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Screening shrubs for establishment and survival on salt-affected soils in south-western Australia

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Editor: D.A.W. Johnston

Summary

Nursery plants of 15 halophytic shrub species were planted into salt-affected soils at 14 sites in the Western Australian wheatbelt.

Plant observations over 12 years indicated major differences in survival, growth habit, seedling regeneration, disease resistance and size. Some species were eliminated by waterlogging, but survival did not appear to relate directly to the salinity levels in the soils. Early growth of species appeared to be reduced by increased soil EC_e at 0.3 to 0.6 m depth.

Rating criteria such as short and long term survival and size measurements did not give a good guide to the best adapted species as judged by agronomic considerations.

On nine test sites, *Maireana brevifolia* volunteered on the non-waterlogged parts of the plot and *Halosarcia* spp on waterlogged sections. One or the other of these species grew at other sites depending on the waterlogging status of the plot. *Atriplex* spp were more tolerant of waterlogging than *M. brevifolia*.

Persistance of species in the trial areas depended either on longevity, (e.g. *A. amnicola*), or recruitment of new plants, (e.g. *M. brevifolia*). Longevity of different selections of *A. halimus* appeared to relate to disease resistance.

Soil samples of the top 0.9 m at all sites ranged in electrical conductivity of the saturation extract (EC_e) from 1200 to 6130 mS/m. Sodium adsorption ratios in the saturation extract ranged from 11 to 112, and pH of the soils ranged from 3.4 to 10.1. Most of the soils consisted of loamy sand up to 0.25 m deep overlying sandy clay subsoil. Sites exhibited extreme spatial and seasonal variability in salt content. Most sites had groundwater of 4000-8000 mS/m electrical conductivity at a depth of about 0.9 to 1.5 m.

No one species was capable of growing on all sections of all sites, but revegetation of all sites, except the highly acidic site 17, appears possible using the suite of species, *M. brevifolia*, *Atriplex* spp, *Halosarcia* spp. The degree of waterlogging appeared to determine which species succeeded on particular parts of a site.

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Atriplex spp. and _Maireana brevifolia_ in a mixed sowing made by using the Mallen Niche Seeder on saline land near Wyalkatchem.

Introduction

In many parts of south-western Australia the native trees and shrubs have been removed for cereal cropping and the planting of winter-growing annual pasture plants. The resulting hydrological changes have caused rises in groundwater levels and salt encroachment in agricultural land in the valley floors (Nulsen and Henschke, 1981). These changes, occurring over several decades, rendered 263,800 ha of arable land unproductive by 1979 (Henschke, 1980) and the area was increasing at about 19,000 ha per annum. Research aims to return these areas to production by reversing the hydrological changes by changing to cropping systems which use more water (Nulsen, 1984) and by installing drains to lower groundwater levels. In cases where these measures are ineffective, a third approach used is to plant salt-affected areas to perennial salt tolerant forage plants for grazing by sheep in late summer and autumn in conjunction with cereal stubbles and dry annual pasture plants.

Early introductions of salt tolerant forage plants to Western Australia included the grasses *Paspalum vaginatum* Sw (in 1936), (Burvill and Marshall, 1951) for growing on summer wet seepages and *Puccinellia ciliata* Bor (Rogers and Bailey, 1963), which grew well under a Mediterranean climate, on the fringes of seepages and on saline areas affected by shallow saline groundwater receiving an annual average rainfall of about 375 to 700 mm. Where rainfall is < 375 mm, shrubs such as *Maireana brevifolia*, *Atriplex nummularia* and *A. semibaccata* were planted (Smith and Malcolm, 1959). This range of plants exhibited some disadvantages. *P. ciliata* grew poorly in low rainfall areas (< mm); *P. vaginatum* had to be vegetatively propagated (Burvill and Marshall, 1951); *A. semibaccata* was shortlived; *M. brevifolia* did not withstand waterlogging and *A. nummularia* had erect branches partly out of reach of sheep or becoming broken down during browsing. Moreover, establishment of the shrubs on saline soils presented major problems (Malcolm, 1972).

In 1966 and 1967 a collection of salt tolerant forage species was obtained during exploration trips in Algeria, Iran, Iraq, Israel, Tunisia, Turkey and the United States of America (U.S.A.) (Malcolm, 1971) in an attempt to find materials not subject to the above disadvantages. The collection was augmented with seeds obtained by seed

Salt-affected land near Tammin in the wheatbelt. Note the bare saline soil and patches of annual plant cover.

***Maireana brevifolia*, an outstanding halophytic browse shrub.**

exchange and by exploration within Western Australia. By 1984 there were over 970 collections (Malcolm *et al.*, 1984).

There have been few attempts to screen shrub species for forage production from salt-affected soils in a semi-arid climate. Judd and Judd (1976) reported that of seven shrub species planted on two non-saline sites in the U.S.A. only one survived for 20 years. On a range of saline and non-saline sites in western New South Wales (N.S.W.), 103 local and exotic shrubs were tested. Of these, only 31 established, six persisted for up to ten years, only two performed well and then only at one site each (Alchin, 1974). Of these two, *Atriplex vesicaria* established from seeds, but *A. nummularia* had to be planted as nursery raised plants.

Studies on plant selections for revegetation of saline mine spoils were conducted in New Mexico, U.S.A. by Quinones *et al.* (1980) and in Zimbabwe by Hill (1977). In New Mexico (85 mm annual rainfall or less) the plantings were from seed and were irrigated. *A. canescens* performed best of ten *Atriplex* spp. Hill (1977) used nursery raised plants to establish a range of trees and shrubs in Zimbabwe on three mine dumps, two of which were highly saline. On the least saline dump the halophytic species died in the second year. On a second dump, high in salinity and nickel, several species grew well initially, but after seven years all plants had died. The cause of death was not determined. The third dump was highly saline and contained arsenic, but *Atriplex amnicola*, *A. lentiformis* and *A. undulata* grew well and were still surviving after ten years (J.R.C. Hill, personal communication, 1984). Some deaths on the dumps were attributed by Hill to competition from grass and others to crowding in the 1.2 x 1.2 m planting. Nevertheless, three species, all exotics, were shown to be well adapted to at least one site.

Screening of the Western Australian collection of forage plants commenced in 1968 (Malcolm and Clarke, 1971) and is continuing. The purpose of shrub screening was to determine the suitability of shrubs for growing in a given environment. Suitability depended on the following criteria:

1. Growth and survival for a sufficient period in a representative environment;
2. Reproduction by seed or by vegetative means;
3. Acceptable growth form for management and use;
4. Production of biomass of sufficient quantity, quality and acceptability to livestock;
5. Ease of establishment;
6. Persistence under a profitable management system;
7. Effectiveness for erosion control, groundwater lowering and improvement of habitat for wildlife.

It was not possible to screen for all of these criteria in one experiment.

This paper reports a screening experiment in which the adaptation of a range of Australian and introduced shrubs to salt-affected areas in Western Australia was assessed according to criteria 1 to 3 above. Detailed site data were collected to assist in recommending to farmers which species to select and to assist in explaining species adaptation.

Methods

Planting

The trials involved planting on 14 sites, 15 shrub species (Table 1), selected during initial screening.

Five test plants were placed at each of the 14 sites as a 3 x 3 m square of four with the fifth plant in the centre. This arrangement was intended to be nearer to a natural stand than a row of plants. Shortage of seeds precluded using larger numbers.

The plants were placed into cultivated soil in August/September 1970 at sites numbered 1, 3, 4, 5, 8, 9, 10-17 on Figure 1. Sites 2 and 6 were used for the initial screening tests and site 7 for seed production plantings. Accession numbers 405, 370 and 471 were not planted until 1971.

The criteria chosen to evaluate the plants were short and long-term survival, size (height and diameter), vigour (subjective assessment, scale 0-5), seed production (yes/no), growth habit, production of volunteer seedlings (yes/no), and susceptibility to insects and disease.

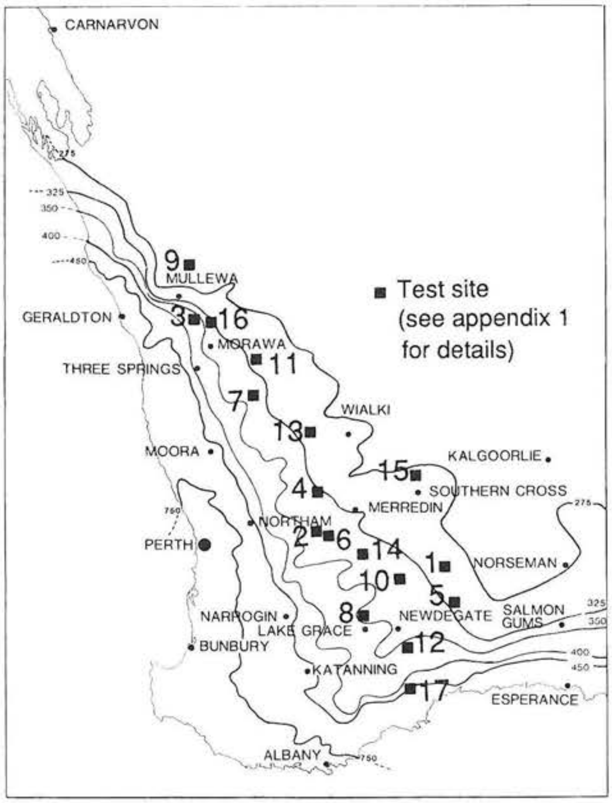


Figure 1.
Location of test sites in south-western Australia.

Table 1. Shrub species planted in screening trials

Species	Source (supplier)	Accession numbers*
Atriplex amnicola Paul G. Wilson	S.W. Australia	405,440
Atriplex atacamensis Phil.	Chile (Israel)	363
Atriplex bunburyana R.Br.	S.W. Australia	435
Atriplex canescens James	U.S.A.	13,43,77
Atriplex glauca L.	Algeria, Tunisia	99,119
Atriplex halimus L.	Algeria, Israel, Tunisia	106,380,386,420
Atriplex lentiformis S. Wats.	U.S.A.	53,88
Atriplex leucoclada Boiss	Iran, Israel	264,370
Atriplex linearis S. Wats.	U.S.A.	70, 73
Atriplex nummularia Lindl.	S.W. Australia	359,439
Atriplex nuttallii S. Wats.	U.S.A.	32
Atriplex polycarpa S. Wats.	U.S.A.	67
Atriplex undulata D. Dietr.	Argentina (Israel)	471
Atriplex sp.	Venezuela	353
Maireana brevifolia (R. Br.) Paul G. Wilson	S.W. Australia	429, 442, 462

* See Malcolm *et al.* 1984

The plots were fenced to prevent grazing during the trials. They were given no fertilizer or water. Sites were sprayed to control Rutherglen bug (*Nysius vinitor* Bergroth) during the first summer.

The plants in the trials were assessed for 12 years by making about 15 visits to all sites and recording the data on evaluation cards adapted from shrub evaluation cards used by the United States Department of Agriculture, Soil Conservation Service, Plant Material Centres. Early visits were at three week intervals, but in later years intervals were commonly of two years.

Soil sampling

Soils at the test sites were sampled at three-week intervals for six months starting at planting time (late winter-early spring 1970). Augered samples were taken at 0-75, 75-300, 300-600 and 600-900 mm depth at two positions in each test site on each sampling visit. Each sampling position was identified on a randomized sampling plan and was 1.5 m from the centre plant in a species plot. No position was re-sampled on a later occasion. The samples were analysed for pH (1:5 soil water suspension) water content and chloride (determined by potentiometric titration against silver nitrate) on the oven dry soil basis. During the sampling programme the profiles were described (Appendix 1).

Composite samples for each depth at each site were obtained by mixing about 5 g of soil from the samples obtained over the six months. After thorough mixing the composite samples were analysed for saturation percentage, water retention at 34 and 1515 kPa, percentages of clay, silt, fine sand, coarse sand and Cl^-, cation exchange capacity, pH, presence of lime and, on the saturation extract, the electrical conductivity (EC_e), sodium adsorption ratio (SAR_e) and boron content.

Towards the end of the plant monitoring period, observation wells were sunk in the sites to determine the depth and salinity of the groundwater.

