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5.2 LANDSCAPE VARIABILITY

The cluster analysis of plots confirms Allen & McIntosh's (1997) observation of high within-site variability of saline soils and vegetation, confirming the need to recognise in protection initiatives the geomorphic variability of the saline ecosystem. Further, the present study also demonstrates high between-region variability. This is exemplified in the differences within the ecosystem at Patearoa and Galloway, principally because of the different origins of salinity at the two locations. On Patearoa's salt plain sites developed on the floodplain, saltiness is derived mainly from groundwater that accummulates the salts within the alluvial sediments, and at Galloway they are derived mainly from in situ sources from weathered schist and Tertiary sediments in surface exposures. Cluster analysis of plots based on soil chemistry also points to moderate sodicity in patches on Patearoa's higher terraces of colluvial schist above the floodplain, despite the absence of recognised native halophytes as indicators.

Because of their regional rarity and probable distinctiveness, the saline patches on Tertiary sediments in the upper Waitaki Valley at Otematata and Otamatapaio need careful appraisal.

Given the strong influence of topography on pedogenesis, we suggest that the saline soils of Pisa Flat are likely to deviate somewhat from those encountered in the present study in the Patearoa and Manuherikia basins. A first analysis of Pisa Flat soils is provided in Allen & McIntosh (1994).

5.3 LOSS OF THE INLAND SALINE ECOSYSTEM

The inland saline ecosystem is represented on a range of landforms (Fig. 1) in six major basins and river catchments in Central Otago. A comparison between our 1990s inventories and soil surveys earlier this century indicates that saline sites have suffered their greatest loss on terraces and fans of all ages, with agricultural development, including irrigation, being the main agent of loss. Accordingly, salt meanders, pans, and plains have probably retracted most. Knolls and aprons on block mountain hill-slopes and toe-slopes are a little better off and dominate the present inventories of sites.

Anthropogenic disturbance has apparently played a role in intensifying the surface expression of salinity and sodicity on knolls and aprons on both weathered schist and on Tertiary sediments. All the sampled examples showed some degree of topsoil loss or truncation of soil profiles. The greater concentrations of subterranean salts now exposed on the surface has somewhat allayed the threat of weeds and enhanced the survival prospects, in particular, of *Puccinellia raroflorens* and *Lepidium kirkii*. Nevertheless, there is a tenuous balance between surface erosion by storm-water, wind, and farm stock, and the recruitment requirements of the native flora. *Lepidium kirkii* commonly occurrs in conjunction with the surface-stabilising crusts of *Lichenothelia* sp., indicating some degree of surface stability was achieved where the plants were established. *Lichenothelia* sp. with its surface-stabilising properties may facilitate establishment of *Lepidium kirkii.* Alternatively, the spatial relationship may be quite coincidental.

There are few exposures of saline soils formed directly on Tertiary clays and silts of the Manuherikia Formation. These substrates are commonly overlain with greywacke- and schist-derived alluvium and loess on the basin floors. Nevertheless, Tertiary sediments form the primary landforms of the Maniototo Plains, Ida Basin, lower Manuherikia Valley around Galloway, and small toe-slope sites in the upper Waitaki Valley. Raeside (1948) points to the floors of salt pans being formed on underlying Tertiary sediments, but there are few, if any, conservationally important exposures remaining of Tertiary soils in that geomorphic unit. Those not entirely eliminated by farming practices, such as soil cultivation, are variously flooded with irrigation water, choked with exotic weeds, or devoid of surface salt concentration. However, these sediments have strongly influenced the genesis of Otago's inland saline ecosystem by acting as a salt source. Soluble salts have leached from subsurface Tertiary clays and been transported to the soil surface via water tables or by down-slope redistribution. The present study shows that salty soils on Tertiary clays and silts at Springvale are chemically quite different from the remainder of soils in the present sample. This result reinforces the need for full recognition of ecosystem variability in the conservation of saline soils.

Nine sites in the McIntosh et al. (1990, 1992) registers contain saline patches on Tertiary substrates: Moa Creek-Top Galloway, Belmont, Wilsons Road, beginning of Nevis Road, Springvale, Dunards (with loess overlay), Rockdale, Otamatapaio, and Otematata. Of these, only Top Galloway, Rockdale, and Belmont support, or more accurately supported, salt pans (sensu stricto). Our tentative conclusion is that salt pans (sensu Raeside 1948) are functionally extinct in New Zealand.

