

Saltland Pastures

in Australia

A Practical Guide

Second edition

E.G. Barrett-Lennard

With contributions from C.V. Malcolm and A. Bathgate

Alison Parsons

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¹ *Land Water & Wool* is a research and development initiative between Australian Wool Innovation Limited and Land & Water Australia for sustainable wool production. Additional investors include Meat & Livestock Australia, WA Department of Agriculture, CSIRO, CRC for Plant-based Management of Dryland Salinity, SA Research & Development Institute, Primary Industries and Resources SA, University of Adelaide, NSW Department of Land, Water and Biodiversity Conservation, Department of Primary Industries Victoria, NSW Agriculture, NSW Department of Infrastructure Planning and Natural Resources, plus grower groups across southern Australia.



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Preface

This book aims to encourage Australian farmers to revegetate salt-affected land with saltland pastures. These pastures can be profitable, sustainable and of benefit to the environment and the broader community.

The book has been written by Australia's foremost authority on saltland pastures, Dr Ed Barrett-Lennard with contributions from Clive Malcolm, who worked with Ed on the development of saltland pastures in the Department of Agriculture of WA for many years, and Andrew Bathgate, a technical specialist in salinity economics from NSW Agriculture.

Dr Barrett-Lennard is acknowledged as a leading researcher in the field of saltland revegetation and productive use and rehabilitation of saline land. He was awarded the National Dryland Salinity Program's 2002 WE Wood Award for excellence in salinity research and development, recognising his long-standing contribution to managing the salinity risk in Australia.

The book aims to make saltland pastures accessible to the widest possible audience. Its major readership is Australian farmers and those who advise them (agency staff, industry advisers and landcare coordinators). However, more specialised information has been provided in the footnotes for technical experts and students of the field.

The first edition of *Saltland Pastures in Australia: a Practical Guide* was published in 1995. Much has changed since then. This new edition has an expanded focus on:

- **designing pastures to improve their nutritive value to grazing animals**
- **the importance of salinity, waterlogging and inundation as factors affecting the ecological zonation of saltland**
- **the benefits of saltland pastures in lowering watertables**
- **the value of less salt tolerant plants, particularly in less severely affected land**
- **the economic value of saltland pastures, and**
- **farmer experiences.**

This publication coincides with increased farmer participation in saltland pastures through the influence of the Land, Water & Wool Sustainable Grazing on Saline Lands (LWW SGSL) Sub-program.

Acknowledgments

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Special thanks are extended to Jo Curkpatrick [Span Communication (Aus) Pty Ltd] who edited the text, and Dr Warren Mason (LWW SGSL National Coordinator) who enthusiastically supported the project throughout.

Many colleagues provided advice, information or photographs. Special thanks go to David Masters and Hayley Norman (CSIRO Livestock Industries) for their comments and support in the writing of Chapter 6 (Grazing value of saltland pastures).

We are enormously grateful for the continuing support of the farmers who have enthusiastically pioneered saltland pastures around Australia. Special thanks goes to the Saltland Pastures Association which provided the critical support necessary to begin this work.



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Chapter 1

Farmer voices for saltland pastures



Farmer champions have been critical to the development of saltland pastures in Australia.



In this Chapter

Ten case studies of saltland pastures in action

- Motivation for producers to manage saltland
- Implementation of saltland systems
- Importance of return on investment
- Benefits of managing saltland

Advocacy – farmer champions, farmer groups and the LWW SGSL

- Farmer champions
- Farmer groups
- Land, Water & Wool Sustainable Grazing on Saline Lands

We begin this book with a chapter summarising the value that farmers place in saltland pastures. We examine 10 case studies on saltland pastures collected around Australia, and we consider the critical role that farmers play in the advocacy of saltland pastures.

1.1 Ten case studies of saltland pastures in action

A team commissioned by the LWW SGSL initiative interviewed producers from 10 farms in the high rainfall and mixed farming zones of the four southern States (Figure 1.1).¹

Case study producers were asked:

- how saltland was affecting them before they started actively managing it?
- what stimulated them to do something about it?
- how they went about developing their saltland management systems?
- what they see as the main benefits of their saltland systems?

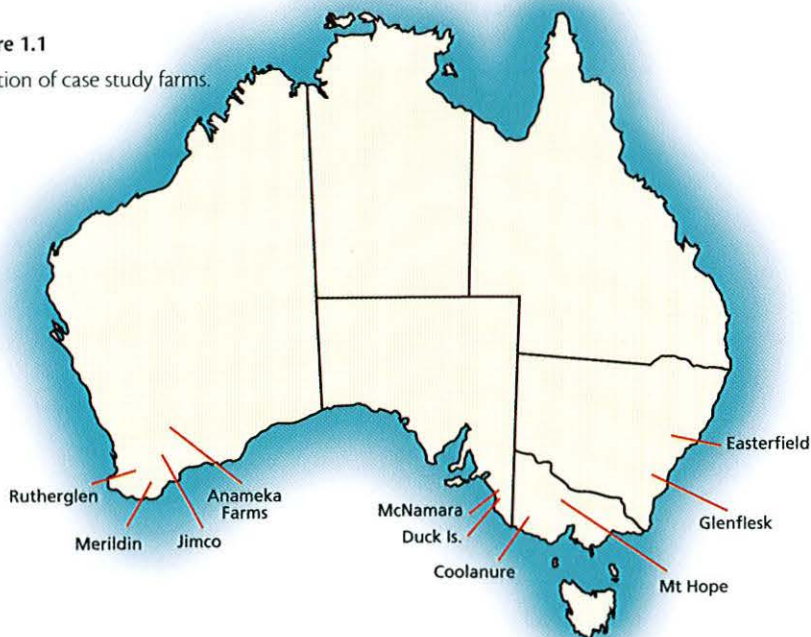
1.1.1 Motivation to manage saltland

The producers interviewed for the case studies are probably not a typical sample of producers, but they had some or all of the following characteristics:

- they were losing some of their best land to salinity and tended to have a larger than average proportion of the farm affected by salinity
- they are an adventurous and innovative group, proactive in the face of declining terms of trade in wool and increasing salinity, and prepared to try something new even if it involved uncertainty and risk
- they remained positive about the future of grazing industries, and had a commitment to improving the productivity, sustainability and profitability of their farms
- they took pride in the appearance of their farms
- for some, protecting and enhancing native vegetation and biodiversity was an important part of their management philosophy, and salinity was compromising these objectives.

Figure 1.1

Location of case study farms.



1.1.2 Implementation of saltland systems

All case study producers invested time and effort, sometimes over several decades, in researching and learning about new grazing management systems. They needed to know:

- what is the most cost effective way to fence saltland?
- what pastures perform best in various salinity and waterlogging situations?
- what is the most cost-effective way to establish these pastures and what applications of fertiliser or other soil amendments are necessary?
- how can stock water be provided and is it too salty for some stock?
- after initial establishment what is the best grazing regime?
- how do animals perform on the pastures, especially young sheep?
- what is the best way to run both sheep and cattle on saltland?
- what is it likely to cost and how much will it return?
- what annual maintenance will it need and will it need resowing?

This information was generally not available when most of these producers were getting started in saltland management in the 1980s. They learned mainly through trial and error. Government advisory staff have become more influential in recent years and in most cases are now working closely with the case study producers to further improve their systems.

In the case studies, producers were aware that the new saltland management systems would be more complex than existing systems. However they accepted this complexity in return for a potential turnaround in the productivity and sustainability of their whole farm system, and in some cases to regain their pride in the appearance of their farm.

They often trialed small areas first and carefully observed the effects of different management practices.

The enthusiasm that these producers feel for saltland pastures is unmistakable when we hear their own words (see box right).

Farmers speaking about saltland pastures

"By the mid to late 1980s we had lost about 120 ha to salinity... this saltland now carries 11 DSE/ha/yr, on average" – Yass NSW.

"The 'out of season' food from saltland is more valuable than conventional supplementary feeding"
– Dunkeld VIC.

"The saline and waterlogged land performs a very important role in maintaining weaner growth in dry autumn" – Mumbil NSW.

"The saltbush paddocks now provide good feed during autumn when it is scarce" – Cranbrook WA.

"Saltbush and wattle certainly fill the autumn feed gap – with the increased feed available from the saltland I have increased sheep numbers and eliminated hand feeding on the home farm"
– Wickepin WA.

"Aside from the obvious contribution that puccinellia makes to our productivity, it is also an essential tool in reclaiming salt-affected land"
– Keith SA.

"Having seen the benefits from the saltland pastures, I would proceed faster if starting again and even borrow money for saltland if necessary"
– Boyup Brook WA.

"Puccinellia has proved to be an excellent pasture for our sheep. It provides a nutritious, seed-free environment for weaners before shearing in November and quality dry feed in autumn... much of this knowledge has come from our own trial and error, but also from a network of like-minded graziers in the Upper South East"
– Keith SA.

"Initially we grazed about 50 dry sheep on the area for about three months each year – since revegetation with bluebush and saltbush we run 300 lambing ewes in there over a four-month period each year. Not a bad effort for land that many people would consider useless!"
– Tammin WA.

1.1.3 Importance of return on investment

Case study producers were asked what they had to do to obtain funds to implement their saltland system. It is interesting that although they conducted trials prior to expanding the size of their saltland systems, none prepared a quantified investment strategy that examined the costs and benefits of investing in saltland before they expanded their systems. Their investment in saltland was usually made as part of normal farm expenditure. The producers and their families appeared to accept the notion that farming in the wheat-sheep belt is inherently risky and even where costs and returns can be reliably estimated, profits are not guaranteed.

For most of the producers interviewed, production and aesthetic benefits from trial areas appeared to be sufficient to justify expanding the area of actively managed saltland. This comment applies particularly to the early 1990s when gross margins for many of the case study farms were low in comparison to today.

Happily, in these cases investments in establishing saltland pastures, were (or will be) repaid in 10 years. The exceptions to this are in situations where expensive earthworks and/or fencing have been required. Improvements in wool prices, sheep prices and in wool production per hectare have significantly increased the income from saltland pastures. In the event of a return to the low sheep and wool prices that prevailed in the early 1990s it is doubtful that investing in saltland for sheep and wool production would be profitable.

1.1.4 Benefits of managing saltland

The case studies show that saltland pastures are diverse and applicable to a range of farming situations throughout southern Australia. The major outcomes of the survey are summarised in Table 1.1.

In general producers aimed to improve the profitability of their whole farming system. The planting of saltland pastures was often only one of a number of changes to the farming system.

It is significant that most of the themes raised in Table 1.1 are echoed elsewhere in this book.

- systems based on the growth of Tall wheat grass, puccinellia and annual clovers prevailed in the less saline, higher rainfall areas in both the east and the west. South Australian saltland systems were dominated by puccinellia, and saltbush formed the basis of saltland systems in the Western Australian wheatbelt and the northern riverine plains of Victoria. (These plants are described in Chapter 4 and their establishment is discussed in Chapter 5.)
- flows of surface water were controlled using a variety of structures. (The effects of waterlogging and inundation on plant growth are discussed in Chapter 3, and the necessity of controlling surface water flows is discussed in Chapter 7).
- feed production in late summer/autumn was explicitly named as the key benefit in many cases. (The factors affecting the feeding value of saltland pastures are discussed in detail in Chapter 6, and the economic benefits of using saltland pastures to fill the autumn feed gap are discussed in Chapter 8).
- pasture growth on saltland decreased salinity at the soil surface and caused watertable drawdown (discussed in greater detail in Chapter 7).
- use of fertilisers was clearly part of the success of puccinellia (discussed in Chapter 7).

Interestingly, four of the case studies used rotational grazing to improve the productivity and diversity of saltland pastures. Although we have hinted at the value of such practices in Chapter 6 (Section 6.2.3), they are not yet widespread. Perhaps innovative farmers are once again leading the debate on this issue.

Other generic benefits arising from the implementation of saltland pasture systems in the case studies included:

- deferred grazing/paddock spelling
- greater surety of feed availability, with seasonal certainty
- enterprise diversification
- changes to flock structure
- improved aesthetic value in the land
- pride in what they have done and are doing.

Table 1.1 Responses of 10 case study farmers to salinity.

Location	Farm name	Enterprise	Rain (mm)	Ground-Water EC (dS/m)	Key changes made to saltland	Key benefits
NSW						
Yass	Glenflesk	Fine wool	740	4–6	Rotational grazing with long rest	More pasture production; lower soil salinity
Wellington	Easterfield	Fine wool	650	4–6	Rotational grazing with long rest	More pasture production; lower soil salinity
VIC						
Pyramid Hill	Mt Hope	Wool, cereals	320	31	Establishment of old man saltbush, native grasses; rotational grazing	Improved feed production in late summer/autumn
Dunkeld	Coolanure	Fine wool	650	28	Establishment of Tall wheat grass, balansa clover, persian clover	Grazing in Jan-Jun, Oct-Nov.
SA						
Keith	Duck Island	Crossbred cattle	500	13	Establishment of puccinellia; use of fertiliser (N, P, K, S)	High quality cattle feed available in autumn
Keith	McNamara	Mixed farming, grazing	500	13	Establishment of puccinellia; use of fertiliser (N, P, K, S)	Excellent pasture; higher lambing percentages
WA						
Boyup Brook	Rutherglen	Mixed farming, grazing	500	23	Establishment of puccinellia, strawberry clover; improved surface water management (grade banks); rotational grazing	Part of improved management for increased productivity over whole farm
Cranbrook	Merildin	Mixed farming, grazing	450	18	Establishment of saltbush, balansa clover; improved surface water management (W-drains)	Improved feed production in autumn; watertable drawdown
Tammin	Anameka Farms	Mixed farming, grazing	325	74	Establishment of saltbush, bluebush; improved surface water control (contour banks)	Increased pasture production, more sheep
Wickepin	Jimco	Mixed farming, grazing	350	28	Establishment of saltbush and WA golden wattle. Improved surface water control (grade drains, diversion banks)	Improved feed production in autumn; watertable drawdown

1.2 Advocacy – farmer champions, groups and LWW SGSL

The widespread adoption of saltland pastures in Australia will require a major change in attitude amongst most farmers about the potential of saltland. Individual farmers and farmer groups can play critical roles as advocates to the broader farming community.

1.2.1 Farmer champions

To a substantial degree, all of the case study farmers in Section 1.1 are important advocates to their communities. However some farmers have taken on even wider roles. Michael Lloyd is a case in point. Michael and Margaret Lloyd own a farm in the Lake Grace district of WA on which about 35% of the arable land is salt affected.² Michael began growing saltbush-based saltland pastures in 1989 and now has approximately 60% of his saltland revegetated. In the face of declining agency interest in saltland pastures he played a key role in the establishment of the Saltland Pastures Association in 1997 and has since served as its Chairman. With passion, humour, and even poetry (see next page), he has argued for change at field days (many at his own property), national workshops and conferences, and through a process of policy reform.³

1.2.2 Farmer groups

A useful start has been made through saltland-focused groups such as *Saltland Solutions* in SA and the *Saltland Pastures Association* in WA, but much more needs to be done.⁵ At the national level the major group that has promoted the development of saltland pastures has been the *Productive Use and Rehabilitation of Saline Land (PURSL) Group*. It operates under a national committee of state and farmer representatives, and conducts national workshops every 1–2

years at various locations around Australia.⁶ Although it has broader interests than saltland pastures *per se*, it has a good track record in drawing farmer practice and technical expertise together, and the proceedings of these workshops have been very useful in documenting the developing practice of farming saltland. The PURSL Group has the potential to evolve into an organisation with a national farmer membership extending information on saltland pastures (and other issues of relevance to the productive use of saltland) throughout Australia.

1.2.3 The Land, Water & Wool Sustainable Grazing on Saline Lands initiative

The evidence seems to show that there are very few farmer groups focused primarily on saltland pastures. However, the Land, Water & Wool Sustainable Grazing on Saline Lands (LWW SGSL) initiative should stimulate further farmer adoption and development of saltland pastures by engaging with a wide range of more general farmer groups.⁷ The Producer Network component of the LWW SGSL initiative aims to:

- facilitate and support a network of producers with salinised land
- share and build on local knowledge and experience
- set local priorities for action
- develop and test practical solutions
- support farm practice change
- provide linkages with and direction to any relevant research projects.

LWW SGSL Producer network activities are now occurring in all southern States and about 120 general farmer groups are being engaged in the process. This stimulus will almost certainly result in a further flowering of saltland pasture uptake and innovation.

Salty? - by Michael Lloyd⁴

*We look across the barren soil,
And think of years gone by.
How once the land seemed so secure,
We'd never wondered why.
Why had our farmland turned to salt?
Production dropped away.
With crops and pastures almost gone,
Is it the end today?
But yesterday, with axe and fire,
They'd cleared the rolling plains.
Their crops and sheep had grown well.
They marveled nature's gains,
For many years they harvested
Their rich and golden crops.
Their wool and meat was world-renowned.
Enthusiasm tops.
They'd cleared more land; they'd surged ahead
Relentless in their haste
To kill the trees and plant the crops.
Never mind the waste.
And on it went, for years and years,
A never-ending spree.
'Til all at once, (or so it seemed),
We hardly had a tree.
And slowly, oh so slowly,
We'd seen the salt appear.
At first it only seemed so slight.
"Don't worry, never fear."
But ever oh so gradually
It started taking hold.
'Til now we see the valley floor
Looking white and cold.
What do we do? Where do we go?
Do we leave it bare?
Or do we stay and fight the curse?
Do any really care?
Researchers shake their heads and say:
"There isn't any gain."
The banks just frown and look away:
"It's money down the drain!"*

*But we have seen the increased wool
From sheep on saltbush land.
Why is it that our very eyes
Defy researchers stand?
We look at saltbush pastures green
And notice something new.
From underneath the saltbush now
Grass and clover grew.
The saltbush uses moisture up
And lowers saline water.
Then clover, grass, abundant feed,
Spring forth from every quarter.
A partnership is born between
The saltbush and the feed.
Support from banks, researchers, too,
Is something we all need.
We look at wool; its glow grows dim,
But other things rise up.
Meat sheep, prime lambs, beef and goats,
May fill the farmers' cup.
But pasture isn't all we have.
Saltland will yield much more.
Brushwood, timber, seed and oil.
New industries galore.
So saltland isn't such a curse.
It's nature's way of saying
We haven't really farmed it right,
And now we all are paying.
We need more trees, we need more shrubs
To lower watertables.
We have to turn the tide around
To make the country stable.
But what of saltland, is it done?
And do we have to move?
No, we need just half a chance
To show what we can prove.
Then do we rest, sit back and smile,
And bask upon the shore?
No, my friends, continue on.
ONE MILLION HECTARES MORE!*

Further reading and notes

- 1 The complete report is available as Powell *et al.*, (2002).
- 2 See Lloyd (1996, 1998 and 2001) and Ghauri and Westrup (2000).
- 3 Lloyd was a member of the Salinity Taskforce established to review salinity management in WA in 2001 (Frost *et al.*, 2001). He was also Chairman of the Animal Production from Saline Land Systems initiative, which was incorporated in 2002 into the CRC for Plant-based Management of Dryland Salinity.
- 4 First delivered to the Landcare Conference at Esperance WA in 1999.
- 5 Saltland Solutions Inc. (SSI) is an association that aims to encourage thoughtful research, and productive, open-minded development of all aspects of saline agriculture. It evolved from a decade of like-minded and innovative farmers interacting with agronomists and hydrologists in the Upper South East of South Australia. It is now a highly influential group of activists developing and promoting saltland management practices in the widest sense on a regional, state and national scale. The major on-ground success of the group has been the establishment of an annual grazing system for saline land in which puccinellia is the key component.

The group has cooperated extensively with Primary Industries South Australia over more than ten years, and has cooperatively published a number of pamphlets on saltland management, including *Puccinellia*, *Perennial Sweet Grass* (Herrmann and Booth, 1996).

The group provided strong input into the South Australian Dryland Salinity Strategy (2001), and SSI members sit on the South Australian Dryland Salinity Committee and Technical Advisory Group that oversee implementation of the Strategy.

One SSI member has been Project Officer for the nationally recognised Coorong District Local Action Plan (LAP) since 1995. On-ground works addressing the area's environmental issues, particularly dryland salinity, have been carried out on a large scale with 69,000 ha of works completed in six years.

SSI members have been consistent contributors and presenters at PURSL and NDSP Conferences throughout Australia, and have addressed Saltland Pastures Association meetings in WA. Members' properties continue to be featured in numerous tours and field days, highlighting practical results.

The Saltland Pastures Association was formed in WA in 1997 partly as a response to the negative publicity generated by the animal nutrition studies of the early 1990s that suggested that saltbush was of limited nutritive value. With about 80 members, it is now WA's leading farmer group dedicated to the revegetation of saline land. The SPA publishes an occasional newsletter. It had a major advocacy role in getting saltland revegetation back onto the State's agenda – compare the Western Australian Salinity Action Plan (1996) with the Western Australian Salinity Action Plan Draft Update (1998). It has recently developed a business plan to revegetate one million hectares of saltland over the next 10 years (Hardy, 2002).

- 6 PURSL has now conducted eight national workshops since its formation in 1990. The proceedings are as follows:

Myers, B.A. and West, D.W. (1990)

Herrmann, T.N. (1992)

Schulz, M.A. and Petterson, G. (1994)

Anon. (1996)

Marcar, N.E. and Hossain, A.K.M.A. (1999)

Anon. (1999)

Grose, C., Bond, L. and Pinkard, T. (2001)

Anon. (2002).

- 7 The Land, Water & Wool Sustainable Grazing on Saline Lands Sub-program is an initiative between Australian Wool Innovation Limited and Land and Water Australia. Meat and Livestock Australia, the CRC for Plant-based Management of Dryland Salinity and the National Dryland Salinity Program support LWW SGSL.

The web page of Land & Water Australia is at: www.lwa.gov.au/downloads/PF020221.pdf

The web page of the National Dryland Salinity Program is at:

www.ndsp.gov.au/10_NDSP_projects/05_project_descriptions/10_industries/project_90.htm



Chapter 2



Salinity and options for saltland in Australia

There is great momentum in the hydrological forces causing Australia's salinity – we are going to have to implement strategies for living with salinity.



In this Chapter

Secondary salinity – causes and extent

Saltland pastures

Saltland pastures and other options
for productive use and rehabilitation
of saline land

Key points

- *Saltland is capable of supporting a range of productive options – saltland pastures are one of these.*
- *Engineering options can be integral to saltland management systems.*
- *Research into integrated saltland farming systems is needed.*

2.1 Secondary salinity – causes and extent

Land affected by salinity falls into two categories:

- Primary salinity (land that is naturally saline)
- Secondary salinity (land that has become saline due to the activities of man).

Australia has about 32 million hectares of salt-affected land¹, most of which is subject to primary salinity, mainly in rangeland areas and of low productive potential.

Secondary salinity usually affects higher value agricultural or irrigated land.

For land to become affected by secondary salinity, a source of salt stored in the soil and a hydrological disturbance that mobilises the stored salts and transports them to the surface are required.

- *Salt stores.* Most of the salt stored in Australia's ancient soil profiles originates as air-borne saline dust blown inland from the sea and dissolved in rain.² Drill cores taken from the deep soil profiles of the Belka Valley, Merredin, WA, show these soils contain an average of 650 tonnes of salt per hectare.³ Since the rainfall here contains about 5.8 milligrams of salt per litre and the annual rainfall is about 340 millimetres, these salts have accumulated over only 33,000 years.⁴ This is a comparatively short period in an environment in which soil formation has been occurring for millions of years.⁵

- *Hydrological disturbance.* This arises with the introduction of irrigation or removal of native vegetation and replacement by annual crops and pastures. In the original landscape, the native vegetation systems used all the rainfall. However, irrigation or the replacement of perennials with annuals has increased percolation into deeper aquifers⁶, causing a rise in watertables, mobilisation of stored salt in the soil and, where watertables rise to within one to two metres of the soil surface, a loss in growth of crops and pastures.