Table 2. Environmental data for sites used in the shrub screening programme

Site no.	Locality	Latitude and longitude	Mean annual rainfall* (mm)	Incidence of frosts: Town and distance to site (km)	Incidence of frosts: Average no. of frosts per year	Incidence of frosts: Temp. (°C)**	Soil type: Principal profile form***	Soil type: Salinity group****	Site hydrology: Frequency of: Water-logging	Site hydrology: Frequency of: Flooding	Site hydrology: Watertable: Depth (m)	Site hydrology: Watertable: Conductivity (mS/m)
1	Hyden	32°52′S 119°4′E	338				Dg2.83	2	Occasional	Occasional	1.0	6890
2	Dangin	32°6′S 117°23′E	341	Wandering (90)	59	31.2 3.8 (-5.7)	Dg2.83	4	Occasional	Rare	1.1	8720
3	Three Springs	29°30′S 115°44′E	399				Dr 3.13	5	Frequent	Occasional	0.75	5780
4	Wyola	31°59′S 117°19′E	363	Kellerberrin (40)	26	33.7 5.6 (-3.3)	Dy 3.81	2	Occasional	Occasional	0.80	6810
5	Newdegate	33°S 119°4′E	335				Dg 2.82	2	Occasional	Occasional	1.37	6110
6	Quairading	32°5′S 117°25′E	340				Ge 1.12	5	Nil	Nil	>3	ns
7	Miling	30°28′S 116°30′E	376				Uf2	5	Occasional	Occasional	not determined	
8	Moulyinning	33°12′S 117°52′E	371				Uf	3	Occasional	Occasional	not determined	
9	Pintharuka	29°5′S 115°58′E	338	Morawa (20)	12	36.5 5.6 (-2.2)	Uf2	5	Occasional	Occasional	0.90	4146
10	Kulin	32°40′S 118°18′E	351				Dy 3.5	5	Frequent	Occasional	not determined	
11	Buntine	29°59′S 116°33′E	353				Dy 3.52	3	Frequent	Occasional	0.60	7430
12	Pingrup	33°55′S 118°31′E	350	Lake Grace (40)	19	32.1 5.3 (-1.9)	Ug 1	1	Nil	Nil	>2	ns
13	Booralaming	31°25′S 117°20′E	310				Dg 1.43	3	Occasional	Rare	not determined	
14	Corrigin	32°21′S 118°2′E	384	Corrigin (30)	36	33.2 4.3 (-3.3)	Dy 1.53	2	Occasional	Occasional	not determined	
15	Walgoolan	31°24′S 118°34′E	300				Um	4	Occasional	Rare	>2	ns
16	Carnamah	29°37′S 116°6′E	396	Carnamah (15)	8	35.4 5.7 (0.0)	Dr 2.83	4	Occasional	Rare	0.80	7640
17	Ongerup	38°58′S 118°33′E	386				Dy 3.51	1	Nil	Nil	>2	ns

* Rainfall and frost data are for the nearest official recording centres. (Commonwealth of Australia, Bureau of Meteorology, 1958, 1959, 1968, indated).
** Data are given for average maximum for January, the hottest month, average minimum for July the coldest month and the coldest temperature ever recorded in brackets.
*** Northcote (1971).
**** See results of soil sampling. Seasonal soil sampling.
ns no sample.

Site descriptions

Some salt-affected soils in south-western Australia were saline before agricultural development (primary salinity), others have become saline since development (secondary salinity). As a consequence many different soil types are involved. The 17 sites used in the screening programme (Table 2) were selected to represent the common problem types in an area of about 600 km by 250 km. The locations of the test sites are shown in Figure 1. All sites were situated on privately owned farming properties; the original owners' names and detailed locations are given in Malcolm and Clarke (1971). The site numbers used in this paper correspond to those used in the earlier report. At each site, the test plot of about 25 m x 25 m was located on an area comprising patches of bare saline soil and patches of saline soil inhabited by Mediterranean barley grass (*Hordeum geniculatum* All.). Salinity patterns beneath patchy plant cover are discussed by Teakle and Burvill (1938). The sites are located low in the landscape in broad valleys of very little relief (see Bettenay and Mulcahy, 1972, for descriptions of the landscape).

The climate is Mediterranean, with cool wet winters and hot dry summers. Distributions of the average annual rainfall and effective rainfall at selected northern, central and southern sites are shown in Figure 2.

Temperature data for towns representative of the northern, central and southern sections (Figure 1) of the test area are given in Table 2. Hot dry easterly winds are common in summer. The elevation of all test sites was $<$ 400 m above sea level.

Frost data for towns ranging from the north to the south of the test area are shown in Table 2. Frosts are more frequent in the south, but there is appreciable variability between stations because of the effect of site conditions on the recordings obtained. The town of Lake Grace most closely approximates the saline test sites topographically as it is situated among salt-affected soils close to a salt lake. Wandering is the town least representative of test site conditions, but gives an indication of the lowest temperature ever likely to be recorded in the whole area.

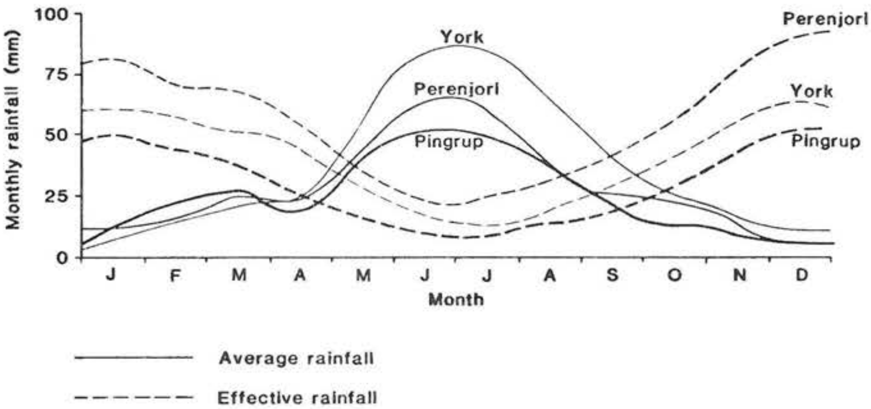


Figure 2.

Rainfall distribution and effectiveness at three sites in the north (Perenjori), centre (York) and south (Pingrup) of the latitude range of test sites. Effective rainfall is determined from rainfall and evaporation data and is defined as the minimum rainfall required to sustain plant growth. (After Commonwealth of Australia, Bureau of Meteorology, 1958, undated & 1959.)

Soil sampling

Composite samples

The results of physical analyses of the composite soil samples are in Appendix 2. About two-thirds of the soils show strong profile development, having a loamy sand texture in the surface and clay to sandy clay loam in the subsoil (see profile descriptions in Appendix 1). These duplex profiles occur throughout the geographical range of the sites. Other sites show less profile development (e.g. 8, 9) and at site 7 the texture profile is uniform although the water holding properties are much lower in the surface than the subsoil. Water retention by the subsoils averages 9% (gravimetric) between 34 and 1515 kPa (range 5 to 18%).

Most sites contain a high proportion of coarse sand especially in the surface. The notable exceptions, sites 6 and 12, are soils formed from aeolian deposits and are referred to as parna (Bettenay and Hingston, 1964). There is a wide range of textures in the soil surface, ranging from 46% clay at site 12, to 7% at sites 11 and 13. There are also wide variations in the silt content of the profiles, sites 4, 5, 10 and 11 being especially low and sites 6, 12 and 17 high.

The results of chemical analyses on the composite samples are shown in Appendix 3. The EC_e levels range from 1200 to 6130 mS/m. At three sites, 6, 8 and 13, EC_e levels were < 2000 mS/m. However, according to Shainberg and Oster (1978) an EC_e of 2000 mS/m is sufficient to reduce the yield of tolerant crops to 50%. EC_e levels about 3200 mS/m are reported to be too high for crop production. At eight of the test sites, EC_e levels exceeded 3200 mS/m, in one case by 200% (Site 15).

All of the soils are high in sodium relative to calcium plus magnesium, as indicated by the SAR_e values (Appendices 3 and 4). Comparison of these SAR levels with standards for irrigation water (Richards, 1954) indicates that the soil solution at saturation is equivalent at all sites to at least a high sodium hazard and for many sites is beyond the quoted standards. At most sites the boron levels are moderate (Richards, 1954), but at sites 4 and 6 boron is sufficiently high to be toxic to even tolerant crop plants. The cation exchange capacities of the soils are low considering their clay content. This is a reflection of the high kaolinite content of south-western Australian soils derived from ancient lateritic materials (Mulcahy and Hingston, 1961).

Results

A feature of the soils at many sites is the high level of magnesium relative to calcium. High exchangeable Mg has been related to ease of puddling, high density, low aggregate stability and low permeability to water in salty marsh soils (Müller and Fastabend, 1963).

All sites, except number 6 are above the limit for high salinity (0-30 cm, 0.15% NaCl and 30-60 cm, 0.30% NaCl) used to define areas as unsuitable for agricultural crops in Western Australian soil surveys (Burvill, 1947).

The pH values for the soils had a wide range of from 3.4 to 10.1. The surface soils range from mildly acidic to mildly alkaline. At most sites there is an increase in pH with depth and in some cases lime was present in the subsoil. At several sites, low pH values recorded in the subsoil reflect the presence of an ancient truncated lateritic profile beneath the more alkaline surface soil (Bettenay and Hingston, 1964).

Seasonal soil sampling

Salinity varied greatly between sites, times of sampling, sampling position and depth. To reduce the volume of data presented, sites with similar characteristics were grouped according to the limits shown in Figure 4. Each group will be described with reference to data for an example site presented in Figures 3a to 3f.

Group 1: Sites 12 and 17. (Figure 3(a)). The group is characterized by having extremely high subsoil salinities (often < 0.6% Cl^-) at some sampling sites while others are moderate (usually < 0.3% Cl^-). Surface increases in salinity in summer are moderate (usually < 0.9% Cl^-). The groundwater is not within 2 m of the surface and the sites are not subject to flooding or waterlogging.