The early literature does not provide a basis to assess the previous extent of the salt meander geomorphic unit. However, our current field knowledge suggests salt meanders are restricted to the Patearoa, Rockdale, and Belmont sites. Further detailed survey of the Taieri scroll wetlands scheduled for the 1999–2000 summer may reveal other remnants of what is assumed to be a dramatically contracted geomorphic unit.

5.4 NATIVE AND EXOTIC HALOPHYTIC FLORA

A high proportion of the native halophytic flora is specialised to particular geomorphic units. We suspect this reflects not only variations in soil chemistry, but also soil moisture gradients. Soil moisture and its seasonal reliability is a pointer to the position that the native halophytic plants occupy in the salt marsh tidal gradient (for the latter see Partridge & Wilson 1987, 1988). Only the most reliably moist and saline habitat, salt meanders and plains (and probably many salt pans in the past), caters for those species lowest in the tidal margins of salt marshes. Accordingly, species such as *Sarcocornia quinqueflora* and *Samolus repens*, which are recorded from only two sites each, indicate a dramatic loss of inland habitat at the wet end of the salt-moisture gradient. Alternatively, both may always have been rare, but this seems unlikely based on the observations of Raeside (1948) on the extent of salt pans and meanders, and the extent of basin floor landforms in Central Otago.

In this study we conclude that *Lepidium sisymbrioides* spp. *matau* is tolerant of subsoil salinity that may be encountered by its deep taproot, even though such plants establish in non-saline and non-sodic topsoils.

Two native species are endemic or near-endemic to the inland saline ecosystem. *Lepidium kirkii* has evolved a tolerance for sodicity, but less so for salinity. Its extant habitats (Grove 1994) confirmed its adaptation to knolls, aprons, and plains. The rare occurrences on salt plains are highly vulnerable to smothering by *Plantago coronopus* as demonstrated at the Wilsons Road site. *Lepidium kirkii* will clearly require assistance to survive in this ecological outlier. Summer aridity goes hand in hand with strong sodicity on knolls and aprons. A substantial taproot and survival as a geophyte (seasonal loss of aerial plant parts with survival of root stock) in seasonal extremes of soil chemistry and aridity suggest that *L. kirkii* has a long history of adaption to these conditions. It is probable that its main habitat, salt knolls, has a relatively long geological history in Central Otago. *Puccinellia raroflorens* is adapted to extremes of sodicity and salinity, and is concentrated on knolls, aprons, and plains. It has adopted a more generalist survival strategy in this inland ecosystem. *Myosurus minimus* ssp. *novae-zelandiae* is tolerant of mild sodicity and salinity, with the proviso that its shallow depression habitat is saturated with winter- and spring-ponded water, which helps reduce the competition of exotic weeds.

Exotic species have proliferated in number, and cover, on all geomorphic units except knolls and aprons. The exotic species *Hordeum hystrix* is common on the high-sodicity knolls and aprons, but it does not form smothering swards. The remainder of the geomorphic units, however, have alarming susceptibility to weed encroachment. Salt plains no longer have partly vegetated transition zone soils surrounding bare-earth patches, but are now encircled by tight swards of mostly herbs and grasses. Further, *Plantago coronopus* shows a strong tolerance to the most saline chemistry of salt plains to the detriment of what remains of the native halophytes. Distinct seasonal and inter-annual changes in soil moisture on salt knolls and aprons apparently generate dramatic changes in plant cover (see also Walker et al. 1999). Although the accompanying pulses of vegetation were not experimentally investigated, inter-annual monitoring of saline sites with *Myosurus minimus* ssp. *novae-zelandiae* in another study (G. Rogers unpubl. data) indicates large increases in biomass following reductions in rabbit populations.

The weed offering the greatest management challenge is *Plantago coronopus* because of its aggressiveness on the three most threatened geomorphic units: salt pans, salt plains, and salt meanders. Opportunities for herbicide control or biocontrol may need to be explored.

Currently there are no monitoring studies to point to the survival prospects of the halophytic natives such as *Sarcocornia quinqueflora, Samolus repens*, *Apium prostratum*, *Puccinellia stricta* and *Selliera radicans* that are threatened by aggressive exotics. *Atriplex buchananii* survives quite well on the barest patches of aprons and knolls, but is threatened by *Plantago coronopus* on plains. *Samolus repens* was previously recorded from two sites only, but has not been recorded from either in 1999, despite detailed survey; it may be extinct in Central Otago. The salt meander species *Schoenoplectus pungens* and *Carex* sp. are only known from a weed-infested meander at Patearoa. Overall, the aggressiveness of the exotic flora has probably led to retreat of the native flora to the limits of their saline and/or sodic tolerances. In general terms, irrigation has probably diluted salinity and mitigated summer aridity to the detriment of the salt-tolerant native species.

