salt tolerance at less than 1.5%, its maximal growth occurred beyond that of *C. divisa* and dropped sharply at the limit of its range. *C. divisa* drops abruptly also, but then lingered with reduced growth to at least 1.5%. *L. scoparium* had a similar range, its slightly higher value was possibly due to its ability to abscise its leaves which occurred in the two higher salinities. The remaining leaves were green but eventually the plants would have perished at this salinity. The range of *L. scoparium* would be even higher if specialised coastal ecotypes were tested (Wardle 1991). The Waikareo Estuary in Tauranga contains *L. scoparium* specimens growing on slight rises above *Juncus kraussii* and *L. similis* and amongst *Plagianthus* (pers. obs.). *L. scoparium* seems to have its optimum growth at 0% salinity but the 0.25% concentration was not tested and may prove critical in determining its optimum as it did for *C. divisa.* Well beyond the other species tolerances is *L. similis* which also retained its maximum growth at 0% salinity. After an early drop in growth it remains steady until beyond 2% where a slight decrease has begun. Its final limit requires further trials but must be closer to that of *Juncus kraussii* at 3.5% (Partridge and Wilson 1987) which it grows amongst but not to its most seaward extent (Wardle 1991). A second test of these species at salinties to extrapolate or interpolate are required to confirm these results. In addition a further extension to these experimental results would be for field transplants to be carried out to ascertain whether these result are applicable to field conditions.

4.4 Vegetation and Environmental Factor Correlation.

The ten environmental factors described above were averaged for each plot and entered into the PATN program for representation as an ordination (Fig 4.9a). The environmental ordination overlays the ordination of species by plots (Fig 4.9b) allowing correlations between them to be identified. The point of each environmental variable represents its highest correlation amongst the plots. Vectors originating at the X and Y axis junction provide the direction of an increasing environmental gradient and its length represents the degree of correlation to the plots.

It can be seen from the ordination that the environmental factors, in order of highest correlation with vegetation species, are the water table, surface elevation, conductivity, water content, bulk density, moisture factor, sand content, clay content, ammonia concentration and mineralizable nitrogen. The variables of nitrate concentration, organic percentage and pH were poorly correlated to the vegetation. Organic percentage increases from mudflat and shell bank to wet *C. divisa* and ryegrass-bur medic vegetation types. Nitrate values increased away from shell bank and pasture plots towards mangrove and salt marsh species. This is possibly a reflection of seawater nitrates or low nitrates after a growing season in the pasture plots. Elevation, particle size and bulk density are all correlated, but is of secondary importance to the effects of physical tidal action and seawater salinity.

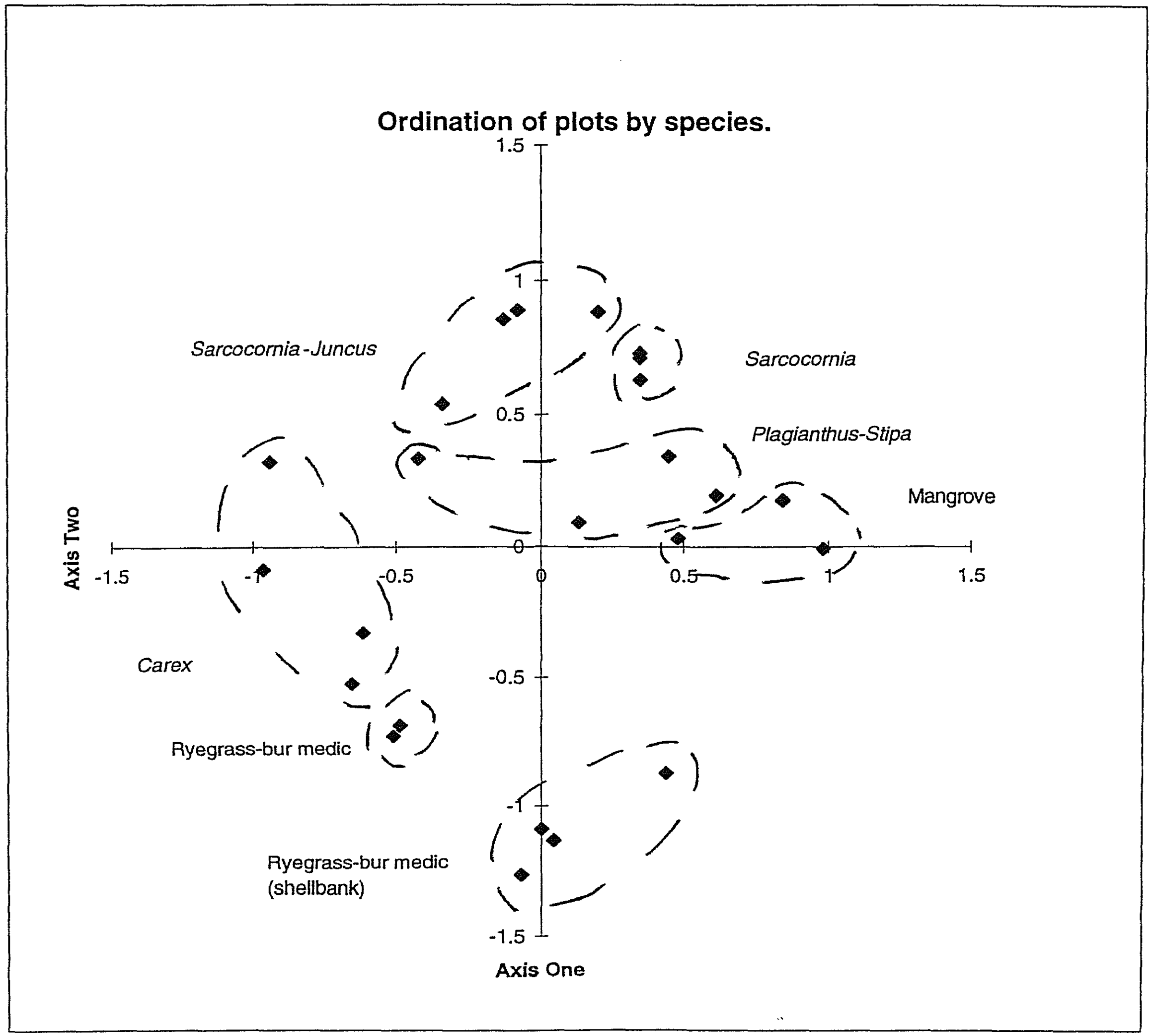

Fig. 4.9 a-b. Ordination of environmental factors overlaid vegetation types. Length of vector represents degree of correlation and direction represents highest level of factor.

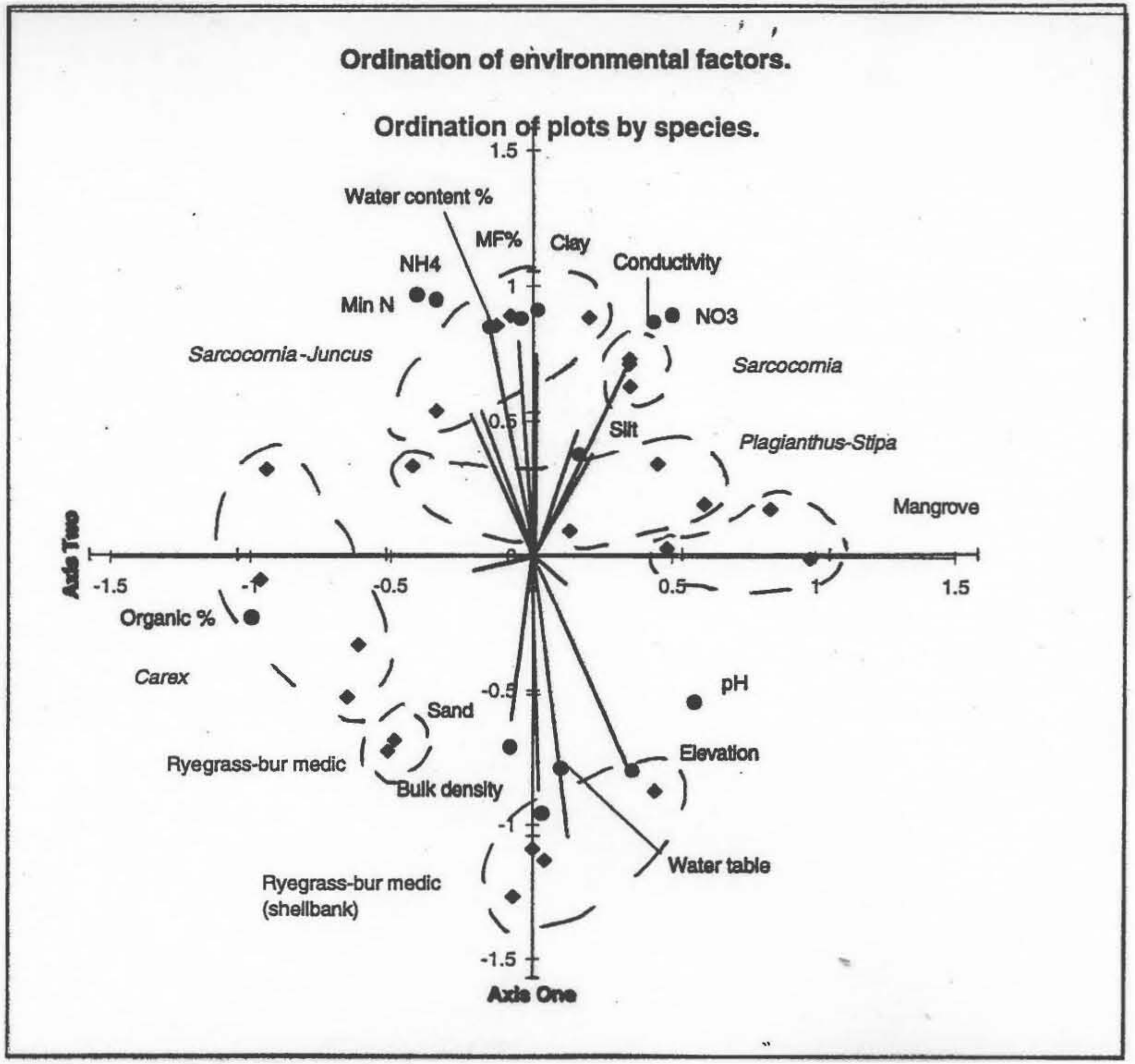

Fig. 4.9 a-b. Ordination of environmental factors overlaid vegetation types. Length of vector represents degree of correlation and direction represents highest level of factor.