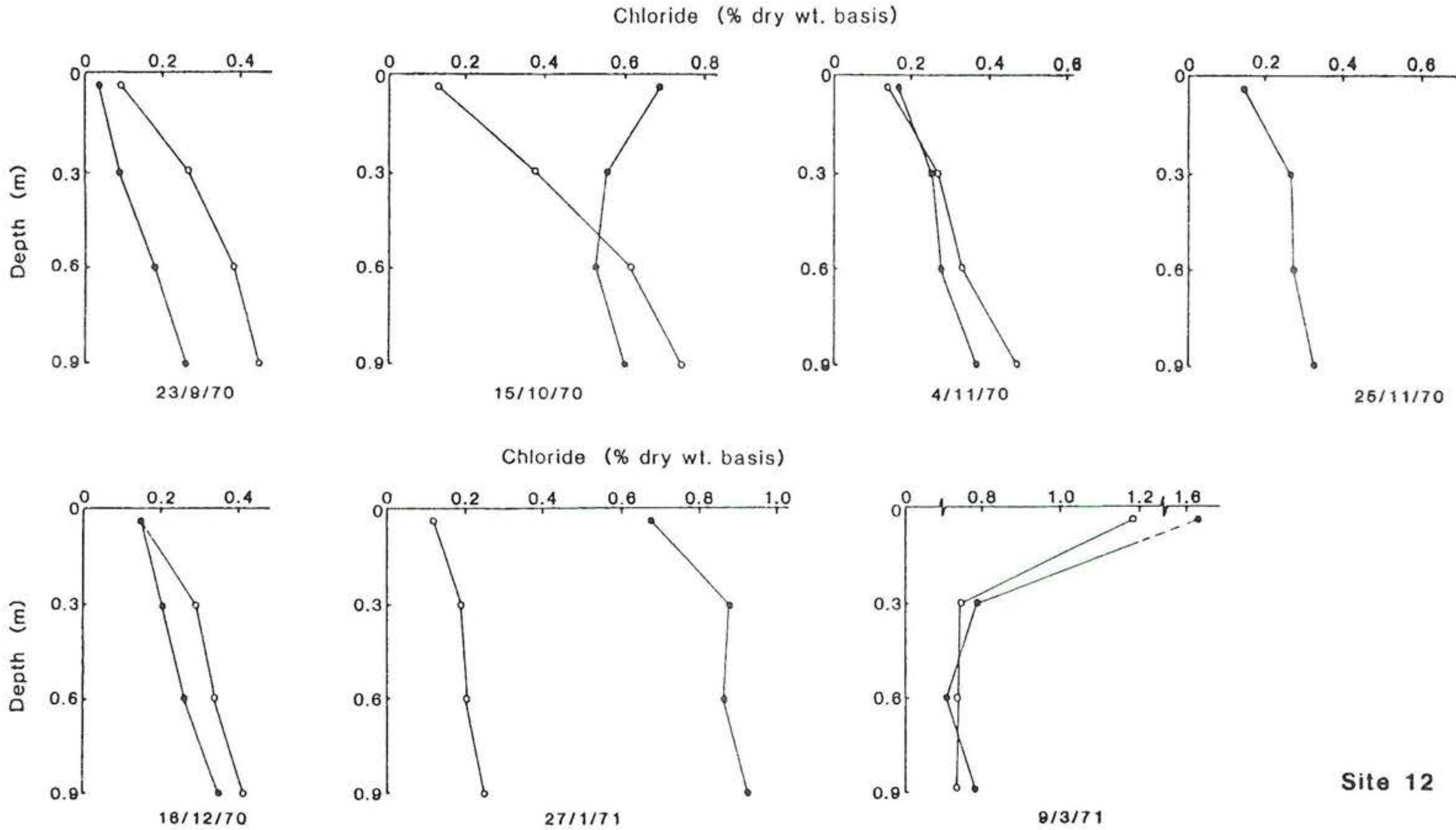
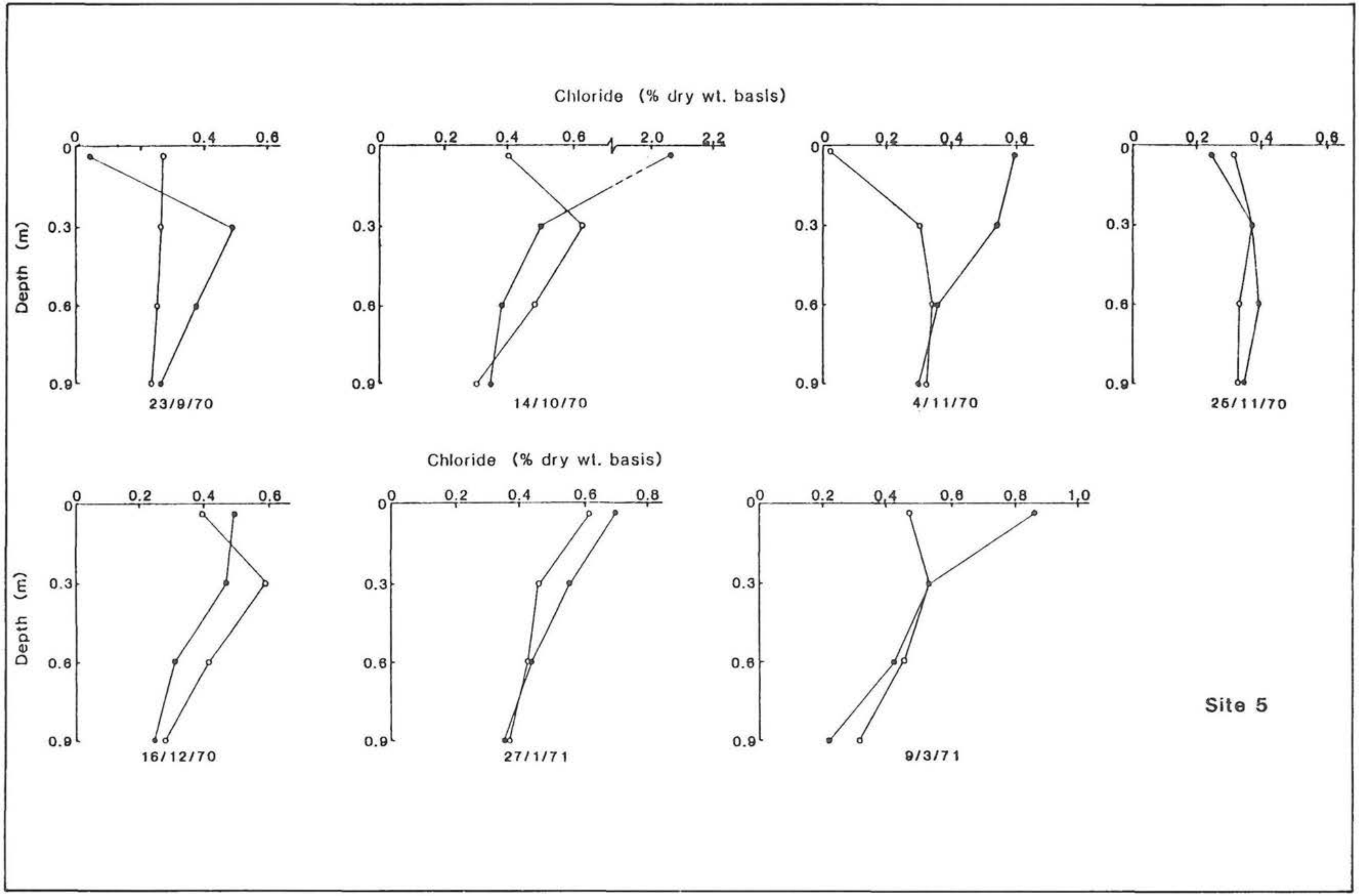
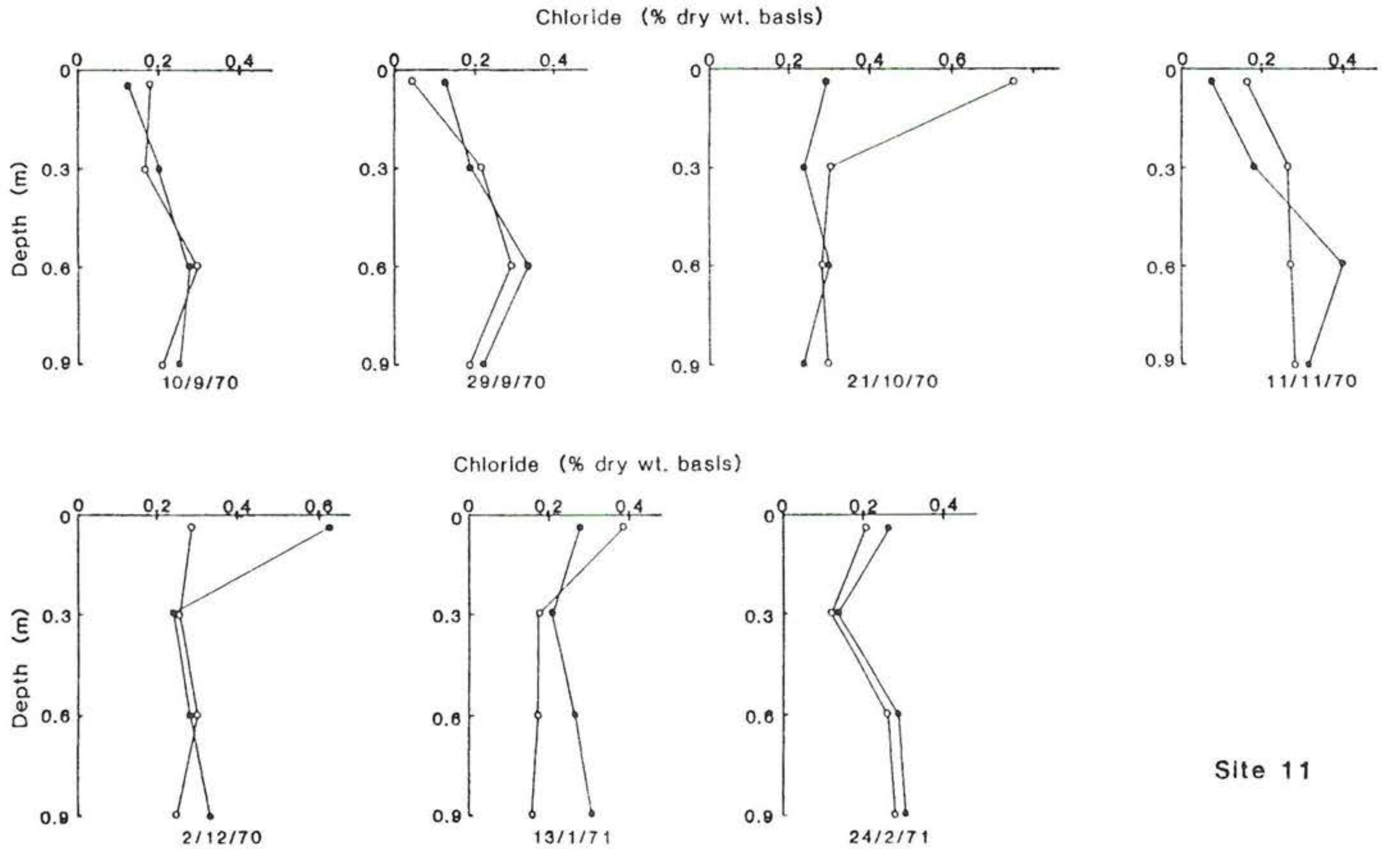
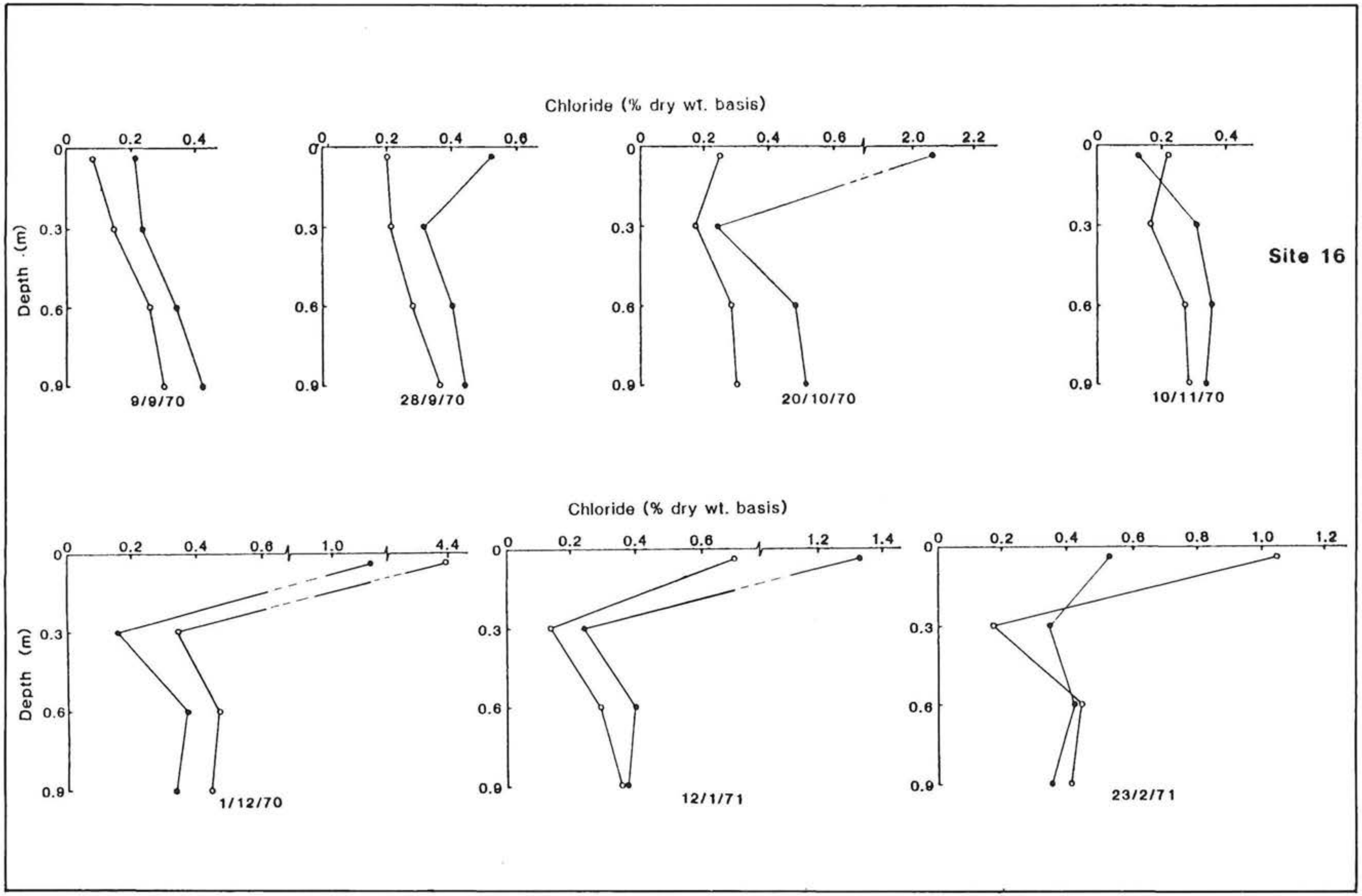