Soil chemistry strongly regulates the weediness of a site. Essentially, this confirms the field impression that the bare-earth patches offer the best prospects for survival of the native halophytic flora. In the absence of selective and efficient control of weeds on weakly to moderately salty soils, management emphasis must increasingly target the saline bare-earth sites.

We now require more information on the competitive exclusion of the native flora by exotic plants and the latter's regulatory role in pedogenesis. With the co-operation of private landowners, further adaptive management experiments beyond those at Chapman Road and Galloway No. 1 are required to evaluate the utility of sheep and, probably by default, rabbits in containing the cover of exotic plants. As Allen & McIntosh (1997) emphasise, cattle are anathema to maintaining soil surface cohesion of saline patches but sheep are less disruptive, perhaps benign or even beneficial in consistently dry soil conditions. Declines in rabbit densities from rabbit haemorrhagic disease add another variable to trends in vegetation condition.

We know of no native shrubs tolerant of the stronger concentrations of salinity and sodicity on saline patches. However, the elimination by burning of native shrubs in Otago's intermontane basins has been so comprehensive that reconstructing compositional and explanatory environmental gradients is extremely difficult. Nevertheless, species of *Pimelea*, *Hebe*, *Melicytus*, *Ozothamnus* (*Cassinia*), *Kunzea*, *Carmichaelia*, and *Discaria* in relict shrub lands on lower valley slopes and on toe slopes point to their previous importance on basin floors, if not tolerance of moderate degrees of salinity and sodicity. For instance, *Carmichaelia compacta* occurs on toe slopes at Galloway on the fringes or transition zones of salt knolls.

There is the potential to use coastal provenances of halophytic plants for restoration planting where the species has become extinct in Central Otago's saline patches. However, the frost tolerances of the coastal provenances will need to be examined.

5.5 AN APPROACH TO A COMPREHENSIVE CONSERVATION STRATEGY

After an initial period of more or less thorough inventory (Olrig Station, Galloway, requires further survey), the conservation of Otago's inland saline ecosystem has progressed slowly. An inland *Lepidium* recovery plan (Allen 2000), while emphasising the needs of *L. kirkii* (and three subspecies of *L. sisymbrioides*), provides further impetis. Just three saline patch sites are formally protected, two are under discussion for Conservation Covenants, and a sixth is in the process of formal protection following a pastoral lease tenure review (Table 6). Unfortunately, *L. kirkii* is protected at just one site, Chapman Road, partly because the Patearoa and Belmont QE II Covenants exclude the local habitat of this apparently obligate saline endemic.

TABLE 6. CURRENT STATE OF PROTECTION FOR THE INLAND SALINE ECOSYSTEM.

SITE	CATCHMENT	GEOMORPHIC UNITS	FORM OF PROTECTION	REGISTERED OR GAZETTED
Belmont	upper Taieri-Maniototo	plain	QE II covenant	yes
Earnscleugh Conservation Area	mid-Clutha	knoll, apron	Conservation area	no
Patearoa	upper Taieri-Maniototo	meander, plain	QE II Covenant	yes
Top Galloway	Manuherikia	knoll, apron, plain	Conservation Covenant	agreement to enter covenant, not registered yet
Galloway No. 1	Manuherikia	knoll, apron	Conservation Covenant	agreement to enter covenant, not registered yet
Chapman Road	mid-Clutha	knoll, apron, meander	Scientific Reserve	gazetted

Currently, the upper Clutha, upper Waitaki, and Ida Valley catchments have no protected saline sites. With the exception of Pisa Flats, the sites shown in Table 6 include the seven top-ranked sites (ranking 3 or higher) of Allen & McIntosh (1997). These authors have gone some way to meeting the objective of a comprehensive protection strategy by ranking 24 sites using salinity and pH tolerances of plants, a soil classification, and the distribution of the native biota. Nevertheless, so dramatic has been the loss of the inland saline ecosystem that much of what remains would rank high on a rarity criterion alone. We suggest that a fully representative reserves system should include the full range of biophysical variation remaining in each of the six catchments. We therefore recommend an ecosystem-based strategy be adopted that recognises the taxonomic and functional variability of the entire system. The present study provides a geophysical framework to typify and inventory ecosystem taxonomy in each of the six catchments. Further, to improve our understanding of ecosystem processes as a component of a conservation strategy, we suggest using electrical conductivity and ESP as useful surrogates for salinity and sodicity gradients respectively, along with analysis of monovalent cations (potassium) and bivalent cations (calcium and magnesium). Our results suggest that these soil properties, along with soil moisture, are the main regulators of ecosystem processes. By plotting the means and standard deviations of electrical conductivity and ESP for each geomorphic unit and considering their accompanying native flora, the variation in ecosystem geochemistry can be compared within and between each catchment. By comparing the plotted environmental space of the present reserves with the full variability of each catchment, gaps in the protection network would emerge.