Australia now has at least 5.7 million hectares of land at high risk of secondary salinity, and 17 million hectares are estimated to be at high risk of secondary salinity by the Year 2050 (Table 2.1). The most visible effects of secondary salinity are the death of vegetation, soil erosion, increases in stream, lake and river salinity, and damage to infrastructure (Photo 2.1).

Table 2.1 Area (millions of hectares) at high risk of secondary salinity in Australia now and in 50 years time.⁷

State	1998 – 2000	2050
Western Australia	4.36	8.80
Victoria	0.67	3.11
South Australia	0.39	0.60
New South Wales	0.18	1.30
Queensland		3.10
Tasmania	0.05	0.09
Total	5.66	17.00

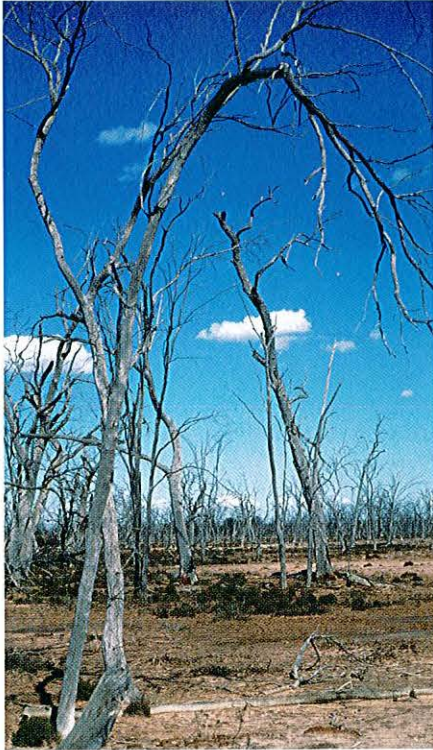


Photo 2.1 (a)

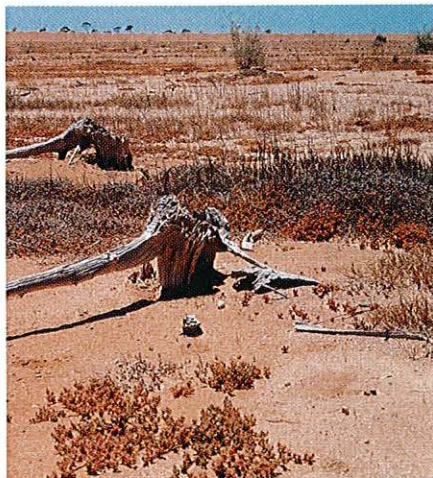


Photo 2.1 (b)

Photo 2.1. Effects of secondary salinity.
 (a) death of vegetation,
 (b) soil erosion,
 (c) increased salinity in water-bodies,
 (d) damage to farm infrastructure.

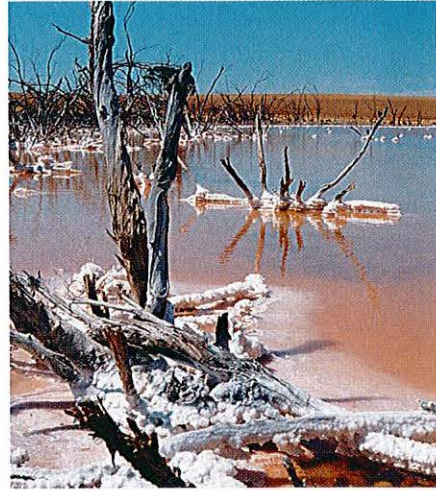


Photo 2.1 (c)



Photo 2.1 (d)

It is becoming increasingly clear there is great momentum in the hydrological forces causing Australia's salinity, and the technical challenge of preventing salinity is greater than previously recognised. Also, the perennial-based agricultural systems required to decrease groundwater recharge are not sufficiently economically attractive to ensure their adoption *on the required scale*. Australia is therefore going to need to implement strategies for living with salinity.⁸



Photo 2.2 Naturally regenerated saltland pasture.
(Photograph: Laurie Benson)

2.2 Saltland pastures

Saltland pastures are associations of salt- and waterlogging-tolerant plants that produce fodder for grazing animals from saline and waterlogged soils (Photos 2.2, 2.3 and 2.4). Useful plants include salt tolerant fodder shrubs, perennial grasses and some annual species which form an understorey. The plant components of saltland pastures are described in more detail in Chapter 4. The growth of these plants can improve the productivity of saltland sites through the use of shallow groundwater and the mulching of the soil surface.



Photo 2.3 Sown mixtures of salt tolerant fodder shrubs and annual under-storey.



Photo 2.4 Sheep grazing Tall wheat grass with annual grasses and balansa clover.
(Photograph: Sara Robinson)

2.3 Saltland pastures and other options for productive use and rehabilitation of saline land

Saltland pastures are one of many means of obtaining productive use and rehabilitation of saline land (PURSL). The National Dryland Salinity Program's OPUS (Options for Productive Use of Saltland) project has identified 12 possible uses for saltland (Table 2.2). Most of these are niche industries that will operate on a relatively small scale. Only the grazing (saltland pasture) options have the existing markets and infrastructure that can enable them to operate on the large scale.

Future users of saline landscapes will most likely implement combinations of landuse options. Figure 2.1 shows several ways in which different PURSL options could be integrated to create different landscape outcomes and industries.

The critical points about these options are:

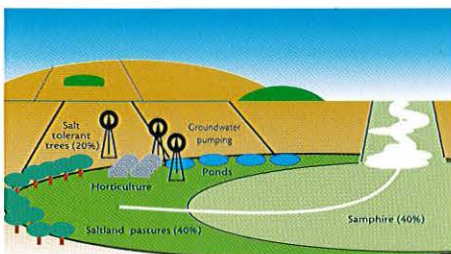
- Saltland is capable of supporting a range of productive options – saltland pastures are one of these. The locations of the different options will depend on saltland capability. This issue is discussed further in Chapter 3.
- Engineering options, such as bedding systems and groundwater pumping, can be integral to saltland management systems.
- There are almost no data on how different saltland industries complement each other to create new saline agricultural farming systems. Research into integrated saltland farming systems is needed to monitor the achievements of innovative famers.

Table 2.2

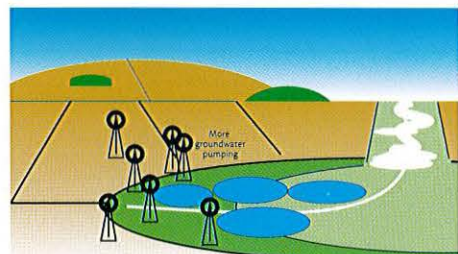
Twelve possible uses for saltland identified by the National Dryland Salinity Program's OPUS project.⁹

Industry	Opportunity
Agriculture	Grazing of sheep and cattle on: Saltbushes (and other salt tolerant fodder shrubs) Salt tolerant grasses (e.g. puccinellia, Tall wheat grass, distichlis) and legumes (e.g. balansa clover, melilotus)
Forestry and horticulture	Production of pulpwood from salt tolerant eucalypt hardwoods. Production of dates from date palms
Fauna and algae	Production of finfish (especially black bream and Murray cod) Production of brine shrimp and cysts in saline ponds Growth of seaweed as a food, for the extraction of thickening agents, the production of fertilisers and for biomedical applications Growth of algae for the production of beta-carotene and other products
Minerals	Harvesting of salt for the chemical and food industries and a range of other applications Extraction of other mineral products
Energy and water	Collection and storage of energy in solar ponds Production of potable water through desalination technologies.

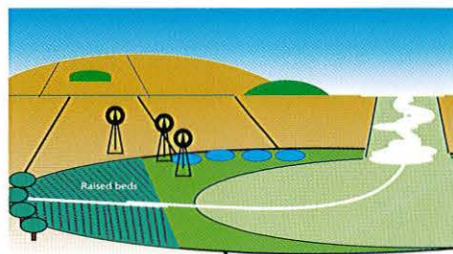
Figure 2.1 Alternative PURSL scenarios for saltland.



A mixture of samphire, saltland pastures, trees, horticulture¹⁰ and ponds.



More groundwater pumping decreases area of saltland.



Similar with cropping on raised beds.

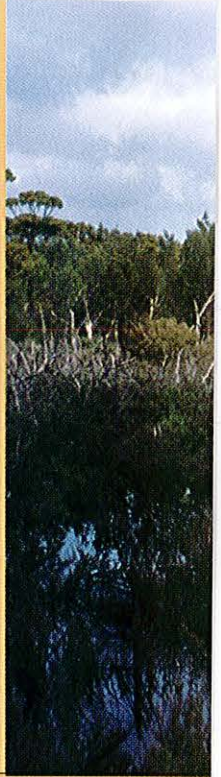
Further reading and notes

- 1 Standing Committee on Soil Conservation (1982).
- 2 The concentration of salt in rainfall decreases with increasing distance from the coast. In Western Australia, Hingston and Gailitis (1975) showed that large quantities of chloride (>100 kilograms per hectare) are precipitated annually at coastal centres in the south-west of the state. This annual amount decreases to about 50 kilograms per hectare approximately 30 kilometres inland, and to 30–40 kilograms per hectare at approximately 200 kilometres inland.
- 3 Bettenay *et al.* (1964).
- 4 Barrett-Lennard and Nulsen (1989).
- 5 Indeed, given that soil formation has been going on in this area for millions of years, we might ask why there is not more salt stored in the soil profiles? Apparently, 30,000–50,000 years ago the climate of WA was far wetter than it is today (Bowler, 1976). At this time most of the salt that had been stored in these profiles was leached out and washed to the sea in the river system. Modern investigators only observe the salt that has accumulated since this leaching ceased.
- 6 Various estimated at 6–12% of rainfall (Peck and Williamson, 1987) or 15–50 mm/year (National Land and Water Resources Audit, 2001).
- 7 Values are from the National Land and Water Resources Audit (2001).
- 8 Pannell (2001).
- 9 National Dryland Salinity Program (2001).
- 10 This scenario envisages growth of salt tolerant horticultural species in glasshouses. Growth of salt tolerant tomatoes is a possible glasshouse enterprise (Rush and Epstein, 1981a,b).



Chapter 3

Factors affecting plant growth on saltland



Ecological zonation on saltland arises primarily because of the interacting effects of salinity, waterlogging, inundation and soil texture.



In this Chapter

Soil salinity

- Measurement of salinity
- Effects on plants
- Causes of salinity effects on plants

Waterlogging

- Measurement of waterlogging
- Effects on plants – causes and consequences

Inundation

Groundwater use and salt accumulation in the root zone

Soil texture

Implications for land capability

Key points

- *Not all saltland is suited to the growth of saltland pastures. To maximise productive potential and reduce failures, revegetation needs to be targeted to the appropriate zones in the landscape.*
- *The major factors affecting ecological zonation in saltland are salinity, waterlogging, inundation and soil texture.*

Not all saltland is equally productive. Saltland plants occur in a range of zones of differing productivity created by variations in the environment (see Photo 3.1a-e).

Ecological zonation on saltland arises primarily because of the interacting effects of salinity, waterlogging, inundation and soil texture. These factors also affect the capability of land for saline agriculture.¹

It needs to be stressed that waterlogging and inundation are different stresses although they may occur in close proximity to each other (Photo 3.2).

This chapter discusses the measurement of these factors and their effects on plant growth, and concludes with a discussion on the capability of land for the growth of saltland pastures.

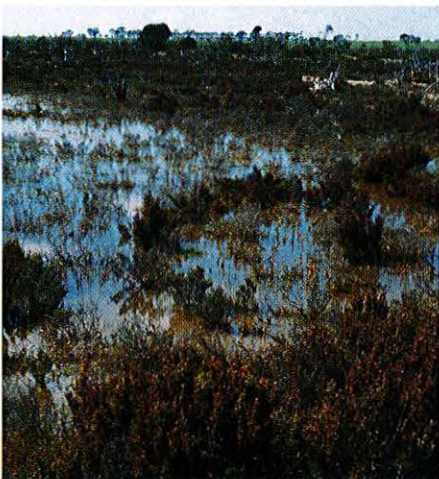


Photo 3.1 (a)



Photo 3.1 (b)



Photo 3.1 (c)



Photo 3.1 (d)



Photo 3.1 (e)

Photo 3.1. Ecological zonation of plants in saltland landscapes. (a) Samphires typically occupy the lowest parts of the landscape, (b) saltbushes (left hand side) occur slightly higher in the landscape than samphire (centre), and (c) small leaf bluebush occurs higher again. With perennial grasses, (d) puccinellia occurs in the more saline/waterlogged parts of the landscape (*Photograph: Steve Vlahos*), whereas (e) Tall wheat grass is found in less severely affected areas.

Photo 3.2. Waterlogging is suggested by the yellowing of: (a) crop, and (b) pasture. Inundation refers to water pooled on the soil surface.



Photo 3.2 (a)

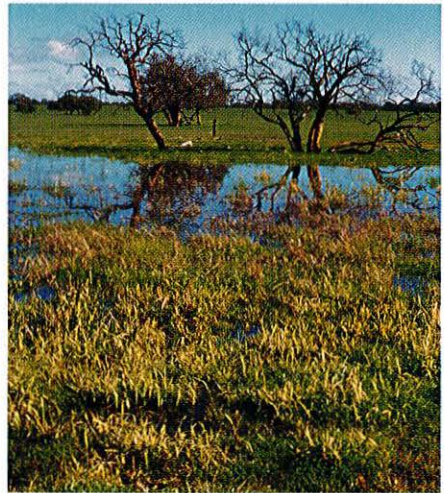


Photo 3.2 (b)

3.1 Soil salinity

Key point

• *Plants can be broadly divided into two groups based on their responses to salinity. Halophytes have a range of physiological mechanisms that allow them to grow in saline soils. Non-halophytes are more sensitive to salinity.*

3.1.1 Measurement of salinity

Soil salinity affects the growth of plants because of high concentrations of dissolved sodium and chloride ions in the soil. Saline soils may also contain significant concentrations of magnesium, sulphate, carbonate, bicarbonate and boron.

The salinity of the soil solution depends on:

- the ratio of salt to water in the soil. Even without a change in the amount of salt in the soil, roots can be exposed to increasing salinity in the soil solution as the soil becomes drier (Figure 3.1).
- the action of roots in concentrating salt. When plants are grown in saline soils, salt can accumulate near the root surface because the plants take up water faster than they take up salt (Figure 3.2).²

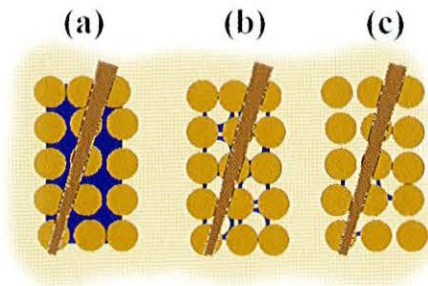


Figure 3.1 A root experiences a range of salinities in the soil solution as the salt becomes concentrated into successively (a – c) smaller amounts of water.

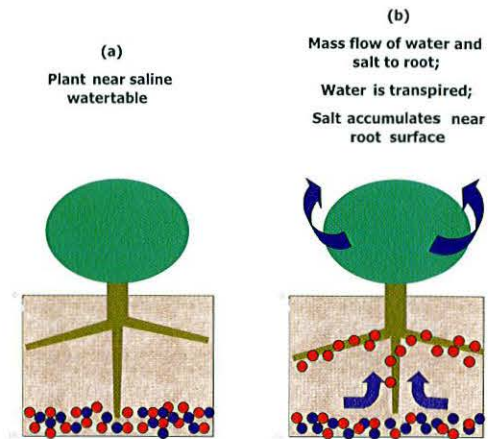


Figure 3.2 Roots concentrate the salt at the root surface because they take up water faster than salt.

The salinity of soils is measured by sampling the soil, drying the sample, extracting it in water and measuring the amount of dissolved salt in the extract.

Concentrations of salt constituent ions (such as sodium and chloride) can be measured in the laboratory using analytical apparatus such as the flame photometer, the chloridometer and the atomic absorption spectrophotometer. However, these techniques are rarely used in salinity research as the equipment required is costly and not suited to field use. In addition, samples may need to be taken through a range of dilution steps before they fall into the measuring range of the machines.

The most common way of assessing the salinity of a soil extract is to measure its electrical conductivity (EC). Salt solutions are conductive because of the electrical charges on the sodium, chloride and other ions. The measuring equipment is conceptually simple (Figure 3.3) and, in some cases, can be used in the field.

For most practical purposes, the conductivity of soil extracts is proportional to the salt concentration. Electrical conductivities of soil extracts are most commonly reported in decisiemens per metre (abbreviated dS/m). These units can be converted to other units using the conversion factors in Table 3.1.

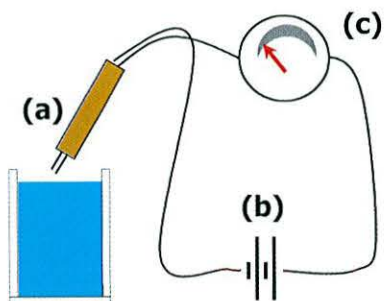


Figure 3.3 The essential components of an electrical conductivity meter are (a) a pair of electrodes which are lowered into the extract, (b) a power source, and (c) a meter to measure the electrical current running through the solution.

There are three common methods for making a soil extract.

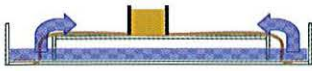
1. *The saturation extract – filter paper method.* A dried and ground sample of soil is placed in a ring over a filter paper kept moist with a shallow water bath (Figure 3.4). Overnight, the soil becomes saturated as water rises by capillary action. Once saturated, the ring of soil is transferred with a spatula to a filter funnel, where the water (containing the dissolved salts) is extracted by suction. The electrical conductivity of this extract is termed the EC_e . It has a similar salinity to that which a plant would experience in a saturated soil.

2. *The saturation extract – soil paste method.* A saturated soil paste is made by adding pure water to a ground sample of soil while stirring with a spatula. At saturation, the soil paste glistens as it reflects light, flows slightly when the container is tipped, and the paste slides freely and cleanly off the spatula for all soils but those with a high clay content. The extract is filtered from the soil as for the saturation extract. The electrical conductivity of this extract is termed the EC_s .
3. *The 1:5 soil water suspension.* 100 grams of ground soil are added to 500 millilitres of water and the slurry is shaken. After an hour or so, the extract is allowed to settle and the electrical conductivity of the unfiltered suspension (termed the $EC_{1:5}$) can be determined. This measurement has the disadvantage that it differs substantially from that in the soil solution. Notwithstanding this, the measurement is widely used because the technique is easy, and simple tables have been developed to derive approximate values for EC_e from $EC_{1:5}$.⁶

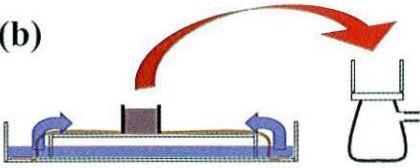
Table 3.1 Conversion factors for salinity units.

To convert:	To:	Multiply by
Parts per million (or milligrams per litre)		0.0017 ³
Grains per gallon		0.026
Microsiemens per centimetre ($\mu S/cm$)	Decisiemens per metre	0.001
Millisiemens per metre (mS/m)		0.01
Millimoles per litre (mM)		0.1 ⁴
Percent of seawater		0.55 ⁵

(a)



(b)



(c)

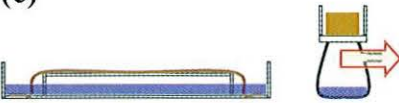


Figure 3.4 Method for preparation of the soil saturation extract (filter paper method), (a) a ring of soil is placed on a filter paper wetted with a shallow water bath, (b) once saturated the soil is placed on a filter funnel, (c) the water (extract) is removed under suction.

Soil salinity is often highly variable horizontally, across the surface of the soil, and vertically down the soil profile. This variation can be related to the presence of bare soil or patches of grass (Figure 3.5). Where the soil is bare, high levels of surface evaporation and movement of water from shallow watertables towards the soil surface create zones of high soil salinity. Where the soil is covered with grass, surface evaporation is reduced and improved infiltration and leaching reduce salinity levels.

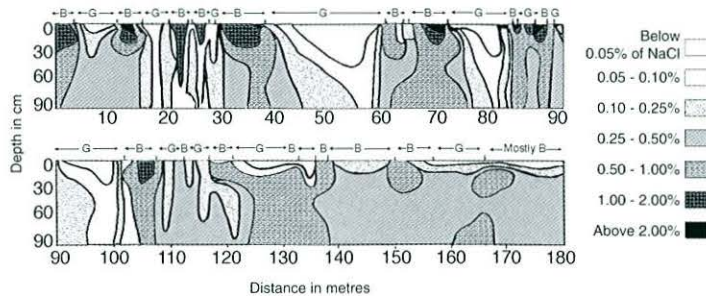
The high level of variation found in saline soils raises important issues regarding soil sampling, such as: how do we obtain representative soil samples in the face of such variation?

In general, the appropriate way to take a soil sample will depend on the objective of the sampling. Principles to be considered include:

1. *Timing.* Soils should be sampled for salinity at times when the analysis enables useful predictions to be made about the likely effects of salinity on plant survival and growth. For example, sampling at the end of summer would be of little value in predicting the value of a site for the growth of annual plants.
2. *Use of composite samples.* Laboratory analyses for salinity are typically laborious and expensive to perform, so it is important to use sampling procedures that ensure the soil samples are representative of the selected area. This is done through the process of composite sampling, i.e. the bulking together of many individual samples to make one representative sample.
3. *Depth of sampling.* Salinity changes with soil depth. It is useful to measure these changes to determine the suitability of the soil profile subsoil to the growth of different plants. In these circumstances, the depth and interval of soil sampling will depend on the rooting pattern of the plant to be grown. For shallow-rooted annual species, sufficient information may be gathered by taking samples at 15 centimetre intervals to a depth of 30 centimetres. However, for deeper-rooted shrubs and trees, sampling may be

Figure 3.5 Variation in the distribution of salt in a typical saline soil.⁷

B = Bare
G = Grass



Avon location 14820 - Wellbungin
April 20, 1932
The distribution of salt in a cleared portion of Campion calcareous loam (morret soil) at Wellbungin which has become affected by salt accumulation in patches.

required at 30–50 centimetre intervals to depths of 1.5–2 metres. Again, there may be value in establishing composite samples. For example, samples from a number of individual holes at depth of 0–15 centimetres could be pooled into one composite; samples from the same holes at depth 15–30 centimetres could be pooled into another, etc.

4. *Salt crusts.* Salt crusts should not be bulked into composite soil samples. If a salt crust is visible at the soil surface, it should be lightly scraped off or sampled separately if required.
5. *Reducing the size of soil samples.* If composite samples have been prepared from a large number of individual samples, they may contain many kilograms of soil. Under these circumstances, each composite sample should be thoroughly mixed and a sub-sample of this (about one kilogram) taken for analysis.

Another method for cheaply measuring soil salinity in the field is to use the EM38 (Photo 3.3). The EM38 provides an immediate reading of the apparent electrical conductivity (termed the EC_a) of the soil. It enables the operator to interact with the readings on-site, e.g. "It's too saline here – let's look over there..."