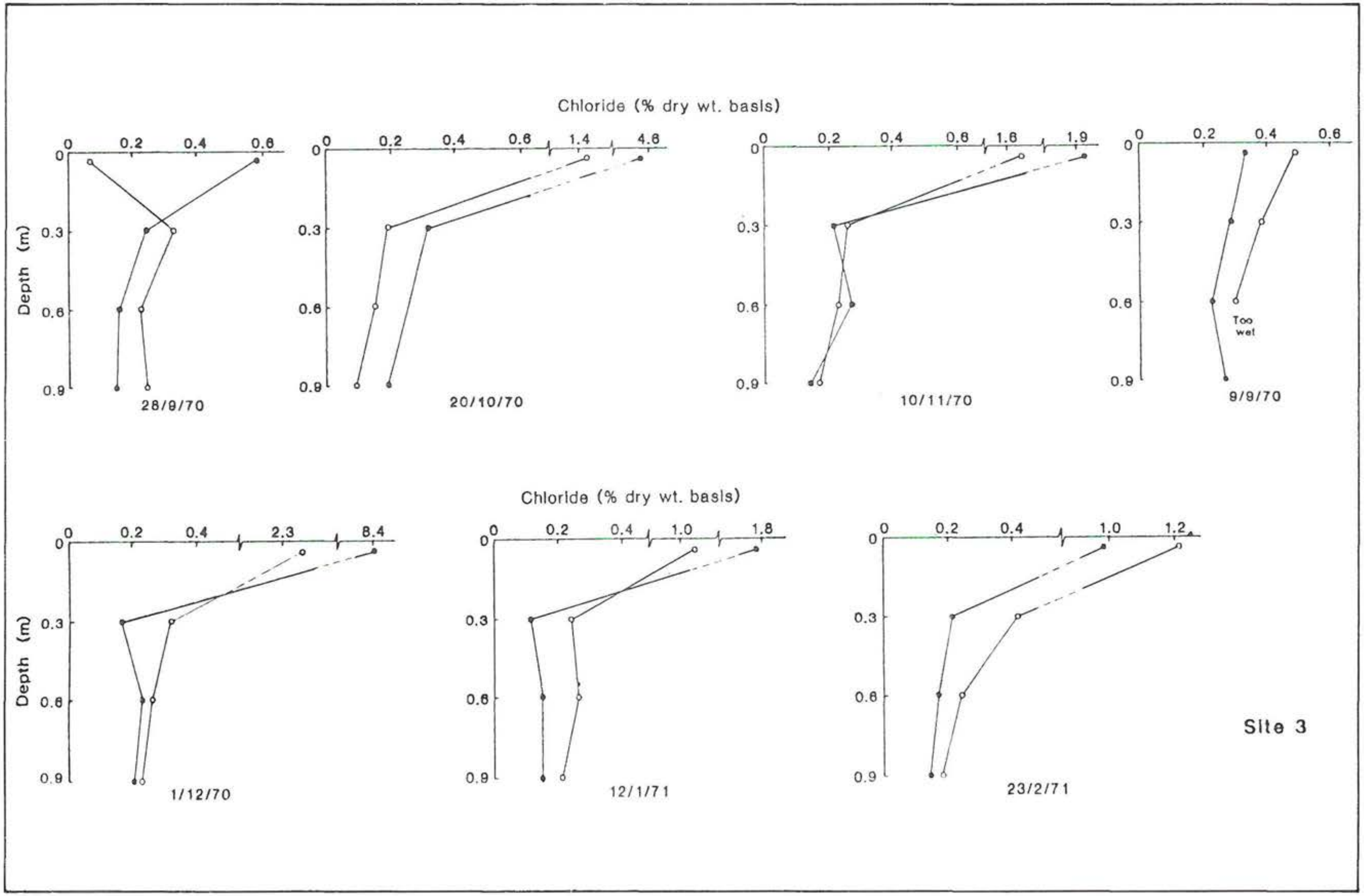
Figure 3. Results of seasonal soil salinity sampling for representative sites (a) Site 12 from Group 1; (b) Site 5 from Group 2; (c) Site 11 from Group 3; (e) Site 3 from Group 5; (f) Site 6. The date of sampling for each pair of sites is shown on the figures.

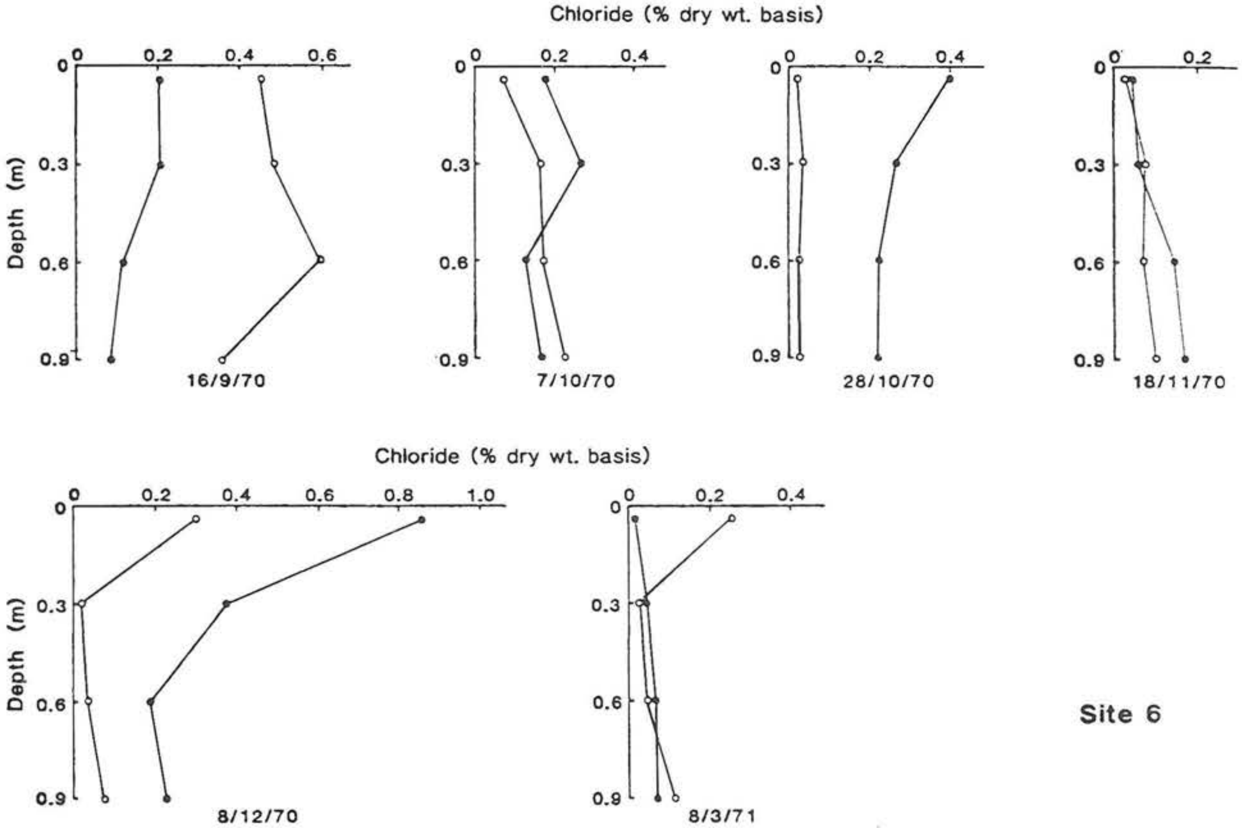


Chloride (% dry wt. basis)
Depth (m)
23/9/70
14/10/70
4/11/70
25/11/70
Chloride (% dry wt. basis)
Depth (m)
16/12/70
27/1/71
9/3/71
Site 5


Chloride (% dry wt. basis)
Depth (m)
0
0.2
0.4
0.6
0.3
0.9
10/9/70
29/9/70
21/10/70
11/11/70
Chloride (% dry wt. basis)
2/12/70
13/1/71
24/2/71
Site 11


Chloride (% dry wt. basis)
Depth (m)
9/9/70
28/9/70
20/10/70
10/11/70
Site 16
Chloride (% dry wt. basis)
Depth (m)
1/12/70
12/1/71
23/2/71


Chloride (% dry wt. basis)
Depth (m)
28/9/70
20/10/70
10/11/70
9/9/70
Too wet
Chloride (% dry wt. basis)
Depth (m)
1/12/70
12/1/71
23/2/71
Site 3


Chloride (% dry wt. basis)
Depth (m)
16/9/70
7/10/70
28/10/70
18/11/70
Chloride (% dry wt. basis)
Depth (m)
8/12/70
8/3/71
Site 6

Group 2: Sites 1, 4, 5 and 14. (Figure 3(b)). The group is characterized by having high subsoil salinities (usually in the range of 0.3 to 0.6% Cl^-). Surface increases in salinity in summer are moderate (usually below 0.9% Cl^-). The sites are occasionally waterlogged and flooded and have a saline watertable within 2 m of the surface at times.

Group 3: Sites 8, 11 and 13. (Figure 3(c)). The group is characterized by having moderate salinity in the subsoil (usually below 0.3% Cl^-). Surface increases in salinity in summer are moderate (usually $<$ 0.9% Cl^-). The sites range from seldom to often waterlogged and vary in flood susceptibility. The watertable is at times within 2 m of the surface.

Group 4: Sites 2, 15 and 16. (Figure 3(d)). The group is characterized by having high subsoil salinity (usually in the range of 0.3 to 0.6% Cl^-). Surface increases in salinity in summer are extreme (usually $>$ 0.9% Cl^-). The watertable is at times within capillary reach of the surface and the sites are sometimes waterlogged.

Group 5: Sites 3, 9 and 10. (Figure 3(e)). The group is characterized by having moderate salinity in the subsoil (usually $<$ 0.3% Cl^-). Surface increases in salinity in summer are extreme (usually $>$ 0.9% Cl^-). The sites experienced flooding during the trial. The watertable is at times within capillary reach of the surface.

Site 6 does not fit readily into any of the above groups. It could be most accurately described as a less saline version of Group 1. The site is never flooded or waterlogged and the watertable, if present, is much deeper than 2 m.

Groundwater

The groundwater depths and salinities are shown in Table 2.

Plant data

Survival and volunteering

The percentages of survival of the original plants of all species (combined) at each site are shown in Figures 5a to 5e. Over the years there was a progressive decline in shrub numbers at all sites. There was a considerable difference in the rate of plant loss with time at different sites. For example, at site 3, 60% of all plants were lost during the first year and a further 25% over the following 11 years. By contrast, at

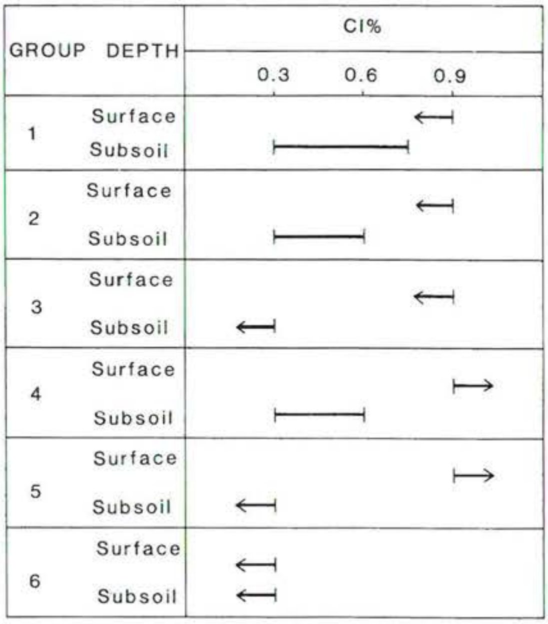


Figure 4. Chloride contents of the soil (per cent dry wt basis) characterizing the profile groups found at test sites.

site 14 about 20% died in year one, but 60% died between years 4 and 6. This later loss of plants was because of a flood of about one month's duration at site 14 in 1974.

The differences in survival did not relate to the degree of salinity at the sites. For example, the survival at the sites in Groups 1, 3 and 4 is similar, but Group 1 has extremely high subsoil salinity, Group 3 has moderate subsoil and surface salinity and Group 4 high subsoil salinity and extremely high surface salinity. Moreover, in Group 2, with high subsoil salinity and moderate surface salinity, survival ranged from the best to the poorest of all sites. At site 5 some early losses were because of blasting and inundation of bushes by windblown saline soil. Sheep gained access to site 17 in 1979.