6. Recommendations

We recommend:

- Extending the present methodology of site and species typification by geomorphology and soil chemistry (electrical conductivity, exchangeable sodium percentage, and monovalent and bivalent cations) to the remainder of saline sites, including the Otamatapaio and Otematata sites in the Waitaki catchment (the latter two in Canterbury Conservancy).
- Identifying gaps and therefore conservation priorities in the environmental space.
- Ensuring that translocation experiments for the native biota recognise the high spatial variability in saline habitats.
- Adopting adaptive management experiments to investigate levels of stock grazing (animal species, stocking densities, seasonality) that nurture the native halophytic flora over their exotic counterparts. Issues requiring experimental evaluation include surface modification to replicate erosion and fresh exposure of salinity and sodicity, containment of exotic plants, and nutrient translocation across the landscape.
- Standardising saline patch place names, with bibliographic reference to synonymy.
- Searching recent comprehensive air photo coverage for the location of any remaining salt pans in the Maniototo and at Galloway.

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Appendix 1

GLOSSARY*

BS, (base saturation) the degree to which the soil CEC is occupied by bases. Calculated by expressing the amounts of bases present as a percentage of CEC. Semi-arid regions usually have high to very high BS (> 60%).

Calcium carbonate, the amount of free lime present.

CEC, (cation exchange capacity) the amounts of calcium, magnesium, potassium, and sodium for exchange in the soil-water-plant root system. It also shows the ability of the soil to hold these exchangeable nutrients. Depends on the amount and type of colloid present, either as clay or organic matter.

Exchangeable sodium percentage, (**ESP**) the percentage of cation exchange sites that are occupied by sodium cations. It is a measure of exchangeable sodium as a percentage of soil sodicity.

Halophytic flora, plants tolerant of moderate to high concentrations of sodicity and salinity (see 1.3 Classification of saline ecosystem soils).

pH, a measure of the acidity or alkalinity of the soil. A neutral soil has a pH of 7. High pH in the lower horizons indicates the presence of sodium carbonate.

Pedogenesis, the developmental process of soils, being the product of interaction of parent material, climate, topography, plants and animals, and the age of the land surface.

Saltiness, a general term to describe high soluble salt concentrations in soils, encompassing both saline, sodic, and saline-sodic soils.

Salinity, the content of soluble salts in the soil. When moist, the salts are in solution in soil pores. When dried, the salts crystalise. Salinity is measured by either the total soluble cations, or estimated by electrical conductivity.

Sodicity, the amount of sodium ions attached to cation exchange sites on the surfaces of clay minerals or soil organic matter. It is measured by exchangeable sodium percentage or estimated by pH.

Soluble salts, usually tested by the electrical conductivity (**EC**) of the soil. Limitations to plant growth caused by salt toxicity are only expected when conductivity values are greater than 0.35 mS/cm @ 25°C, and it is then usually desirable to measure the salts by chemical methods. The salts present are usually mixtures of chlorides, sulphates, bicarbonates, and carbonates of sodium, magnesium, calcium and potassium. Carbonates of calcium and magnesium are relatively insoluble and tend to accumulate in bands within the soil profile, while the more soluble salts, such as sodium chloride, move more freely. The latter often accumulate on the surface with evaporation.

TEB, (total exchangeable bases) a measure of the nutrients actually held by the soil. In semi-arid regions, the amounts of exchangeable bases are as high as the capacity of the soil to hold them.

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* (draws principally upon Orbell 1974)

Appendix 2

SOIL CHEMICAL DATA FROM SAMPLED SITES IN CENTRAL OTAGO

Where **ts** is topsoil, **ss** is subsoil, **EC** is electrical conductivity, **CEC** is cation exchange capacity, **BS** is base saturation, **ESP** is exchangeable sodium percent. The term **cmol** stands for centimol, or 100 mols, and is equivalent to the older term milliequivalents (me). It refers to the number of charges on the soil surface to which cations are bound.