4.5 Conclusion

A survey of the vegetation in 24 plots discovered seven different vegetation types are present at Miranda with broadly different habitats. Nine key environmental factors were tested in the field and detected a trend of decreasing salinity, water content with an increase in elevation, particle size and bulk density.Organic matter percentages and nitrogen values are less clearly correlated.

Chapter Five

Plant Communities of New Zealand Estuarine Wetlands

5.1 Introduction

Large saline areas of coastal wetlands form in estuaries and lagoons that are sheltered from the open sea by barriers of sand or gravel. Smaller areas can be found in dune slacks and on exposed headlands maintained by salt spray (Wardle 1991). Salt marsh is a term broadly applied to land regularly inundated by sea water (Johnson and Brooke 1989). Salt marsh vegetation in New Zealand is normally arrayed in zones; four general zones are recognised: (1) below mid-tide, (2) above mid-tide, (3) reached only by spring tides, and (4) reached only by storm tides. The latter three correspond to areas described as lower, middle and upper marsh respectively (Wardle 1991). From just below the lowest tides to about midtide, beds of *Zostera* grow in rhizomatous swards. Mangroves grade from scattered individuals into dense, closed canopy forests before dissipating into the lower marsh. Lower marsh is characterised by mat forming succulents such as *Sarcocornia quinqueflora*, *Suaeda novae zealandiae*, and *Samolus repens* (Johnson and Brooke 1989). Plant cover and diversity increases landward into the mid-marsh communitites that are made up of a tight turf often termed a salt meadow. Salt meadow commonly includes *Selliera radicans*, *Triglochin striata*, *Isolepis cernua* and *Plantago coronopus*, and relates to the 'general salt marsh' described by Chapman (1975, see Fig. 4.1). Around the margins and amongst the salt meadow and lower marsh are zones of tall sedges and rushes normally growing in pure swards where site conditions are favourable. *Leptocarpus similis* is the most abundant tall plant in New Zealand salt marshes and is distributed throughout New Zealand (Wardle 1991). It grows in clumps and dense swards, but does not extend as low as *Juncus kraussii* which was found to be the most salt tolerant rush tested by Partridge and Wilson (1989). The upper marsh supports the shrub *Plagianthus divaricatus* and the grass *Stipa stipoides* on better drained sites and is associated with *Coprosma propinqua, Leptospernum scoparium, Phormium tenax* in less saline areas (Wardle 1991, Thannheiser and Holland 1994). The high tide limits support *Festuca arundinacea* and *Agrostis stolonifera* which can regenerate quickly after submergence in salt water. Other grasses include *Parapholis incurva*, *Puccinelli stricta, Lagurus ovatus* and *Hordeum marinum* in drier sites and *Polypogon monspeliensis* in muddier areas (Wardle 1991).

New Zealand salt marshes lack the thick matted swards of salt marsh grasses, salt rush and sedges commonly found in the Northern Hemisphere (Thannheiser and Holland 1994). Typically, these are made up of *Spartina* species of which three varieties have been introduced into New Zealand for their sediment trapping ability (Partridge 1987). In some estuaries *Spartina* has become a major problem as an invasive weed displacing salt meadow species and areas of *Zostera* (Wardle 1991). Nationally, three broad zones of salt marsh can be differentiated by their abundance. *Avicennia marina* var *australasica* is predominant in the north to 38° S, after which *Juncus kraussii* dominates to 44° S which is in turn is replaced in frequency by extensive communities of *S. quinqueflora* in the south (Thannheiser and Holland, 1994). Other large scale differentiation includes the more diverse glycophytic vegetation on the west coast of the South Island due to high rainfall lowering salinities. The east coast of the South Island is less saline than northern marshes due to fog precipitation during winter and has less evapotranspiration in the summer compared to the North Island and is also more diverse in its species assembalges (Thannheiser and Holland 1994).

5.2 Miranda Salt Marsh Communities

The vegetation at Miranda comes under the *A. marina* zone identified above. From the 24 plot survey, seven vegetation groups are discernable (see Fig. 4.1). The small sample size of this survey did not cover all the vegetation types present therefore they have been grouped into a wider survey of 88 plots conducted by Merrett and Clarkson (1997). The following lists the 17 vegetation communities and identifies the correlating survey plots.

1. *A. marina.* Pure stands of mangrove including scattered individuals and those forming a 3m tall closed canopy. Plots 1.2, 1.3 and 1.5.
2. Young shell bank vegetation comprised of scattered individuals of *Medicargo nigra*, *Parentucellia viscosa* and *Calystegia sepium.* Also present is *Parapholis incurva*, *Lolium perenne*, *Plantago lanceolata*, *Bromus diandrus*, *B. hordaceous*, *Sedum acre* and *Sonchus asper.* Partially relates to plot 2.4
3. *Sarcocornia* salt marsh.
   (i) *Sarcocornia-Suaeda.* In addition are species of *Spergularia media* and *Parapholis incurva.* No plots.
   (ii) *Sarcocornia-Samolus.* Often in association with *Carex*, other species include P. *divaricatus*, *Plantago coronopus*, *Plantago lanceolata*, *Selliera radicans*, *Stipa stipoides* and *Triglochin striata.* Plots 3.3, 3.5 and 3.6 and higher in the marsh at 1.1, S.1 and S.6.
   (iii) *Selliera-Samolus.* Also present were *Juncus krausii* var. *australiensis* and *Sarcocornia.* Plot 3.3.
   (iv) *Parapholis incurva-Plantago coronopus.* Also *Sarcocornia*, *Samolus*, *M. nigra*, *Cynodon dactylon* and *B. diandrus.* Plot S.2.
4. *Cotula coronopifolia-Mimulus repens.* Associated with *B. caldwellii* and *Samolus. Parapholis strigosa* and *Festuca arundinacea* were associated on the margins towards the drier areas. Plot S.5.
5. *Carex divisa.*
   (i) wet *Carex divisa* including *Cynodon dactylon* and *Festuca arundinacea.* Plots 2.1, S.4 and S.5.
   (ii) dry *Carex divisa* more scattered and occur in association with *Sonchus asper*, *Lollium* and *P. coronopifolia* and *P. viscosa.* No plots.
6. *Lolium-Medicago nigra.* Including *Sedum acre*, *B. diandrus*, *B willdenowii*, *E. vulgare*, *C. rigidum*, *C. dactylon*, *T. repens*, *P. lanceolata*, *C. divisa*, *P. echoides*, *P. incurva*, *Samolus*, *B. hordaceous*, *H. marinum* and *P. monspeliensis.* Plots 2.2, 2.3, 3.1, 3.8 and 3.9.
7. *Plagianthus divaricatus-Coprosma* and *Muehlenbeckia complexa.* No plots.

The communities above are not an exhaustive list but cover all the general vegetation types at Miranda salt marsh. They were surveyed at various times between February 1996 and March 1997. Seasonal differences mean some species may not have been present when surveying took place.

Further subgroups can be identified using the results of this studies survey and the findings of Chapman (1974) and Ward (1974) on salt marshes in the Auckland region. Firstly, pure swards of *Sarcocornia* are present at Miranda (plots 1.4, 3.4, 3.7). Four quadrats in Merrett and Clarkson's survey contain pure swards of *Sarcocornia,* two of which have a cover value of 95%. The *Sarcocornia* community has also been separately listed by Chapman (1974) and Ward (1967b) using Clement's (1936) classification of a 'family' of scattered colonising plants. A low lying area adjacent to Transect 3 either side of the tidal stream is composed of a pure sward of dense *Sarcocornia.* A second vegetation sub-group is that of *Juncus kraussii* with *Samolus* and *Sarcocornia* mixed between them in plots 3.2, 3.5, 3.6 and 3.3 in the Transect 3. Four out of 19 plots in the *Sarcocornia-Samolus* group of Merrett and Clarkson's study contained only these three species, allowing the formation of a sub group. Plot 3.3 has some *Selliera* and associated species but this is because it crossed two vegetation types due to an abrupt elevational rise and change in substrate.

The *Sarcocornia-Samolus* group is quite broad as it also attempts to include *Plagianthus* and *Stipa.* This is not a sound association to make as the range of *Plagianthus* comes down to the high tide and overlaps with *Sarcocornia* and *Samolus* but also then extends further back where *Stipa* and *Plagianthus* make up the dominant species. Plots 1.1, S.1 and S.6 all contain some *Sarcocornia* and lower marsh species as they abutt the high tide margin. However, further back on the drier shell banks above high tide at plot S.6 *Plagianthus, Leptospernum scoparium* and *Stipa* are the dominants. In more damp and less saline areas the *Plagianthus-Coprosma* grouping is to be found.