The greatest plant loss occurred in the first year and in particular periods such as in 1974 to 1976 when flooding was a factor. The effects of floods varied from site 14 where over 60% of surviving bushes were killed between years 4 and 6, to site 4 where a flood occurred in 1971, but there was no evidence of high mortality. A flood at site 9 in 1971 caused few deaths and was of a few hours duration, but the flood at site 14 caused waterlogged conditions for several weeks. *A. amnicola*, *A. nummularia* and *A. halimus* survived the combined

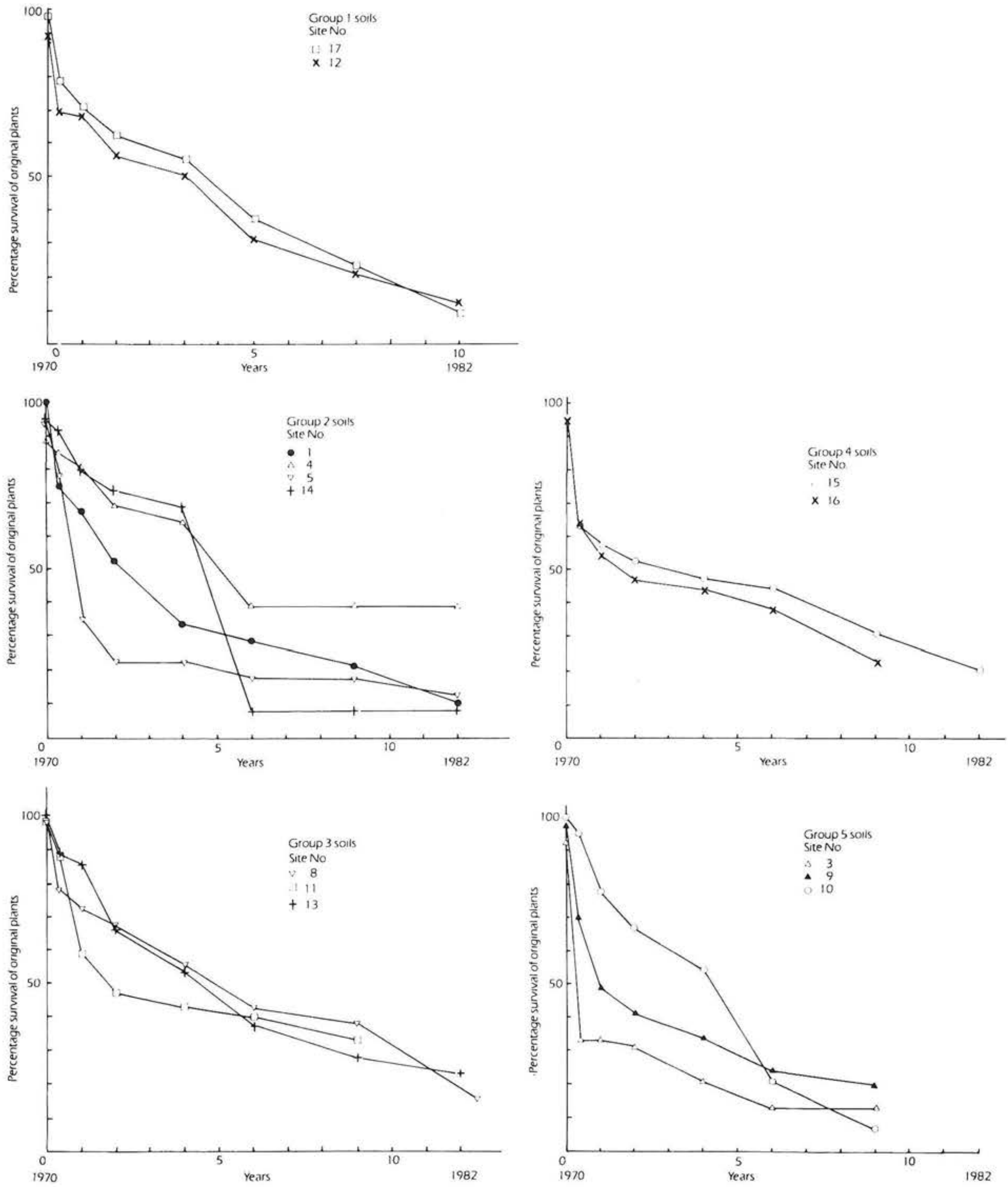
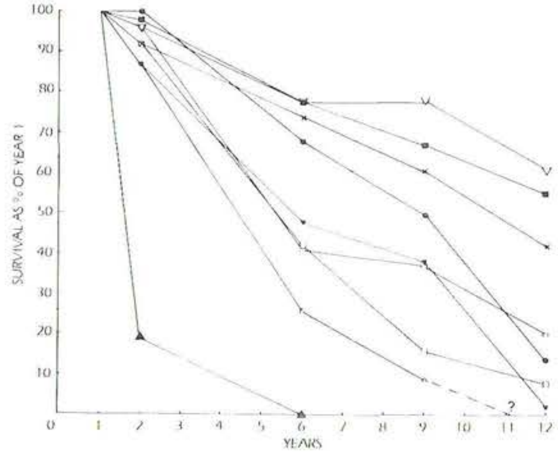


Figure 5. Survival of test shrubs over 12 years, expressed as site totals and shown for five soil type groups.



	Accession number	Number of plants survival 1 year	Number of plants planted
○	70	49	70
●	88	44	70
△	119	46	70
▲	264	32	70
□	380	50	64
■	386	51	65
▽	405	46	70
▼	429	52	70
×	471	38	70

Figure 6. Survival of several species at 12 sites as a percentage of survival after one year.

effects of salt and waterlogging at site 14. *A. amnicola*, *A. halimus*, *A. undulata* and *A. lentiformis* survived at site 3, probably the most frequently waterlogged site.

The survival data were totalled over sites and expressed on a species basis (Figure 6) (owing to problems in obtaining a sufficient number of plants to put all species at all sites, some sites did not have a full complement of plants and have been excluded from the summation). The number of bushes surviving the first year is given in Figure 6. It has been assumed that first year survival may be affected by problems in the raising of plants or their placement in the field and the subsequent survival is therefore expressed as a percentage of the number of year old plants. The species which survived best was *A. amnicola* followed by *A. halimus* (No. 386) and *A. undulata*. A second line of *A. halimus*, No. 380, gave much poorer survival and was noted to suffer more from dieback. Most of the separation of the species on a survival basis occurred after the second year and differences still developed after year 6.

Volunteering ability is expressed as the number of sites on which volunteer seedlings were recorded over the 12 years (Table 3). It ranges from zero to nine out of 14 sites. There is an important difference between species such as *A. glauca* which produced volunteers at eight sites, but failed to produce a stand in the long term, and *M. brevifolia* which produced many new bushes which still survived both inside and outside the plot after 12 years and easily compensated for the poor survival of its original bushes. The numbers of volunteers were not recorded.

Some plants suffered from dieback disease because of the fungus *Coniothyrium atriplicinum* (P.McR. Wood, personal communication, 1981). The disease, first noted on severely attacked bushes of *A. atacamensis*, is endemic in Western Australia and is also found on *Atriplex* spp. in the U.S.A. It has been seen by the senior author in Tunisia. The presence of *C. atriplicinum* was noted on *A. amnicola* and *A. bunburyana*, but it appeared to cause them no harm. On *A. halimus* the difference in susceptibility to the fungus may have been a factor in the marked difference in survival between Nos 380 and 386. Subsequently, the disease has been studied, but not found to be highly pathogenic (Napier, 1983).

Insects and rabbits caused only minor damage.

Seed production and layering

Table 3 shows the number of sites and months during which seed production was noted.

Many of the species of *Atriplex* in the experiment had natural stem layering. This property was strongly exhibited by *A. amnicola* and *A. undulata*.

Growth of salinity

In Figure 7 the mean size measurements of shrubs are related to soil salinity at each site. These data, for the first five months of growth, show that best growth occurred in the least saline plots as indicated by the EC_e of the soil at a depth of 30-60 cm. Other depths gave a poorer relationship. The EC_e levels range from 1500 to 4500 mS/m and compare with those expected to give about a 25-75% reduction in yield in some halophytes grown under controlled conditions (Greenway and Munns, 1980, Malcolm, 1986a). Salinities in the root zone soil solution with the soil at water contents from field capacity to wilting point in the field plots would have been from 50-200% higher than the saturation extract salinities (see water retention data in Appendix 2). No attempt was made to sample the soil salinity in later years and relate it to growth of the bushes.

Growth and ranking

Various criteria may be used to rank the species and aid selection. The size and vigour ranking measurements made on the bushes after five months, and 3.5 years respectively are shown in Table 4. The two measurements produced entirely different rankings for the species concerned. *A. lentiformis* grew to the largest size in five months, but after 3.5 years *A. amnicola* was given the highest vigour rating and *A. nummularia* and *A. halimus* scored higher than *A. lentiformis*.

Species may be ranked according to many criteria. Table 4 includes rankings for growth, vigour and survival. Different criteria produce different rankings and three

***Atriplex amnicola*; note the postrate growth habit and stem layering.**

Table 3. Summation of observations on several aspects of shrub growth made over 12 years

Species and no.		Number of sites with volunteers*	Layering	Disease	Number of sites with seed	Seed months
Atriplex						
A. amnicola	440	2	L	D	11	1-3,5,12
A. bunburyana	435	3	L	D	9	1,2,12
A. canescens	77	1	-	-	5	-
A. glauca	99	8	L	D	14	1-5,8,12
A. glauca	119	8	L	D	10	1-5,8,9,12
A. halimus	106	3	L	D	11	5,8
A. halimus	380	3	L	D	7	5,8
A. halimus	386	4	L	-	12	4,5,8
A. lentiformis	53	3	-	D	10	5,8
A. lentiformis	88	3	-	D	8	5,8
A. leucoclada	264	2	-	-	9	2,5,8
A. linearis	70	2	L	-	10	5,8
A. nummularia	439	3	L	-	11	1-3,5,12
A. polycarpa	67	0	-	-	1	5
A. species	353	3	-	D	9	2,4,8
Maireana						
M. brevifolia	429	9	-	-	13	1-5,12
M. brevifolia	462	7	-	-	14	1-5,12

* The number shown is the total number of sites at which the species was observed to have produced at least one volunteer seedling during the 12 year period. In some cases the seedling(s) may not have been still present in year 12.

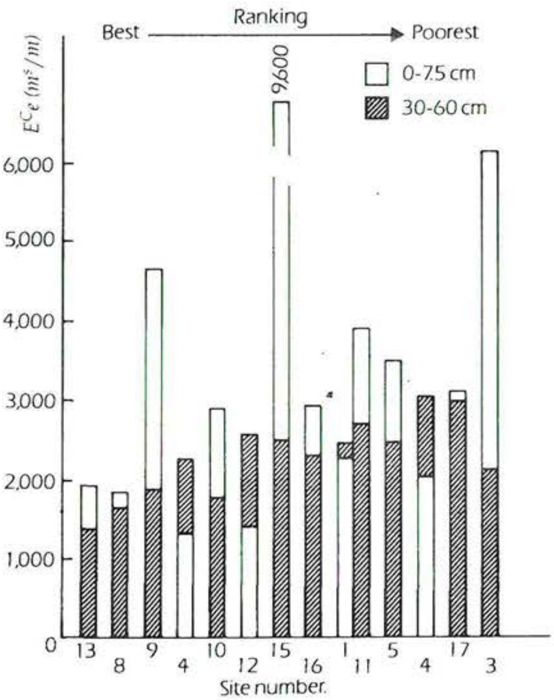


Figure 7. Sites ranked from best to poorest (L to R) on the basis of mean plant height x diameter (all species) after five months in the field, compared with soil EC_e on composite samples.

rankings have been combined to give a ranking by totals. The species are listed in Table 4 in the order of preferred choice as a forage shrub (Table 5), with the best first. None of the rankings in Table 4 coincides with the agronomic rankings in Table 5. This listing is based on a wider range of criteria.

The growth habits of the species are described in Appendix 5.

In this study such a wide range of conditions is represented in the plots that it would be reasonable to expect several shrubs to offer candidacy for different sites. Moreover, there are so many selection criteria that different shrubs may excel for different but important reasons. The shrubs are discussed in turn, starting with those which can most readily be discarded.

A. polycarpa, *A. nuttallii* and *A. canescens* grew and survived poorly and produced none or few volunteers. *A. atacamensis* was very susceptible to disease. *A. leucoclada* and *A.* sp. made good growth initially, but were shortlived and failed to maintain presence in the long term. *A. glauca* grew well, but was shortlived. It produced volunteers on many sites and may be worthy of further investigation if managed to ensure that seedling regeneration occurred regularly. *A. linearis* survived and volunteered on several sites, but its growth was not vigorous and it was so brittle that grazing damage would probably be severe.

The above species can be readily screened out, but the remainder performed sufficiently well to warrant more careful consideration. *A. halimus* grew and volunteered well on several sites. Its most serious disadvantage is its susceptability to disease (although there appear to be resistant lines). *A. lentiformis* made good early growth. It has grown best at one northern (hotter) site (9) where it has acceptance with farmers. Its erect, open, angular growth form is not well suited to grazing, but its large size affords shelter to stock. It is not as long lived as some other species, but regenerates from seedlings on some sites.

A. nummularia grew well at many sites exhibiting high salt and waterlogging tolerance. Its main disadvantages are its upright growth habit and poor ability to produce volunteer seedlings. It is also less palatable than species such as *A. amnicola*, *A. undulata*, and *A. paludosa* (A.J. Clarke, personal communication, 1983).

A. bunburyana grew and survived well at many sites and has the advantage, compared with *A. nummularia*, that, of the *Atriplex* species it volunteers most readily. Its adaptation to the wheatbelt environment in Western Australia is undisputed as it is the species most commonly found on naturally saline sites. The ecotype used in this study has the disadvantages of upright growth, branches which break down and low palatability (A.J. Clarke, personal communication, 1983).

A. undulata survived very well in the long term, produced volunteers on many sites (not shown in Table 3) has easily harvested fruits and is readily eaten by sheep (Malcolm and Pol, 1986). It has the disadvantage that it was observed to suffer some dieback possibly because of disease.