PLOT NUMBER AND SITE LOCATION	pH	EC (1:5) mS/cm	CEC cmol(+) /kg	BS (%)	EXCHANGEABLE CATIONS cmol(+)/kg				ESP (%)	WATER SC cmo				
					Ca	Mg	K	Na		Cl	NO_3	SO_4	CO_3	H
1 Patearoa salt plain, ts	8.9	3.79	9.11	144	5.78	2.66	0.64	4.05	44.45	1.84	0.12	0.42	0.01	C
2 Patearoa salt plain, ts	9.5	10.47	11.03	427	33.93	3.32	0.60	9.27	84.02	4.39	0.09	1.16	0.09	C
3 Patearoa salt plain, ts	8.8	4.70	6.14	1043	42.61	19.05	0.45	1.99	32.42	2.46	0.04	0.49	0.02	C
4 Patearoa salt plain, ts	9.3	6.46	7.66	137	3.39	1.73	0.51	4.86	63.45	4.36	0.16	0.88	0.03	C
5 Patearoa salt plain, ts	9.7	3.22	5.35	209	6.74	0.71	0.66	3.06	57.08	1.55	0.11	0.29	0.08	C
5 Patearoa salt plain, ss	9.9	3.33	5.29	241	7.58	1.00	0.55	3.62	68.33	1.73	0.15	0.28	0.11	C
6 Patearoa salt plain, ts	9.1	3.94	9.10	177	8.38	2.35	0.57	4.82	52.97	1.56	0.07	0.32	0.04	C
6 Patearoa salt plain, ss	9.6	5.85	5.37	156	2.85	2.29	0.22	3.03	56.31	3.77	0.02	0.95	0.06	C
7 Patearoa salt plain, ts	6.8	0.91	7.61	81	2.50	1.38	0.35	1.91	25.11	0.56	0.06	0.06	0.00	C
8 Patearoa salt plain, ts	9.5	7.32	7.99	131	3.47	1.02	0.63	5.34	66.86	4.75	0.09	1.70	0.06	C
9 Patearoa salt meander, ts	6.9	1.60	29.38	123	27.75	7.34	0.49	0.49	1.65	0.38	0.16	0.22	0.00	C
10 Patearoa salt meander, ts	5.9	0.92	17.38	56	5.57	2.69	1.37	0.15	0.86	0.20	0.47	0.12	0.00	C
11 Patearoa salt meander, ts	6.4	1.27	10.26	88	4.74	2.84	0.34	1.15	11.20	0.80	0.04	0.13	0.00	C
11 Patearoa salt meander, ss	8.8	0.86	7.77	119	3.98	3.57	0.21	1.47	18.88	0.45	0.02	0.10	0.00	C
12 Patearoa salt plain, ts	9.9	9.08	6.23	282	10.36	1.68	0.25	5.26	84.39	4.04	0.11	2.48	0.23	C
13 Patearoa salt plain, ts	8.0	5.33	11.95	110	3.89	3.14	0.76	5.31	44.47	3.87	0.30	1.00	0.00	C
14 Patearoa salt apron, ts	7.8	4.57	6.40	106	2.07	3.77	0.27	0.67	10.49	3.78	0.01	0.57	0.00	C
15 Patearoa non-saline terrace, ts	6.0	0.15	7.20	75	3.52	1.30	0.57	0.00	0.00	0.27	0.06	0.04	0.00	C
16 Galloway non-saline terrace, ts	5.6	0.10	6.32	52	2.11	0.69	0.49	0.00	0.00	0.04	0.02	0.01	0.00	C
16 Galloway non-saline terrace, ss	6.4	0.05	4.17	95	3.06	0.81	0.13	0.00	0.00	0.03	0.01	0.01	0.00	C
17 Galloway non-saline terrace, ts	5.6	0.10	6.34	47	1.82	0.65	0.54	0.00	0.00	0.03	0.02	0.01	0.00	C
17 Galloway non-saline terrace, ss	6.2	0.05	4.72	96	3.33	1.05	0.10	0.06	1.19	0.02	0.01	0.00	0.00	C
18 Gallloway non-saline terrace, ss2	6.3	0.10	9.57	99	6.14	2.79	0.14	0.43	4.49	0.90	0.07	0.23	0.00	C
19 Dunard salt apron, ts	9.5	1.81	4.84	155	3.58	0.65	1.08	2.21	45.65	0.32	0.05	0.21	0.03	C
19 Dunard salt apron, ss	9.9	1.82	5.35	150	3.19	1.44	1.05	2.34	43.68	0.23	0.04	0.19	0.10	C
20 Patricks non-saline plain	6.1	0.15	10.12	79	5.73	1.29	1.03	0.00	0.00	0.10	0.04	0.02	0.00	C
21 Springvale salt plain, ts	7.6	18.55	8.58	291	19.57	5.42	0.14	0.00	0.00	23.84	0.00	1.11	0.00	C
21 Springvale salt plain, ss	8.4	2.96	10.79	115	7.38	3.75	0.15	1.10	10.17	2.81	0.00	0.20	0.00	C
22 Springvale salt knoll, ts	6.7	2.42	17.66	105	12.27	5.23	0.20	0.90	5.07	2.63	0.01	0.11	0.00	C
22 Springvale salt knoll, ss	8.2	1.02	9.64	105	6.59	2.91	0.13	0.49	5.08	1.06	0.01	0.04	0.00	C
23 Galloway salt apron, ts	8.7	4.23	3.84	217	5.30	1.49	0.13	1.44	37.49	3.71	0.06	0.60	0.00	C
24 Galloway salt apron, ts	9.9	8.81	3.09	978	23.20	3.91	0.41	2.75	88.82	5.99	0.02	1.62	0.15	C
24 Galloway salt apron, ss	9.7	2.16	3.26	683	17.14	3.99	0.35	0.82	25.23	1.17	0.00	0.21	0.06	C
25 Galloway non-saline hill-slope, ts	5.7	0.30	5.29	74	2.63	0.98	0.26	0.07	1.33	0.22	0.01	0.02	0.00	C
26 Galloway non-saline hill-slope, ts	5.9	0.51	7.87	85	3.19	3.03	0.28	0.15	1.92	0.29	0.02	0.13	0.00	C