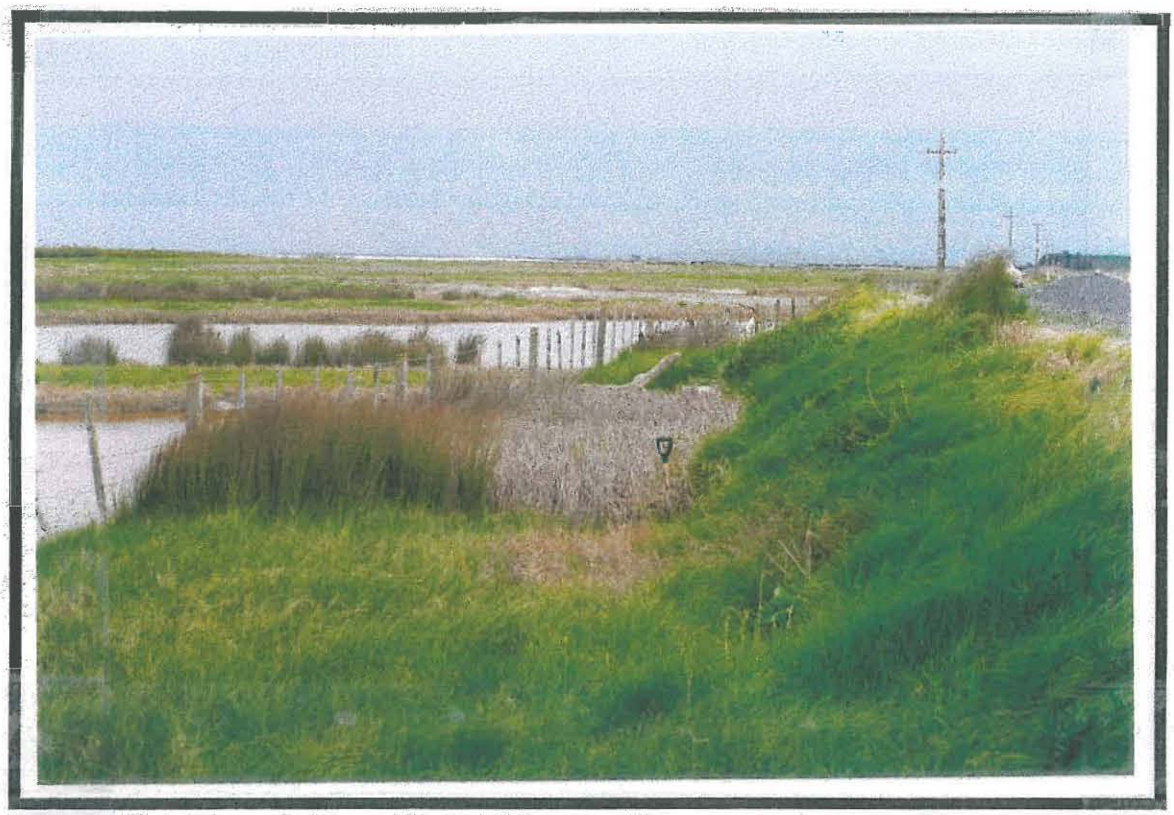

Fig. 5.1. Two discrete patches of *Carex* and *B. caldwellii* growing in pooled freshwater, the *B. caldwellii* is in its winter die back stage neighbouring them is the remnant *L. similis* stand.

A third vegetation sub-type observed clearly in the field are the pure swards of *B. caldwellii* and *C. divisa* growing adjacent to each other (see Fig. 5.1). The tallest stands of *B. caldwellii* grow in pooled freshwater approximately 30cm deep and grade into *Carex* swards with decreasing water level.

The fourth subgroup *Cotula coronopifolia-Mimulus repens* is mentioned to have a transition zone made up of *Parapholis strigosa* and *Festuca arundinacea*. Plot S.5 relates well with a high proportion of *P. strigosa*. There is no *Festuca* due to grazing but the adjacent plot S.4 has *Festuca*. Both these plots occur on a slight bank moving into a *Sarcocornia* and *Samolus* zone. On the other side of the bank *Sarcocornia* and a more saline habitat open to the tide adjoins a compact shelly substrate. A thin but clear band of *Parapholis strigosa* occurs along this before reducing in frequency further into the pasture grasses. Compact, drier, shelly, saline substrates are tolerated by *P. strigosa*, no *Festuca* was present possibly due to grazing.

5.3 Comparision with Other Salt Marsh Communities

Vegetation communities in the Auckland region have been identified by Chapman and Ronaldson (1958) and Ward (1975). The vegetation communities most resembling those of Miranda salt marsh are those described for the Manukau and Waitemata harbours by Chapman and Ronaldson (1958) and comprise 17 ecological communities which are listed below for comparison and illustrated in Fig. 5.2.

(1) *Zostera* pure.

(2) Scattered mangroves with *Zostera.*

(3) Mangroves associated with *Sarcocornia*, *Juncus kraussii* and *Samolus.*

(4) *Samolus*, normally pure but there may be isolated plants of glasswort, *Selliera*, *Juncus*, *Triglochin striatum* and *Apium prostratum.*

(5) *Sarcocornia* as scattered colonising plants.

(6) *Sarcocornia* with mangrove, *Samolus*, *Cotula coronopifolia*, *Stipa stipoides*, *Juncus*, and *Triglochin.*

(7) *Juncus kruassii* as scattered colonising plants.

(8) *Juncus* with *Plagianthus divaricatus*, *Samolus*, *Apium*, *Selliera*, *Aster subulatus*, *Cotula*, *Leptocarpus*, *Stipa*, *Baumea juncea* and *Triglochin.*

(9) *Leptocarpus* associated with *Plagianthus*, *Apium*, *Selliera*, *Samolus*, *Aster*, *Stipa*, *Juncus* and *Festuca arundinacea.*

(10) *Juncus-leptocarpus*: combining communities (8) and (9).

(11) General salt marsh community, containing *Plantago coronopus*, *Selliera*, *Samolus*, *Cotula*, *Aster*, *Isolepis cernua*, and *Triglochin.*

(12) *Triglochin striatum* colonies usually pure but with *Paspalum dilatum* in pans.

(13) *Bolboschoenous medianus* and/or *Schoenoplectus pungens*, in association with *Baumea*, *Leptocarpus*, and *Juncus.*

(14) *Carex divisa*: usually pure.

(15) *Cyperus ustulatus*: usually pure.

(16) *Stipa stipoides* associated with *Plagianthus*, *Muehlenbeckia complexa*, *Ranunculus* sp., *Sarcocornia*, *Plantago*, *Selliera*, *Samolus*, *Apium*, *Aster*, *Leptocarpus*, *Juncus*, *Baumea* and *Festuca.*

(17) *Baumea juncea* associated with *Leptocarpus* and *Juncus.*

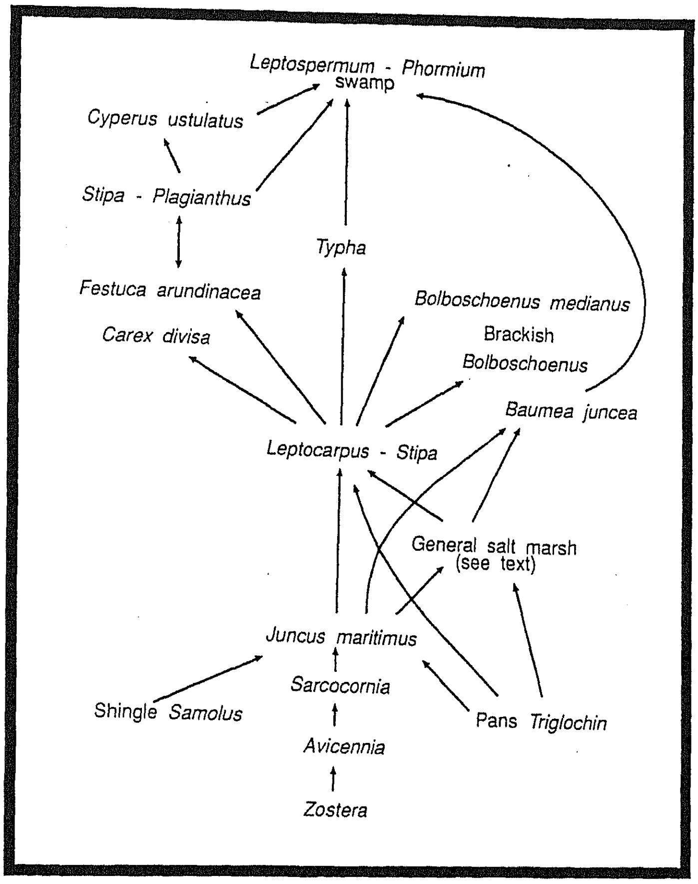

Fig. 5.2. The sequence proposed for the Waitemata and Manukau harbours following increasing elevation and decreasing salinity (after Chapman and Ronaldson 1958).

Zostera communities (1) are not present at Miranda salt marsh as the seaward side of the shell ridge is too erosive and the landward side is not inundated by the tide for long enough periods. The scattered mangrove community (2) is present as well as mangroves associated with *Sarcocornia* (3). *Juncus* and *Samolus* occur together at the cleared mangrove site and may have been amongst the mangroves. However, no *Juncus* and *Samolus* and mangrove occur at Miranda although this combination does occur near mangroves growing next to tidal channels. It isa possibility that grazing may be preventing them from establishing. No particular group or plot associates with (4) but this mixture of plants is present at the locality of plot S.2. The sequence follows from scattered *Sarcocornia* to *Samolus* pure sward to *Selliera* pure sward and then to *Plantago coronopus*. *Sarcocornia* as a scattered colonising plant (5) has been identified. Community (6) is not clearly present at Miranda. *Juncus* as scattered plants (7) were observed in the cleared field and next to mangroves growing beside the creek at flap gate 2. Groups (8), (9) and (10) relate to a lower range of *Plagianthus* and the presence of *Selliera*, *Aster*, *Baumea* suggest a lower salinity. None of this community exists at Miranda but may have once existed around present remnants of *L. Similis* which is at the right elevation to contain all these species.

General salt marsh represents the transition between plots S.2 and S.3 which contain some of these species. No community (12) was observed at Miranda but *Triglochin* was noted on the mudflat cleared of mangroves. Community (14) relates to plot 2.1, S.2, S.4 and S.5. There are no species of *Bolboschoenus medianus*, *Schoenoplectus pungens* and *Baumea juncea* (13). *Cyperus ustulatus* occurs occasionally as individual plants (15). Both these habitats seem to be covered by *B. caldwellii*, it was found growing in the freshwater pool next to *Juncus kraussii* and on the otherside of the fence with *L. similis*. Individual plants of *C. ustulatus* (15) are found in isolated sites at Miranda but *B. caldwellii* is the dominant forming pure stands.

The *Stipa* community (16) covers a broad range of possible species assemblages as *Stipa* grows at the margins of Spring tide and many mid-marsh species overlap into it. Ward (1967b) divided this group up into four facies: *Stipa-Sarcocornia; Stipa-Plantago coronopus; Stipa-Plagianthus; and, Stipa-Festuca.*

Stipa-Sarcocornia represents its seaward extent and may also contain *Samolus* and *Suaeda*, an example of this is plot S.6. The second facies was recorded in one plot by Merrett and Clarkson (1997) at Miranda. The following two facies contain species found together at Miranda but could not be clearly classed as two subgroups. No *Baumea* was found at Miranda (17).