A. amnicola exhibited the best long term survival and scored very well in the growth ratings. It has an excellent growth habit, grazing recovery and high palatability (A.J. Clarke, personal communication, 1983). It has the disadvantages that it is difficult to establish from seed (Malcolm *et al.*, 1982) and produces few volunteer seedlings, problems which are compensated for by its longevity. It has been observed that some types of *A. amnicola* volunteer readily, but these types have a more upright growth habit (H. Runciman, personal communication, 1985).

M. brevifolia must be considered in a somewhat different category from the foregoing species. It is shorter lived than some *Atriplex* spp., but maintains a stand because of its excellent volunteering ability. Its main disadvantage is that it does not withstand prolonged waterlogging. It is more palatable than the *Atriplex* spp., higher in protein and lower in salt content (Malcolm, 1963).

On many sites, plants of *Halosarcia pergranulata* volunteered on sections of the experiment sites. (*H. bibens* and *H. pterygosperma* also occur, but are less common and widespread.) Sites 3 and 10 were colonized by this species. On other sites such as 1, 4, 11, 14 and 16 *H. pergranulata* volunteered on the poorer drained sections of the plot and *M. brevifolia* on the better drained sections. Species such as *A. amnicola* grew well in either area except at site 16.

No single factor evaluation is adequate for screening the species. Taking all of the data in this study into consideration, *M. brevifolia* must be favoured for well drained sites because of its excellent volunteering ability. Where waterlogging

Table 4. Species ranked in order of performance by several criteria

Species*	Ranking criteria: Mean H x D 5 months (a)	Vigour 3.5 years (b)	Survival 9 years† (c)	Survival 12 years† (d)	Total excluding year 12 (a + b + c)
Maireana brevifolia	8	8	6	6	6
Atriplex amnicola	4	1	1	1	1
Atriplex bunburyana	5	4	4	-	4
Atriplex nummularia	3	2	3	-	2
Atriplex lentiformis	1	5	5	4	3
Atriplex halimus (380)	2	6	8	5	5
Atriplex halimus (386)	6	3	2	2	3
Atriplex linearis	10	7	7	3	7
Atriplex glauca	12	9	9	7	8
Atriplex leucoclada	7	12	11	-	8
Atriplex canescens	12	10	10	-	9
Atriplex polycarpa	9	10	11	-	8
Atriplex sp.	11	11	11	-	10

* = Species are listed in order of preferred choice (Table 5) with the best first. *A. indulata* is not included because it was planted in the second year
H = Height
D = Diameter
† = Year 9 or Year 12 survival as a per cent of the number of bushes that survived the first year

Table 5. Species ranking best to poorest by including data from other studies*

Rank	Species	Condition	Advantages	Disadvantages
1	*M. brevifolia*	No waterlogging	Vol. graz. rec., nutr., pal.	Seed, oxalate
1	*A. amnicola*	High salt mod. waterlogging	Surv., graz. rec., gr. hab. pal., low salt	Establ., low % leaf
1	*H. pergranulata*	High salt, high waterlogging	Vol., survival	High salt
2	*A. undulata*	High salt, mod. waterlogging	Surv., seed, gr. hab., graz. rec.	Disease
3	*A. lentiformis*	High salt mod. waterlogging & high temp.	Early growth, vol.	Surv., gr. hab.
3	*A. bunburyana*	High salt, mod. waterlogging	Surv., vol., adaptation	Low pal., gr. hab. seed
3	*A. paludosa*) *A. cinerea*	Not in study but very promising		
4	*A. nummularia*	High salt mod. waterlogging	Survival	Vol. gr. hab., pal.
5	*A. halimus*	High salt mod. waterlogging	Surv., vol.	Disease, pal.
Low	*A. linearis* *A. glauca* *A. leucoclada* *A. atacamensis* *A. canescens* *A. nuttallii* *A. polycarpa*			

(Abbreviations: vol. = volunteer seedlings; graz. rec. = grazing recovery; nutr. = nutritive value; pal. = palatability; mod. = moderate; surv. = survival; gr. hab. = growth habit; seed = harvestability; estab. = establishment)

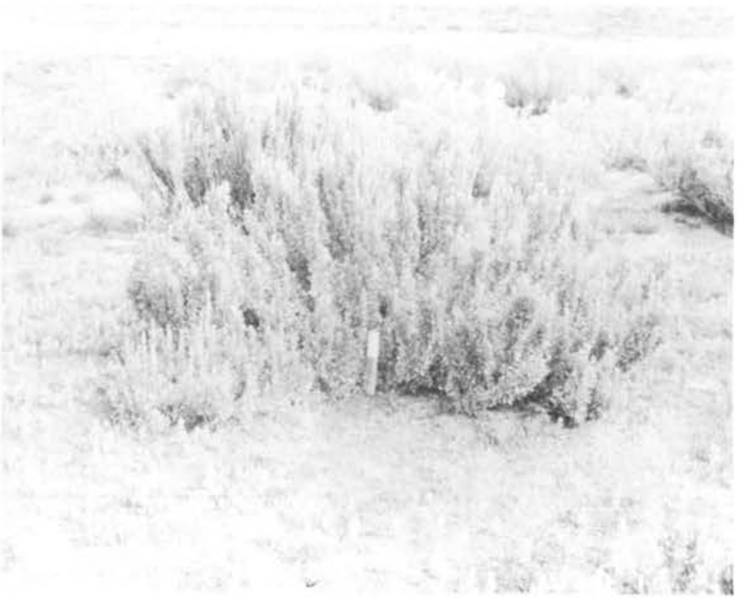
* Other studies include the authors' unpublished data and A.J. Clarke, personal communication, 1984.

threatens the survival of *M. brevifolia*, *A. amnicola* would be favoured for its excellent growth habit and survival. If establishment proves too difficult, species such as *A. undulata* or *A. bunburyana* may be preferred.

The adaptation study, including evidence from volunteering by *Halosarcia* spp., indicates that on sites 1, 4, 5, 8, 9, 11, 13, 14 and 15, *M. brevifolia* will grow on the least waterlogged sections, *A. amnicola* on the intermediate areas and *Halosarcia* spp. on the most waterlogged sections of the plots or their surroundings. Sites 3 and 10 did not support *M. brevifolia* because of waterlogging and site 10 was suited only to *Halosarcia* spp. Site 12 did not suffer from waterlogging and grew both *M. brevifolia* and *A. amnicola* well. Site 16 supported *M. brevifolia* and *Halosarcia* on the higher and lower sides and *A. nummularia* and *A. bunburyana* grew and volunteered in the transition zone. *A. amnicola* died out in the *Halosarcia* side of the plot. Site 17 presents the most difficult conditions of any of the plots. *M. brevifolia* and *A. nummularia* grew and volunteered nearby, but on the bare saline and acidic soil of the plot no species flourished. It is concluded that, except for the highly acidic soil at site 17, the suite of species, *M. brevifolia* - *A. amnicola* - *Halosarcia* (usually *H. pergranulata*) is capable of growing on the whole spectrum of soils represented in this study, providing account is taken of the degree of waterlogging in sowing the species on different sections of the sites. Using data from our research, information from studies on grazing production (Clarke 1982), and forage composition (Malcolm *et al.*, 1988) and ecotype comparisons (unpublished) it is possible to construct the species ranking in Table 5. This information has been used to construct a table to assist farmers to choose which species to establish on their salt-affected land (Malcolm, 1983, 1986b).

Species not included in the present study (*A. paludosa* and *A. cinerea*) have subsequently been introduced to the screening programme and have performed well (Table 5).

***Atriplex cinerea*, only eight months old, on a saline seepage. The stems readily self-layer.**



***Atriplex bunburyana* showing the ability of the species to produce volunteer plants.**

Williams (1960) has recommended that the search for species for revegetating degraded areas in western New South Wales should concentrate on climax species such as *A. nummularia*. However, *A. nummularia* presents establishment and seedling regeneration problems not yet solved. In our research the best species include one indigene, (*M. brevifolia*), one from a hotter area with rainfall less in amount and different in incidence, (*A. amnicola*), and one from a climatic area in Argentina receiving a greater incidence of summer rainfall and poorer rainfall efficiency (*A. undulata*). These results indicate that it is not essential to restrict consideration to indigenous or climax species or even species from homoclimes.

The present screening has shown that some species are capable of persisting on a range of saline sites either by surviving or by providing replacements. Factors important to persistence such as volunteering ability, resistance to waterlogging and disease and longevity have been identified. The multifactorial nature of the screening process has been emphasized. The limitations of the site sampling programme for forecasting adaptation have become apparent because of the omission of data on waterlogging events. The species which performed well, survived salinity (EC_e) and sodium (SAR_e) levels well beyond the highest levels quoted for salt tolerant crop plants. An index of site waterlogging condition is needed, but it may be determined by events which occur each decade or less. Where there is a risk of waterlogging, plants of less sensitivity should be used.

Discussion

Future screening studies could be improved by including an assessment of recovery from grazing or hand stripping. Ease of establishment must be separately researched. The studies should include analyses for leafiness, feeding value and salt content of the plants.

Farmers commonly use *M. brevifolia* because of its palatability, grazing recovery and seedling regeneration and *A. undulata* is now being sown on farms in preference to *A. amnicola* because of the greater ease of seed harvesting which enables seed to be supplied in quantity at a lower price. *A. lentiformis* is commonly planted in combination with *A. undulata* because of its good early growth, ease of establishment and value for shelter.

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Appendix 1

Soil profile description for each test site.

Depth (cm)	Colour (Munsell soil colour charts)	Soil description
Site 1		
0- 7.5	10 YR/5/2	Gritty loamy sand
7-23	10 YR/7/2	Gritty loamy sand
23-27	10 YR/7/2	Loamy sand with coarse grit
27-30	10 YR/7/1	Loamy sand with coarse grit
30-50	2.5 Y/7/2	Loamy sand with coarse grit
50-55	2.5 Y/7/2	Sandy clay loam with coarse grit
55-70	2.5 Y/7/2	Sandy clay with coarse grit and streaks of 7.5 YR/7/4
70-75	10 YR/6/1	Sandy clay with coarse grit
75-86	10 YR/7/1	Sandy clay with coarse grit
86-91	10 YR/7/1	Sandy clay with coarse grit and streaks of 7.5 YR/6/4
Site 2		
0-15	10 YR/5/3	Loamy sand
15-23	10 YR/6/2	Sandy clay loam
23-30	10 YR/6/3	Sandy clay
30-53	10 YR/6/4	Sandy clay with occasional Mn nodules
53-61	10 YR/8/2	Sandy clay with occasional Mn nodules Distinct line of 10 YR/8/3
61-69	10 YR/8/2 & 2/5 Y/7/2	Mottled sandy clay
69-76	2.5 Y/7/2	Sandy clay with traces of 10 YR/6/4 & some Mn nodules
76-84	2.5 Y/7/2 & 10 YR/6/4	Mottled sandy clay with some Mn nodules
84-91	10 YR/6/4	Sandy clay with traces of 2.5 Y/7/24 larger numbers of Mn nodules
Site 3		
0- 5	2.5 YR/4/4	Sandy clay loam
5-10	5 YR/4/6	Sandy loam
10-15	5 YR/4/6	Loamy sand
15-20	5 YR/4/6	Loamy sand with fine gravel
20-25	5 YR/4/6	Gravelly sandy loam
25-56	5 YR/4/6	Gravelly sandy clay
56-66	5 YR/4/6	Very gravelly sandy clay
66-86	7.5 YR/5/6	Very gravelly sandy clay with mottles of 10 YR/8/4
86-91	7.5 YR/5/6	Very gravelly sandy clay with mottles of 10 YR/8/4 and very coarse gravel
Site 4		
0-10	10 YR/6/2	Loamy sand
10-15	10 YR/7/2	Coarse loamy sand
15-22	10 YR/7/1	Coarse loamy sand
22-38	10 YR/7/3	Coarse loamy sand with grit
38-46	10 YR/7/2	Coarse sandy clay
46-53	5 Y/8/2	Coarse sandy clay
53-61	5 Y/8/2	Coarse sandy clay with grit
61-69	5 Y/8/2	Coarse sandy clay with small mottles of 5 YR/5/6
69-76	5 Y/8/2	Gritty sandy clay mottles increasing
76-91	5 Y/7/1	Gritty sandy clay with mottles of 2.5 YR/3/6
Site 5		
0-10	2.5 YR/5/2	Gritty loamy sand
10-15	10 YR/7/2	Sandy clay
15-23	5 Y/7/2	Clay with slight grit
23-30	5 Y/8/2	Clay with slight grit
30-38	5 Y/8/2	Clay
38-46	5 Y/7/2	Clay
46-61	2.5 Y/7/2	Clay with some grit
61-69	2.5 Y/7/2	Clay with some grit and slight 10 YR/7/8 mottling
69-76	2.5 Y/7/2	Gritty clay with 10 YR/7/8 mottling
76-84	2.5 Y/7/2	Gritty clay with some 2.5 YR/5/4 mottling
84-91	2.5 Y/7/2	Very gritty clay
Site 6		
0-15	10 YR/5/3	Sandy clay loam
15-23	10 YR/5/3	Loamy clay
23-30	7.5 YR/7/4	Fine sandy clay
30-46	7.5 YR/7/3	Fine sandy clay
46-76	7.5 YR/6/3	Fine sandy clay
76-84	7.5 YR/6/3	Fine sandy clay with 7.5 YR/8/3 mottling
84-91	7.5 YR/6/3	Fine sandy clay with 7.5 YR/8/3 mottling increasing
Site 7		
0- 8	10 YR/6/3	Sandy clay loam
8-15	10 YR/7/2	Sandy clay
15-46	10 YR/7/3	Sandy clay
46-53	10 YR/7/2	Gritty sandy clay
53-66	10 YR/7/2	Gritty sandy clay some 10 YR/7/8 mottles
66-71	10 YR/8/2	Gritty sandy clay some 10 YR/7/8 mottles
71-76	5 YR/7/1	Sandy clay with 10 YR/6/6 mottles
76-86	10 YR/8/1	Sandy clay streaked with 10 YR/5/6
86-91	10 YR/8/1	Sandy clay streaked with 10 YR/5/6
Site 8		
0-20	5 YR/4/4	Clay
20-46	10 YR/5/4	Clay with Fe nodules increasing with depth
46-51	10 YR/5/4 - 6/6	Clay with Fe nodules increasing with depth
51-61	10 YR/5/8	Clay with Fe nodules and some gravel and coarse grit
61-81	7.5 YR/5/6-5/8	Coarse grit and gravel with clayey matrix and Fe nodules
81-91		Gravel and Fe nodules decreasing with depth
Site 9		
0 - 7.5	2.5 YR/3/6	Sandy clay with Fe rich nodules
7.5-15	(Sample lost)	
15 -41	2.5 YR/3/6	Sandy clay with Fe rich nodules
41 -51	2.5 YR/4/8	Sandy clay with Fe rich nodules