PLOT NUMBER AND SITE LOCATION	pH	EC (1:5) mS/cm	CEC cmol(+) /kg	BS (%)	EXCHANGEABLE CATIONS cmol(+)/kg				ESP (%)	WATER SC cmo				
					Ca	Mg	K	Na		Cl	NO_3	SO_4	CO_3	H
26 Galloway non-saline hill-slope, ss	6.0	0.76	6.91	95	2.15	3.83	0.10	0.46	6.72	0.38	0.00	0.31	0.00	(
27 Galloway non-saline hill-slope, ts	5.8	0.15	6.79	78	3.58	1.29	0.40	0.02	0.36	0.08	0.02	0.02	0.00	(
28 Galloway non-saline hill-slope, ts	5.4	0.76	8.98	86	4.78	2.81	0.12	0.05	0.51	0.76	0.01	0.02	0.00	(
28 Galloway non-saline hill-slope, ss	5.4	3.64	7.39	102	3.54	3.68	0.03	0.26	3.52	3.89	0.00	0.00	0.00	(
29 Galloway non-saline hill-slope, ts	5.8	0.15	5.55	72	2.82	0.90	0.31	0.00	0.00	0.11	0.02	0.05	0.00	(
29 Galloway non-saline hill-slope, ss	8.6	2.62	5.13	138	3.48	2.81	0.41	0.40	7.83	1.20	0.00	1.19	0.00	(
30 Galloway salt apron, ts	8.2	4.63	3.12	176	2.79	2.24	0.42	0.05	1.50	3.49	0.03	1.53	0.00	(
31 Galloway non-saline hill-slope, ts	5.4	0.40	6.68	69	3.11	0.97	0.48	0.03	0.47	0.26	0.01	0.05	0.00	(
31 Galloway non-saline hill-slope, ss	7.7	4.69	7.68	114	4.11	3.63	0.15	0.90	11.70	2.30	0.01	2.35	0.00	(
32 Galloway non-saline hill-slope, ts	5.7	1.16	5.57	91	2.35	2.49	0.17	0.05	0.86	1.07	0.01	0.18	0.00	(
32 Galloway non-saline hill-slope, ss	5.9	4.79	5.49	105	2.17	2.96	0.16	0.46	8.36	3.37	0.00	1.60	0.00	(
33 Moa Creek salt knoll, ts	6.6	2.03	8.93	107	4.40	4.69	0.23	0.28	3.14	1.64	0.01	0.38	0.00	(
33 Moa Creek salt knoll, ss	8.4	1.01	5.19	122	2.25	3.88	0.07	0.12	2.37	0.75	0.00	0.18	0.00	(
34 Chapman Rd salt knoll, ts	8.6	6.43	4.57	582	18.83	6.58	0.19	1.00	21.94	5.52	0.04	0.84	0.00	(
34 Chapman Rd salt knoll, ss	9.4	2.57	3.95	293	7.00	4.11	0.10	0.36	9.13	2.00	0.00	0.34	0.01	(
35 Chapman Rd salt knoll, ts	7.7	2.42	4.00	116	2.40	2.12	0.15	0.00	0.00	1.57	0.02	0.60	0.00	(
35 Chapman Rd salt knoll, ss	9.0	11.48	3.76	547	16.42	4.62	0.10	0.00	0.00	10.82	0.00	3.13	0.00	(
36 Chapman Rd salt plain, ts	7.0	4.76	9.99	109	3.87	5.40	0.61	0.96	9.59	2.76	0.03	2.16	0.00	(
37 Chapman Rd salt meander, ts	7.4	7.07	13.15	121	7.76	5.62	0.58	1.96	14.87	5.95	0.04	1.38	0.00	(
37 Chapman Rd salt channel, ss	8.4	8.66	6.66	133	4.16	3.42	0.45	0.83	12.4	6.63	0.00	3.42	0.00	(
38 Earnscleugh salt knoll, ts	9.9	6.31	12.83	443	41.59	6.41	0.87	7.95	61.98	2.04	0.03	1.50	0.23	(
38 Earnscleugh salt knoll, ss	9.9	2.93	7.13	795	45.59	8.36	0.46	2.30	32.2	0.61	0.00	0.23	0.18	(
39 Earnscleugh salt knoll, ts	8.6	2.43	9.37	120	3.82	3.79	0.72	2.90	30.89	0.68	0.02	0.44	0.01	(
40 Butchers Dam salt apron, ts	7.7	0.91	11.73	102	5.25	3.46	0.33	2.95	25.16	0.33	0.00	0.12	0.00	(
40 Butchers Dam salt apron, ss	9.8	1.47	11.76	207	16.25	5.18	0.13	2.80	23.84	0.05	0.04	0.04	0.09	(
41 Patricks salt knoll, ts	6.2	1.87	7.73	93	3.48	2.59	0.33	0.77	9.91	1.55	0.00ss	0.23	0.00	(