Photo 3.3 Measuring soil salinity with the EM38 (Photograph: Sue Wilkins).

The EM38 has two modes enabling salinities to be estimated to depths of about 100 centimetres (vertical mode – readings abbreviated as EC_{av}) and about 40 centimetres (horizontal mode – readings abbreviated as EC_{ah}) (Figure 3.6).

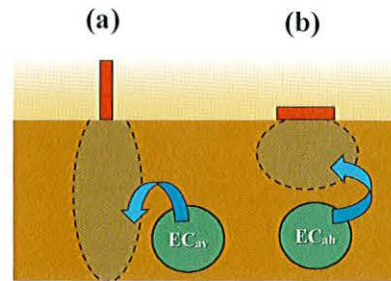


Figure 3.6 Vertical (a) and horizontal (b) modes of the EM38.

The major disadvantages of the EM38 are that the bulk conductivity of the soil is affected by two other factors besides salinity – the presence of clay and soil moisture. Calibration curves are required when using EC_a readings to estimate EC_e or $EC_{1.5}$ readings.

3.1.2 Effects on plants

Plant responses to salinity are well understood.⁸ Figure 3.7 shows plants can be broadly divided into three groups according to their growth responses to salinity:

- *Halophytes (salt plants).* Halophytes actually have increased growth at low salt concentrations, with decreased growth at much higher concentrations. River saltbush (*Atriplex amnicola*) is typical: there is a 10% increase in shoot dry weight at 5 dS/m (a salt concentration equivalent to 10% of seawater). It has a 50% decrease in growth at 40 dS/m (a salt concentration equivalent to 70% of seawater) and is still alive at 75 dS/m (a salt concentration equivalent to 140% of seawater). Other plants in this group include other saltbushes, samphire, puccinellia and distichlis.⁹

- *Salt tolerant non-halophytes.* These plants maintain growth at low salt concentrations, but have decreased growth at higher concentrations. Barley is typical: it has a 50% reduction in shoot growth at 13 dS/m (a salt concentration equivalent to about 20% of seawater). Other plants with 50% decreases in yield at salt concentrations equivalent to 20–30% of seawater include wheat, cotton and sugarbeet.¹⁰
- *Salt sensitive non-halophytes.* The growth of these plants is sensitive to even low concentrations of salt. Beans (*Phaseolus vulgaris*) are typical: they have a 50% decrease in growth at salt concentrations of 5 dS/m (a concentration equivalent to about 9% of seawater). Other plants with 50% decreases in yield at salt concentrations equivalent to 7–9% of seawater include carrots, grapefruit and peaches.¹⁰

The 1950s through to the 1970s were fruitful for investigations of salt tolerance in the USA. Led by scientists at the US Salinity Laboratory at Riverside in California, attempts were made to determine the salt tolerance of most of America's major crop plants. In many experiments, the crops were grown in deep columns of sand irrigated frequently with saline nutrient solutions. In this way the researchers were able to precisely define the salt concentrations around plant roots.

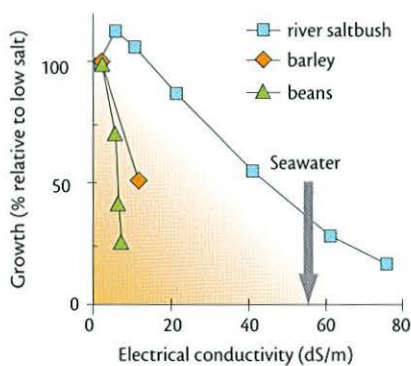


Figure 3.7 Growth response of three plant species to salinity.¹¹ Barley and beans are typical non-halophytes. River saltbush is a typical halophyte.

The results were summarised by Maas and Hoffman in 1977.¹² They suggested the growth response of a plant species to increasing salinity could be summarised in terms of a bent stick growth curve (Figure 3.8) defined by:

- A threshold salinity, up to which there is no effect of salinity on growth,
- A slope that defines the percentage decrease in yield per unit increase in salinity above the threshold.

Based on their yield response curves, plant species were categorised by Maas and Hoffman as being 'sensitive', 'moderately sensitive', 'moderately tolerant' or 'tolerant' to salinity. Figure 3.8 shows the estimated relationship between yield and salinity for barley (threshold salinity 8 dS/m; slope of 5% per dS/m in excess of threshold) which falls into Maas and Hoffman's tolerant category (threshold salinity 8 dS/m; slope of 5% per dS/m in excess of threshold). The salt tolerance of most common crop and fruit tree species has now been assessed in terms of these parameters.

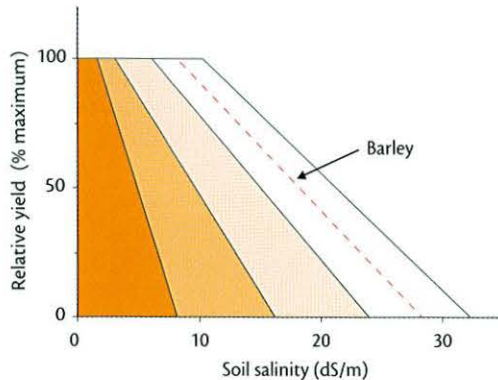


Figure 3.8 Response of the relative yield of barley to increasing soil salinity.¹³

Typical plant responses to salinity are categorised as

- sensitive,
- moderately sensitive,
- moderately tolerant or
- tolerant.

The line for barley lies in the tolerant area.

How high are the salt concentrations in affected soils? Figure 3.9 shows the relative frequency of salt concentrations in composite samples from 17 sites in Western Australia. In this survey, half the soils had salt concentrations greater than 40 dS/m (about 80% of seawater), and some soils had concentrations more than 100 dS/m (about double the concentration of seawater).

Comparisons of these concentrations with the salt tolerances of river saltbush, barley and beans (Figure 3.7) show that barley and beans would probably not have grown on any of the sampled soils. In contrast, river saltbush would have grown well on half of the sampled soils, and would have survived on most of the soils.

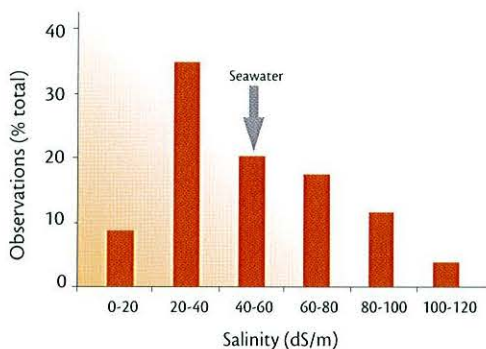


Figure 3.9 Frequency distribution of the salt concentrations (soil water basis) in 17 saline WA soils.¹⁴

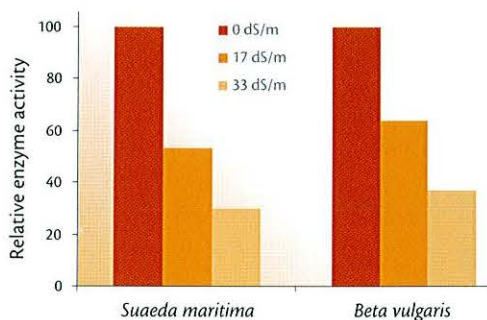


Figure 3.10 Effects in two halophytes of increasing salinity on the activity of a typical metabolic reaction (the activity of the enzyme malic dehydrogenase).¹⁶

3.1.3 Causes of salinity effects on plants

Salinity has two effects on plant cells:

- *Osmotic effect.* This refers to the damage caused by the water within cells being pulled out of the cell (across the cell membrane) into the more saline soil environment. This results in a loss of hydrostatic pressure (turgor) within the cells and can result in the outer membranes of the cells falling away from the cell walls, a process called 'plasmolysis'.¹⁵
- *Specific ion effect.* This refers to plant metabolic processes running slower in the presence of salt. This can be demonstrated by extracting plant enzymes and examining how well they work in the presence of salt in the test-tube. A typical example (malic dehydrogenase) is given in Figure 3.10 in which enzymes were extracted from two halophytes (*Suaeda maritima* and *Beta vulgaris*). There were 40–50% decreases in enzyme activity with a salinity of 17 dS/m (equivalent to 30% of seawater), and 60–70% decreases in enzyme activity with salinity of 33 dS/m (equivalent to 60% of seawater).

Plants have three major mechanisms for handling salt:

- *Exclude it at the root surface.* For most plants, concentrations of chloride in the xylem are less than 5% of the concentrations externally.¹⁷ The roots of these plants filter more than 95% of the salt from the water taken up. This sieving of salt from the soil water is accomplished through a combination of low membrane permeability and active (energy consuming) pumping mechanisms that expel salt from the root.
- *Move it to the vacuoles.* Here the strategy is to move the salt out of the cytoplasm of cells (where most metabolic processes occur) and locate it in the large vacuoles (where there are few metabolic processes and it can be of advantage in osmotic adjustment).¹⁸
- *Excrete it from leaves.* Salt glands (in halophytic grasses and mangroves) and bladder cells (in saltbushes) are an excellent means for plants to remove salt from the leaf tissues.

Highly salt tolerant plants employ all of these mechanisms.

Movement of salt from roots to shoots – a few principles of root cell and tissue function

Structures at the cellular and tissue levels play key roles in regulating the movement of salt ions from roots to shoots.

At the cellular level (Figure 3.11), we need to distinguish between the cytoplasm (which occupies just 5–10% of cell volume, but is the seat of most metabolic activity) and the vacuole (which occupies 90–95% of the cell volume and has few metabolic functions). These compartments are bounded by the outer cell membrane (the plasma membrane) and the tonoplast (containing the vacuole). The cells are contained within the cell walls, a network of cellulose fibers, which may be strengthened by infill with lignin. Often the cytoplasm of adjacent cells are connected by fine strands called plasmadesmata. Therefore, the cytoplasm of a group of cells can be thought of as a larger multicellular compartment called the symplasm.

At the tissue level, salt ions can move into the root through:

- *The symplastic pathway.* The ions are absorbed by the root hairs and the epidermis, and are transported through the symplasm of the cortical cells to the xylem, where they are transported to the shoots (Figure 3.11).
- *The apoplastic pathway.* The ions move through the extracellular spaces and cell walls of the cortex until they reach the impenetrable (suberised) layer of the endodermis called the casparian strip. At this point, they must move across the plasma membrane to the symplasm to gain access to the xylem (Figure 3.11).

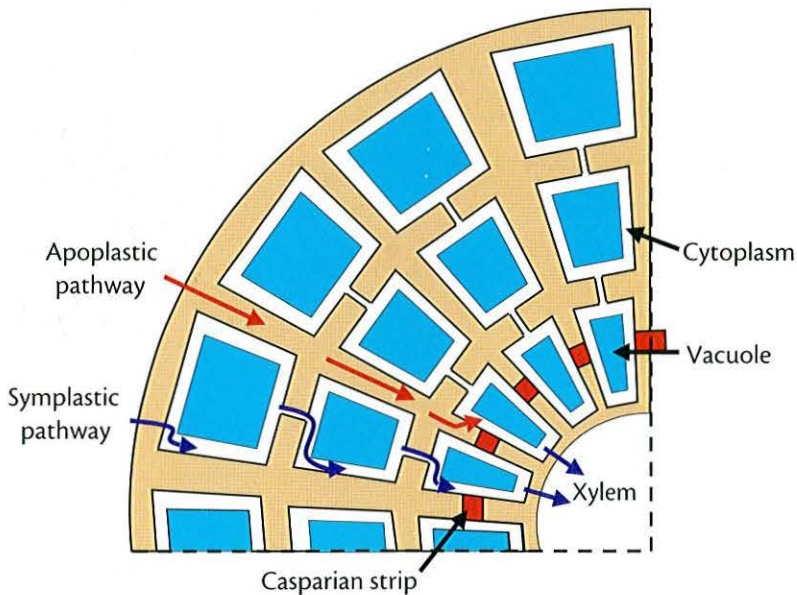


Figure 3.11. Schematic diagram showing means by which salt moves across the root to the xylem.

3.2 Waterlogging

Key points

- *Waterlogging can be a major problem on saline soils. It causes roots to become permeable to salt, which increases salt uptake to the shoots, resulting eventually in leaf and plant death.*
- *Waterlogging also causes nutrient deficiencies in plants.*
- *Plants growing on saltland need to have tolerance to salinity and waterlogging.*

3.2.1 Measurement of waterlogging

Much of Australia's saltland is also subject to waterlogging (soil saturation) because of the presence of shallow watertables. Waterlogging has been called the hidden constraint¹⁹ and its extent is substantially under-estimated, since it is often not visible at the soil surface and can be ephemeral (Photo 3.4).



Photo 3.4 Waterlogging is usually not visible at the soil surface unless a hole is dug.

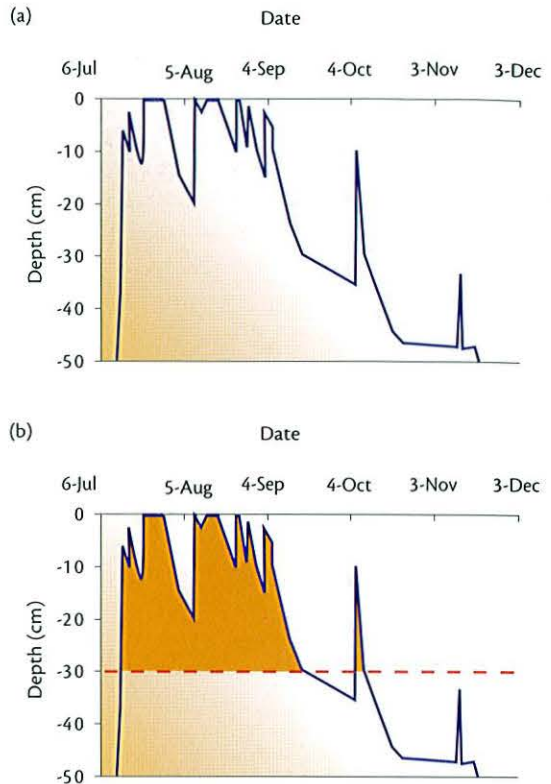


Figure 3.12 The measurement of waterlogging: (a) A typical hydrograph,²¹ (b) SEW₃₀ (shaded area) for these data.

The most common way to measure waterlogging is to observe changes in the depth of the shallow watertable over time. Observations can be used to develop a hydrograph (e.g. Figure 3.12a). In our experience, watertables should be measured about twice a week to generate a reasonably accurate hydrograph.

For many crop species, waterlogging only becomes damaging when average watertables are less than 30 cm for periods of four to six weeks (e.g. Figure 3.13). The SEW₃₀ index (sum of excess water greater than 30 cm) can be used to describe the intensity of waterlogging in the field. This index is calculated knowing the depth of the watertable and its duration at depths less than 30 cm from the soil surface (see Figure 3.12b).

The SEW₃₀ has the units of centimetre days.²⁰

Waterlogging of areas of land can be measured using arrays of shallow wells dug at intervals across the landscape. For example, the extent of waterlogging in the experiment in Figure 3.13 was estimated from rows of shallow wells to depths of about 50 centimetres at five-metre intervals across a waterlogged valley floor (Figure 3.14).

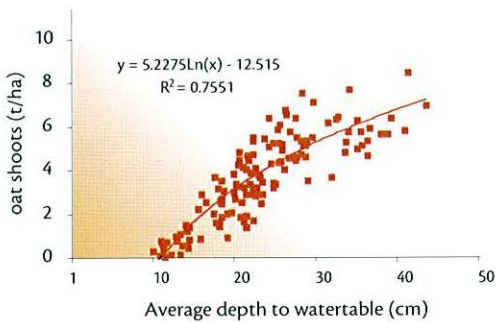


Figure 3.13 Effects of waterlogging on the shoot biomass of oats.²²

3.2.2 Effects on plants

Waterlogging causes oxygen deficiency in soils,²³ because:

- oxygen has a low solubility in water (about 9 parts per million at 20°C)
- oxygen has a lower diffusivity in water filled pores (about 10,000 fold slower than through gas-filled soil pores)²⁴
- dissolved oxygen is rapidly used by bacteria and roots.

Waterlogging can also cause the accumulation of ethylene (a plant hormone) and harmful products of root and bacterial anaerobic metabolism (carbon dioxide, ethanol, lactate, etc).

Roots normally require oxygen for optimal production of adenosine triphosphate, a plant's major energy supply compound. Waterlogged conditions can decrease production of adenosine triphosphate by 95% within a few minutes.

Waterlogging-induced energy deficiencies:

- rapidly decrease plant growth, initially of roots and subsequently of shoots²⁵
- increase the death of roots, beginning with root tips,²⁶ and cause a loss of internal cell constituents²⁷
- decrease all processes associated with active ion transport across membranes, such as the uptake of inorganic nutrients²⁸ and maintenance of electrical potentials on cell membranes²⁹
- decrease stomatal conductance and leaf water potentials.³⁰

In addition to these effects, waterlogging-induced energy deficiencies damage the ability of roots to exclude salt.³¹ As a result, there are increases in salt concentrations in the shoots. Data on effects of waterlogging under saline conditions on sodium and chloride concentrations in shoot tissues are available for 33 species.³² Our data for young wheat plants are typical. Seven days of waterlogging caused 70–100% increases in the concentrations of sodium in the shoots of plants grown with an electrical conductivity in the soil solution of 6–12 dS/m (Figure 3.15).

Not surprisingly, waterlogging under saline

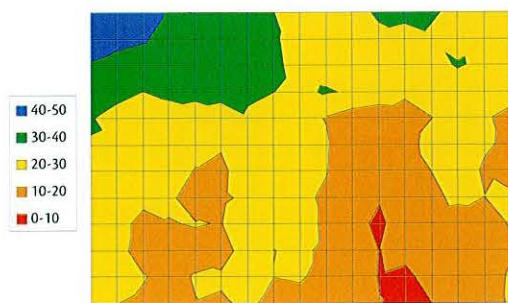


Figure 3.14 A typical map of average depths (cm) of the watertable determined using rows of shallow wells at five-metre intervals across the landscape.

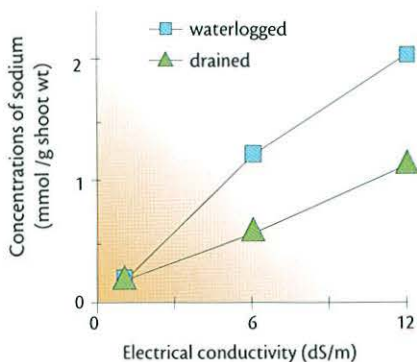


Figure 3.15 Effects of waterlogging on the concentrations of sodium in the shoots of young wheat plants.³³

conditions affects leaf and plant survival. The effects can be illustrated in wheat grown in aerated nutrient solutions (simulating drained soils) or nitrogen bubbled nutrient solutions (simulating waterlogged soils).³⁴

After the first week the roots stop growing; there are increased rates of uptake of sodium and chloride, which result in increased concentrations of sodium and chloride in the older leaves.

After 2 weeks the older leaves of the main culm begin to die.

After 3 weeks, for plants grown in nitrogen bubbled solutions and a salinity of 3 dS/m, the older leaves on the main culm die at least as fast as new leaves are produced.

After 7 weeks, plants in nitrogen bubbled solutions and a salinity of 3 dS/m are largely moribund, do not grow and presumably do not yield grain.

Photographic evidence with wheat in nitrogen bubbled nutrient solutions for 33 days shows that at all salinities greater than 2 dS/m (4% of the salinity of seawater), waterlogging caused extensive leaf damage to plants (Photo 3.5). This damage was not a result of salinity alone, because when plants were grown in aerated nutrient solutions, shoot growth continued even at concentrations as high as 12 dS/m (about 20% of the salinity of seawater – Photo 3.5).

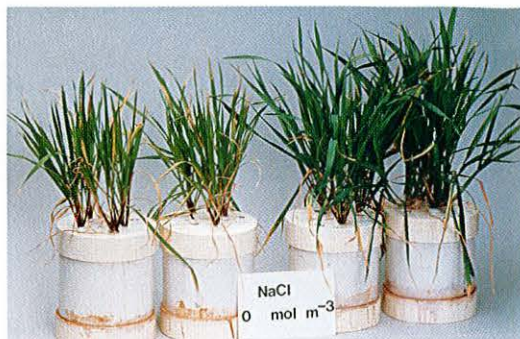


Photo 3.5 (a)

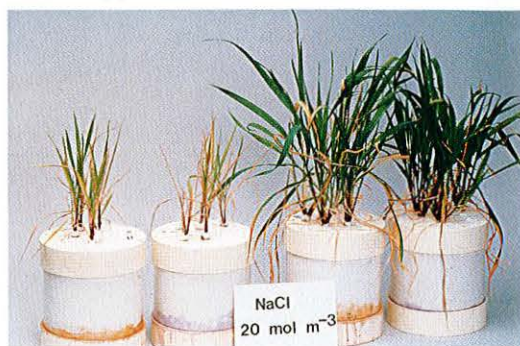


Photo 3.5 (b)

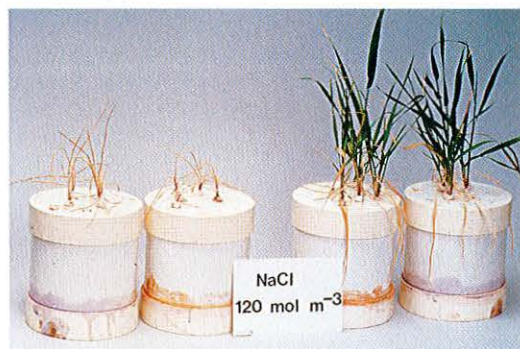


Photo 3.5 (c)

Photo 3.5 Effects of waterlogging on wheat grown with: (a) zero salinity, (b) 2 dS/m (equivalent to 4% seawater), and (c) 12 dS/m (equivalent to 20% seawater – bottom). Plants on the left were grown in nitrogen bubbled nutrient solutions (simulating waterlogged soils) for 33 days. Plants on the right were grown in aerated nutrient solutions (simulating drained soils).³⁵

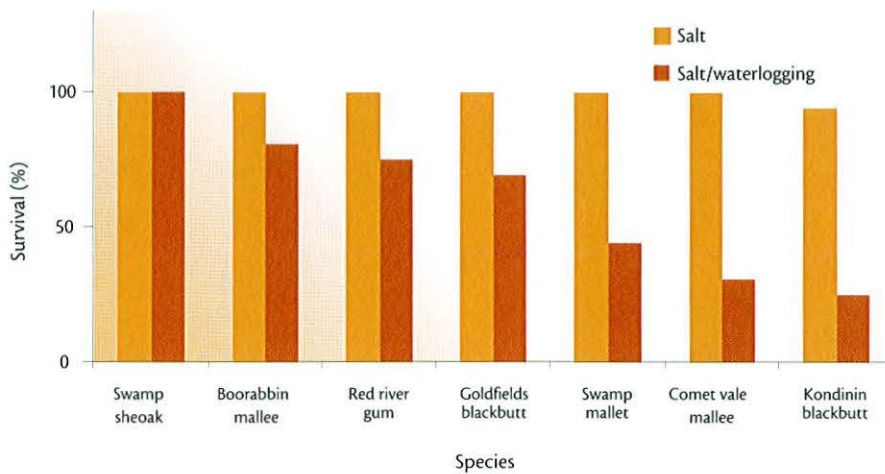


Figure 3.16 Effects of waterlogging under conditions of increasing salinity on the survival of seven Australian tree species.³⁷ The plants were grown in drained ■ or waterlogged ■ sand under conditions of increasing salinity (7 dS/m per week) for six weeks.