51 -86	2.5 YR/3/6	Sandy clay with Fe rich nodules
86 -91	2.5 YR/5/6	Sufficient Fe nodules to make hand texturing difficult. Matrix fine textured

Site 10

0 - 7.5	10 YR/4/2	Gritty loamy sand
7.5-15	10 YR/3/3	Gritty loamy sand
15 -23	10 YR/4/2	Gritty loamy sand
23 -28	10 YR/5/2	Gritty loamy sand
28 -30	10 YR/6/1	Gritty loamy sand
30 -38	10 YR/6/3	Gritty clay
38 -43	5 YR/6/3	Gritty clay
43 -48	5 YR/7/2	Gritty clay
48 -53	5 YR/7/2	Weak sandy clay
53 -86	5 YR/7/3	Weak sandy clay
86 -91	5 YR/7/2	Weak sandy clay

Site 11

0 - 7.5	7.5 YR/5/4	Coarse loamy sand
7.5-23	5 YR/5/3	Coarse loamy sand
23 -30	5 YR/5/3	Coarse sandy clay
30 -46	10 YR/6/4	Coarse sandy clay
46 -56	10 YR/6/4	Coarse sandy clay with 10 YR/5/6 mottling
56 -61	10 YR/6/4	Sandy clay with 10 YR/5/6 mottling
61 -71	10 YR/6/4	Sandy clay with increased 10 YR/5/6 mottling
71 -90	10 YR/6/4	Sandy clay mottling increasing with depth
90 -91	10 YR/6/4	Sandy clay 10 YR/5/6 mottling and small Fe nodules

Site 12

0-15	10 YR/6/2	Silty clay
15-28	10 YR/6/3	Silty clay
28-30	10 YR/7/4	Silty clay
30-86	5 YR/7/2	Silty clay
86-91	5 YR/7/3	Silty clay

Site 13

0 - 7.5	2.5 Y/6/2	Loamy sand
7.5-15	2.5 Y/7/2	Loamy sand
15 -25	10 YR/7/1	Sandy loam
25 -30	10 YR/7/1	Sandy clay loam
30 -41	2.5 Y/7/2	Gritty sandy clay
41 -46	10 YR/7/1	Gritty sandy clay
46 -51	5 Y/7/2	Gritty sandy clay
51 -56	5 Y/7/3	Gritty sandy clay
56 -66	2.5 Y/7/2	Sandy clay
66 -76	10 YR/7/4	Gritty loamy sand
76 -81	10 YR/7/4	Gritty sandy clay loam
81 -86	10 YR/7/4	Very gritty sandy clay loam
86 -91	10 YR/7/4	Gritty sandy clay

Site 14

0 - 7.5	10 YR/6/2	Sandy loam
7.5-23	10 YR/6/2	Silty clay
23 -30	10 YR/7/1	Clay with Mn nodules
30 -41	10 YR/6/3	Clay with Mn nodules
41 -48	10 YR/7/3	Clay with Mn nodules
48 -53	2.5 Y/7/2	Clay with Mn nodules
53 -61	2.5 Y/7/3	Clay with Mn nodules
61 -64	2.5 Y/7/2	Clay with Mn streaks
64 -66	2.5 Y/7/2	Clay with Mn streaks
66 -79	2.5 Y/7/2	Clay heavily stratified with Fe and Mn
79 -84	2.5 Y/7/2	Clay heavily stratified with Fe and Mn with slight 10 YR/7/8 and 10 YR/6/8 mottling
84 -89	2.5 Y/7/2	Clay with increased mottling and with Fe, Mn and quartz in evidence
89 -81	2.5 Y/7/2	Clay with 10 YR/7/8 and 10 YR/6/8 mottling and increased evidence of Fe, Mn and quartz

Site 15

0 - 7.5	10 YR/5/4	Sandy clay loam
7.5-23	7.5 YR/5/4	Sandy clay loam
23 -28	7.5 YR/5/4	Fine sandy clay
28 -30	7.5 YR/5/4	Fine sandy clay with 7.5 R/3/8 mottles
30 -46	7.5 YR/5/4	Fine sandy clay with Fe and Mn nodules increasing with depth
46 -58	7.5 YR/5/4	Fine sandy clay with pebbles of Fe and Mn rich material
58 -61	7.5 YR/5/4	Fine sandy clay no nodules or pebbles
61 -91	7.5 YR/5/4	Fine sandy clay with Fe and Mn rich nodules and large 7.5 R/8/3 mottles, nodules increasing at 76 cms

Site 16

0- 5	5 YR/4/6	Loamy sand
5-10	5 YR/5/4	Loamy sand
10-15	5 YR/5/4	Coarse sandy loam
15-61	5 YR/4/6	Coarse sandy clay
61-66	5 YR/4/6	Coarse sandy clay with Fe and Mn nodules
66-71	5 YR/4/6	Coarse sandy clay with plentiful Mn and some Fe nodules
71-76	5 YR/4/6	Coarse sandy clay, no nodules
76-86	5 YR/4/6	Coarse sandy clay, a few Fe nodules
86-91	5 YR/4/6	Coarse sandy clay, a few Fe nodules and a little Mn

Site 17

0 - 7.5	10 YR/5/2	Gritty loamy sand
7.5-28	10 YR/5/2	Gritty sandy clay
28 -43	10 YR/5/2	Gritty sandy clay with 10 YR/7/6 mottling increasing with depth
43 -53	10 YR/8/2	Gritty clay with 10 YR/7/6 mottling increasing still further with depth
53 -58	10 YR/8/2	Slightly gritty clay slight 10 YR/7/6
58 -69	10 YR/8/2	As above with less grit and less mottle
69 -91	10 YR/8/2	Slightly gritty clay, no mottling

Appendix 2

Physical properties of soils from plant adaptation test sites (composite samples)

Site	Depth (cm)	Saturation percentage	Water retention at 34kPa %	Water retention at 1515kPa %	Clay %	Silt %	Fine sand %	Coarse sand %
1	0 - 7.5	13.5	5.62	2.84	8.5	2.5	26.4	62.6
	7.5-30	22.2	17.63	11.60	13.5	20.5	13.0	53.0
	30 -61	29.6	20.82	11.37	21.5	24.5	14.7	39.3
	61 -91	31.6	20.61	13.27	20.5	25.5	14.0	40.0
2	0 - 7.5	21.4	9.21	4.20	10.0	8.0	32.4	49.6
	7.5-30	33.3	23.81	13.88	37.0	7.0	19.1	36.9
	30 -61	33.7	20.52	11.86	35.5	6.5	19.5	38.5
	61 -91	36.5	24.07	14.45	39.0	7.0	18.8	35.2
3	0 - 7.5	20.1	11.00	5.10	12.0	12.0	36.0	40.0
	7.5-30	23.3	15.32	9.70	22.0	12.0	30.8	35.2
	30 -61	29.6	18.69	11.04	26.0	10.0	27.0	37.0
	61 -91	33.2	20.41	12.26	22.0	12.0	19.5	46.5
4	0 - 7.5	18.0	6.00	2.35	8.0	0.0	32.7	59.3
	7.5-30	29.1	17.94	10.37	30.0	6.0	20.7	43.3
	30 -61	32.2	20.47	12.82	35.5	1.0	23.5	40.0
	61 -91	33.2	22.24	14.17	42.5	1.5	20.0	36.0
5	0 - 7.5	12.8	8.51	4.86	16.0	2.0	18.0	64.0
	7.5-30	39.5	29.25	17.63	52.0	2.0	14.0	32.0
	30 -61	36.3	26.18	15.67	46.0	0.0	14.0	40.0
	61 -91	34.3	21.54	13.53	36.0	0.0	11.0	53.0
6	0 - 7.5	41.4	25.71	14.03	16.5	28.5	36.4	18.6
	7.5-30	41.4	29.28	15.73	31.0	33.5	22.5	13.0
	30 -61	37.5	27.47	14.59	40.0	30.0	16.2	13.8
	61 -91	35.8	29.68	14.96	15.5	36.5	22.2	25.8
7	0 - 7.5	14.2	9.49	5.47	33.0	5.0	15.6	46.4
	7.5-30	22.1	16.22	9.08	37.0	3.0	16.7	43.3
	30 -61	24.2	16.86	8.59	36.0	2.0	15.6	46.4
	61 -91	23.2	16.60	8.43	34.0	0.0	15.0	51.0
8	0 - 7.5	34.0	21.92	11.66	24.5	12.5	39.0	24.0
	7.5-30	40.3	27.22	16.40	39.0	11.0	22.7	27.3
	30 -61	34.1	20.30	12.53	31.5	7.5	22.7	38.3
	61 -91	36.3	24.51	14.87	40.0	7.0	20.2	32.8
9	0 - 7.5	20.7	11.36	6.80	20.0	8.0	30.4	41.6
	7.5-30	21.3	13.29	7.86	31.0	4.0	25.0	40.0
	30 -61	22.7	14.14	8.14	29.0	7.0	25.5	38.5
	61 -91	23.0	13.85	7.99	24.0	8.0	26.4	41.6
10	0 - 7.5	16.7	5.88	2.83	8.0	2.0	32.4	57.6
	7.5-30	21.0	14.87	7.56	19.0	3.0	22.6	54.4
	30 -61	34.3	21.49	11.48	19.0	7.0	27.6	46.4
	61 -91	28.3	14.74	7.24	10.0	6.0	26.3	57.7
11	0 - 7.5	13.0	4.55	2.40	7.0	1.0	20.0	72.0
	7.5-30	16.7	13.79	8.12	30.0	2.0	15.0	53.0
	30 -61	28.1	16.89	10.77	34.0	4.0	17.0	45.0
	61 -91	28.5	19.10	11.62	40.0	0.0	12.0	48.0

Site	Depth (cm)	Saturation percentage	Water retention at 34kPa %	Water retention at 1515kPa %	Clay %	Silt %	Fine sand %	Coarse sand %
12	0 - 7.5	29.1	23.91	16.48	46.0	24.0	18.8	11.2
	7.5-30	42.2	32.48	22.72	42.0	32.0	22.8	3.2
	30 -61	42.2	35.24	23.34	74.0	14.0	8.72	3.28
	60 -91	43.8	37.15	24.71	82.0	14.0	2.53	1.47
13	0 - 7.5	12.7	6.49	2.85	7.0	9.0	29.5	54.5
	7.5-30	22.3	11.82	6.53	31.0	5.0	22.3	41.7
	30 -61	29.5	18.06	10.46	40.0	8.0	15.0	37.0
	61 -91	27.3	11.84	6.61	26.0	2.0	16.0	56.0
14	0 - 7.5	26.8	14.40	7.12	22.0	8.0	31.6	38.4
	7.5-30	43.2	33.30	19.69	57.0	7.0	18.4	17.6
	30 -61	40.0	29.90	17.01	49.0	3.0	20.7	27.3
	61 -91	35.2	25.20	14.65	41.0	3.0	16.0	40.0
15	0 - 7.5	24.7	17.67	10.66	12.0	20.0	26.4	41.6
	7.5-30	28.2	21.05	12.54	16.0	20.0	32.0	32.0
	30 -61	31.4	22.27	13.49	27.0	17.0	24.0	32.0
	61 -91	32.0	21.89	8.05	33.0	13.0	18.8	35.2
16	0 - 7.5	15.9	6.70	3.73	10.0	8.0	26.0	56.0
	7.5-30	23.4	12.43	7.87	20.0	12.0	21.6	46.4
	30 -61	35.0	22.81	14.68	27.0	17.0	22.4	33.6
	61 -91	34.2	23.02	15.34	18.0	22.0	29.6	30.4
17	0 - 7.5	25.9	16.60	9.32	13.5	11.5	28.0	47.0
	7.5-30	33.3	23.82	16.32	40.0	13.0	13.2	33.8
	30 -61	39.9	38.90	20.00	36.0	24.0	11.2	29.8
	61 -91	53.2	37.04	22.49	28.0	42.0	8.3	21.7