Appendix 3

SOIL CLASSIFICATION OF SAMPLED SITES IN CENTRAL OTAGO'S INLAND SALINE ECOSYSTEM

Plot numbers and therefore site descriptors are identical to those of Appendix 2.

PLOT NO.	FIELD PLOT NO.	pH	EC (1:5) (mS/cm)	ESP (%)	SOIL CHEMISTRY CLASS	NZ SOIL CLASSIFICATION
1	F1	8.9	3.79	44	Saline-sodic	Saline Immature Semiarid Soil
2	F2	9.5	10.47	84	Saline-sodic	Saline Immature Semiarid Soil
3	F3	8.8	4.70	32	Saline-sodic	Saline Recent Gley Soil
4	F4	9.3	6.46	63	Saline-sodic	Saline Fluvial Recent Soil
5	F5	9.7	3.22	57	Saline-sodic	Saline Immature Semiarid Soil
6	F6	9.1	3.94	53	Saline-sodic	Saline Argillic Semiarid Soil
7	F7	6.8	0.91	25	Saline-sodic	Saline Immature Semiarid Soil
8	F8	9.5	7.32	67	Saline-sodic	Saline Immature Semiarid Soil
9	F9	6.9	1.60	2	Saline	Saline Recent Gley Soil
10	F10	5.9	0.92	1	Saline	Saline Recent Gley Soil
11	F11	6.4	1.27	11	Saline	Saline Recent Gley Soil
12	F12	9.9	9.08	84	Saline-sodic	Saline Immature Semiarid Soil
13	F13	8.0	5.33	44	Saline-sodic	Saline Immature Semiarid Soil
14	T1	7.8	4.57	10	Saline	Fluvial Raw Soil
15	T2	6.0	0.15	0	Not saline, not sodic	Typic Immature Semiarid Soil
16	T3	5.6	0.10	0	Not saline, not sodic	Typic Immature Semiarid Soil
17	T4	5.6	0.10	0	Not saline, not sodic	Typic Argillic Semiarid Soil
19	L1	9.5	1.81	46	Saline-sodic	Typic Immature Semiarid Soil
20	P1	6.1	0.15	0	Not saline, not sodic	Typic Immature Semiarid Soil
21	M1	7.6	18.55	0	Saline	Mottled Saline Immature Semiarid Soil
22	M2	6.7	2.42	5	Saline	Saline Argillic Semiarid Soil
23	W1	8.7	4.23	37	Saline-sodic	Orthic Raw Soil
24	W2	9.9	8.81	89	Saline-sodic	Orthic Raw Soil
25	W3	5.7	0.30	1	Not saline, not sodic	Typic Argillic Semiarid Soil
26	W4	5.9	0.51	2	Not saline, not sodic	Typic Argillic Semiarid Soil
27	W5	5.8	0.15	0	Not saline, not sodic	Typic Immature Semiarid Soil
28	W6	5.4	0.76	1	Saline	Saline Immature Semiarid Soil
29	W7	5.8	0.15	0	Not saline, not sodic	Typic Argillic Semiarid Soil
30	W8	8.2	4.63	2	Saline	Orthic Raw Soil
31	W9	5.4	0.40	0	Not saline, not sodic	Saline Argillic Semiarid Soil
32	W10	5.7	1.16	1	Saline	Fluvial Raw Soil
33	W11	6.6	2.03	3	Saline	Saline Immature Semiarid Soil
34	W12-1	8.6	6.43	22	Saline-sodic	Saline Argillic Semiarid Soil
35	W12-2	7.7	2.42	0	Saline	Orthic Raw Soil
36	W13	7.0	4.76	10	Saline	Saline Argillic Semiarid Soil
37	W14	7.4	7.07	15	Saline	Saline Argillic Semiarid Soil
38	W15	9.9	6.31	62	Saline-sodic	Saline Argillic Semiarid Soil
39	W16	8.6	2.43	31	Saline-sodic	Saline Argillic Semiarid Soil
40	W17	7.7	0.91	25	Saline-sodic	Orthic Raw Soil
41	W18	6.2	1.87	10	Saline	Saline Immature Semiarid Soil