Not included in Chapman's sequence are the adventive grasses of the higher marsh rarely reached by sea water such as *Parapholis strigosa*, *Lagurus ovatus* and *Hordeum marinum* on the drier sites. *Polypogon monspeliensis and Agrostis stolonifera* colonise more damp areas (Wardle 1991). Ward (1967b) identifies *Atriplex prostrata* as a family of colonising plants. *Atriplex* is well represented at Miranda forming dense bands on shelly substrates where the tide encounters increased elevation. On more sloping salt marsh *Atriplex* plants are spread thinly, reflecting their distribution by spring tides.

5.4 Limits to Community Descriptions

Community composition in each salt marsh zone is related to the tide primarily and to secondary factors including tidal ponding, soil moisture and freshwater inflow. These factors allow simple vegetation patterns to be applied locally and broadly between regions (Partridge and Wilson 1988). However, detailed sampling reveals more complex vegetation patterns, at times unique to individual salt marshes, that are atypical of general trends identified by less intensive sampling. As strong controlling factors such as salinity decrease there is greater community diversity and less correlation between regions (Partridge and Wilson 1988). Only a general correlation can be made to the other salt marshes in the region because of the unique conditions of each estuary.

Where pure swards of a species occur it is easier to delineate vegetation types, but increasing species diversity and environmetal variabilities make other communities more difficult to define except at a general level. Abrupt changes in elevation at Miranda mix communities together, reducing clarity of species associations. Community types are more easily determined on a gradually rising slope with steadily decreasing salinity and without disturbances temporarily establishing species uncharacteristic of the community. The random nature of establishment may also mean species are not present in an otherwise optimum habitat. Distributions of plants may respond to a gradient with a continum of change. Others respond more discretely so that communities are never predictable yet still maintain a level of order. For example, the response of *Selliera* to salinity (Partridge and Wilson 1987) showed abrupt stepped tolerance of increasing salinity. Seasonal changes constantly transform a community's cover, structure and composition. Regional differences in environmental factors and local ecotypes mean that only general comparisions can be made at this level.

The salt marsh at Miranda is also highly modified by human activity such as over sowing in exotic grasses and only small populations of certain communities remain. These are impacted by grazing, trampling and reduced tidal flows. This results in unnatural community assemblages, for example, exotic species outcompeting turf communities in the mid-marsh. Less obvious are the community types containing *Stipa, Leptocarpus similis, Plagianthus, Muelenbeckia complexa, Phormiun tenax* or *Coprosma propinqua.* Their distribution is restricted to alongside fencelines outside grazed areas. The only locality of *L. similis* in the grazed area is in the middle of a dense *Juncus* sward possibly protecting it from grazing.This may be a remnant of a *Juncus-Leptocarpus* community (10) described by Chapman and Ronaldson (1958). For these reasons the communities described are idealistic and restricted to the more obvious community groupings formed on a clear gradient of salinity and elevation.

5.5 Environment Vegetation Correlation

The results of this study only provide general characteristics of the vegetation types discovered. Fine scale longterm research is required to determine definitive vegetation interactions with physical processes operating in Miranda wetland. Such a research programme is outside the scope of this studies time frame and objectives. In this section the more important environmental factors are discussed in relation to the vegetation types identified.

5.5.1 Salinity

The strongest correlating factor tested was soil conductivity representing salinity which has been termed the 'master factor' by Chapman (1974). Salinity levels are linked to the duration of tidal inundation and normally follow gradients of decline with increasing elevation. Generally this trend is followed but other patterns have been found. Bakker *et al* (1985) discovered temporary and local increases in salinity at higher elevations due to evaporation raising soil water to the surface and concentrating salts within the top 5cm. Generally this occurs during summer in bare areas that are open to seawater entry from surface or subsurface flow (Daly and Rijkse 1976). The *Sarcocornia-Juncus* community had similar salinities to the mangrove communitites of lower elevation and were higher than the pure *Sarcocornia* community. Unexpectedly, plot 3.2 had the highest average salinity even though it is at a higher elevation than most of the other salt marsh plots. This was found to be due to a slight rise in elevation on its seaward side preventing proper drainage and contributing to the formation of evaporative pools. This may be a reason for the abscence of *Samolus* in the plot and a high proportion of *Sarcocornia*. Plots 3.5 and 3.6 also have higher salinity values, higher water contents of 40-50% agree with surface ponding as a factor. Pure *Sarcocornia* communities are normally associated with higher salinities but levels are lower in this group than the rest of the low-marsh communities. This is due to better drainage in plot 1.4 which has a sandy substrate, the other two plots are on sloping surfaces reducing pooling of salt water. Pooling of seawater would have had added importance over this year during the higher than average winter temperatures. Less organic matter was found in the less densely vegetated Transect One plots but the more sheltered and high vegetation cover values of the lower-marsh plots of Transect Three had more organic matter. *Carex* plot 2.1 had a high level as it accumulated a 5-7cm black peaty leaf litter built up in anaerobic waterlogged conditions.

5.5.2 Particle Size

Partidge and Wilson (1989) considered soil particle size to be an important factor in determining a species distribution. Plot S.1 containing *Plagianthus* had a high silt and sand component ensuring rapid drainage of sea water and flushing via rainfall. The shell bank vegetation can be ranked in order of oldest to youngest, that is, 3.1, 3.8, 3.9 to 2.4. Plot 3.1 has a higher organic matter and silt content and so has a higher moisture factor and water content. It had a smaller shell and sand component reducing its bulk density. Plot 2.4 was the reverse and resembles more closely the young shell banks described by Merrett and Clarkson (1997). Its vegetation is made up of shallow rooted annuals that established after cyclone Drena. Its species diversity is lower and dominated by *Medicargo lupulina* and *Trifolium species* which are able to fix nitrogen that is easily flushed out in the porous sand.

5.5.3 Water Table

The water table had a high correlation with the vegetation types but this may be a spurious finding as depth to water table is linked strongly to elevation. Plots closest to the water table were also inundated by the tide and for longer periods than plots at a greater depth to the water table making it difficult to separate their effects. The water table offers potential benefits in providing water to the root zone. Schlichting and Blume (1966) found capillary rise of water at an evaporation rate of 1mm/day to be between 65 and 100cm in moderately fine sand. Alternatively, extended waterlogging or high soil water salinities can be an inhibiting factor. The depth of the water table is approximately 1.2m above MSL at Miranda. Shallow rooted vegetation on the high shellbanks cannot reach the water table and cappillary rise is greatly reduced in the sandy shell substrate but, internal dew formation may supply part of their water requirements (Ward 1967b).

During summer the water table drops lower than winter levels. Fluctuations brought about by the tidal cycle may lift the water table within reach of the root zone of some species. A spring tide covered plot S.2 under 15cm of water measuring 32ms, while the neighbouring plot S.3 had a water table of 24ms at only 23cm depth. Therfore the salinity was lowered by the substrate that it had to move through and any freshwater that was present within it. Soil water in a pipe to the water table approached the conductivity of seawater (40ms) in plot 1.1 as did S.2 during a spring tide suggesting tidal fluctations do not assist this community as the water table is still very saline. Plots containing *Juncus*, *Sarcocornia* and *Samolus* in the mid-marsh would receive some water as their roots extend to a depth of 30-40 cm (Ward 1967b). Above 1.0m above MSL only plants with roots at least 50cm would be able to reach the tide some of the time and would include *Plagianthus.*

5.5.4 Bulk Density

Bulk density generally increased with elevation from clay and silty substrates to the higher more sandy shell ridges. A higher bulk density is positively correlated to an increasing rate of water percolation and aeration. All sites containing large proportions of sand had lower nitrogen values as these substrates are easily leached. The vegetation present in these locations included *Sarcocornia* in plot 1.4 which had low cover values and scraggly growth. Plot S.4 and S.5 supported *C. divisa* which still had high cover values. This is in agreement with the low nutrient requirements observed in *Carex* by Moog and Janiesch (1989).Shell bank species include nitrogen fixing species such as *Medicago* and *Trifolium.* The lower marsh vegetation was less porous and often waterlogged. Plots 3.2 and 2.2 had the lowest pH values of less than 7 in the feild. Readings are normally less acidic than field conditions when placed in a 1:5 soil to water solution used to test for pH (Rayment and Higginson 1992). Both were waterlogged and had high organic matter content .

Chapter Six

Restoration Options at Miranda Wetland

6.1 Introduction

Miranda wetland vegetation has been adversely affected through shell mining, pasture establishment, drainage and grazing impacts. These physical impacts can be more easily addressed than the biotic component that includes *C. divisa* and also overgrowths of *Foeniculum vulgare* and dense stands of *Bromus* species. This chapter examines options for restoring wetland vegetation at Miranda and focuses particulary on methods to control the invasive species *C. divisa* which poses the main treat to species diversity. The characteristics and distribution of this species is discussed. Important land management methods are identified, and the physical restoration of a wetland hydrology is addressed. The chapter concludes with a summary of key findings and recommendations.

6.2 General Description of *Carex divisa*

The genus *Carex* (Cyperaceae) is made up of approximately 2000 species of herbaceous perennials distributed in a wide range of habitats around the world (Bernard 1990). Most species in the genera are not true aquatics but inhabit wetland margins (Kukkonen and Toivonen 1988). There are four subgenera with 70 sections; wetland *Carices* are part of the subgenera *Carex* and *Vignea. Carex* are distributed from the tropics to the high arctic and antarctic latitudes. More than 3000 species have been listed, however, reduced influences and stems and wide hybridization have made them difficult to identify and the number of species is undoubtedly less (Kukkonen and Toivonen 1988).