Appendix 3

Chemical properties of soils from plant adaptation test sites (composite samples, except pH, see footnote)

Site	Depth (cm)	EC_e (mS/m)	SAR_e	Be (mg/L)	CEC (m.equiv./ 100 g)	Cl^- (%)	pH*	Lime
1	0 - 7.5	2250	28.0	1.4	4.2	0.19	6.5- 8.5	-
	7.5-30	2160	27.5	2.2	9.7	0.24	7.4- 8.6	-
	30 -61	2450	38.5	3.5	9.7	0.30	4.6- 8.3	-
	61 -91	3090	45.3	5.3	9.0	0.35	4.2- 6.8	-
2	0 - 7.5	4010	30.7	1.1	5.6	0.72	6.5- 7.9	-
	7.5-30	2800	38.5	1.9	14.7	0.40	7.7- 9.1	+
	30 -61	2230	37.0	2.2	12.8	0.27	8.1- 9.3	-
	61 -91	2440	36.4	1.6	14.0	0.28	7.6- 9.1	-
3	0 - 7.5	6130	46.0	0.9	6.0	1.96	6.3- 7.5	-
	7.5-30	2980	31.0	0.9	9.5	0.25	6.1- 8.1	-
	30 -61	2140	26.5	0.8	11.4	0.25	6.6- 8.9	-
	61 -91	1430	24.5	0.8	N.A.	0.26	7.0- 9.1	-
4	0 - 7.5	2030	17.5	7.6	4.6	0.31	7.1- 8.6	-
	7.5-30	2880	40.6	4.3	12.3	0.37	6.9- 8.5	-
	30 -61	3040	41.8	2.7	11.6	0.37	4.7- 8.7	+
	61 -91	2580	37.5	1.4	11.2	0.39	4.4- 7.9	-
5	0 - 7.5	3500	39.4	1.5	5.5	0.42	7.4- 9.0	-
	7.5-30	3220	42.0	2.2	18.6	0.52	8.1- 8.6	-
	30 -61	2460	39.2	2.7	14.9	0.40	7.8- 8.3	-
	61 -91	2080	35.6	2.9	11.1	0.32	4.8- 8.0	-
6	0 - 7.5	1900	44.8	9.7	15.8	0.07	8.6- 9.5	+
	7.5-30	1960	53.8	10.5	10.4	0.18	9.4- 9.9	+
	30 -61	1760	112.0	12.2	10.1	0.14	9.5-10.0	+
	61 -91	1530	96.3	12.0	9.7	0.15	9.5-10.1	+
7	0 - 7.5	4760	40.8	3.6	8.7	0.76	5.5- 7.0	-
	7.5-30	2630	28.4	2.3	9.5	0.29	5.0- 7.1	-
	30 -61	2580	29.9	3.0	7.8	0.27	5.3- 7.5	-
	61 -91	2740	32.9	3.8	6.8	0.25	4.8- 7.3	-
8	0 - 7.5	1860	19.1	0.4	18.0	0.24	6.9- 8.1	-
	7.5-30	1640	25.5	0.5	19.4	0.22	8.2- 8.8	-
	30 -61	1650	28.5	0.7	13.4	0.18	8.4- 8.9	-
	61 -91	1800	29.5	1.1	14.8	0.21	8.4- 8.9	-
9	0 - 7.5	4650	19.2	0.3	5.8	1.12	6.0- 7.2	-
	7.5-30	2110	12.1	0.3	4.6	0.19	5.4- 7.7	-
	30 -61	1880	12.3	0.5	5.2	0.17	5.6- 8.0	-
	61 -91	1290	10.5	0.6	5.8	0.18	6.4- 7.2	+
10	0 - 7.5	2900	33.5	2.4	5.1	0.25	6.8- 9.1	-
	7.5-30	2240	24.4	1.0	6.4	0.17	6.7- 8.6	-
	30 -61	1780	26.9	1.0	15.0	0.21	7.2- 9.1	-
	61 -91	1390	24.4	0.9	11.2	0.14	7.3- 8.7	-

Site	Depth (cm)	EC_e (mS/m)	SAR_e	Be (mg/L)	CEC (m.equiv./ 100 g)	Cl^- (%)	pH*	Lime
11	0 - 7.5	3900	32.7	3.3	2.9	0.62	5.8- 6.6	-
	7.5-30	2190	31.5	2.7	6.1	0.24	5.3- 6.6	-
	30 -61	2700	33.6	3.7	10.4	0.27	5.3- 7.0	-
	61 -91	2230	33.5	3.5	9.7	0.25	4.8- 7.1	-
12	0 - 7.5	1410	28.7	0.5	21.7	0.33	6.9- 8.3	-
	7.5-30	2260	61.3	1.6	21.5	0.46	8.7- 9.5	-
	30 -61	2590	58.1	1.4	17.3	0.50	8.8- 9.5	-
	61 -91	3000	75.6	0.8	18.1	0.65	8.7- 9.2	-
13	0 - 7.5	1950	18.6	1.3	3.8	0.70	6.2- 6.6	-
	7.5-30	1200	17.9	1.2	8.5	0.12	6.3- 7.8	-
	30 -61	1390	21.9	1.9	12.8	0.16	6.7- 8.6	-
	61 -91	1480	26.30	2.8	8.5	0.11	7.1- 8.8	-
14	0 - 7.5	1340	16.6	1.6	8.4	0.23	7.3- 8.6	-
	7.5-30	1940	41.5	2.3	18.5	0.28	8.4- 9.6	+
	30 -61	2270	42.5	2.0	16.2	0.28	8.0- 9.4	-
	61 -91	2200	43.5	1.4	16.2	0.30	6.3- 8.8	-
15	0 - 7.5	9600	37.7	1.3	14.4	1.42	7.4- 9.0	+
	7.5-30	4330	38.7	4.5	13.0	0.58	8.3- 9.2	+
	30 -61	2500	35.5	6.0	12.4	0.33	8.6- 9.1	-
	61 -91	1690	32.1	5.1	10.2	0.28	8.6- 9.0	++
16	0 - 7.5	2960	24.5	1.4	5.7	1.12	6.0- 7.2	-
	7.5-30	2350	31.3	1.4	10.0	0.24	6.5- 7.6	-
	30 -61	2300	34.0	1.8	13.8	0.37	7.2- 8.4	+
	61 -91	2700	36.7	2.1	15.8	0.41	8.1- 8.6	+
17	0 - 7.5	3100	43.0	2.1	12.5	0.51	4.9- 7.7	-
	7.5-30	3300	38.5	1.8	4.8	0.39	3.4- 6.8	-
	30 -61	2990	38.0	1.2	2.6	0.65	3.8- 4.5	-
	61 -91	2890	36.0	0.8	1.7	0.62	3.9- 4.5	-

* The pH values are the extremes of the range obtained for samples at that depth over the seven sampling times

Appendix 4

Soluble cations in saturation extract of composite soil samples from sites used for testing of shrubs

Site	Depth (cm)	Soluble cations (mg/L) Na	Mg	Ca
1	0 - 7.5	3,700	580	370
	7.5-30	3,750	700	260
	30 -60	4,300	450	200
	61 -91	5,700	650	130
2	0 - 7.5	6,600	1,540	950
	7.5-30	5,200	630	340
	30 -61	4,100	440	200
	61 -91	4,250	550	132
3	0 - 7.5	11,600	1,900	1,700
	7.5-30	3,800	770	540
	30 -61	3,350	480	430
	61 -91	2,400	300	230
4	0 - 7.5	2,900	760	820
	7.5-30	5,400	580	380
	30 -61	5,700	580	460
	61 -91	4,800	560	310
5	0 - 7.5	6,300	800	620
	7.5-30	5,800	620	420
	30 -61	4,350	420	240
	61 -91	3,800	420	170
6	0 - 7.5	3,750	140	300
	7.5-30	4,000	230	42
	30 -61	3,750	42	16
	61 -91	3,200	36	24
7	0 - 7.5	8,500	1,400	1,000
	7.5-30	4,500	950	340
	30 -61	4,450	860	260
	61 -91	4,900	880	230
8	0 - 7.5	490	25	9
	7.5-30	1,400	180	46
	30 -61	2,450	400	114
	61 -91	2,850	390	134
9	0 - 7.5	2,650	410	780
	7.5-30	2,700	280	380
	30 -61	2,850	300	260
	61 -91	3,250	360	240
10	0 - 7.5	5,600	1,700	3,600
	7.5-30	2,250	740	1,400
	30 -61	2,000	620	970
	61 -91	1,400	390	710
11	0 - 7.5	4,950	840	270
	7.5-30	3,650	910	200
	30 -61	2,900	430	170
	61 -91	2,250	340	84
12	0 - 7.5	6,500	1,380	700
	7.5-30	3,900	580	210
	30 -61	4,750	710	330
	61 -91	3,900	550	130
13	0 - 7.5	2,500	300	84
	7.5-30	4,600	230	48
	30 -61	5,300	360	35
	61 -91	6,100	270	48
14	0 - 7.5	2,800	590	760
	7.5-30	1,900	370	240
	30 -61	2,350	400	210
	61 -91	2,550	310	200
15	0 - 7.5	2,250	780	108
	7.5-30	3,700	300	108
	30 -61	4,100	380	82
	61 -91	4,050	360	62
16	0 - 7.5	18,750	2,250	5,700
	7.5-30	8,000	840	1,850
	30 -61	4,600	480	480
	61 -91	3,150	260	300
17	0 - 7.5	4,600	770	1,400
	7.5-30	3,850	480	350
	30 -61	3,850	340	400
	61 -91	4,700	430	530

Appendix 5

Growth habit of shrub species

The growth habit of most species was observed during the experiment, but growth of *A. nuttallii* and *A. polycarpa* was too poor to allow adequate description. The other species may be decribed as follows (sizes given are for bushes over two years old):

A. amnicola: semi-prostrate, densely branched bushes, somewhat brittle, but reinforced by strong stem layering; shoots vigorously from layered stems after grazing; size about 2.5 m x 0.6 m (diameter x height); fruits borne in dense clusters somewhat inside the canopy, necessitating damage to the bush during collection.

A. atacamensis: prostrate bushes branching from the base; it was destroyed before it reached full size.

A. bunburyana: an upright species with branches which may fall down and shoot upwards from a prostrate position; strong frame, densely shooting. Size about 2.5 m x 0.8 m. Fruits borne in terminal clusters.

A. canescens: spreading shrub with angular, rather sparse branching; strong frame; size about 1 m x 1 m; clustered terminal fruits.

A. glauca: prostrate dense ground cover with strong branches; size about 1 m x 0.2 m; fruits in clusters along branchlets.

A. halimus: spreading to semi-prostrate shrub densely branching from the base; branches very tough; size about 2 m x 0.7 m; fruits on long flowering spikes.

A. lentiformis: spreading shrub with very open angular branching; branches strong but bushes sometimes break off at ground level; size about 3 m x 1.7 m; fruits in large bunches over outside of bush.

A. leucoclada: prostrate dense ground cover, somewhat brittle; size about 0.8 m x 0.2 m; fruits in terminal clusters.

A. linearis: small, fine, brittle stemmed bushes; size about 0.6 m x 0.4 m; fruits in terminal clusters.

A. nummularia: tall erect growing bushes with a very strong woody stem; grows more spreading with age; size about 1.5 m x 1.2 m fruits in large bunches.

A. undulata: semi-prostrate bushes sending up branchlets from readily layering stems; strong woody frame; size about 1.3 m x 0.5 m; fruits in terminal bunches.

A. sp.: prostrate finely branched bushes; size about 0.5 m x 0.2 m; fruits in terminal clusters.

The fruits of all the tested *Atriplex* spp. were readily harvested when they had reached maturity.

Maireana brevifolia: semi-erect, succulent, fine leaved shrub branching densely along branches or from the base; size about 0.5 m x 0.6 m; fruits borne diffusely over the canopy, ripen progressively over several months and are readily dislodged by wind.

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