The effect of waterlogging and salinity on the survival of Australian tree species has been examined in six experiments.³⁶ Data from one of those experiments is given in Figure 3.16. In this, seven different tree species were grown in drained or waterlogged sand cultures with salinities that increased over six weeks to about 75‰ of the salinity of seawater. While most of the species were able to withstand the salinity under drained conditions, their survival was reduced by

the combination of salinity and waterlogging. The major exception was *Casuarina obesa* (swamp sheoak), which had 100% survival under both saline drained and saline waterlogged conditions.

The experiments examining the survival of Australian tree species to salinity and waterlogging show that many species have poor survival under saline/waterlogged conditions. However, there are some tolerant *Melaleuca*,

Table 3.2 Tree species with high tolerance to conditions of waterlogging and salinity.³⁸

Species	Common name	Species	Common name
Very highly tolerant trees		Highly tolerant trees	
<i>Casuarina glauca</i>	Swamp oak	<i>Eucalyptus intertexta</i>	Gum-barked coolibah
<i>Casuarina obesa</i>	Swamp sheoak	<i>Eucalyptus microtheca</i>	Coolibah
<i>Melaleuca acuminata</i>	Creamy honey myrtle	<i>Eucalyptus occidentalis</i>	Flat-topped yate
<i>Melaleuca eleuterostachya</i>		<i>Eucalyptus raveretiana</i>	Yellow box
<i>Melaleuca glomerata</i>	Inland paperbark	<i>Eucalyptus sargentii</i>	Salt river gum
<i>Melaleuca halmaturorum</i>	Kangaroo Island paperbark	<i>Eucalyptus socialis</i>	Red mallee
<i>Melaleuca lanceolata</i>	Moonah, Rottneat Island tea tree	<i>Eucalyptus striatocalyx</i>	Kopi mallee
<i>Melaleuca lateriflora</i>	Oblong-leaf honey myrtle		
<i>Melaleuca thyoides</i>	Scale-leaf honey myrtle		



Photo 3.6 (a)



Photo 3.6 (b)



Photo 3.6 (c)

Photo 3.6 A few structures to alleviate shallow waterlogging. (a) Bedding systems, (b) a seepage interceptor bank, and (c) a W-drain (Photograph: Simon Eyres).

Casuarina and *Eucalyptus* species (Table 3.2).

The effects on saltland pasture species of waterlogging under saline conditions is discussed further in Chapter 4.

Understanding the interaction between waterlogging and salinity can help inform the debate about design criteria for drainage. The level of drainage required to decrease soil salinity

can be substantial. Depending on soil texture and rainfall the watertable may need to be drawn-down to critical depths of 2–3 m.³⁹ However, studies of the interaction between waterlogging and salinity show that substantial improvements in plant growth can be possible with slight decreases in *waterlogging*. These kinds of changes may be achievable with relatively cheap structures that improve the control of surface water (Photo 3.6). We suggest that saltland pastures be established once waterlogging has been slightly alleviated. Further lowering of the watertable may then be possible through the use of shallow groundwater by these salt tolerant plants (discussed in Chapter 7).

3.3 Inundation

Key point

Inundation is a largely undocumented stress on saltland. Even brief periods of inundation are highly damaging to plant survival and growth.

As salinity in valley floors increases because of shallow watertables, inundation (flooding) becomes more severe (Photo 3.7). In effect, less rainfall is able to seep into the ground and more becomes available for run-off. Modelling suggests peak flows in one WA catchment will double over the next 50 years as the percentage of saltland also doubles.⁴⁰ Similar results can be expected in other catchments in southern Australia.

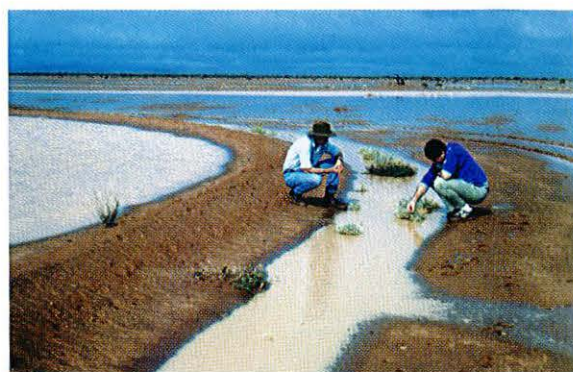


Photo 3.7 Inundation of saltland.

Even brief periods of inundation appear to be highly damaging to plants and the environment. Despite this likely damage (with the exception of rice), there are very few well-documented examples of the effects of inundation on plants. The data in Figure 3.17 suggest one mechanism by which plants avoid inundation – grow quickly so that total immersion in the water is avoided. The data are derived from an experiment with clones of river saltbush grown on the banks of the Kabul River in Pakistan. After the plants were established, the river rose and flooded the site for a few days. The tallest plants (100 cm high or more) had greatest survival (97%); the shortest plants (60 cm or less) had lowest survival (36%).

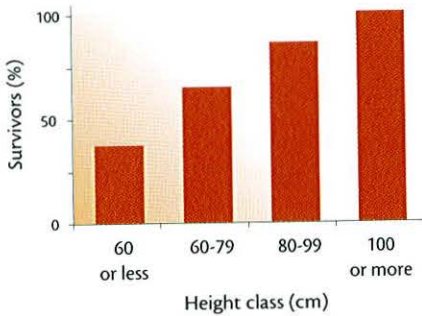
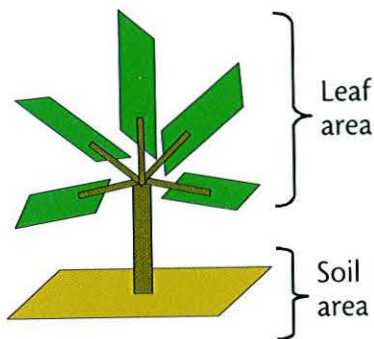


Figure 3.17 Relation between plant height and survival of river saltbush plants after inundation.⁴¹



$$LAI = \frac{\text{Leaf area}}{\text{Soil area}}$$

Figure 3.18 Definition of leaf area index.

3.4 Groundwater use and salt accumulation in the root zone

Key point

One of the means by which plants protect themselves from salinity is to filter salt from water at the root surface. For plants growing above saline watertables, this can lead to an accumulation of salt in the root zone. Over long periods of time (10–20 years), this effect may damage plant growth and affect zonation in the landscape.

Leaf area index (LAI) is the ratio of leaf area in a canopy to the area of the land beneath that canopy (Figure 3.18). The critical principles relating leaf area index and water use by plants are:

1. In natural ecosystems, the LAI of plant communities depends on the ability of the site to provide water to the vegetation. Moist sites develop rainforests with high LAIs; dry sites develop shrublands with low LAIs.⁴²
2. The amount of water used by vegetation is generally proportional to the LAI on that site. All saltland pastures therefore use water to some degree.

Communities of plants on saltland can influence salinity, waterlogging and inundation by using groundwater and lowering watertables. Although some researchers have questioned the long-term sustainability of such plantations, there are now good indications that revegetation with trees can lower watertables on land of low to moderate salinity.⁴³ What remains in question is how long these stands of trees will persist.

One consequence of the use of groundwater by perennial vegetation can be a gradual accumulation of salt in the root zone, an effect that could influence plant zonation on saltland in the longer term.

The failure of trees to thrive in saline locations may be caused by just such an effect.

The following sequence leading to tree death seems plausible based on current knowledge (see Figure 3.19 a–d):

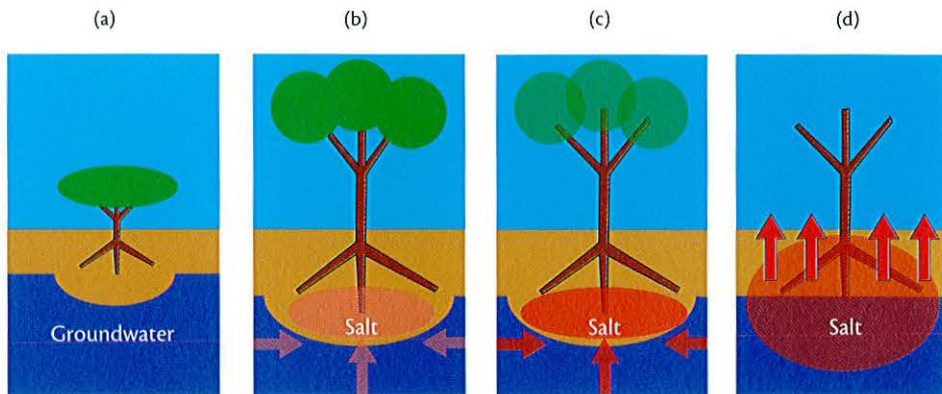


Figure 3.19 Sequence of damage to trees caused by salt accumulation in the root zone (see text).

- 1 Prior to revegetation on sites with shallow watertables, salt accumulates seasonally at the soil surface due to capillarity and the evaporation of groundwater. Amounts of salt in the soil profile reach a steady state when the amount of salt intruding into the soil profile is equalled by the amount of salt leaving the soil surface in the streamflow.
- 2 After revegetation, if the groundwater is accessible (shallow) and not too saline, the vegetation grows rapidly, increases in LAI and lowers the watertable. With decreased sub-soil waterlogging, roots grow deeper than the pre-existing watertable (Figure 3.19a).
- 3 Decreases in local watertables increase the hydraulic gradient towards the root zone and rates of intrusion of groundwater into the root zone. Despite this, watertables remain low because the vegetation copes by having high LAI and high rates of transpiration. Salt concentrations increase at faster rates in the root zone (Figure 3.19b).
- 4 Eventually, salt concentrations reach levels that substantially decrease the availability of water to the plants. As a consequence, there is a reduction in LAI, a decrease in transpiration and the watertable begins to rise. At this point, waterlogging of the deeper roots impairs salt exclusion and there is increased transport of sodium and chloride to the shoots, which damages leaves. Waterlogging also kills deeper roots (Figure 3.19c).
- 5 Continuing senescence of shoots further decreases LAI and transpiration. Watertables return to their prior level. Acute waterlogging in what are now highly saline soils (because of salt accumulation in the root zone) causes the trees to die. The accumulated salt in the root zone moves to the soil surface by capillarity (Figure 3.19d).

The sequence outlined above could take 10–20 years to complete and a layman observing the latter stages of the sequence might assume the trees had died because of an increase in salinity and/or waterlogging at the site. However, these effects might be longer-term consequences of salt accumulation in the root zone.

Shallower rooted saltland pastures are inherently more tolerant to salt accumulation in the root zone than deeper rooted trees, because the accumulated salt can escape from the root zone. For waterlogging tolerant pasture species, leaching of salt out of the root zone can occur when soils become waterlogged and off-site movement of salt from the soil surface is possible in inundation water. Saltland pastures can therefore be expected to persist in the long-term in areas where trees may not.

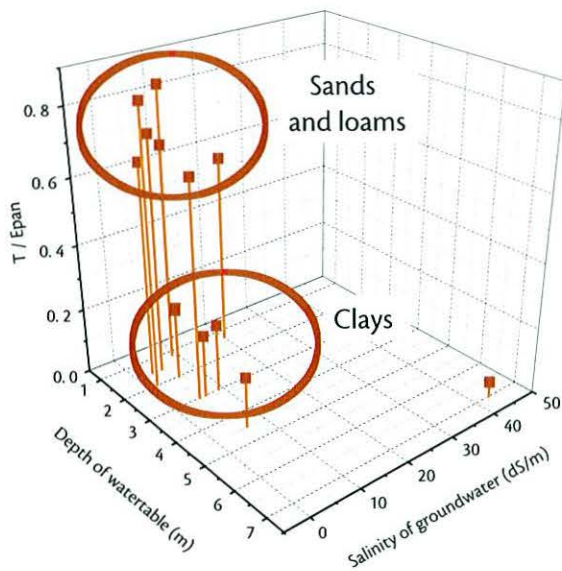


Figure 3.20. Three dimensional relationship between T/E_{pan} and the depth and salinity of the groundwater for clays and sands and loams.⁴⁵

3.5 Soil texture

Key point

Soil texture may affect rates of plant growth on saltland and rates of transpiration by trees on saline soils. At similar salinities and depths to the watertable, transpiration rates are lower for stands of trees growing on clays than for stands growing on sands or loams.

Some evidence suggests water use by plants is affected by soil texture, being lower on clays than on sands and loams. If this is true, then we would expect plant growth to also be slower on clays than on sands and loams.

The evidence for effects of soil texture on plant water use was obtained by comparing the rates of transpiration by stands of Australian *Eucalyptus* species growing at seven sites around the world.⁴⁴ To enable comparisons between locations with very different climates, calculations were made of the ratio T/E_{pan} , where T is the annual water use of trees and E_{pan} is an indicator of the dryness of the climate at each site. This ratio was plotted as a function of soil texture, and the depth and salinity of the watertable (Figure 3.20). T/E_{pan} was substantially lower on clays (0.2 or less) than on sands and loams (0.5–0.8).⁴⁵

Although we can infer possible effects of soil texture on growth, clear data to confirm this are not yet available and further investigations of the effects of soil texture on growth and water use are needed.

3.6 Implications for land capability

The capability of saltland for pasture growth is affected by soil salinity, susceptibility to waterlogging and inundation and soil texture.⁴⁷ We suggest saltland be divided into at least three different classes based on its productive potential:

- *Land of 'low' productive potential* will be dominated by clays of the valley floors in lower rainfall areas, and by shallow duplex soils and clays of the valley floors in higher rainfall areas.⁴⁸ This land is subject to high levels of salinity and waterlogging, and inundation. In general, the soils in this capability class will be bare where there is severe inundation and will otherwise support self-sown samphire (*Halosarcia* species), or a patchy cover of highly salt tolerant annual grasses and forbs. These soils should not be planted to forage shrubs like saltbushes, as their rates of production will be low (cf. Photo 3.8). Planting of saltland pastures on these sites is unlikely to be economically feasible. These sites should be stabilised by controlling grazing and allowing natural regeneration.
- *Land of 'moderate' productive potential* will be dominated by duplex and gradational soils of lower salinity and waterlogging. Salt accumulation in the root zone may occur in clayey B-horizons, but not in the more leachable A-horizons. These sites will be highly suited to the growth of saltland pastures. In winter-dominant rainfall regions with



Photo 3.8. Establishment of saltbush in land of low productive potential at York WA.

300–400 mm rainfall saltbush species and small leaf bluebush can be established by niche seeding or the planting of nursery-raised seedlings. These plants will have value as forages and will act as water pumps when grown in partnership with annual understorey species. Perennial-annual partnerships are also likely to be profitable in higher rainfall areas (400–500 mm), but the perennial partner plants will be *Acacia* species and perennial grasses (puccinellia and Tall wheat grass). As far as trees are concerned, only the most highly salt and waterlogging tolerant species (the *Casuarina* and *Melaleuca* species in Table 3.2) should be grown. Other species may grow for several

years; however we expect they may die in the longer term (five to 20 years) because of the irreversible accumulation of salt in the deeper root zones.

- *Land of high productive potential* will be dominated by sandplain seeps (areas where deep sands shelf out onto clays). This land is primarily affected by waterlogging. It will grow trees of lower tolerance to salinity and waterlogging (e.g. the *Eucalyptus* species in Table 3.2) and some of the less salt-tolerant pasture species (balansa clover, kikuyu, rhodes grass). Areas with shallow accessible groundwater of low salinity may be suited to dryland horticulture.

A priority for research – quantification of the relationships between ecological zonation and soil stresses

Even though salinity, waterlogging, inundation and soil texture cause zonation on saltland, there has been no quantification of the critical levels of these factors associated with zonation. This question is crucial to the targeting of plants to landscape: until it is settled there will continue to be expensive revegetation failures.

Further reading and notes

- 1 This issue is discussed more fully by Barrett-Lennard *et al.* (1999b).
- 2 For example, when wheat and maize were grown in salinised soil ($EC_e \sim 4$ dS/m) under glasshouse conditions for 14 days, concentrations of sodium and chloride were about twice as high in the soil closely adhering to the roots as in the bulk soil (Sinha and Singh, 1974, 1976).
- 3 The conversion of concentrations in parts per million to decisiemens per metre depends on the type of salt being measured. The factor given here applies to areas where the salt is primarily sodium chloride (NaCl).
- 4 The conversion of concentrations in millimoles per litre to decisiemens per metre also depends on the type of salt being measured. The factor given here applies to areas where the salt is in the form of monovalent ions like sodium chloride (Richards, 1954).
- 5 The salinity of seawater can vary. We use the figures of Munns *et al.* (1983). 100% seawater has an electrical conductivity of 55 dS/m, and is equivalent to about 550 mM NaCl.
- 6 George and Wren (1985) have derived the following rule of thumb:
 $EC_e = (364 * EC_{1.5}) / \text{saturation percentage}$
 This gives the following approximate values for the ratio $EC_e/EC_{1.5}$

Soil texture	Typical saturation percentage	$EC_e/EC_{1.5}$
Sands	25	~ 14
Loams	32	~ 11
Clays	45	~ 8
- 7 After Teakle and Burvill (1938). These data were obtained on a degrading 'morrel' soil at Welbungin, about 75 km north of Merredin in WA. Similar data are available from same paper for a locality near Grass Patch (about 75 km north of Esperance) and for a locality near Ghooli (about 15 km east of Southern Cross).
- 8 Relevant proceedings, reviews and bibliographies include: Aronson (1989); Barrett-Lennard *et al.* (1986a); Greenway and Munns (1980); Munns *et al.* (1983); Maas (1986).
- 9 References include: Old man saltbush (*Atriplex nummularia* – Greenway, 1968), samphire (*Halosarcia pergranulata* – Short and Colmer, 1999), puccinellia (*puccinellia peisonis* – Stelzer and Lauchli, 1977) and Distichlis (*Distichlis spicata* 'forage' clone – Leake *et al.*, 2001).
- 10 Maas (1986).
- 11 Sources of data are: barley (Gauch and Eaton, 1942; Greenway, 1965), beans (Eaton, 1942) and river saltbush (Aslam *et al.*, 1986).

- 12 The major themes of this paper were republished in Maas (1986). This second paper also included outcomes from more recent research.
- 13 Maas and Hoffman (1977).
- 14 Calculated from the study of Malcolm and Swaan (1989) using their published measurements of soil salinity and their unpublished soil moisture data.
- 15 The biophysics of plasmolysis are simple. The water outside plant cells has a 'potential' by merit of its salt concentration. This potential is usually a negative number increasing to maximum of zero when the water is non-saline. The water inside cells also has a potential caused by the concentration of dissolved solutes. For a cell membrane at equilibrium, the relationship between the water potential outside the cell (Ψ), the solute potential inside the cell (Ψ_s) and the pressure on the inside of the membrane forcing the cell to grow (P) is:

$$\Psi = \Psi_s + P$$
 Making water more saline has the effect of lowering Ψ . As Ψ_s remains at the same level, at least in the short-term, P therefore declines. Cells plasmolyse when $P = 0$.
- 16 Flowers (1972). Assays were conducted at pH values between 5.5 and 7.8. The results reported here were conducted at pH 7.8 (*Suaeda*) and 7.0 (*Beta*), which gave the greatest activities in the absence of salt.
- 17 Munns *et al.* (1983).
- 18 Reviewed by Greenway and Munns (1980).
- 19 McFarlane *et al.* (1989).
- 20 The use of the SEW₃₀ index has been promoted by Cox and McFarlane (1990, 1995).
- 21 Data of Cox and McFarlane (1990).
- 22 After Barrett-Lennard and Ratingen (unpublished). Oats were grown at a site near Popanyinning in WA. Watertables were averaged over the period 24 June to 1 August 1988. Shoots were harvested in a 0.5 m² quadrant in December.
- 23 For effects of waterlogging on concentrations of oxygen in soil see Cannell *et al.* (1985) and Barrett-Lennard *et al.* (1986b).
- 24 Grable (1966).
- 25 Drew (1983), Barrett-Lennard (1986).

Further reading and notes

- 26 Huck (1970), Webb and Armstrong (1983), Barrett-Lennard *et al.* (1988).
- 27 Buwalda *et al.* (1988b)
- 28 Trought and Drew (1980), Buwalda *et al.* (1988a).
- 29 Contardi and Davis (1978), Buwalda *et al.* (1988b).
- 30 Pereira and Kozłowski (1977), Jackson *et al.* (1978), West and Black (1978), Sena Gomes and Kozłowski (1980), Aloni and Rosenshtein (1982), Bradford and Hsiao (1982), Kriedemann and Sands (1984), Ali (1988), Huang *et al.* (1995) and Moezel *et al.* (1989a).
- 31 Barrett-Lennard (1986).
- 32 Reviewed by Barrett-Lennard (2003).
- 33 After Barrett-Lennard (1986). Plants were grown in sand irrigated with nutrient solution at various salinities. The waterlogging treatment was imposed for 7 days when the plants were 13 days old.
- 34 Barrett-Lennard *et al.* (1999a).
- 35 Barrett-Lennard (2003).
- 36 These are reported in Moezel *et al.* (1988, 1989b, 1991) and Craig *et al.* (1990).
- 37 After Moezel *et al.* (1988).
- 38 Based on Moezel *et al.* (1988, 1989b, 1991)
- 39 Reviewed by Malcolm (1983).
- 40 Bowman and Ruprecht (2000).
- 41 Data of Prof. Abdur Rashid and Mr Pervez Khan, reported by Qureshi and Barrett-Lennard (1998).
- 42 Specht (1972).
- 43 Critics include Heuperman (1992) and Thorburn (1996). Success in lowering watertables has been documented by Schofield *et al.* (1989), Bari and Schofield (1992) and Schofield (1992).
- 44 The analysis is described in more detail by Qureshi and Barrett-Lennard (1998) and Barrett-Lennard *et al.* (1998). In each study, tree water use was measured by the 'heat pulse' technique. This relies on the insertion of a heating element and two sensors, one upstream and one downstream of the element into the live sapwood of the plant. The element is electrically heated at regular intervals resulting in pulses of heat that move through the sapwood. The speed of water movement in the sapwood affects the way the heat is detected by the sensors.

- 45 The mechanism for this effect is presumed to be as follows (Qureshi and Barrett-Lennard, 1998). Soil texture affects the resistance to water flow in the soil. The rate of water flow through soil pores is proportional to the fourth power of the diameter of the pores. Thus, if the pressure gradient remains constant, halving the diameter of pores will reduce flow sixteen-fold (Russell, 1973, p. 429). In general, pore sizes are largest in sands and smallest in clays. Rates of water flow to the root are therefore expected to be: sands > loams >> clays.
- 46 After Qureshi and Barrett-Lennard (1998) and Barrett-Lennard *et al.* (1998).
- 47 Barrett-Lennard *et al.* (1999b).
- 48 Up to half of all saltland in Western Australia could fall into this category (estimated from Table 2, Barrett-Lennard *et al.* 1999b). Our justification for this assertion is based on three considerations:
- sands have a higher hydraulic conductivity than clays; they will therefore drain more easily and be less subject to salt/waterlogging interactions than clays
 - the likelihood of leaching of salt accumulated in the root zone is much lower for clays than loams and sands
 - the transpiration by stands of woody perennials appears to be substantially lower on clays than on sands and loams (for trees see Barrett-Lennard *et al.*, 1998; for saltbushes see Barrett-Lennard and Malcolm, 1999).