Carex are perennial, monoecious herbs and strongly rhizomatous. Flowers are unisexual and normally wind pollinated (Kukkonen and Toivonen 1988). Fruits lack characters assisting dispersal; most seeds fall close to the parent plant. Long distance transport is facilitated when seeds are caught in mud in the fur or on the hoof of an animal (Healy and Edgar 1980). The main differences between *Caracie* are firstly vegetative shoots, which may be either pseudoculms not having internodes or vegetative culms or true culms that do have internodes. Secondly there are three major rhizome growth forms are produced: either short and clumped, long or a combination of these (Bernard 1990). *C. divisa* has a pseudoculm and utilises both clumped and long rhizome growth forms. The other main characteristic of *C. divisa* is the height reached. Forest species attain 50cm while open wetland species reach 1.5m. *C.divisa* falls into the latter category attaining 1m.

C. divisa is wide spread across Britain, Asia and Spain in primarily coastal localities (Clapham *et al* 1989). It was probably introduced to New Zealand as a grass seed impurity from Europe (Healy and Edgar 1980). The literature on *C. divisa* is sparse, however, overseas work has been carried out in Spain where *C. divisa* forms part of the pasture species. Research reveals *C. divisa* populations increase through cattle trampling and increased NO3 and NH4 levels in conjunction with overgrazing (Tascon Alvarez *et al* 1983). *C. divisa* is present in the neighbouring paddocks at Miranda and landward at least to the base of the surrounding cliff face but is left ungrazed unless there is no other fodder available. Jeannin and Lafon (1975) describe a pasture containing *C. divisa* growing on silty clay soils adjacent to estuaries in France in a climate of high winter and low summer rainfall. When pastures were fertilized, drained and irrigated and placed under rotational grazing there was a reduction of *C. divisa* and an increase in *Lollium perrene*. *C. divisa* standing crop is correlated to the highest average mean monthly temperature. Previous years shoots can form a mat over the ground reducing temperature and light inputs. Where the litter has been removed growth is greatly enhanced and is more lush in fertilized sites.

Carex divulsa is very similar to *C. divisa* and though not observed by Merrett and Clarkson (1997) was identified as present in the survey by Ogle (1982). An isolated individual *C. divulsa* specimen was collected near plot 3.1 in this study confirming their presence. They are not limited to the coast and are found on dry calcareous grassland (Healy and Edgar 1980). *C. divulsa* can be differentiated from *C. divisa* in that its seed heads are spaced along the stem tip unlike *C. divisa* which has them clumped at the tip.

6.3 Revegetation Options to Displace *Carex divisa*

The potential to displace *C. divisa* by removal of vegetation and replanting requires the selection of species able to inhabit the same environment as *C. divisa* and resist reinvasion. Two important factors determine the distribution of *C. divisa*, salinity and canopy shading. *C. divisa* combats salinity with vigorous regrowth after surface dieback of stems from seawater flooding and is able to withstand temporary inundation by seawater. Temporary populations of *C. divisa* can establish in areas outside their long term natural habitat range. Rhizomal transport of solutes from adjoining vegetative units enable a higher saline environment to be encroached upon. Canopy shading is the primary competitive advantage *C. divisa* has on the surrounding plant species. The three following species are discussed as potential species to be used in a revegetation program.

Bolboschoenus caldwellii.

In the field, patches of *B. caldwellii* are usually surrounded by a dense sward of *C. divisa* that restrict its distribution to deeper standing water. *B. caldwellii* has optimum growth in standing water up to 30cm deep in which it can attain heights of 1m but also inhabits temporarily pooled and waterlogged sites. Areas that have pooled standing water cannot be colonised by *C. divisa*. However, established vegetation at plot 2.1 withstood shallow standing water of 5cm for part of the winter. Bulbs of *B. caldwellii* were found under the root mat of surrounding *C. divisa* swards during field collections. This suggests that *B.*

caldwellii is out-competed in this environment and is restricted to deeper water environments. Its poor competitive ability is due to its widely spaced stems compared to the impenetrable root mass and stem density of *C. divisa*. *B. caldwellii* also has an autumn die back stage whereas *C. divisa* can continue to grow all year round. Results of the salinity test reveal *C. divisa* has a higher salinity tolerance than *B. caldwellii* which enables it to continue to grow in situations limiting to *B. caldwellii*. Unless the habitat of *B. caldwellii* continues to be flooded in winter *C. divisa* will have the potential to invade and displace this species.

Leptocarpus similis.

L. similis occurs in two isolated populations, one in freshwater beside the road and the other in a clump hemmed by a dense stand of *J. kraussii*. Its limited abundance may be due to preferential grazing and its thin rigid stems are susceptible to trampling. Of the three species tested for salinity *L. similis* has the most potential as a competitor of *C. divisa*. It has a higher salinity tolerance enabling it to out compete *C. divisa* at its greatest extent into the salt marsh. *L. similis* also has can grow well in the high-marsh in waterlogged conditions which is where *C. divisa* has its optimum growth. Once established *L. similis* develops a very thick and tightly packed vegetative root mat that would be difficult for *C. divisa* to invade. Its canopy does not die back over the winter and reaches 1.5m without becoming wind blown. This species has been successfully trialed in transplant experiments in Maketu estuary but required large clump sizes (10cm x 10cm x 15cm depth) planted less than 0.5m apart for long term establishment success (Bergin 1994). Transplants would need to be obtained outside the immediate area as populations at Miranda are too small to be used as a source. Transplants would require protection from stock and weeding until canopy closure is achieved. Initial areas suitable for transplant trials are areas of lush *C. divisa* swards. Such sites have a high organic matter percentage and soil water content, and are ideal conditions for the establishment of *L. similis* (Wardle 1991, Bergin 1994). An important feature of *L. similis* in revegetation at Miranda is that its height will not negatively impact open views of the coast from the road.

Leptospernum scoparium.

Initial results of *Leptospernum scoparium* salinity tolerance reveal it is able to compete with *C. divisa*. Coastal ecotypes would undoubtedly extend this tolerance range and should be used in any plantings at Miranda. Although no species are present for local sourcing. *L. scoparium* could be planted in water logged and dry substrates to displace *C. divisa* further inland. Fencing and weeding would be required until canopy closure was attained. A suitable trial site would be that recommended by Merrett and Clarkson (1997) inside the fence boundary adjoining the small *Plagianthus-Coprosma* community (see Fig. 3.-). Plantings included in this community are *Muelenbeckia complexa* which has been found amongst *Stipa* and *Plagianthus* communities and can grow down to the high spring tide mark (Brock 1966). *M. complexa* is able to establish on a wide substrate particle size preferably well drained and copes with salt spray and at least 1.0% salinity in solution (Brock 1966). It can form dense low growing mats but is shade sensitive growing over small shrubs and other species in these conditions (Wardle 1991), including C. divisa (pers. obs.). Further north of Kaiaua *M. complexa* growing on raised gravel beaches is the closest site for sourcing transplants. An established community would prevent direct views to the coast but would also enhance the diversity of habitat available to birds.

6.4 Grazing Management

Grazing is permitted in the QEII covenanted area and is carried out under lease on property owned by the Department of Conservation. Habitats that afford some grazing value include the raised shell bank sites supporting the ryegrass-bur medic community, the lower elevation damp and waterlogged sites containing *C. divisa* and sites on the edge of the salt marsh high tide mark containing *Parapholis strigosa*. The land is valuable for its extra fodder and is also used during winter when higher quality pasture is susceptible to pugging.

Grazing Impacts

Grazing impacts include pugging and alien weed dispersal (Hull and Beovich 1996). Assessment of grazing impacts and regimes require long term field trials, however, general principles are outlined in Riemold et al 1975, Bakker et al 1985 and Jensen 1985. Grazing directly increases species diversity by opening up establishment sites, reducing the litter layer and decreasing canopy shading (Bakker et al 1985). Treading in the soil allows species to establish more readily, particularly if their dispersal mechanism is via seeds. Examples are *Parapholis incurva*, *Spergularia marina*, *Cotula coronopifolia* and *Polypogon monspeliensis* which have established in the *Selliera* sward at plot S.2. Halophytic species are normally tolerant of high light levels (Adam 1994) and are out competed in the higher marsh by shading. When competition is reduced by the removal of litter the canopy of surrounding vegetation lower salt marsh species and other glycophytes can inhabit the site. This is evident in the comparison of plots S.4 and S.5 Plot S.5 also has a proportion of mid-marsh halophytes such as *Sarcocornia*, *Selliera* and *Suaeda novae zealandiae*. The movement of lower marsh species into the higher marsh has been termed "retrogressive succession" (Bakker 1985). This process is possible as more seeds are transported on the incoming flood tide than the out going ebb tide (Bakker et al 1985). Another factor aiding the establishment of lower-marsh species in the higher marsh is an increase in salinity of the top 5cm of soil after grazing (Bakker et al 1985, Hansen 1982 and Joenje 1978). Temporary and local increases in soil salinity occur in areas open to salt intrusion from groundwater, inundation or salt spray inputs due to increased evaporation with removal of the canopy and litter by grazing (Bakker et al 1985). Grazing is required at Miranda to prevent *C. divisa* from forming a dense canopy thus shading other species and reducing diversity.

Stocking rate

The carrying capacity of a habitat can change from season to season and should not be exceeded by stocking rates which require supplementary feed (Hull and Beovich 1996). In one instance at Miranda during wet winter conditions over stocking and feeding out with hay was practiced in one field of poor drainage containing the habitat of *C. divisa* and *B. caldwellii* leaving the vegetation bare and pugged (pers. comm. C. Hendy).

Livestock management

Cattle readily enter water and pug wet soils and are able to graze higher shrubs and lower branches of trees. Sheep do not pug as deeply, are less likely to enter water and have a lower reach in grazing shrubs, however, woody seedlings are more likely to be grazed (Hull and Beovich 1996). Sheep are more selective and have less impact on the root system while feeding than cattle (Jensen 1985). However, *C. divisa* is very coarse and may not be suitable for sheep. Grazing trials would be needed to ensure *C. divisa* would be adequately controlled. Soil pugging and water quality are best protected by grazing in drier months at Miranda or restricting cattle to the higher shell banks during wet conditions.

Removal of Grazing.