Appendix 4

FLORA ENCOUNTERED IN SAMPLE PLOTS IN SALINE AND ASSOCIATED NON-SALINE AREAS OF THE PRESENT STUDY

* = exotic species.

ACAAGN *Acaena agnipila**
AGRCAP *Agrostis capillaris**
AGRSTO *Agrostis stolonifera**
AIRCAR *Aira caryophyllea**
ALOGEN *Alopecurus geniculatus~~a~~**
ANAARV *Anagallis arvensis**
ANTORD *Anthoxanthum odoratum**
APHARV *Aphanes arvensis**
ATRBUC *Atriplex buchananii*
BROLIC Brown lichen
BRODIA *Bromus diandrus**
BROMOL *Bromus mollis**
BROTEC *Bromus tectorum**
CARCOM *Carmichaelia compacta*
CERPUN *Ceratocephalus pungens*
CHEAMB *Chenopodium ambiguum*
CHOSEM *Chondropsis semiviridis*
CIRARV *Cirsium arvense**
CIRVUL *Cirsium vulgare**
DACGLO *Dactylis glomerata**
ECHVUL *Echium vulgare**
ELEGRA *Eleocharis gracilis*
ELYAPR *Elymus apricus*
GYPAUS *Gypsophila australis**
HOLLAN *Holcus lanatus**
HORDIS *Hordeum distichon**
HORHYS *Hordeum hystrix**
HORMUR *Hordeum murinum**
HYPRAD *Hypochoeris radicata**
JUNART *Juncus articulatus**
JUNSP *Juncus* sp.
LACSTR *Lachnagrostis striatum*
LAGOVA *Lagurus ovatus**
LEPKIR *Lepidium kirkii*
LEPMAT *Lepidium sisymbrioides* ssp. *matau*
LICHENO *Lichenothelia* sp.
LOLPER *Lolium perenne**
MALNEG *Malva neglecta**
MARVUL *Marrubium vulgare**

MOS Moss
MYODIS *Myosotis discolor**
MYOPYG *Myosotis pygmaea* var. *minutiflora*
MYOMIN *Myosurus minimus* var. *novae-zelandiae*
PLACOR *Plantago coronopus**
PLASPA *Plantago spathulata* var. *spathulata*
POALIN *Poa lindsayi*
POAMAN *Poa maniototo*
POAPRA *Poa pratensis**
PUCDIS *Puccinellia distans**
PUCRAR *Puccinellia raroflorens*
PUCSTR *Puccinellia stricta*
RANREP *Ranunculus repens*
RAOAUS *Raoulia australis*
RUMACE *Rumex acetosella**
RUMCRI *Rumex crispus**
RYTMAC *Rytidosperma maculatum*
RYTPUM *Rytidosperma pumilum*
SCHPUN *Schoenoplectus pungens*
SCLUNI *Scleranthus uniflorus*
SEDACR *Sedum acre**
SELRAD *Selliera radicans*
SONOLE *Sonchus oleraceus**
SPERUB *Spergularia rubra**
STEGRA *Stellaria gracilenta*
TAROFF *Taraxacum officinale**
TRIARV *Trifolium arvense**
TRIDUB *Trifolium dubium**
TRIFRA *Trifolium fragiferum**
TRIREP *Trifolium repens**
VERVER *Veronica verna**
VITGRA *Vittadinia gracilis**
VULBRO *Vulpia bromoides**
VULMYU *Vulpia myuros**