Chapter 4

Pasture plants for saltland



Spring herd on a salt flat: *Puccinellia* is a major pasture in South Australia
(Photograph: James Darling)



In this Chapter

Samphires (*Halosarcia* species)

Saltbushes (*Atriplex* species)

- River saltbush (*A. amnicola*)
- Wavy leaf saltbush (*A. undulata*)
- Quailbrush (*A. lentiformis*)
- Old man saltbush (*A. nummularia*)
- Grey saltbush (*A. cinerea*)

Small leaf bluebush (*Maireana brevifolia*)

Salt tolerant grasses

- Puccinellia (*Puccinellia ciliata*)
- Tall wheat grass (*Thinopyrum ponticum*)
- Distichlis (*Distichlis spicata*)
- Saltwater couch (*Paspalum vaginatum*)
- Marine couch (*Sporobolus virginicus*)
- Kikuyu (*Pennisetum clandestinum*)
- Rhodes grass (*Chloris gayana*)

Legumes

- Balansa clover (*Trifolium michelianum*)
- Melilotus (*Melilotus alba*)

This chapter describes a range of plants for saltland broadly grouped as: samphires, saltbushes, bluebushes, grasses and legumes. These plants have differing tolerances to salinity and waterlogging, and fit into different niches in the saltland landscape.

No quantitative data are available on the effects of combinations of salinity and waterlogging on plant ecological zonation. This issue has therefore been considered in Figure 4.1 in a matrix of *relative tolerance*, in which plants are ranked against *each other*.

Differences between plants in tolerance to salinity and waterlogging can often be seen in the revegetation near banks, drains and roads. For example:

- *Ponding bank* (Photo 4.1a). Samphire grows in the most saline location, puccinellia grows adjacent to the bank where water ponds, and saltbush grows on the bank where there is less waterlogging.
- *W-drain* (Photo 4.1b). Bluebush grows on the elevated bank where there is less waterlogging; river saltbush grows in the more waterlogged land on the flats.
- *Old road* (Photo 4.1c). Bluebush grows on the old road embankment where there is less waterlogging; samphire grows on the flats.



Photo 4.1 (a)



Photo 4.1 (b)



Photo 4.1 (c)

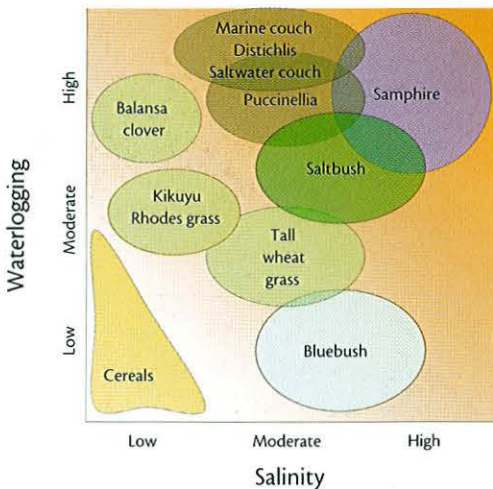


Figure 4.1 Relative rankings of different saltland pasture species in the salinity/waterlogging matrix.¹

Photo 4.1 Vegetation on banks, drains and old roads indicates differences in the tolerance of plants to salinity and waterlogging. (a) Ponding bank (Meckering WA), (b) W-drain (Miling WA), (c) Old road embankment (Pithara WA).

In a similar manner, we can also use the salinity/waterlogging matrix to understand factors affecting the ecological zonation of plant 'indicators' of saltland severity. Figure 4.2 plots the relative rankings of eight species that commonly occur on Australian saltland. The power of this capacity is that the presence of 'indicator' species (Figure 4.2) can be used to suggest the appropriate pasture species to establish on a site (from Figure 4.1).

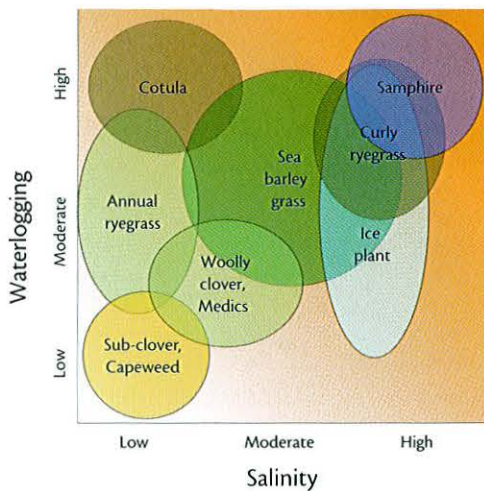


Figure 4.2 Indicator species in the salinity/waterlogging matrix.²

Care needs to be exercised in the use of indicator plants in the field for two reasons:

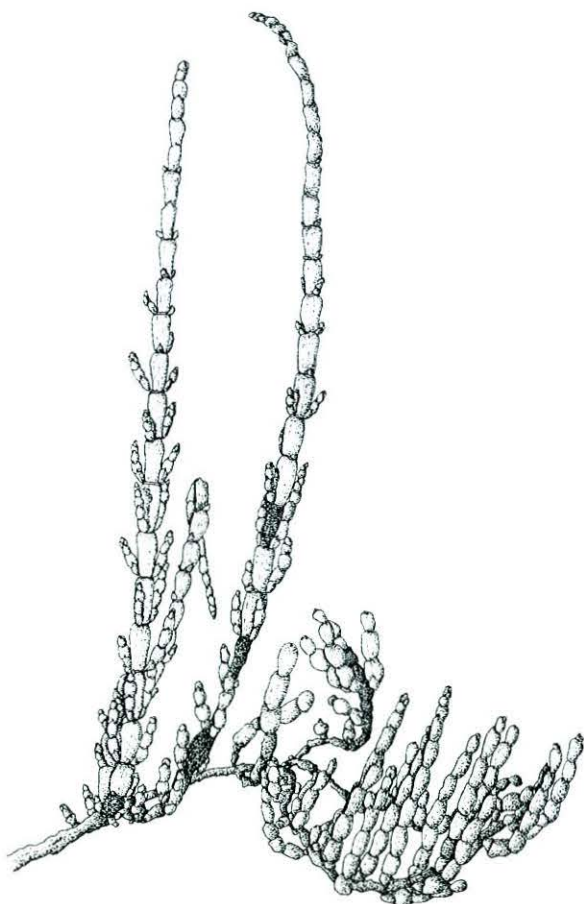
- The absence of indicators in a paddock is not unequivocal – the plants may not be present because of overgrazing. Evidence from fenced road verges (which offer better protection from grazing) can be used to augment observations of indicators in the paddock.
- The use of plant indicators to diagnose sites is not completely risk free. What has happened in the past does not necessarily indicate what will happen in the future. In times of drought, sites may appear to be less susceptible to waterlogging than they are in times of high rainfall.

A few other general points should be made at the outset:

- 1 It is highly likely future saltland pastures will be based around a broader range of plant species than at present. An unpublished database developed by Dr Nicholas Yensen lists more than 100 plant species with potential as saltland forages for Australia. However, adaptation studies in the field have been conducted for only a small proportion of potential species.³
- 2 Saltland pastures should be composed of diverse and interacting plant species (see Chapter 6). In areas where the rain falls predominantly in winter, halophytic shrubs and puccinellia are likely to be key groundwater-using elements. However, in areas with substantial summer rainfall, halophytic grasses are likely to be more important users of groundwater. Virtually no adaptation testing has focused on the value of saltland plants in mixtures.
- 3 No quantitative information is available on the impacts of the interactions of salinity, waterlogging and inundation on plant growth. In Figures 4.1 and 4.2, we have used relative rankings (low, moderate and high) to indicate a range of severities of salinity and waterlogging.
- 4 Some of the most useful species for Australian saltland have been introduced from overseas. Examples include puccinellia (*puccinellia ciliata* from Turkey), wavy leaf saltbush (*Atriplex undulata* from Argentina), Tall wheat grass (*Thinopyrum ponticum* from Turkey), Quailbrush (*Atriplex lentiformis* from the USA) and distichlis (*Distichlis spicata* from the USA).



Photo 4.2 Self sown stand of samphire near Wongan Hills WA.



4.1 Samphires (*Halosarcia species*)

Samphire is the common name for native plants from the genus *Halosarcia*.⁴ Although slower growing than saltbush and bluebush species, samphires have high tolerance to salinity and waterlogging (Photo 4.2).⁵

Occurrence Samphires grow in intermittently flooded, saline land. They generally form the first fringing community adjacent to the bare margins of salt lakes and are found in many drainages in Australia's pastoral and agricultural areas.⁶

Description Perennial shrubs, with either a spreading or more erect habit, up to one metre high. Branches comprise succulent, hairless stem segments (Figure 4.3), varying in colour from green to red-purple. Flowers and seeds are hidden between the fleshy segments. The seed is small (less than one millimetre in diameter) and may be brown or black, depending on the species. Seeds mature in late summer but the fleshy seed heads may not dry off until autumn.

Grazing Samphire shrubs survive moderate grazing, but their use for this purpose is *not* recommended. The plants adapt to salinity by storing salt in the vacuoles of their fleshy stem segments and can have salt concentrations of 30-45%.⁷ They must be grazed in conjunction with other feed such as crop stubble or dry annuals and sheep must have access to fresh water.

Establishment For the most salt tolerant species, germination can occur at salinities up to about 40 dS/m.⁸ Samphire spreads rapidly when protected from grazing. It may occupy sites capable of growing more useful saltland pasture species. Establishment may be promoted by harvesting green mature seed heads in late summer. These may then be dried and broadcast onto scarified soil before the first autumn rains.

Figure 4.3 Branch of typical samphire shrub (Drawing: Kathy Shapland).

4.2 Saltbushes (*Atriplex* species)

Halophytic shrubs (including saltbushes) were widely studied in WA from the 1950s to the 1980s. In the late 1950s, it became clear production could be achieved from saltland using Old man saltbush (*Atriplex nummularia*), creeping saltbush (*A. semibaccata*) and small-leaf bluebush (*Maireana brevifolia*).⁹ However, these species had problems: Old man saltbush was unpalatable and had erect branches partly out of reach of sheep, creeping saltbush was short-lived, and small-leaf bluebush was sensitive to waterlogging. A two-phase program was initiated to select better halophytic shrubs.¹⁰

Between 1972 and 1982 selected genetic material was assessed at 14 test sites throughout the WA wheatbelt. Assessments were made of soil conditions, plant growth and habit, flowering, seed production and ability to produce volunteers, resistance to pests and diseases, waterlogging tolerance, drought tolerance and resistance to sand blasting. The highest-ranked saltbushes from this study were river saltbush (*Atriplex amnicola*), wavy leaf saltbush (*A. undulata*) and quailbrush (*A. lentiformis*). After these studies were completed, two other species came into focus: grey saltbush (*Atriplex cinerea*) and Old man saltbush (*Atriplex nummularia*).

These saltbush species are generally dioecious, with female flowers ripening to produce fruits that contain a single seed. If fruits develop without a nearby source of pollen, they will be empty. The implications of this for germinability are discussed further in Chapter 5.

Field and pen trials suggest that saltbushes (which contain high concentrations of salt) should be fed with low salt hay, stubble or understorey. On its own, saltbush leaf is a maintenance forage for sheep (see Chapter 6).¹¹ It has relatively low digestibility (46–62%)¹² and high ash concentrations (17–33%)¹³ reducing its value as a source of metabolic energy. However, saltbush leaves also contain high concentrations of nitrogen. Average crude protein concentrations of 15% have been found.¹⁴ The exact form of this nitrogen is not known, but it is accessible to ruminants provided adequate energy is available from other sources.

Saltbush does not tolerate long-term continuous grazing and plants should be allowed to recover after grazing.

The plants use groundwater,¹⁵ which can assist in the growth of other higher value understorey species (see Chapter 7). It seems likely at least some of the grazing benefits achieved on saltbush-based pastures have been caused by improvements in understorey.

Climate can affect the choice of saltbush species to be planted. In WA, river saltbush grows well in the warmer northern agricultural areas, but in the cooler areas of the south coast there is little difference in productivity between river and wavy leaf saltbush.¹⁶

4.2.1 River saltbush (*Atriplex amnicola*)¹⁷

Of all saltbushes tested on saltland in Western Australia, river saltbush (*Atriplex amnicola*) had the best long-term survival.¹⁸ It has moderate–high salinity tolerance and high drought tolerance.¹⁹ Once established, it can tolerate winter waterlogging although prolonged waterlogging, especially in summer, will cause death.²⁰ It will survive partial inundation, but total immersion will kill it (Figure 3.17).

Occurrence It is native to the creeks and outer margins of salt lakes in the Murchison and Gascoyne River Basins of WA (Photo 4.3).²¹



Photo 4.3 River saltbush growing on Boolardy Station WA near the Murchison River (line of trees) in the background.



Photo 4.4 River saltbush fruits growing at the end of branches (Photograph: Simon Eyres).

Description River saltbush is a perennial shrub that can have a prostrate to erect habit. The branches of the prostrate types form roots where they rest on the ground. The bushes are usually one metre wide and high, but larger ecotypes may reach four metres across and 2.5 metres high. Leaf size and shape, and leafiness and fruit shape vary widely. Leaves are often elongated and spear-shaped, but can be oblong with rounded ends, 1–3 centimetres long (Figure 4.4). The species is mainly dioecious, although monoecious plants may occur. Male flowers are in dense clusters on the ends of branches (Figure 4.5). Female flowers are at stem nodes (Figure 4.6) and in short clusters on the ends of branches (Photo 4.4). Fruits may be woody or more papery, 2–6 millimetres across, roughly triangular or spherical in shape.

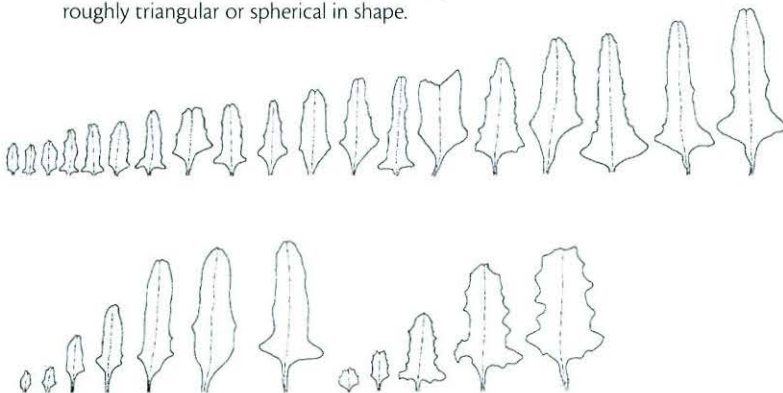


Figure 4.4 Variation in leaf form in river saltbush (Drawing: Kathy Shapland).

Seed is usually harvested in late summer. Flowering varies, depending on seasonal conditions.

Grazing River saltbush is palatable and has a remarkable ability to recover from heavy grazing (Photo 4.5a–c).

Establishment Clones of river saltbush (see Chapter 7) strike readily from cuttings.²² Special care needs to be given to establishment from seed (see Chapter 5). River saltbush is more susceptible to waterlogging during germination than wavy leaf saltbush.²³ It has been difficult to establish by direct seeding. Two more easily established lines (Rivermor and Meeberrie) have been selected.²⁴ Except for Rivermor and Meeberrie, river saltbush usually produces few volunteer seedlings.

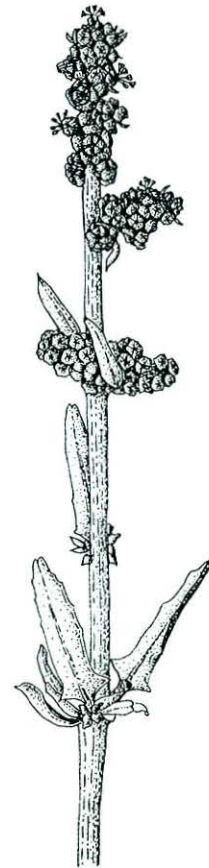


Figure 4.5 Typical male flowers of river saltbush (Drawing: Kathy Shapland).

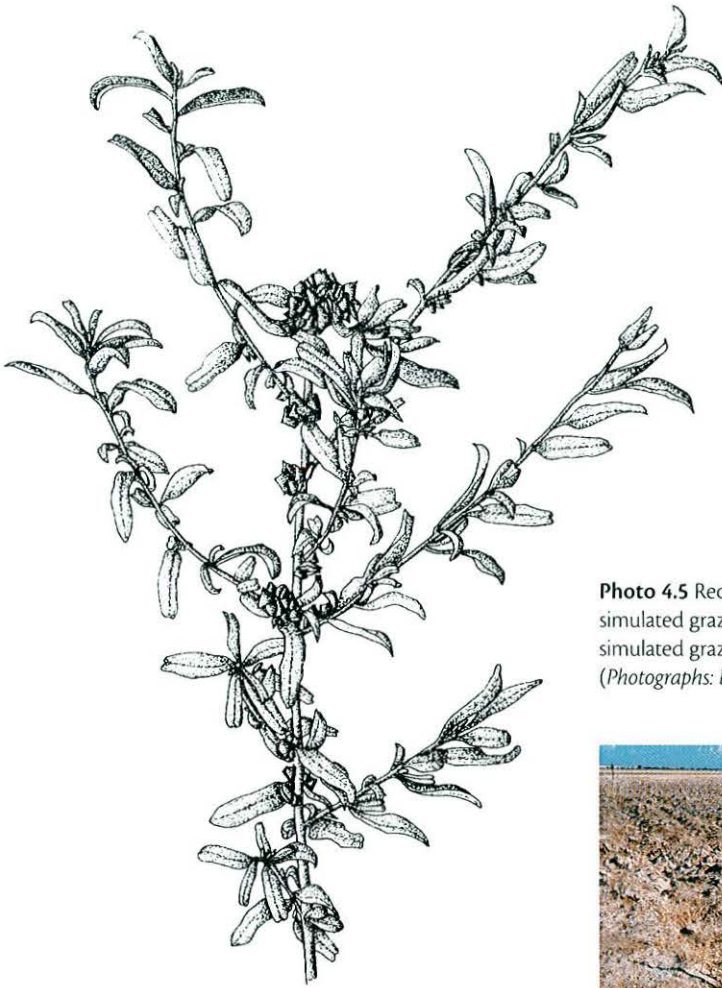


Figure 4.6 Typical branch of river saltbush. Note clusters of female flowers at nodes
(Drawing: Kathy Shapland).

Photo 4.5 Recovery of river saltbush from simulated grazing. (a) 8 month old plant, (b) simulated grazing, (c) recovery 3 months later
(Photographs: Brett Ward).



Photo 4.5 (b)

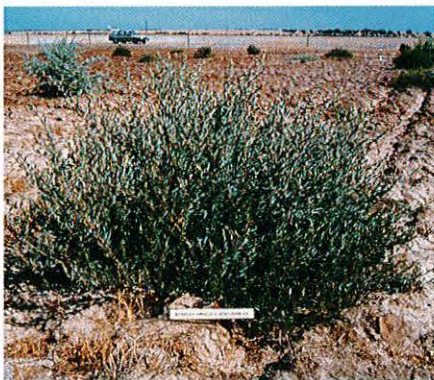


Photo 4.5 (a)



Photo 4.5 (c)

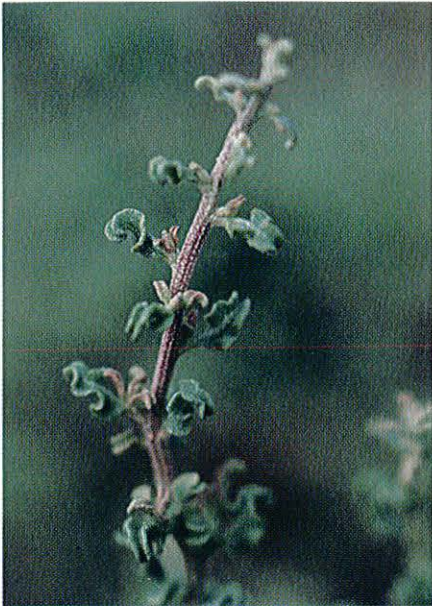


Photo 4.7 Typical curling leaves of wavy leaf saltbush.

4.2.2 Wavy leaf saltbush (*Atriplex undulata*)

Wavy leaf saltbush grows well on salt affected soils in areas receiving 250–500 mm annual rainfall (Photo 4.6) and establishes readily from seed in the field. It does not appear to be as tolerant to waterlogging as river saltbush.

Occurrence Wavy leaf saltbush comes from the semi-arid rangelands of central Argentina.

Description Perennial shrub, up to one metre high and two metres across. This shrub has erect as well as low spreading stems. The stems growing along the ground can form roots. As the name suggests, the leaves are crinkly or wavy, and are 0.5–1.5 cm long (Photo 4.7). Male and female flowers occur in clusters on the ends of the branches. The fruits are soft and rounded, from 1–3 millimetres diameter and contain a single seed, which ripens in April–May.



Photo 4.6 Stand of wavy leaf saltbush established with niche seeder at Maya WA.



Photo 4.8 Germination of wavy leaf saltbush from sheep faeces. Sheep dung accumulated where the sheep camped in the corner of this paddock (fence now removed).

Grazing With repeated grazing every autumn, wavy leaf saltbush may die.²⁵

Establishment Wavy leaf saltbush establishes readily from seed using the niche seeder. Seed can spread through animal faeces; volunteer seedlings establish in large numbers following autumn grazing (Photo 4.8).

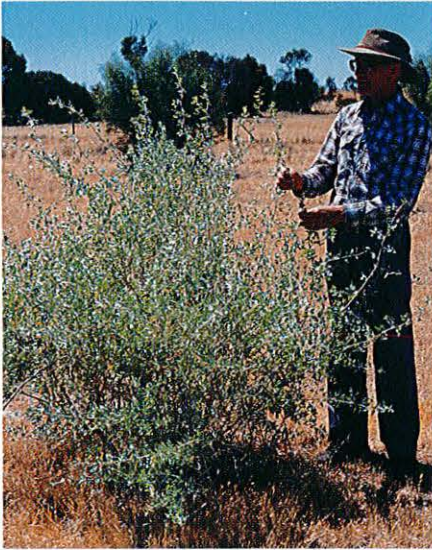


Photo 4.9 Quailbrush growing at Tammin WA.

4.2.3 Quailbrush (*Atriplex lentiformis*)

Quailbrush is a rapidly growing species, moderately tolerant to salinity, tolerant to heat and drought, and well adapted to warmer climates (Photo 4.9).²⁶ Its erect, open, angular growth habit is not well suited to grazing, but its large size provides shelter. For reasons that are unclear, it tends to die back in saline waterlogged land after several years. It is being grown in areas receiving 300–450 mm average annual rainfall.

Occurrence Quailbrush comes from the hot arid deserts of southern California and Arizona, USA.

Description Fast-growing perennial shrub with open, upright structure up to 2.5 metres high and wide. The silvery blue-green leaves are about two centimetres long (Figure 4.7). Male flowers are clustered on the ends of branches. Female flowers, which often turn pink before ripening, hang in dense bunches. Fruits are flat and round, 2–5 millimetres in diameter. The seed ripens in April–May.

Grazing The bush is erect and woody. Sheep graze it readily.

Establishment It readily establishes from seed using the niche seeder. Seedlings also establish naturally after autumn grazing.