Removal of grazing will not restore wetland vegetation unless the natural hydrological regime prevails, there is a local supply of native plants and animals, weed sources are limited and the soil has not increased in nutrient levels (Hull and Beovich 1996). Bakker (1985) characterized ungrazed salt marsh by litter accumulation, dominance of a single species and poor diversity of species with a coarse grained vegetation distribution. The exclosure at plot S.4 has become overgrown by a dense sward of *C. divisa*. Species diversity is very low compared to the grazed plot S.5 immediately adjacent to it. This option is advisable where the native species have a higher competitive advantage without grazing for example treading opened establishment sites and reduced cover in the *Selliera* turf at the site of plots S.2 and S.3, now the tidal flow has been returned *Selliera* are able to form continuous turf again.

6.5 Mowing Impacts.

Mowing and grazing have similar impacts, however, mowing does not remove ground litter which accumulates with the addition of cut plant material. There is no species selectivity as all plants are affected. Mowing can be precisely timed with stages of *C. divisa* growth, for example just before seed ripening (Bakker 1978). An area of *C. divsa* has been mown by the District Council at the picnic site at Miranda bridge and resulted in increased species diversity including *Atriplex prostrata*, *Taraxicum officinale*, *Parapholis strigosa* and *Trifolium* species (see Fig. 6.1). Mowing would need to be carried out at least once a year to control the growth of *C. divisa* but could be linked to the production of hay or silage to make it more economical. Mowing would be restricted to sites accessible to a tractor and so would be less effective controlling *C. divisa* to riparian edges.

Fig 6.1. *J. maritimus* with an abrupt *C. divisa* zone invading strongly because of the reduced tidal influence, the greener *C. divisa* is in a more waterlogged environment across the fence is mown *C. divisa*.

6.6 Herbicide Control

Herbicides for the control of *C. divisa* must be effective in waterlogged conditions. Paraquat is a herbicide that acts as a desiccant and is used on sedges and rushes but is not effective on plants in standing water. RoundUp G2 is widely used because of its low toxicity to other organisms. It can be used in aquatic situations and has a 30 minute drying time and so is less affected by rainfall and tidal inundation. Stock can graze the sprayed area immediately after application. However, at least seven days are recommended before grazing resumes to allow the herbicide to be fully absorbed. *C. divisa* has the potential for regrowth after an application due to its rhizomes' ability to vegetatively reproduce. In this instance a spring application followed by an autumn application is suggested to kill any regrowth (pers. comm. M. Lawn Monsanto). Herbicide control would be useful to remove *C. divisa* swards before introducing transplants and to remove patches of *C. divisa* in between *Selliera* turf.

6.7 Restoring Hydrology.

The most effective large scale control of the distribution of *C. divisa* would be to return the tidal regime. Areas behind stopbanks and flapgates support populations of *C. divisa* that potentially can be returned to salt marsh. The following discussion highlights one opportunity available to restore tidal flow.

Transect A-B (Map 3.) reveals a potential for returning the tidal factor from the mudflat across the stopbank into the field towards the pool. The adjacent mudflat contains the most extensive, pure swards of *Selliera* present at Miranda. A band of dense *Spergularia* and *Cotula coronopifolia* is present along the seaward side of the mudflat grading into a wide band of *Atriplex* and *Parapholus strigosa*. There are *Juncus kraussii*, *Samolus*, *Plantago coronopus*, and scattered *Sarcocornia* plants present. Until land clearance in the 1980's, a mature mangrove forest covered the mudflat site. Comparisons with adjacent mangrove forest and remnant individuals suggest a canopy height of 2-3m once existed. Consequently, shading producing a lower salinity may have extended the *Selliera* and *Samolus* communities that are now present. Cattle were grazed on the higher ground towards the chenier ridge and crossed the salt marsh to the embankment adjacent the road. Treading has opened up establishment sites in the *Selliera* and *Samolus* turf for *C. divisa* that have developed into discrete patches through vegetative reproduction.

A tidal channel exists on the mudflat following the roadside bank, turning toward the old house site and terminating at its drive way which forms a stopbank. Its flow was re-established in 1996 with the removal of flap gate 1. (see Map 3). The cut has gradually widened but the flow rate is still restricted, reducing the potential tidal prism and consequently the marsh surface area. The channel and surrounding area is largely bare except for a few scattered colonising individuals of *Sarcocornia,* although mangrove seedlings are rapidly establishing along the channel. Removal of the shading mangrove canopy has undoubtedly raised surface salinities in the summer months, reducing seedling establishment. For a period of some weeks during the unusually warm temperatures and low rainfall over the months July to August time large desiccation cracks and encrusting salt was observed on the mudflats. Treading also hampers re-establishment by breaking off vegetation and pugging retains seawater that turns hypersaline in summer.

The path of the tidal channel is still obvious past the stopbank. It is now covered in pure swards of lush *C. divisa* growing to a height of 1m but is windblown to less than half this height. Following the tidal channel into the pool at 1.3m above MSL the *C. divisa* declines and *Cotula coronopifolia*, *Rununculus scleratus* and *B. caldwellii* dominate. At 1.2m above MSL *B. caldwellii* dominates fully and eventually reaches a height of 1.5m in standing water 30-40cm deep, after which it then grades into open water. These elevations suggest *C. divisa* cannot endure water depths of more than approximately 10cm for extended periods of time.

The pool itself fluctuates seasonally in water level and salinity. Conductivity measurements on 20 October were 4ms at the northern end and 5ms at its southern end.

By 20 November these values had dropped to 600-700us respectively. In December it had almost completely dried up, but on 21 February all temporary pools at Miranda were recharged to approximately half their capacity over night after heavy rain. An eel was observed in the pool on 20 November it was only 20cm deep. A ditch connects the pool to run off from the roadside.

Returning the tidal regime would increase the salinity of the pool and if this becomes too high associated *B. caldwellii* stands will disappear. The pool already supports vegetation adapted to brackish conditions as the pool is inundated during high spring tides and storm events. A drift line was measured on the shell bank beside the pool at a height of 2.5m. Altering channel widths across the stopbank could control seawater entry. The Taramaire reserve has good potential as a pilot restoration site as the full range of vegetation types can potentially be supported - from the mangrove communities to brackish pool species and the higher *Plagianthus-Coprosma* community. The area is small, and a project would be cost effective as replanting would not need to be extensive. The *C. divisa* communities represent possible sites to trial *L. similis* transplants. The mix of freshwater and seawater may see the return of *Juncus spp* found in plot 2.1 and 2.2. If successful experience in this project would provide important information for restoration of the larger salt marsh area behind flapgate 2.

6.8 Conclusions and Recommendations

At Miranda, all three options of grazing, mowing and herbicide control will be useful in bringing about more natural and stable wetland vegetation communities. At present, full restoration is unlikely as the past state is not fully known. Leaving the salt marsh ungrazed to revert to its natural state is not possible due to well established exotics, poor native seed sources (particularly of glycophytes) and an altered hydrology. Principle recommendations for *C. divisa* control and restoration of salt marsh vegetation types are:

1. Grazing should be maintained to stop *C. divisa* from developing a closed canopy and reducing species diversity.
2. Larger areas of low- and mid-marsh areas containing turf communities composed of *Selliera radicans*, *Samolus repens*, *Sarcocornia quinqueflora*, *Spergularia media*, *Parapholis incurva* and *Plantago coronopus* require fencing particularly if they are between two grazing sites. These areas are of low grazing value and most susceptible to damage from trampling and pugging opening establishment sites for *C. divisa.*
3. Planting of *L. similis* should be trialed in areas of *C. divisa* following the transplant recommendations of Bergin (1994).
4. Opportunities to re-establish hydrology are at flapgate 1 and the stopbank adjoining the transect two plots. Flapgate 2 has the potential to be widened and provide a greater salt marsh area (see Map 3).
5. Planting of *Plagianthus*, *Coprosma propinqua* and *Muelenbeckia* should adjoin the *Plagianthus-Coprosma* community near the Miranda natuaralist trust as recommended by Merrett and Clarkson (1997). Mowing would best be employed around any

proposed plantings of *Muelenbeckia* or *Plagianthus* until they are well established and have achieved a dense canopy. All plantings should be fenced.

6. Herbicide spot spraying is necessary on the *C. divisa* patches in *Selliera* turf.
7. Monitoring trial plots of grazed, mown and ungrazed sites is required over at least 5 years to discover long term changes in community composition. Factors such as grazing duration, time of year, stock density and stock management need to be taken into account. Seasonal visual inspections and permanent photo points could be established as an inexpensive tool. Three line transects consisting of plots across existing separately fenced fields or specially fenced strips should be monitored (Merrett and Clarkson 1997). The transects need to cover a range of communities and also contain the same communities for comparison. Vegetation dynamics should be recorded at the detailed permanent plot level and at the overall level of vegetation maps (Bakker 1985).
8. A restoration team including representatives of all the parties involved should be formed. Department of Conservation staff could facilitate with the planning framework, resourcing and co-ordination of voluntary input.