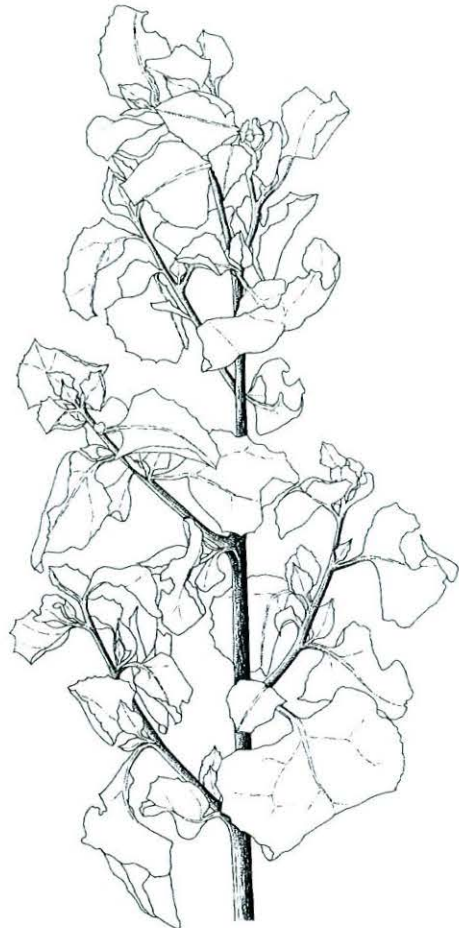


Figure 4.7 Typical branch of quailbrush
(Drawing: Kathy Shapland).

4.2.4 Old man saltbush (*Atriplex nummularia*)

To a substantial degree, Old man saltbush is Australia's iconic saltbush species (Photo 4.10). It grows well on saline soils in agricultural and rangeland areas where annual rainfall ranges from 175–400 mm. It is a deeper rooted plant than many other saltbushes.²⁷ Waterlogging, especially in summer, bleaches the leaves and can kill the plants. Its main disadvantages as a fodder plant are its upright growth habit, a poor ability to produce volunteer seedlings and low palatability to grazing sheep. It has been advocated as a fodder reserve in times of drought in NSW.²⁸

Occurrence Old man saltbush is native to the semi-arid and arid zone of southern and central Australia; it is often associated with heavy soils or flood plains.²⁹

Description Highly drought tolerant, moderately tolerant to salinity; it is long-lived on soils not subject to waterlogging. It has an upright habit, and may grow to two metres high and 1.5 metres wide. The leaves are grey-green, 2–4 centimetres long and irregularly shaped. Male flowers occur in dense clusters (Photo 4.11a). Female flowers are in 20 cm long bunches (Figure 4.8). Fruits are fan-shaped to nearly round, woody towards the base and up to six millimetres across. Fruits ripen by late summer (Photo 4.11b).

Grazing Old man saltbush has a lower palatability than some other saltbushes. A variety, De Kock, with better palatability is gaining acceptance. The species recovers from grazing, but the branches are brittle and may get trampled.

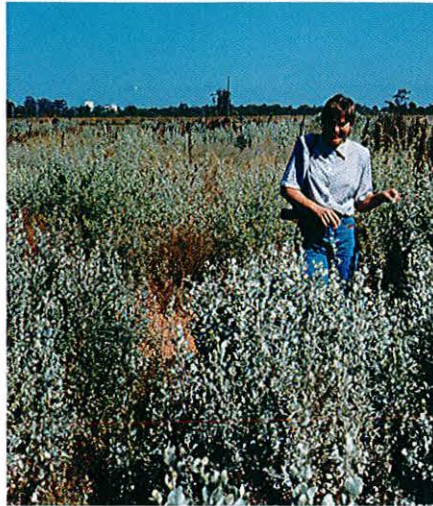


Photo 4.10 Immature Old man saltbush stand, Tatura VIC.

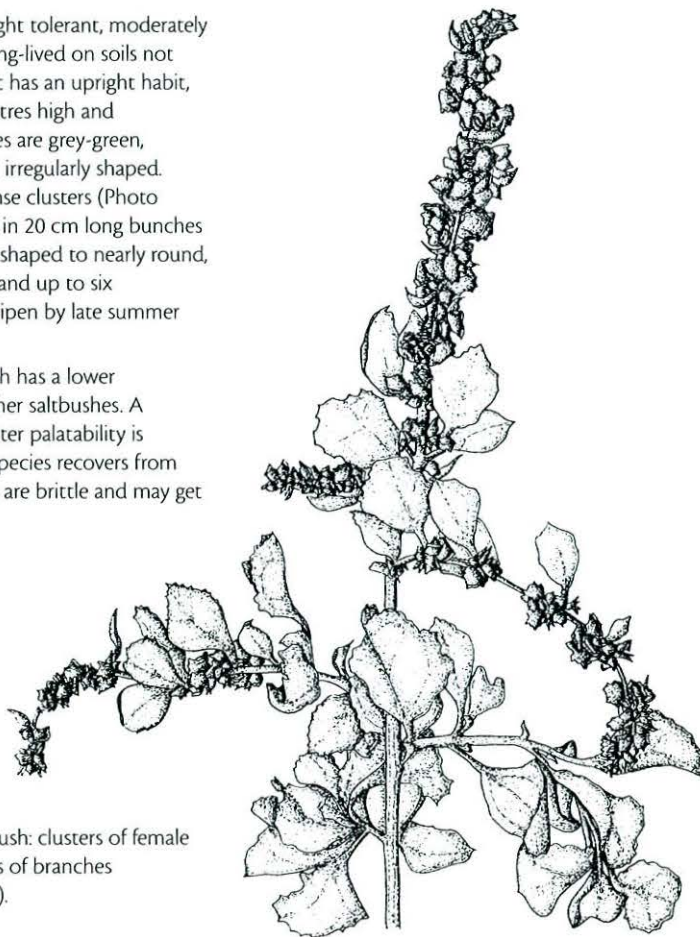


Figure 4.8 Old man saltbush: clusters of female flowers occur on the ends of branches (Drawing: Kathy Shapland).



Photo 4.11 (a) Old man saltbush. Male flowers.
(Photograph: Simon Eyles).

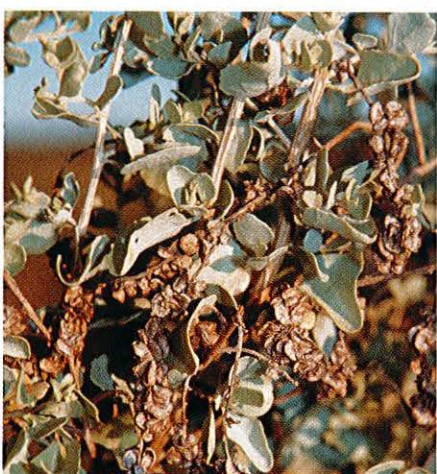


Photo 4.11 (b) Old man saltbush. Mature fruits
(Photograph: Simon Eyles).

Establishment In NSW, extensive areas have been established since the 1990s in the Western Districts and on saltland using the 'speedling' technology developed by Narromine Transplants.³⁰ However, this use of nursery raised seedlings is expensive at high planting densities (more than \$500 per hectare).

Historically, Old man saltbush has been difficult to establish by direct seeding on clay soils. However, good results at much lower cost have been obtained on clay soils in the Murray-Darling Basin using a new seeder developed by Greening Australia Victoria and Kerang Engineering.³¹ Before sowing, fruits of Old man saltbush should be washed under running water for two to four hours to leach salt and other compounds that inhibit germination.



Photo 4.12 Grey saltbush, prostrate form, growing on coastal sand dunes near Geraldton WA.

4.2.5 Grey saltbush (*Atriplex cinerea*)

Grey saltbush is a highly productive shrub that grows on saline seepages in the WA wheatbelt and tolerates moderate waterlogging.

Occurrence Grey saltbush grows on coastal dunes of southern Australia.³²

Description Perennial shrub with prostrate (Photo 4.12) and erect (Photo 4.13) forms. Prostrate form can grow 6–8 metres in diameter and 0.5 m high. Its leaves are up to two centimetres long, grey-green, with a sheen on the upper and lower surfaces. The erect form found in southern and eastern Australia has larger, greyer leaves. It is dioecious or monoecious. Male flowers occur in dense clusters on the ends of branches. Female flowers occur in clusters in leaf axils of upper parts of branches. Fruits are hard, 2–6 millimetres long and wide, roughly triangular, containing a single seed, which ripens in late summer.

Grazing Few grazing data are available. The species is variable in palatability³³ and recovers well from grazing.

Establishment Establishment from seed is possible. Cuttings strike readily.



Photo 4.13 Grey saltbush, erect form.

4.3 Small leaf bluebush (*Maireana brevifolia*)

Bluebushes belong to the genus *Maireana* (57 species recognised) and are mostly found in saline environments. They are generally low shrubs with small, round, fleshy leaves. Their most distinctive characteristic is the seed case, a woody structure not more than five millimetres across and surrounded by a papery wing up to two centimetres in diameter.³⁵

The major *Maireana* species of relevance to saltland revegetation in agricultural areas is small leaf bluebush (*M. brevifolia*)³⁵ (Photo 4.14). It is shorter-lived than some of the saltbush species, but maintains a stand because of its excellent volunteering ability (Photo 3.1c). It grows on well-drained soils of low to high salinity.³⁶ Its main disadvantage is that it will not withstand waterlogging or inundation for more than a few days (Photo 4.15).

Occurrence Small leaf bluebush is native to non-saline and mildly saline areas in southern Australia receiving 250–400 mm average annual rainfall. It is an early coloniser of disturbed lands.³⁷

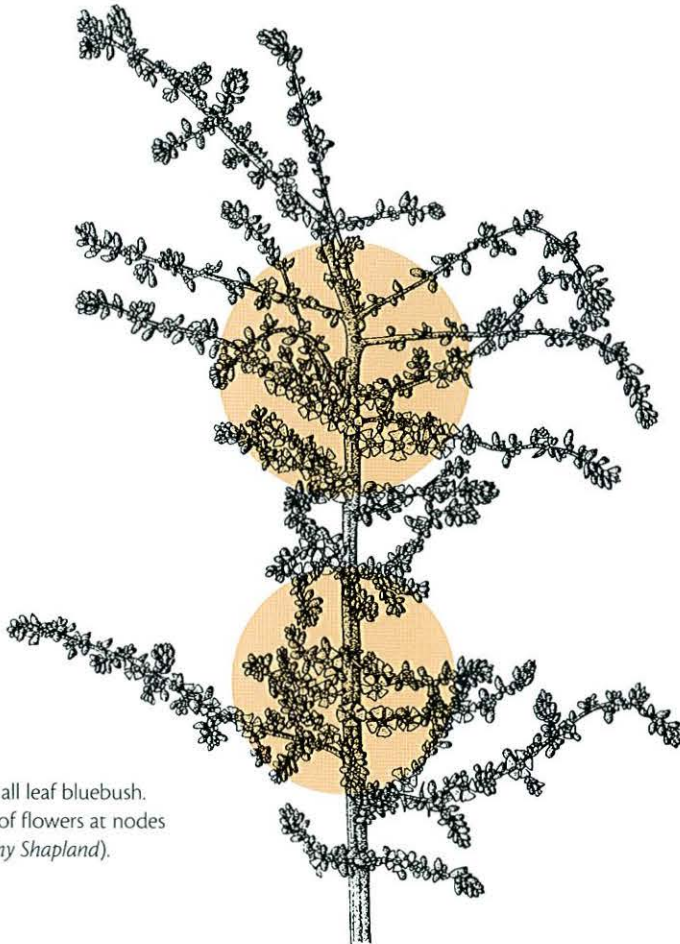


Figure 4.9 Small leaf bluebush.
Note clusters of flowers at nodes
(Drawing: Kathy Shapland).

Description Small leaf bluebush is a deep-rooted perennial shrub, up to one metre high and wide. The dark bluish-green leaves are short and fleshy, 2–5 millimetres long. The plant has an upright to semi-erect habit and flowers from late November to July. The flowers are bisexual and are borne in leaf axils (Figure 4.9). The light papery seeds ripen most profusely in February and March, and are widely scattered by the wind (Photo 4.16).

Grazing Bluebush provides good grazing and recovers well. Fodder from plants grown in the field has average crude protein concentrations of ~18% and ash concentrations of 22–30%.³⁸

Farmers in many districts regularly graze sheep on bluebush in summer to late autumn, with pasture or stubble. This strategy is necessary to avoid poisoning by the oxalate (9–12%) in the leaves. *Hungry sheep should not be introduced to bluebush unless adequate other feed is available.*

Establishment If there is a nearby stand of bluebush, fencing and protecting an adjacent area for two or three years will lead to colonisation – the low cost establishment strategy (see Chapter 5). Bluebush can be readily introduced into a suitable area by sowing with a niche seeder, or less reliably, by spreading seed onto cultivated soil. Only recently collected seed should be sown. Even with careful control of relative humidity, the seed loses its ability to germinate *within one to two years of collection.*³⁹

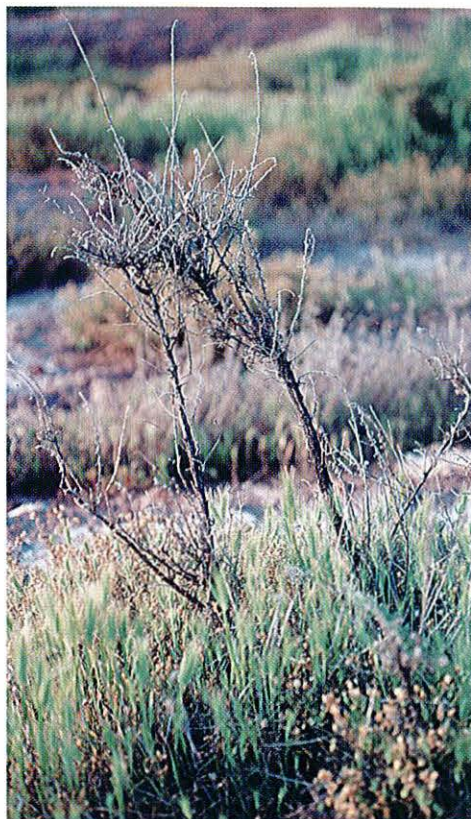


Photo 4.15 Waterlogging damage to small leaf bluebush.



Photo 4.14 Young small leaf bluebush plant.



Photo 4.16 Ripe seed shed by small leaf bluebush.



Photo 4.17 Puccinellia grows on waterlogged salt-affected soils.

4.4 Salt tolerant grasses

The major salt tolerant grasses used in Australia are puccinellia and Tall wheat grass – often sown as mixtures, with puccinellia colonising the more waterlogged parts of the landscape and Tall wheat grass occupying the less affected parts of the landscape. Five other grasses of value are Distichlis (*Distichlis spicata*), saltwater couch (*Paspalum vaginatum*), marine couch (*Sporobolus virginicus*), kikuyu (*Pennisetum clandestinum*) and rhodes grass (*Chloris gayana*); these all have high tolerance to waterlogging, low to moderate tolerance to salinity, and are most reliably propagated by vegetative means. Some research has also been done with other grasses, but these will not be further considered here.⁴⁰

Salt tolerant grasses provide fodder and use groundwater in saltland pasture systems in summer rainfall areas. Their growth appears to be highly responsive to the application of nitrogen.

4.4.1 Puccinellia (*Puccinellia ciliata*)

Puccinellia (cv. Menemen) is one of the great saltland pasture success stories of South Australia, where it is widely grown on saline waterlogged soils of the Eyre Peninsula and the Upper South East.⁴¹

Puccinellia grows on alkaline (but not acid) saline waterlogged soils with EC_e values in the range 10–40 dS/m (Photo 4.17).⁴² It will withstand brief periods of inundation. It is suited to areas that may be bare because of salinity and inundation, and to sites carrying sea barley grass where the annual average rainfall is more than 400 mm. It grows on salt affected soils too waterlogged during winter for saltbushes.⁴³

Occurrence puccinellia was originally collected from the west coast of Turkey in 1951 by C.M. Donald and J.F. Miles at Kaklic, a village 12 km from the town of Menemen (after which the cultivar was named).⁴⁴



Photo 4.18 (a) Puccinellia. Green in spring.

Description Perennial grass forming tussocks up to 40 cm high and wide. Its leaves are long and thin; the growing points are embedded in the base of the plant, which is compact and resistant to grazing. The plants hay-off in December and remain dormant over summer (Photo 4.18). They shoot vigorously after the opening rains of autumn. The plants are monoecious. Flowers are formed in September and the seed is ripe by December.

Grazing The grazing value of puccinellia depends on the stage of growth. It should not be grazed in the first year, although stands can be lightly grazed in the second year. During winter and early spring, when the leaves are green, the plant has a high protein content (10–18%) and digestibility (60–78%).⁴⁵ Nutritive value declines as the plant flowers and matures. Salt concentrations of about 10% have been reported.⁴⁶ Although the grass is palatable in late summer and early autumn (possibly due to the retention of some sappy green stems), its nutritive value appears to be fairly low at this time (crude protein less than 5%, digestibility less than 50%).



Photo 4.18 (b) Puccinellia. Dry in summer/autumn.

Growth is highly responsive to applications of nitrogen in late winter. In one trial in South Australia, a split application of 65 kilograms of nitrogen per hectare (about 25% in June, 75% in August) increased dry matter production from 2.2–7.8 tonnes per hectare (Figure 7.11).⁴⁷

Establishment Weeds must be controlled for good establishment. Puccinellia is established by seeding onto cultivated ground, but must be protected from grazing during the first year. The stand should be moderately grazed in the second year, and thereafter managed to maintain a healthy stand.

Management Seed ripens by December and can be harvested at any time during the summer with little risk of shedding. The seed is difficult to harvest because it is small and light.⁴⁸



Photo 4.19 Tall wheat grass at Mt Barker WA.

4.4.2 Tall wheat grass (*Thinopyrum ponticum*)⁴⁹

Tall wheat grass (Photo 4.19) is widely grown in summer-moist areas and on soils of low to moderate salinity (EC_e values 10–30 dS/m) dominated by sea barley grass.⁵⁰ It does not persist in soils that are waterlogged over spring and into summer. The most widely used cultivar in Australia is Tyrrell. A new cultivar, Dundas (recently bred by Agriculture Victoria) has enhanced leafiness and quality. Tall wheat grass can be grown as a companion species to legumes (balansa clover, strawberry clover and persian clover), and perennial grasses (puccinellia, phalaris and tall fescue).⁵¹

Tall wheat grass is summer-active, with most growth occurring from late spring onwards. This species can lower shallow watertables and decrease soil salinity⁵², providing an opportunity to promote the growth of companion legumes.⁵³

Occurrence The Tall wheat grass grown in Australia was collected by the American Westover-Enlow expedition near Bandirma in northern Turkey in 1934. The plant was bulked up and released in 1937 by the United States Department of Agriculture as the cultivar Largo. After introduction to Australia, selection pressure changed the genetic constitution of the line, and it was renamed Tyrrell after a salt-affected parish and salt lake in Victoria.⁵⁴

Tall wheat grass has been grown on saltland in Australia since at least 1945.⁵⁵ Its growth is highly economic on moderately saline and waterlogged land in southern Australia.⁵⁶

Description Tussock-forming perennial grass up to one metre tall or more. The leaves are greyish or bluish green, up to 30 cm long, 4–8 mm wide and rough on the upper surface and margins. The seed head is a spike 10–15 cm long. The spikelets are side-on to the rachis, which is recessed opposite each spike. It gives good seed yields, although mature spikes shatter easily.

Tall wheat grass is adapted to alkaline soils and saline seepage areas. It is moderately tolerant to salinity, but less tolerant to waterlogging than puccinellia (Figure 4.1). It grows in the warmer months, setting seed from January to March; winter growth is poor, although it is tolerant of frost. Subsoil moisture or rain over summer is necessary for good production.

Establishment Tall wheat grass has good germination but slow early growth. It should not be grazed during the first year.

Grazing The quality of Tall wheat grass stems declines rapidly in late summer, so it is important to graze the pasture before the stems are fully mature. Heavy crash grazing encourages leafiness and helps maintain feed quality.⁵⁷

If Tall wheat grass is planted as a companion species with balansa clover, then the grazing should be regulated to allow the balansa to complete its growth cycle. Grazing needs to stop when the balansa is flowering (usually in September) and can recommence when the balansa seed has set (usually in December).⁵⁸ Mixed stands of Tall wheat grass and balansa clover may be managed for the production of silage.⁵⁹

Management Growth, palatability and feed value are responsive to the application of nitrogen. Seed can be harvested in early autumn by cutting and swathing the grass two to three weeks after flowering, then picking up the material about five days later with an open front header.⁶⁰

4.4.3 *Distichlis* (*Distichlis spicata*)

One way to obtain productive use of saltland is to identify and develop new crops based around the domestication and breeding of halophytes. US company, NyPa International, has patented selections of *Distichlis* species (perennial halophytic grasses) for grain, turf and forage.

A consortium including NyPa Australia and Elders Ltd is trialling and marketing *distichlis* in Australia, and has established trial sites in WA, SA and VIC. Our comments focus on the use and value of a selection of *Distichlis spicata*, marketed as NyPa Forage™ (Photo 4.20). No final verdict can yet be reached on this plant as it is still being assessed under Australian conditions.

Occurrence *Distichlis spicata* is a C4 grass that is highly tolerant to waterlogging, partially tolerant of inundation, and moderately–highly tolerant to salinity.⁶¹ The roots are able to form aerenchyma that enable the diffusion of oxygen from the soil surface to the root tips. In Australia, this species appears to occupy a similar landscape niche to saltwater couch and marine couch. In its natural state, it occurs in coastal areas of North and South America, in brackish to saline marshes and on beaches and salt flats, usually above the high tide line, but occasionally in the upper intertidal zone.⁶²

Description NyPa Forage™ is a low perennial grass with creeping surface stolons (Photo 4.20b) and near-surface rhizomes (horizontal root-like stems). The culms bearing the leaves form erect branches from the stolons/rhizomes. The leaf blades, in two ranks on opposite sides of the culm, are pointed, stiff and covered with microscopic bi-cellular salt glands. NyPa Forage™ produces no seed; it is propagated vegetatively.

Grazing Both sheep and cattle have been observed grazing *distichlis*, but there is little documented information on the value of the plants for animal production. Crude protein concentrations of 10% have been reported in young leaves. As the leaves have highly efficient salt glands,⁶³ salt concentrations in the leaves are likely to be lower than for other plants grown under comparable conditions of salinity and waterlogging.



Photo 4.20 (a)



Photo 4.20 (b)

Photo 4.20 *Distichlis* near Wickiepin WA. (a) stand in paddock, (b) detail of shoot.

Establishment The species is difficult to establish in the field. It cannot be sown as seed and vegetative propagation relies on transplanting established root material.⁶⁴ One farmer has established one to two hectares per day using a broccoli planter to plant harvested tillers about five centimetres into the soil.



Photo 4.21(a) Saltwater couch, close up.
(Photograph: Simon Eyres).

4.4.4 Saltwater couch (*Paspalum vaginatum*)⁶⁵

This grass has been transported extensively around the world for two reasons. It was initially used as bedding in the bottom of slave ships as they moved between Africa, North, South and Central America and the Caribbean Islands. It was later introduced into salt-affected areas as a forage. The plants were introduced into SA from South Africa in 1935.⁶⁶ By 1945, it was being used in WA for similar purposes.⁶⁷ It has performed very well at a range of sites in NSW.⁶⁸

This species has high tolerance to waterlogging, some inundation tolerance and moderate tolerance to salinity. It is shallow rooted and clearly forms aerenchyma. It should be grown on seepage areas that remain wet throughout the summer.⁶⁹ In the field, the species is tolerant to irrigation with water with electrical conductivities between 6 and 22 dS/m.⁷⁰ In glasshouse experiments, four ecotypes survived the highest level of salinity (40 dS/m), and there were 50% decreases in shoot growth at electrical conductivities between 18 and 29 dS/m.⁷¹ Some ecotypes tolerate salinity levels equivalent to seawater.

Occurrence Salt water couch is an ecologically aggressive warm-season perennial grass normally found on shore-lines between latitudes of 30° and 35° in the northern and southern hemispheres. It occurs on sandy beaches, banks of estuaries frequently inundated by saltwater, and along the banks of coastal rivers. It can be found inland near the edge of saline water on sandy soils, is suited to aquatic, semi-aquatic and moist environments, and has weed potential in these areas (Photo 4.21).



Photo 4.21(b) Saltwater couch, in a partly inundated drain near Moora WA
(Photograph: Simon Eyres).

Description⁷² This species produces rhizomes and stolons. Flowering culms are from 8–60 cm high. Stolon nodes have a covering of short hairs. Leaves are arranged in two ranks on opposite sides of the culm; they are hairless, 50–200 mm long and 1–4 mm wide, gradually tapering to a narrow apex. The flower is composed mainly of two primary branches 20–60 mm long, with 16–32 twin-rowed spikelets on each primary branch. Each spikelet is 2.5–4.5 mm long, and 0.9–1.5 mm wide. Anthers are 1.2–1.6 mm long. Seeds are 2.5–3.0 mm long and 1.5 mm wide.

Grazing No information is available on the grazing value of the plants. As the plants grow on very waterlogged sites, care will be required to prevent the sites being pugged. Dry matter production can range from one to seven tonnes per hectare on saline land.⁷³ Yields will be affected by the fertility of the site.

Establishment Salt water couch must be vegetatively propagated from sprigs or sod since seed production has not been reliable. In the US, vegetative material has been planted mechanically using hydrospriggers.



Photo 4.22(a) Marine couch near Bundaberg QLD, detail of shoot. (Photograph: Matthew Roche).

4.4.5 Marine couch (*Sporobolus virginicus*)

Marine couch is a highly regarded halophytic perennial grass on seepage areas in Queensland and NSW. It grows in a similar ecological niche to saltwater couch, having high tolerance to waterlogging and moderate tolerance to salinity. It tolerates pH values between 5 and 9.⁷⁴

Occurrence Marine couch is a C4 perennial grass with a world-wide distribution in latitudes ranging from tropical to temperate. It occurs over much of the Australian coastline, bordering sandy beaches, salt marshes and mangroves (Photo 4.22).

Description Marine couch occurs as morphologically distinct variants and chromosomally distinct races. The plants vary from short prostrate, mat forming to tall erect ecotypes, with fine-textured to coarse leaves. Typically the leafy culms emerge from creeping, branched rhizomes. The leaf blades are flat, and taper to a fine point. They occur almost opposite each other on the culms, which have alternate long and short nodes. The flowers (which can occur throughout the year) occur on lead-coloured spike-like panicles, that are 2–8 cm high and 5–10 mm wide.⁷⁵ The leaves have salt glands.⁷⁶

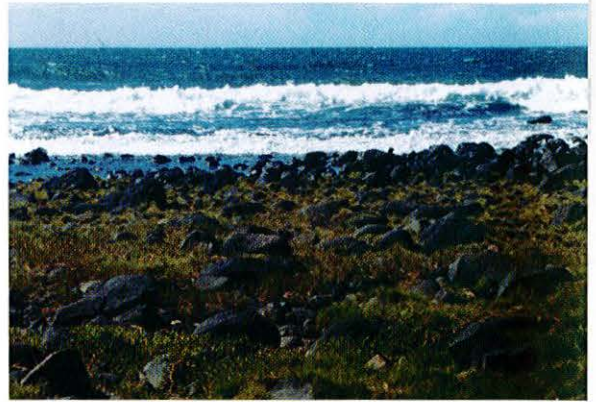


Photo 4.22(b) Marine couch near Bundaberg QLD, coastal location. (Photograph: Matthew Roche).

Grazing Despite its lack of bulk, it can provide useful grazing. The fine-leaved forms have provided valuable grazing during droughts on coastal beef properties, but the more fibrous coarse-textured types have little forage value.⁷⁷

Establishment It rarely sets seed; it is therefore generally vegetatively propagated. It spreads rapidly from rhizomes and stolons, forming a sward of tussocks.

Little is known about its agronomic management (weed control and fertiliser use). There is a report of the application of 'Crop King 88' (832 kg/ha) and urea (273 kg/ha) doubling production over 16 months, although tissue analysis suggested that the plants were still phosphorous deficient.⁷⁸

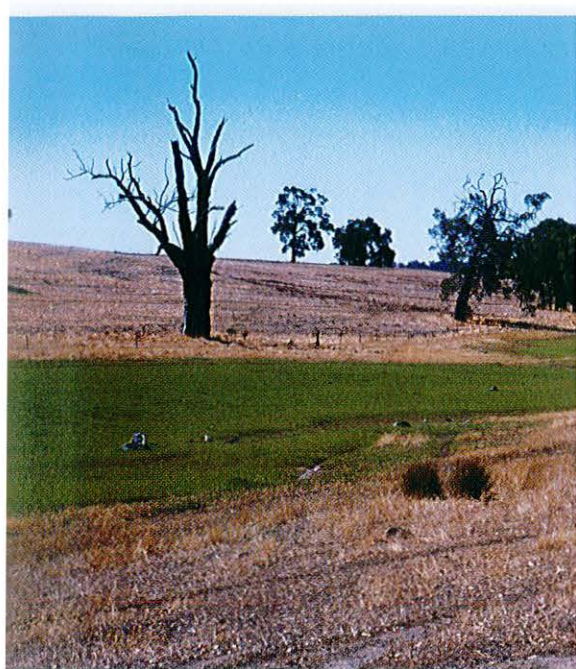


Photo 4.23 Kikuyu growing on saline soil near Mt Barker WA.

4.4.6 Kikuyu

*(Pennisetum clandestinum)*⁷⁹

Kikuyu has not been traditionally recognised as being adapted to saltland. However, recent results from NSW (where the cultivars Whittet and Noonan have grown successfully on scalds with EC_e values in the range 12–20 dS/m),⁸⁰ suggest that it cannot be over-looked as a plant for seepages of low-moderate salinity (Photo 4.23).

Kikuyu has an excellent capacity to use moisture at depths of 0–60 centimetres in the soil profile. In the salinity/waterlogging matrix (Figure 4.1), we have ranked this species as of similar tolerance to rhodes grass (low tolerance to salinity, moderate tolerance to waterlogging).

Occurrence Kikuyu originated as a forest margin species of the highland plateaus of east and central Africa in areas that received 1000–1600 mm of average annual rainfall. It is named after the Kikuyu people of Kenya who traditionally lived east of the Aberdare Mountains in a region where the grass thrives. Seed was introduced to Australia from the Congo in 1919.

Description Kikuyu is a prostrate perennial grass, which may form a loose sward up to about 50 cm high when ungrazed, but becomes a dense turf when grazed. The grass spreads aggressively from profusely branching rhizomes and stolons, which form adventitious roots at



Photo 4.24. Kikuyu leaves close up (Department of Agriculture Photographic Unit).

the nodes. Short leafy branches are produced from the stolons. Leaves expand to 50–100 mm long and 6 mm wide (Photo 4.24). The leaf surface has sparse soft hairs.

The small flower consists of a cluster of 2–4 short (1.5–2.0 mm) spikelets, partly enclosed in the uppermost leaf sheath. Each spikelet has up to 15 delicate bristles up to 1.5 mm long and two florets.

Grazing On non-saline land, productivity is highly dependent on soil fertility. Production on saltland is therefore likely to be affected by the use of nitrogen fertilisers.

No information is available on the nutritive value of kikuyu on saltland. However, on non-saline land digestibility declines from early summer to late autumn. Stands are likely to be of better value in autumn if they are hard-grazed and not allowed to become woody.

Establishment From seed or using stem or root cuttings (depending on cultivar).



Photo 4.25 Rhodes grass in winter near Moora WA (Photograph: Simon Eyres).

4.4.7 Rhodes grass (*Chloris gayana*)⁸¹

Like kikuyu, rhodes grass has not been widely regarded as a saltland pasture species. However this plant has salt glands on the surface of its leaves, and pot trials and field trials in NSW and QLD suggest that it may be of value on mildly saline seepages (Photo 4.25).⁸² We have ranked rhodes grass as having similar tolerance to salinity and waterlogging as kikuyu, and less tolerance to salinity than puccinellia and Tall wheat grass (Figure 4.1).

Occurrence Rhodes grass is believed to have been introduced into Australia around 1900 from South Africa. The most common variety is Pioneer, which appears adapted to alkaline soils with EC_e values less than 20 dS/m.⁸³

Description Rhodes grass is a subtropical tufted perennial grass growing to a height of about 1.5 metres and spreading by means of stolons. These readily root, resulting in the rapid spread of the plant. The plant is readily recognised by its brown coloured flowers consisting of 8–12 spikes clustered at the apex of a rachis (Photo 4.26). The seeds are small and fluffy, averaging 3.3–4.4 million per kilogram.

Grazing Grazing should be managed in summer and autumn so that annual species (especially legumes) establish in the stand following winter rains. Avoid heavy grazing during the first two seasons' growth to allow the stand to thicken through stolon development.



Photo 4.26 Characteristic seed head of rhodes grass (Photograph: Simon Eyres).

Establishment Rhodes grass should be sown in spring at less than 1 cm depth and rates of 1–4 kg/ha. The plant has given poor establishment from seed on saltland trials in NSW.⁸⁴ In this situation, stands may need to be established vegetatively, with grazing being withheld for a number of years to allow stands to thicken. Stands have been reported to be responsive to applications of fertilisers.⁸⁵



Photo 4.27 Balansa clover growing on a waterlogged marginally saline site at Beaufort WA (Photograph: Simon Eyres).

4.5 Legumes

Most forage legumes are relatively sensitive to salinity and waterlogging. However, there is a niche for some of the more tolerant species in mildly saline land and as understorey partners with halophytic species that use water, lower watertables and promote better conditions for shallow-rooted species (see Chapter 7).

Legume species with potential include: balansa and persian clovers, burr medic, *Trigonella balansae*, *Melilotus alba* and *Lotus* species. For at least some of these, substantial improvement will be possible by intra-species selection.⁸⁵

4.5.1 Balansa clover (*Trifolium michelianum*)⁸⁷

Balansa clover is a highly waterlogging-tolerant pasture legume with low tolerance to salinity (Figure 4.1, Photo 4.27).⁸⁸ Its waterlogging tolerance is based around the production of aerenchyma in the stems and roots, which allows oxygen to diffuse to the root tips.⁸⁹

The original cultivar, Paradana, was a relatively long-season variety and produced little seed in environments with rainfall of less than 450 mm. However, a new earlier flowering ecotype, Frontier, was released commercially in the Year 2000 (Photo 4.28). This cultivar has excellent herbage production, a broad adaptation to a variety of soil types and is well adapted to waterlogging.⁹⁰

Occurrence Balansa clover was collected from Turkey in 1973 by the South Australian Department of Agriculture.

Description⁹¹ Annual clover forming hollow stems, growing to 50 cm high. The leaves are trifoliate with no hairs and variable markings. It is a cross pollinating species. The flower heads are



Photo 4.28 Cultivar Frontier (left hand side) flowers about 30 days earlier than cultivar Paradana (right hand side) at Lake Grace WA.

large and contain many flowers, each on a separate stem, which produce two to four seeds. The flower heads are about 25 mm high; they are white with a pink tip. The seeds are yellow, brown or black and are relatively small (0.6 mg). Paradana flowers about 120 days after seeding; Frontier flowers 30 days earlier.

Establishment *Good weed and insect control before seeding is essential.* Being small seeded, balansa clover is a poor early competitor against weeds and is highly susceptible to attack from red legged earth mite. Before seeding, use a knockdown herbicide containing Lemat or Rogor insecticide and treat seed with a sub-clover inoculum. Deep planting (i.e. to greater than one centimetre) is a major cause of poor establishment; apply seed at five kilograms per hectare to the soil surface and cover lightly with harrows. Plant growth will be responsive to phosphorous and potassium; fertilise at seeding with 100 kilograms per hectare superphosphate and 100 kilograms per hectare potash. On suitable sites and non-grazed conditions, vegetative yields of up to five tonnes per hectare are common.⁹²

For re-establishment in subsequent years, sites need to be grazed hard over the summer. The seeds have high levels of hard-seededness, which can be broken by incubation at high temperatures in bare soil in late summer. Given appropriate management, seeds will germinate out of sheep faeces and from the ground to produce dense stands in subsequent years.

Grazing Leaves contain 15–18% protein. In the establishment year, lightly graze to ensure that grasses and broadleaf weeds do not flourish. Stands should not be grazed during the spring flush and flowering.

Balansa clover is highly nutritious to stock. In one experiment, young sheep grazing a mixture of balansa and Concord ryegrass gained weight at a rate of 60 grams per head per day over two months in summer. In contrast, animals grazing the natural pasture, Tall wheat grass or puccinellia lost weight.⁹³

Management. Annual red legged earth mite control is essential. Growth in subsequent years will respond to superphosphate (150 kilograms per hectare) and potash (50 kilograms per hectare).

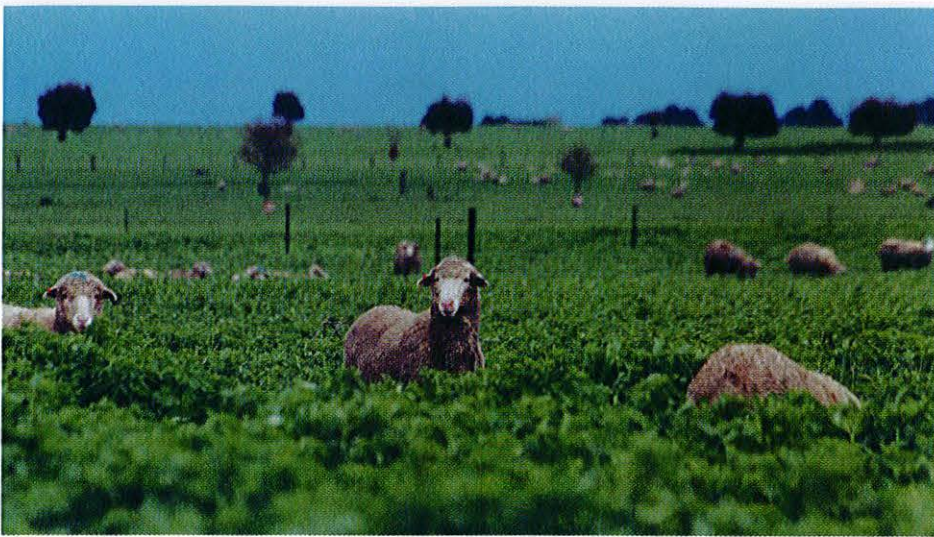


Photo 4.29 Sheep grazing melilotus at Glenthompson VIC (Photograph: Pedro Evans).

4.5.2 Melilotus (*Melilotus alba*)⁹⁴

Melilotus alba is a promising long-season legume on mildly saline waterlogged land, with higher production than clover on high rainfall sites in southern Victoria (Photo 4.29).⁹⁵ The plants generally mature in March the year after sowing and are capable of exceptional growth over the summer, providing moisture is available.

At one site, six regenerating annual lines of *Melilotus alba* produced an average of 13 tonnes per hectare in four simulated grazings over 22 months. In comparison white and strawberry clover produced 52% and 45% of this yield respectively.⁹⁶

The large quantity of dry matter produced over summer offers potential for this species to play a major role in filling the summer-autumn feed gap. However, more research is required to develop genetic lines better suited to grazing by livestock and to Australian conditions. Certain species of melilotus are classed as weeds in Australia.

Occurrence *Melilotus alba* is a legume native to temperate Europe and Asia. It grows well on neutral to alkaline soils. It is widely found in North America, where it provides vegetative cover on disturbed areas. The varieties being tested in Australia were collected from Argentina, where the plant has a reputation as a fodder for saltland.⁹⁷

Description Annual (in Australia) and biennial (in the USA) with a deep taproot and one to 10 ascending flowering stems from one to two metres high. The flower is a raceme with 40 to 80 white flowers. The fruit is a one-seeded pod.

Establishment Little information is yet available on establishment techniques. The normal need to control weeds and insects can be expected to apply. In experimental plantings, the seed has been treated with a commercial lucerne inoculant, sown at 20 kilograms per hectare to the soil surface and covered lightly. Plots have been fertilised with superphosphate (250 kilograms per hectare) containing molybdenum, copper and zinc (0.015, 0.5 and 0.5% respectively) and muriate of potash (150 kilograms per hectare). Fertiliser requirements will be site specific.

Grazing Melilotus contains the secondary metabolite coumarin; in mouldy hay, this breaks down to form dicoumarol, which is toxic and can cause blood loss and death.⁹⁸ Varieties with lower coumarin levels are being selected.

In its early growth stages, melilotus is of similar nutritive value to lucerne. It is highly palatable to animals in spring, but the plants become less palatable as they become woody and the concentrations of bitter tasting coumarin increase.

At Glenthompson in southern Victoria, stocking rates over summer for melilotus-based and control pastures (Tall wheat grass and barley grass) were 2,480 and 520 sheep grazing days per hectare respectively. During grazing, the sheep grazing melilotus had a liveweight gain of 6.5 kg, while there was no gain for animals on control pastures.⁹⁹

Further reading and notes

1 The matrix in Figure 4.1 was compiled using the following key information.

- **Cereals** With waterlogging, barley and wheat grow crown roots that contain aerenchyma – longitudinal air filled channels that allow oxygen to be conducted from shoots to roots (Benjamin and Greenway, 1979; Trought and Drew, 1980). This adaptation enables cereals to tolerate 'low' to 'moderate' waterlogging (McFarlane *et al.*, 1989; Setter and Waters, 2003). Under drained conditions, wheat and barley have 50% decreases in yield at EC_e values of 13 and 18 dS/m respectively (Maas, 1986). However, cereals will be susceptible to salinity/waterlogging interactions – low yields are expected with moderate waterlogging at EC_e levels of 3–6 dS/m (cf. Barrett-Lennard *et al.*, 1999a). Cereals are therefore ranked as tolerant to low salinity.
- **Samphire, saltbush and bluebush** Ecological zonation in samphire, saltbush and bluebush is often apparent across gradients of salinity and waterlogging on the fringes of salt lakes and in revegetated saltland (Malcolm and Swaan, 1989). Samphire (*Halosarcia* species) has high tolerance to salt and waterlogging, and survives partial inundation in winter for several months. Young black-seeded samphire (*H. pergranulata*) plants survived with EC values in the soil water of 200–300 dS/m, and waterlogging had little adverse effect on plant growth at 80 dS/m (English *et al.*, 1999, 2001). Saltbushes (*Atriplex* species) occur at slightly higher elevations in the landscape than samphire. They survived irrigation with seawater (55 dS/m – Watson *et al.*, 1987) and brief waterlogging at 40 dS/m (Galloway and Davidson, 1993a), and grew well at EC_e values of 25 dS/m (Barrett-Lennard and Malcolm, 1995, p. 61). Saltbushes are ranked as tolerant to moderate levels of both salinity and waterlogging. Small leaf bluebush (*Maireana brevifolia*) occurs at higher elevations in saline landscapes than saltbushes. It did not withstand prolonged waterlogging (Malcolm and Swaan, 1989), but grew in soil water at EC values of 60 dS/m (Malcolm, 1963). It is ranked as tolerant to similar levels of salinity as saltbushes (moderate) but low levels of waterlogging.
- **Tall wheat grass and puccinellia** When sown together, Tall wheat grass (*Thinopyrum ponticum*) and puccinellia (*puccinellia ciliata*) show strong ecological zonation with puccinellia occurring in more severely affected land than Tall wheat grass (McCarthy, 1992). In the field, both species occurred over similar EC_e ranges (5–40 dS/m, Hamilton, 1972) but best growth was at 16–32 dS/m (Semple *et al.*, 2003a). In sand cultures under drained conditions, these two species had similar growth responses, with a 50% decrease in growth at about 25–28 dS/m (Marcar, 1987). Zonation therefore appears to be due more to differences in waterlogging than salinity tolerance. In keeping with this, *puccinellia* species are found at the edges of coastal salt marshes in Europe (Armstrong *et al.*, 1985; Cooper, 1982), and (in one case) grew better under waterlogged than drained conditions at EC values in the range 0–25 dS/m (Stelzer and Läubli, 1977). In Australia, puccinellia can withstand periods of partial inundation (Rogers and Bailey, 1963). These grasses are ranked as less tolerant to salinity than the saltbushes and bluebush, but more tolerant than kikuyu and rhodes grass. Puccinellia is more tolerant to waterlogging than saltbush, but Tall wheat grass is less tolerant to waterlogging than saltbush.
- **Kikuyu and rhodes grass** In pot experiments under drained conditions, kikuyu (*Pennisetum clandestinum*) and rhodes grass (*Chloris gayana*) had a 50% decrease in yield at EC_e values of 21 and 23 dS/m respectively (Russell, 1976). However, on winter-waterlogged field sites, best growth occurred with EC_e values in the range 12–20 dS/m, lower values than for puccinellia and Tall wheat grass in the same investigation (Semple *et al.*, 2003a). These grasses have been ranked as less salt tolerant than Tall wheat grass and puccinellia, but between these grasses in waterlogging tolerance.

Further reading and notes

• **Salt water couch, marine couch and distichlis** It is difficult to separate these grasses in the salinity/waterlogging matrix; they have been ranked as having high tolerance to waterlogging, and similar (moderate) tolerance to salinity as puccinellia and Tall wheat grass. Salt water couch (*Paspalum vaginatum*) grew in shallow standing water at lower locations in the landscape than puccinellia (Rogers and Bailey, 1963). In NSW, it gave better cover on two winter-waterlogged sites with EC_e values in the range 16–40 dS/m, than at a non-waterlogged site in this EC_e range (Semple *et al.*, 2003a). It is tolerant to irrigation with water with EC_w values between 6 and 22 dS/m (Malcolm and Smith, 1971). In glasshouse experiments, 50% decreases in shoot growth occurred at EC_w values between 18 and 29 dS/m, and plants survived EC_w values of 40 dS/m (Dudeck and Peacock, 1985). Notwithstanding this tolerance, we do not see saltwater couch growing with samphire. Marine couch (*Sporobolus virginicus*) also grew in standing water, forming aerenchyma in the rhizomes and new adventitious roots from the nodes of inundated stems (Naidoo and Naidoo, 1992). It survived salt concentrations in excess of seawater, but gave better growth at lower salinities (Gallagher, 1979, 1985). At Laidley in southern Queensland, there was more than 90% survival of marine couch in seepage areas with EC_e values of 6–10 dS/m in the upper 20 cm of the soil profile and it was associated with saltwater couch (Truong and Roberts, 1992). At Mahasarakam in NE Thailand, it had better survival (75–100%) than distichlis at EC_e values between 20 and 42 dS/m (Yuvaniyama and Arunin, 1991), but this may be a function of the particular genotypes tested. It has been argued that the 'NyPa forage' clone of *Distichlis spicata* is highly tolerant to both salinity and waterlogging (Leake, 1999). Under drained conditions, NyPa forage tolerated electrical conductivities in the root zone as high as 80 dS/m (145% of the salinity of seawater), although best growth was at less than 20 dS/m. The plant is also known to have exceptionally efficient salt glands in the leaves (Liphschitz and Waisel, 1982). Under waterlogged conditions the plants survived 40 dS/m (73% of salinity of seawater – Leake *et al.*, 2001). The roots were able to form aerenchyma.