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Appendix One

Tables of Results

% water content and averages from May to Jan 1997									
Date	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4
2-May	25.15	36.35	41.35	37.05	53.40	49.40	44.50	39.65	10.85
19-May	38.70	39.80	41.00	39.30	52.90	48.50	41.60	42.20	3.80
12-Jul	28.36	43.95	37.59	40.05	53.40	46.02	49.07	44.68	8.53
13-Aug	38.50	42.86	39.50	39.55	56.36	43.54	42.04	31.55	7.67
13-Sep	40.86	44.55	41.37	39.97	54.65	50.48	42.85	30.87	6.19
13-Oct	26.96	37.07	42.56	39.08	54.78	53.81	41.29	40.92	3.56
13-Nov	26	38.19	42.31	28.8	52.06	64.59	32.49	33.17	2.13
15-Jan	31.63	31.63	32.85	31.86	42.77	18.19	23.86	19.07	0.65
Average	32.02	39.30	39.82	36.96	52.54	46.82	39.71	35.26	5.42
Date	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
2-May	16.25	49.65	36.70	42.00	50.35	47.25	46.55	18.10	14.45
19-May	10.50	49.20	36.60	40.20	49.60	46.20	47.70	6.10	4.90
12-Jul	15.53	49.70	16.55	42.41	48.05	48.55	50.80	12.21	12.08
13-Aug	10.06	50.55	18.12	46.13	49.25	47.26	48.53	11.68	11.32
13-Sep	22.73	51.93	15.77	48.34	50.33	43.87	49.38	13.23	13.4
13-Oct	11.79	46	41.4	44.59	48.5	44.87	51.98	7.37	4.46
13-Nov	4.4	47.64	42.02	40.07	49.2	42.9	44.52	2.82	3.98
15-Jan	1.29	32.57	34.92	34.04	35.02	29	30.68	0.91	1.22
Average	11.57	47.16	30.26	42.22	47.54	43.74	48.49	10.22	9.23
Date	S.1	S.2	S.3	S.4	S.5	S.6			
2-May	21.45	44.55	10.70	17.20	16.40	12.95			
19-May	18.50	44.30	10.70	39.50	16.60	20.00			
12-Jul	21.02	44.81	19.65	23.24	34.20	33.17			
13-Aug	16.83	43.86	16.90	8.54	31.84	14.22			
13-Sep	21.38	47.35	11.2	38.79	18.79	13.19			
13-Oct	19.49	42.89	12.87	19.8	20.03	11.77			
13-Nov	15.59	43.28	8.4	20.09	14.32	13.9			
15-Jan	13.48	33.41	3.54	16.18	8.61	9.8			
Average	18.47	43.06	11.75	22.92	20.10	16.13			

	Monthly soil conductivity readings in ms, for each plot.								
Date.	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4
13-Jun	3.22	6.18	5.63	4.75	8.95	1.65	1.09	0.94	0.17
12-Jul	0.56	3.08	4.20	3.34	4.62	1.12	0.61	0.71	0.13
13-Aug	1.26	4.19	4.43	4.02	5.48	1.12	0.60	0.56	0.10
13-Sep	2.16	3.23	3.25	2.64	6.91	0.56	0.13	0.31	0.06
13-Oct	1.20	2.25	4.35	3.64	3.54	0.91	0.24	0.18	0.08
13-Nov	1.47	8.20	7.64	3.00	6.40	1.08	0.15	0.24	0.09
15-Dec	4.80	5.29	11.22	2.98	8.18	1.28	0.38	0.17	0.06
15-Jan	5.60	9.13	9.30	6.80	10.36	0.88	0.27	0.20	0.11
Average	2.53	5.19	6.25	3.90	6.81	1.08	0.43	0.41	0.10
Date	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
13-Jun	0.42	8.82	4.30	6.18	7.75	7.36	5.52	0.17	0.24
12-Jul	0.34	7.17	1.01	2.45	3.97	4.61	1.87	0.17	0.01
13-Aug	0.31	6.89	0.99	3.39	4.00	3.30	2.98	0.14	0.15
13-Sep	0.12	7.20	2.46	4.34	2.45	3.31	2.66	0.10	0.01
13-Oct	0.17	6.42	2.72	3.42	3.72	2.90	3.48	0.08	0.07
13-Nov	0.10	9.68	4.06	5.35	5.44	6.35	0.40	0.13	0.07
15-Dec	0.15	6.94	5.33	7.13	5.60	6.20	5.80	0.11	0.14
15-Jan	0.30	8.80	5.20	6.13	8.49	7.65	5.40	0.22	0.84
Average	0.24	7.74	3.26	4.80	5.18	5.21	3.51	0.14	0.19
Date	S.1	S.2	S.3	S.4	S.5	S.6			
13-Jun	2.11	4.44	0.33	1.09	0.82	0.65			
12-Jul	0.25	2.29	0.33	0.28	1.94	0.43			
13-Aug	0.19	3.21	0.23	0.24	0.80	0.23			
13-Sep	0.90	3.84	0.15	0.19	0.67	0.23			
13-Oct	0.23	2.55	0.18	0.14	0.25	0.24			
13-Nov	0.94	5.53	0.83	0.80	0.62	0.97			
15-Dec	1.88	3.98	1.22	1.06	1.50	0.44			
15-Jan	2.98	6.32	0.25	2.70	2.61	1.81			
Average	1.18	4.02	0.44	0.81	1.15	0.62			

Gram dry weight increase and relative growth rate for each species and % salinity.								
	Bolboschoenous caldwellii		*Carex divisa*		*Leptospernum scoparium*		*Leptocarpus similis*	
% Salinity	dry wgt (g)	RGR	dry wgt (g)	RGR	dry wgt (g)	RGR	dry wgt (g)	RGR
0.0000	13.4450	0.0140	1.0590	0.0022	47.2500	0.0097	1.3160	0.0011
0.2500	22.9810	0.0171	15.5550	0.0115	-	-	0.9960	0.0028
0.5000	40.3060	0.0193	8.6490	0.0083	27.4800	0.0123	0.6500	0.0021
0.7500	14.9200	0.0119	2.2670	0.0046	18.3500	0.0060	-	-
1.0000	6.2670	0.0117	2.5470	0.0040	15.7700	0.0065	-	-
1.2500	-	-	1.4820	0.0029	0.5800	0.0003	-	-
1.5000	0.1440	0.0005	0.6410	0.0014	-	-	0.6300	0.0016
1.7500	0.0710	0.0003	-	-	-	-	-	-
2.0000	0.0000	0.0000	0.3000	0.0000	-	-	0.5300	0.0012
2.5000	0.0000	0.0000	-	-	-	-	-	-
3.0000	0.0000	0.0000	-	-	-	-	-	-
3.5000	0.0000	0.0000	0.0000	0.0000	-	-	-	-
5.0000	0.0000	0.0000	0.2210	0.0000	-	-	-	-

Plot.	13-Jun	12-Jul	13-Aug	13-Sep	Oct-13	13-Nov	15-Dec	Average pH
1.1	8.45	8.31	7.84	7.66	8.55	8.14	8.12	8.2
1.2	8.3	8.24	7.82	8.33	8.48	8.38	8.35	8.3
1.3	8.26	8.33	7.8	8.26	8.26	8.2	7.94	8.2
1.4	8.2	8.16	7.76	8.23	8.36	8.74	8.49	8.2
1.5	7.61	8.01	7.35	8.09	8.25	7.7	8.35	7.8
2.1	8.36	7.5	7.55	7.84	7.94	8.15	7.7	7.9
2.2	7.36	6.58	6.94	6.94	7.34	7.48	7.8	7.1
2.3	8.26	7.48	7.55	7.78	8.31	7.96	7.7	7.9
2.4	9.03	8.2	8.28	8.043	8.15	8.08	8.47	8.3
3.1	8.15	7.31	7.79	7.18	7.47	8.06	7.5	7.7
3.2	6.85	7.13	6.61	6.86	7.5	7.44	6.77	7.1
3.3	8.47	8.75	8.69	7.88	8.3	8.31	8.37	8.4
3.4	8.26	8.31	7.74	8.08	8.53	8.43	8.47	8.2
3.5	7.65	7.58	7.2	7.63	8.07	7.65	7.77	7.6
3.6	7.89	8.01	7.29	7.33	8.05	7.48	7.96	7.7
3.7	7.67	7.3	7.67	7.9	8.15	7.58	8	7.7
3.8	9.09	7.82	7.93	7.63	8.3	8	7.9	8.1
3.9	9.07	8.28	8.12	7.92	8.33	8.17	7.83	8.3
S1	8.69	7.91	8.07	8.48	9.22	8.5	8.44	8.5
S2	7.76	7.99	7.26	7.58	8.43	7.94	7.98	7.8
S3	9.54	8.07	8.04	8.53	8.73	8.2	8.13	8.5
S4	8.37	8.05	8.17	8.36	8.78	8.48	8.15	8.4
S5	8.8	7.86	8.54	8.73	8.84	8.4	8.3	8.5
S6	9.47	8.22	8.76	8.79	9.18	8.81	8.79	8.9

Site.	Bulk D	Cond	pH	%H2O	Elev	Org%	NH4ug/cm3	NO3ug/cm3	Min N ug/g	MF%
							Unincubated	Unincubated	Incub-unincub	
1.1	1.53	1.53	8.2	32.08	191.24	5.1	113.42	28.35	126.97	4.03
1.2	1.17	4.5	8.3	40.40	161.74	2.6	83.87	15.95	31.18	8.03
1.3	1.2	4.74	8.2	40.81	156.74	2.4	75.17	16.15	28.06	7.79
1.4	1.4	3.64	8.2	37.69	156.24	1.8	85.86	15.61	48.98	6.9
1.5	0.97	6.17	7.8	53.94	181.74	4.5	119.88	15.98	91.38	10.19
2.1	0.97	1.12	7.9	50.91	144.01	6.9	106.65	3.99	188.69	6.62
2.2	1.31	0.54	7.1	41.98	148.01	3.7	158.48	41.57	48.65	9.01
2.3	1.41	0.53	7.9	37.58	236.75	7	112.26	7.28	109.04	6.49
2.4	2.3	0.11	8.3	6.1	248.01	1.3	32.98	3.6	1.8	1.02
3.1	1.84	0.25	7.7	13.04	271.3	12.4	10.19	4.49	10.58	3.1
3.2	1.09	7.62	7.1	49.24	184.3	8.4	144.37	13.66	115.62	10.31
3.3	1.62	2.26	8.4	29.59	187.3	4.1	57.46	7.07	6.25	3.95
3.4	1.14	4.1	8.2	43.39	180.55	3.3	101.89	13.05	200.31	10.68
3.5	1.06	4.76	7.6	49.33	181.05	5.8	153.51	10.48	166.15	9.25
3.6	1.19	4.68	7.7	45.84	180.05	5.3	167.39	23.91	208.58	8.33
3.7	1.02	3.47	7.7	48.49	179.55	6.2	156.27	35.12	120.51	8.32
3.8	2.11	0.13	8.1	10.21	259.8	5.2	17.02	4.95	6.52	1.32
3.9	2.04	0.09	8.3	9.23	278.8	2.9	20.99	2.12	6.93	0.82
S.1	1.81	0.91	8.5	19.18	181.74	1.4	42.23	11.86	25.13	1.67
S.2	1.1	3.55	7.8	44.43	158.5	4.6	108.01	12.51	105.06	7.94
S.3	1.98	0.31	8.5	12.92	187.5	4.3	51.54	19.09	21.68	2.25
S.4	1.7	0.51	8.4	23.88	180.82	2.1	21.55	4.28	6.96	5.05
S.5	2.11	0.8	8.5	21.74	178.82	4.9	119.76	7.88	46.25	3.35
S.6	1.91	0.44	8.9	18.2	202.32	2	45.82	7.69	13.41	1.82

Appendix Two

Miranda Species List

MIRANDA SPECIES LIST 1997

+ = recorded 1981 (Ogle 1981), x = recorded Feb.1996 (Merrett & Clarkson 1997).
p = planted, *= introduced spp.

				Dicotyledon Trees and Shrubs	Common name
+	x			*Avicennia marina* ssp. *australasica*	mangrove
+	x	p	*	*Casuarina* sp.	she-oak
	x	p		*Coprosma* x*cunninghamii*	
	x			*C. propinqua*	
+		p	*	*Erybiotrya japonica*	loquat
+		p	*	*Ficus carica*	fig
	x			*Ileostylus micranthus*	
	x			*Muehlenbeckia complexa*	pohuehue
	x	p		*Melicytus obovata*	
+		p	*	*Myoporum insulare*	Tasmanian ngaio
+		p		*Olearia lineata*	shrub daisy
+		p		*O. traversii*	Chatham Is shrub daisy
+	x			*Plagianthus divaricatus*	saltmarsh ribbonwood
	x		*	*Rosa rubiginosa*	sweet briar
+	x	p	*	*Tamarix* sp.	tamarix
+	x		*	*Ulex europaeus*	gorse

			Dicotyledon Herbs	
+	x	*	*Anagallis arvensis*	scarlet pimpernel
	x	*	*Aphanes inexspectata*	parsley piert
+		*	*Apium nodiflorum*	water celery
+		*	*Arenaria serpyllifolia*	sandwort
+	x	*	*Aster subulatus*	sea aster
	x	*	*Athemis cotula*	stinking mayweed
+		*	*Atriplex* sp.	orache
	x	*	*A. prostrata*	orache
	x	*	*Bellis perennis*	daisy
	x	*	*Beta vulgaris*	beet
		*	*Bidens sp*	beggars ticks
	x	*	*Calystegia sepium*	pink bindweed
+	x		*C. soldanella*	shore bindweed
+	x	*	*Capsella bursa-pastoris*	shepherds purse
+		*	*Carduus tenuiflorus*	wing thistle
+	x	*	*Centaurium erythraea*	centaury
+	x	*	*Cerastium glomeratum*	mouse-eared chickweed
	x	*	*Chenopodium pumilio*	clammy goosefoot
+	x	*	*Cirsium vulgare*	Scotch thistle
+	x	*	*Conyza albida*	fleabane
+	x	*	*Coronopus didymus*	twin cress
+	x	*	*Cotula coronopifolia*	batchelors button
+	x	*	*Crepis capillaris*	hawkbeard
+	x	*	*Daucus carota*	wild carrot
+		*	*Echium plantagineum*	Patersons curse
	x	*	*E. vulgare*	vipers bugloss
+	x	*	*Erodium* sp.	cranesbill
	x	*	*E. cicutarium*	storksbill
		*	*Euphorbia lathyris*	caper spurge

	x	*	*E. peplus*	milkweed
	x	*	*Foeniculum vulgare*	fennel
+		*	*Galium aparine*	cleavers
+		*	*G. divaricatum*	slender bedstraw
	x	*	*G.* sp.	
	x		*G. propinquum*	
+	x	*	*Geranium molle*	doves foot
+	x	*	*G. purpureum*	lesser herb Robert
	x	*	*G. robertianum*	herb Robert
+			*Haloragis erecta*	
+	x	*	*Helminotheca echioides*	ox-tongue
	x	*	*Hypochaeris radicata*	catsear
+	x	*	*Leontodon taraxacoides*	hawkbit
	x	*	*Lepidium africanum*	peppercress
		*	*L. bonariense*	Argentine cress
		*	*L. pseudotasmanicum*	narrow-leaved cress
	x		*Lilaeopsis novae-zelandiae*	
	x	*	*Linaria arvensis*	field linaria
	x	*	*Linum bienne*	pale flax
+		*	*Lotus pedunculatus*	lotus major
+	x	*	*L. suaveolens*	hairy lotus
+		*	*Lythrum hyssopifolia*	purple loosestrife
+	x	*	*Malva neglecta*	mallow
+		*	*Medicago arabica*	spotted bur medick
+	x	*	*M. lupulina*	black medick
+	x	*	*M.nigra*	bur medick
+	x	*	*Melilotus indicus*	King Island melilot
	x	*	*M. officinalis*	yellow sweet clover
	x	*	*Mentha pulegium*	pennyroyal
	x		*Mimulus repens*	creeping musk
+	x	*	*Modiola caroliniana*	creeping mallow
	x	*	*Orobanche minor*	broomrape
+	x	*	*Parentucellia viscosa*	tarweed
+		*	*Phytolacca octandra*	inkweed
	x	*	*Plantago australis*	swamp plantain
+	x	*	*P. coronopus*	bucks horn plantain
+	x	*	*P. lanceolata*	narrow-leaved plantain
+	x	*	*P. major*	broad-leaved plantain
+	x	*	*Polygonum aviculare*	wire-weed
+	x	*	*Portulaca oleracea*	pig-weed
	x	*	*Prunella vulgaris*	selfheal
	x	*	*Ranunculus repens*	creeping buttercup
		*	*Ranunculus sceleratus*	celery-leaved buttercup
+	x	*	*Raphanus raphanistrum*	wild radish
+	x	*	*Rumex crispus*	curled dock
+	x	*	*R. pulcher*	fiddle dock
+	x		*Sarcocornia quinqueflora*	glasswort
+	x		*Samolus repens*	sea primrose
	x	*	*Sedum acre*	stonecrop
+	x		*Selliera radicans*	selliera
+			*Senecio glomeratus*	fireweed
+		*	*S. jacobaea*	ragwort
+	x	*	*S. vulgaris*	groundsel
	x	*	*Sherardia arvensis*	field madder
+	x	*	*Sisymbrium officinale*	hedge mustard
+	x	*	*Sonchus asper*	prickly sowthistle

+	x	* *S. oleraceus*	puwha, sowthistle
+	x	*Spergularia media*	
	x	* *Stellaria media*	chickweed
+	x	*Suaeda novae-zelandiae*	sea blite
+		* *Taraxicum officinale*	dandelion
+		* *Torilis arvensis*	spreading headgehog parsley
+	x	* *Trifolium dubium*	suckling clover
	x	* *T. fragiferum*	strawberry clover
+		* *T. glomeratum*	clustered clover
	x	* *T. pratense*	red clover
+	x	* *T. repens*	white clover
+		* *T. resupinatum*	reversed clover
+	x	* *T. scabrum*	rough clover
+	x	* *Verbascum virgatum*	moth mullein
+	x	* *Veronica arvensis*	speedwell
	x	* *V. persica*	scrambling speedwell
	x	* *Vicia* sp.	

Grasses

+	x	* *Agrostis stolonifera*	creeping bent
	x	* *Arrhenatherum elatius*	tall oat grass
+		* *Avena fatua*	wild oat
	x	* *B. maxima*	quaking grass
+	x	* *Briza minor*	shivery grass
	x	* *Bromus diandrus*	ripgut brome
+	x	* *B. hordeaceus*	soft brome
+	x	* *B. willdenowii*	prairie grass
+		* *B. sterilis*	
	x	* *Catapodium rigidum*	feather grass
+	x	* *Cynodon dactylon*	Indian doab
+	x	* *Dactylis glomerata*	cocksfoot
	x	*Dichelachne crinita*	
+	x	* *Festuca arundinacea*	tall fescue
+	x	* *Holcus lanatus*	Yorkshire fog
	x	* *Hordeum marinum*	sea barley grass
+		* *H. murinum*	barley grass
+	x	* *Lagurus ovatus*	harestail
+	x	* *Lolium perenne*	perennial ryegrass
+	x	* *Parapholis incurva*	curved sea hard-grass
	x	* *P. strigosa*	sea hard grass
	x	* *Paspalum dilatatum*	Paspalum
	x	* *P. distichum*	Mercer grass
	x	*Pennisetum clandestinum*	kikuyu
+	x	* *Poa annua*	annual poa
	x	*P. pratensis*	smooth meadow grass
+	x	* *Polypogon monspeliensis*	beard grass
+	x	*Puccinella stricta*	salt grass
	x	*Rytidosperma* sp.	
+	x	* *Sporobolus africanus*	rats tail
+		*Stipa stipoides*	
+	x	* *Vulpia bromoides*	vulpia hair grass

			Sedges	
+	x		*Bolboschoenus caldwellii*	
	x		*B. medianus*	
+	x		* *Carex divisa*	divided sedge
+	x		* *C. divulsa*	grey sedge
+			* *Cyperus eragrostis*	
+			*C. ustulatus*	Purua 'grass'
+	x		*Isolepis cernua*	
+			*I. nodosa*	knobby clubrush
	x		*Lepidosperma australe*	
			Other Monocotyledons	
			(i.e. other than grasses and sedges)	
+			* *Allium vineale* var. *compactum*	wild onion
+	x		* *Juncus bufonius*	toad rush
	x		*Juncus gerardii*	salt marsh rush
+	x		*J. kraussii* var. *australiensis*	sea rush
			J. spp	
			Leptocarpus similis	jointed wire rush
+		p	*Phormium tenax*	NZ flax
+	x		*Triglochin striata*	arrow 'grass'

Appendix Three

Hewitt Nutrient Stock Solution

Hewitt Nutrient Stock Solution

	grams per litre
KNO_3	202
$Ca(NO_3)_2$(anhyd)	328
$MgSO_4.7H_2O$	184
$NaH_2PO_4H_2O$	208
$NaNO_3$	340
Ferric Citrate	60
$MnSO_4.4H_2O$	22.3
$CuSO_4.5H_2O$	2.5
$ZnSO_4.7H_2O$	2.9
H_3BO_3	31
NaCl	58.5
H_2MoO_4	0.45

(Source: Hewitt 1966)