• **Balansa clover** Balansa clover (*Trifolium michelianum*) has hollow stems, forms aerenchyma and will grow in severely waterlogged soil. However, its salinity tolerance is lower than that of cereals (50% decrease in growth at 7 dS/m – Rogers and Noble, 1991). This plant is ranked as having moderate to high tolerance to waterlogging, but low tolerance to salinity.

- 2 There are few authoritative data on the place in the salinity/waterlogging matrix of indicator species. One exception is annual ryegrass, which had a 50% decrease in yield in drained sand culture at 13 dS/m (Marcar, 1987).
- 3 Studies that have tested the adaptation of forages for Australian saltland include:
 - Halophytic tolerant shrubs – Malcolm and Clarke (1971), Malcolm and Swaan (1989)
 - A range of grasses and forbs – Rogers and Bailey (1963), Russell (1976), Semple *et al.* (1998, 2003a)
 - Mildly salt tolerant clovers – Rogers and Noble (1991), Rogers and West (1993), Evans (1995).
- 4 The taxonomy of the samphires has been revised (Wilson, 1980). The genus *Halosarcia* was formerly known as *Arthrocnemum*.
- 5 Under glasshouse conditions, *Halosarcia pergranulata* grew at salt concentrations of 800 mM NaCl (=EC of 80 dS/m) and survived at salt concentrations up to 2,000 mM NaCl (=EC of 200 dS/m) (Short and Colmer, 1999; English *et al.*, 2001). In the field *Halosarcia pergranulata* has been observed growing on mudflats waterlogged to the surface for 20 months (T. Colmer, personal communication). Under waterlogged conditions, *Halosarcia pergranulata* forms highly porous adventitious roots (English *et al.*, 1999). In other species, the formation of these roots allows oxygen to be conveyed from the shoots to the root tips enabling the tissues to survive in the absence of oxygen (reviewed by Barrett-Lennard, 2003).

- 6 Mitchell and Wilcox (1994).
- 7 Barrett (2000) found ash concentrations in the range 32–42% in *Halosarcia halocnemoides* and 32–46% in *H. pruinosa*. Jeremy English (personal communication, 2002) found ash concentrations in the range 22–39% for *H. pergranulata* growing on mudflats near Hannan's Lake WA.
- 8 Malcolm (1964).
- 9 Smith and Malcolm (1959).
- 10 Malcolm and Clarke (1971); Malcolm and Swaan (1989).
- 11 Published field grazing trials include: Clarke (1982), Malcolm and Pol (1986), Warren and Casson (1992a,b, 1994) and Casson and Warren (1994). Pen feeding trials have been conducted by Warren *et al.* (1990) and Atiq-ur-Rehman (1995).
- 12 *In vivo* digestibilities from diets of 100% saltbush leaf with sheep in pen feeding studies (Warren *et al.*, 1990; Atiq-ur-Rehman, 1995).
- 13 Range from 82 samples (database of B.E. Warren and T. Casson, unpublished).
- 14 Average of 96 samples (database of B.E. Warren and T. Casson, unpublished).
- 15 Barrett-Lennard and Galloway (1996); Barrett-Lennard and Malcolm (1999).
- 16 Own observations (northern agricultural area) and Hearn (1991) (south coast).
- 17 Prior to 1984, this species was known as *Atriplex rhagodioides*.
- 18 Malcolm and Swaan (1989).
- 19 In nutrient solution culture, it will withstand salinities of 75 dS/m (~140% of the salinity of seawater – cf. Figure 3.7, Aslam *et al.*, 1986).
- 20 Galloway and Davidson (1993a) have examined the effects on growth, ion relations and water relations of this plant in nitrogen bubbled (simulating waterlogging) nutrient solutions. The plants had excellent regulation of chloride uptake to the shoots even at 40 dS/m, due to an ability to maintain salt exclusion at the root surface and regulate rates of flow in the xylem through stomatal control (discussed by Barrett-Lennard, 2003).
- 21 Wilson (1984).
- 22 See Strawbridge and Barrett-Lennard (1993).
- 23 Malcolm (1963), Barrett-Lennard and Gavelle (1994).
- 24 The concept of saltbush ecotypes needs to be considered with care: they are quite dissimilar to the ecotypes of self-pollinating species such as cereals. The genetic composition of seed of volunteering natural stands of saltbushes can change with time as the progeny of crosses between male and female plants establish in the stand and also become engaged in those crosses. Thus, depending on when and where they were collected, seed of the ecotypes 'Rivermor' and 'Meeberrie' might have quite different genetic properties.

Further reading and notes

- 25 Malcolm and Pol (1986).
- 26 This species has been grown with seawater irrigation in Israel (Pasternak *et al.*, 1985) and at salinities up to and exceeding seawater in the USA (Glenn and O'Leary, 1984, 1985). It grew exceptionally well on saline land in Pakistan (Qureshi and Barrett-Lennard, 1998).
- 27 Galloway and Davidson (1993b).
- 28 Nicholson (1999).
- 29 Wilson (1984).
- 30 Nicholson (1999).
- 31 Millsom (2001).
- 32 Wilson (1984).
- 33 For example, the prostrate ecotype from Rottneest Island WA is highly unpalatable, whereas the prostrate ecotype from Geraldton WA is highly palatable.
- 34 Wilson (1984), Mitchell and Wilcox (1994).
- 35 Prior to 1975 this species was known as *Kochia brevifolia*.
- 36 Malcolm (1963) measured the salinity and moisture in soil profiles at several bluebush sites on the edge of Lake Jilikin, east of Kulin in Western Australia. If we assume that the salt in each soil sample was dissolved in the water found in those samples, then it can be calculated that the plants were able to grow at EC_w values in excess of 60 dS/m (i.e. 110% of seawater). Glenn and O'Leary (1984) have grown the plant hydroponically at EC_w values up to 72 dS/m.
- 37 Wilson (1984).
- 38 Range of seven samples (database of B.E. Warren and T. Casson, unpublished). Reports (Glenn and O'Leary, 1984) of ash concentrations in the range 30–50% seem anomalous.
- 39 Control of relative humidity is essential if bluebush is to remain at least partially germinable during storage. Bluebush seed with an initial germinability of 50–60% became non-germinable after three months storage at 54% and 84% relative humidity, but lost only about half of its germinability over two years if stored at 9% relative humidity (Malcolm, 1963).
- 40 Other grasses that have been tested on saltland in Australia include:
 - Vetiver grass (*Vetiveria zizanioides* – Truong 2000; Truong and Baker, 1998; Gordon *et al.*, 1998)
 - Green couch (*Cynodon dactylon* – Gordon *et al.*, 1998; Semple *et al.*, 2003b)
 - Brown beetle (or 'kallar') grass (*Diplachne fusca* – Sandhu *et al.*, 1981; Qureshi *et al.*, 1982; Malik *et al.*, 1986; Warwick, 1994; Gordon *et al.*, 1998).There has also been screening in the glasshouse (Russell, 1976; Marcar, 1987; Rogers *et al.*, 1996) and field (Rogers and Bailey, 1963; Semple *et al.*, 2003a,b) of a wider range of species.

- 41 In a survey of the Upper South East of SA, puccinellia was found to be grown on 67% of all identified saltland (Morris, 2001). The more favourable experiences that farmers have with puccinellia in South Australia may be due to the highly (alkaline) nature of these soils. Further work is required to clarify this issue.
- 42 Hamilton (1972), Semple *et al.* (2003a).
- 43 One critical adaptation to waterlogging appears to be an ability to form aerenchyma in the roots (Stelzer and Läuchli, 1977, 1980).
- 44 Oram (1990).
- 45 Herrmann (1996), Herrmann and Booth (1996), Morris (2001).
- 46 Smith *et al.* (1998).
- 47 McCarthy (1992).
- 48 Saunders (1996) suggests the use of a conventional closed-front cereal harvester. Use the maximum drum speed with a drum clearance of 1.5 mm front and rear. Cut off the air blast completely by loosening belts and covering vents. Use a wheat riddle on top, a lupin screen fitted to the rear and a rape screen on the bottom. The puccinellia seed is taken off into the seconds box.
- 49 The taxonomy of this species is confusing. Other Latin names encountered in the literature include: *Agropyron elongatum*, *Thinopyrum elongatum*, *Elytrigia pontica* and *Elytrigia elongata*. We have adopted the species name used here based on the advice of Smith (1996).
- 50 Hamilton (1972), Nichols (1998), Semple *et al.* (2003a).
- 51 Nichols (1998, 1999); Chin (1999).
- 52 Stands of Tall wheat grass can use up to 4 mm/day of groundwater in summer (Bleby *et al.*, 1997). There are reports of surface soil salinities (EC_e values in the upper 10 cm of the soil profile) declining from 5.3 to 1.2 dS/m in four years (Nichols, 1999).
- 53 This possibility was canvassed by Barrett-Lennard and Ewing (1998) and Chin (1999). Robinson *et al.* (1999) found that watertables at a moderately saline site in Western Australia were about 20 cm lower in summer beneath Tall wheat grass/balansa mixtures than beneath balansa clover alone.
- 54 Hanson (1972), Oram (1990), Smith (1996).
- 55 Teakle and Burvill (1945).
- 56 Halpern (1976), Semple *et al.* (1998, 2003a), Smith *et al.* (1998), Nichols (1999).
- 57 Smith *et al.* (1994).
- 58 Nichols (1999).

Further reading and notes

- 59 Carland *et al.* (1998).
- 60 Saunders (1996).
- 61 Glasshouse studies in WA showed that under drained conditions, the plant can tolerate electrical conductivities in the root zone (EC_w) levels as high as 80 dS/m (145% of the salinity of seawater), although best growth was at EC_w levels less than 20 dS/m. Under waterlogged conditions the plants survived at EC_w levels of 40 dS/m (73% of salinity of seawater – Leake *et al.*, 2001).
- 62 Yensen *et al.* (2000).
- 63 Liphschitz and Waisel (1982).
- 64 Sargeant *et al.* (2001).
- 65 This species also has the common name of seashore paspalum. In 1976, some taxonomists tried to change the Latin name of this species to *Paspalum distichum*. The ensuing debate lasted for seven years. Finally *Paspalum vaginatum* O. Swartz was recognised as the correct name (Report of the Committee for Spermatophyta, 1983). However, the confusion in nomenclature is reflected in some publications where *P. distichum* is used in place of *P. vaginatum*.
- 66 Duncan and Carrow (2000).
- 67 Teakle and Burvill (1945) refer to its growth on saline soils at the Chapman Research Station.
- 68 Semple *et al.* (1998).
- 69 Malcolm (1977).
- 70 Malcolm and Smith (1971).
- 71 Dudeck and Peacock (1985).
- 72 After Duncan and Carrow (2000).
- 73 Malcolm (1986a).
- 74 Gordon *et al.* (1998), Loch and Lees (2001), Semple *et al.* (2003b).
- 75 Gardner (1952), Black (1978), Smith-White (1988), Loch and Lees (2001).
- 76 Naidoo and Naidoo (1998).
- 77 Gordon *et al.* (1998).
- 78 Gordon *et al.* (1998). 'Crop King 88' is 15.3% N, 4.0% P and 11.7% K (by weight).
- 79 After Mears (1970) and Oram (1990).

- 80 Semple *et al.* (1998, 2003a).
- 81 After Oram (1990), Sudmeyer *et al.* (1994).
- 82 Lipschitz *et al.* (1974), Russell (1976), FitzGerald and Fogarty (1992), Gordon *et al.* (1998), Semple *et al.* (1998, 2003a).
- 83 Semple *et al.* (2003a).
- 84 In trials with Pioneer on six sites in NSW, there was an acceptable success with seed (more than one plant per metre of row) in only one of twelve attempts (Semple *et al.*, 2003a).
- 85 Application of superphosphate (550 kg/ha), ammonium sulphate (100 kg/ha) and gypsum (2.5 t/ha) has been reported to give a 76% yield benefit to a stand in south-east Queensland (Gordon *et al.*, 1998).
- 86 Craig (1999).
- 87 This species has also been referred to as *Trifolium balansa*. Accessible information on balansa is available from a range of sources including: Cransberg (1990), Rogers and Shaw (1991) and Latta *et al.*, (1999).
- 88 At Dumbleyung in WA, cultivar 'Paradana' had 50% decreases in yield at EC_{1.5} values of 100 mS/m, equivalent to EC_e values of about 13 dS/m (Evans, 1995).
- 89 New roots that formed during 15 days of waterlogging had nearly double the porosity of new roots grown without waterlogging (Rogers and West, 1993).
- 90 Craig *et al.* (1999).
- 91 After Cransberg (1990).
- 92 Evans (1995).
- 93 Unpublished experiment by B.E. Warren and T. Casson – cited by Evans (1995).
- 94 Although not a true clover, this species goes by the common name of white sweetclover in the USA.
- 95 This account is based on: Evans (2001), Evans *et al.* (2001), Thompson *et al.* (2001).
- 96 These data are for the Woornadoo site – Table 1, Evans (2001). This site was a self-mulching clay with a pH of 7 and EC_{1.5} values between 1 and 3 dS/m.
- 97 Maddaloni (1986).
- 98 Hynd (2001).
- 99 Thompson *et al.* (2001).

Chapter 5

Establishing saltland pastures





The lowest-cost method of establishing halophytic shrubs is fencing off the affected area, restricting grazing and allowing the site to regenerate naturally.

In this Chapter

Seed quality and germination

- Age of seed
- Fruit fill
- Hard seededness
- Inhibitors

Environmental stresses and establishment

- Salinity
- Waterlogging
- Seed burial
- Moisture deficiencies and weed competition
- Insect attack

Establishing shrubs on saltland

- Direct (niche) seeding
- Planting nursery-raised seedlings
- Natural regeneration

Establishing salt tolerant grasses

Key points

- **Successful saltland plant establishment requires the use of good quality fresh seed**
- **Germination can be improved by scarifying or soaking the seed**
- **Salinity and waterlogging can reduce germination, as can planting seeds too deeply, deficiencies of moisture and insect attack**

Establishing saltland plants can be difficult, as the seeds are generally small and exposed, and the seedlings are vulnerable. This Chapter focuses on the factors affecting, and ways to optimise, saltland plant establishment.

5.1 Seed quality and germination

Farmers are advised to test all saltland pasture seed for its ability to germinate, before purchase.¹

Saltbush (*Atriplex* species) often has poor germination. Figure 5.1 shows that germination of river saltbush can be less than 25%.

Germination of the seed of saltland pasture species is affected by age of seed, fruit fill, hard-seededness and the presence of inhibitors.³

5.1.1 Age of seed

In general, saltland pasture seed germination decreases over time, so use the freshest seed possible.

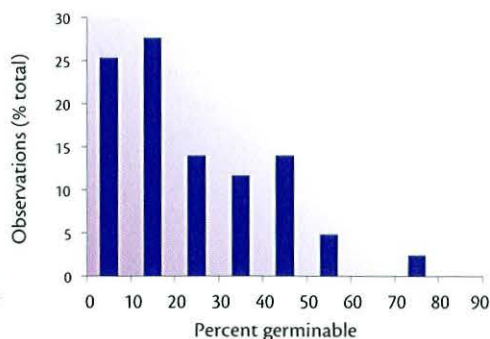
Storage affects the longevity of seed in varying ways. In general, saltbush seed can be stored for up to three years without losing its ability to germinate.⁴ However, for small-leaf bluebush storage conditions are critical; its seed loses all ability to germinate within three months at relative humidities of 54–84%, and half its ability to germinate after two years at a relative humidity of 9%.⁵

Figure 5.1 Germinability of samples of river saltbush (*Atriplex amnicola*) tested by the WA Department of Agriculture between 1988 and 1990.²

5.1.2 Fruit fill

Saltbush commonly propagates via its fruit, which consists of two bracts enclosing (in some cases) a single seed (Photo 5.1). Among the commonly-used saltbushes, germination is affected by seed fill in the fruit, which in turn is affected by:⁶

- **Fertilisation.** Most of the important saltbush species for saltland revegetation are *dioecious* – that is, with male and female flowers occurring on separate plants. Fertilisation occurs when wind carries pollen from male flowers to female flowers. If male plants are not close to female plants fruits still develop, but a substantial proportion are empty.⁷
- **Embryo abortion.** Saltbush fruits ripen over six to seven months. In stands with an appropriate ratio of male to female plants nearly all fruits initially develop embryos, but many abort as the fruits ripen.⁸ Embryo abortion increases with waterlogging during fruit ripening.⁹ Improvements in fruit fill and ability to germinate may be possible by grading fruits according to size.¹⁰



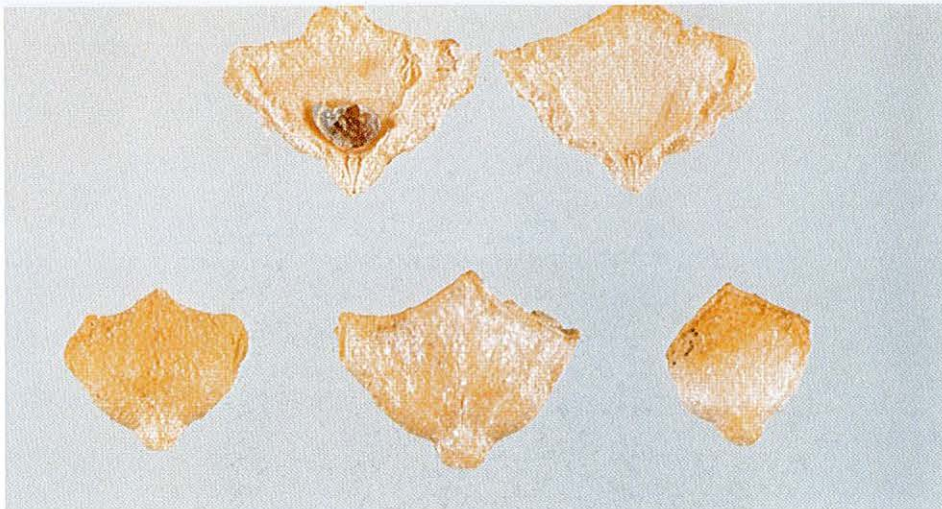


Photo 5.1 (a)

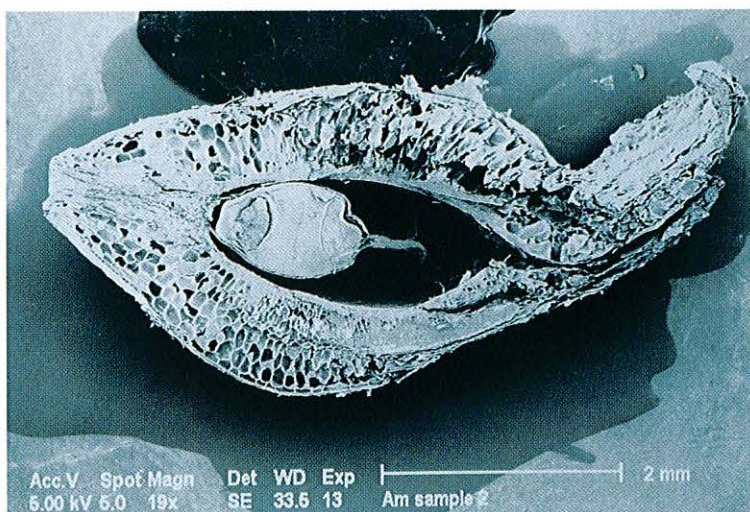


Photo 5.1 (b)

Photo 5.1 Detail of saltbush fruits. (a) fruits of creeping saltbush. Left hand side, view of fruit with upper bract in place; right hand side, view of same fruit with upper bract removed to reveal seed. (b) cross-section of fruit of river saltbush.

5.1.3 Hard seededness

Some saltland species are hard seeded, i.e. their tough seed coat prevents water entering the seed and beginning germination. Hard seededness is an adaptation enabling saltland plants to maintain a seed-bank over many years, in response to unpredictable and harsh climatic conditions.¹¹ In the natural condition, a proportion of the seed softens with time, enabling them to germinate once soil moisture conditions become favourable.

When sowing hard seeded species, the seeds can be mechanically scratched (scarified), to break the seed coat.

5.1.4 Inhibitors

The bracts of saltbush fruits can contain high levels of salts, which inhibit or delay germination. Evidence for this comes from studies showing that removing the bracts can increase the germination of the seed and washing saltbush fruits can increase germination percentages to levels similar to naked seed.¹² Bracts can contain salt concentrations of up to 30% dry weight.¹³ However, washing saltbush fruits does not improve germination in all cases.¹⁴ We recommend fruits be washed under a stream of running water for 10 minutes or so if the fruits contain high concentrations of salt.



Photo 5.2 Emerging seedlings of river saltbush are only a few millimetres high.

5.2 Environmental stresses and establishment

Emerging seedlings on saltland are mostly very small (Photo 5.2). Establishment, even of good quality seed, can be decreased by environmental stresses including salinity, waterlogging, seed burial, moisture deficiencies and weed competition and insect attack.

5.2.1 Salinity

Salinity reduces germination of all plants, including halophytes. Figure 5.2 shows the effects of salinity on three saltland species: a samphire (*Halosarcia halocnemoides* subsp. *halocnemoides*), puccinellia (*Puccinellia ciliata*) and balansa clover (*Trifolium michelianum*). Not surprisingly, the samphire had higher germination under saline conditions than the less salt tolerant puccinellia and balansa clover. Nevertheless, the data show that virtually no germination would have occurred with any species at the salinities typical of seawater (~55 dS/m).

While plants may be unable to germinate at high levels of salinity, they can successfully colonise saline environments by waiting for salt levels to fall after rainfall. Steve Vlahos reports an experiment in which fruits of river saltbush were placed in water with an electrical conductivity of 50 dS/m.¹⁶ Not surprisingly, there was virtually no germination of the fruits. After 50 days, the fruits were removed from the saline solutions, washed and returned to distilled water; they then germinated after 29 days. It appears many halophytes have the capacity to suspend their germination under saline conditions and reanimate once salinity decreases.¹⁷

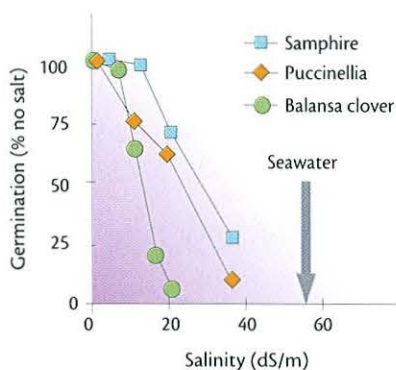


Figure 5.2 Effects of salinity on the germination of three saltland species.¹⁵



Photo 5.3 (a)



Photo 5.3 (b)

Photo 5.3 Typical damage due to waterlogging and inundation. (a) during waterlogging (b) after waterlogging.

5.2.2 Waterlogging

Waterlogging has the potential to damage the germination of nearly all plant species. As noted in Chapter 3, waterlogging causes soils to become oxygen deficient, plant tissues to become energy deficient and seeds to rot (Photo 5.3).

Interestingly, waterlogging can adversely affect the germination of saltbush seeds at the soil surface. As we have previously noted (Photo 5.1), in saltbushes the seed is enclosed between two bracts. Waterlogging can decrease seed germination because the air space between the bracts becomes saturated, making it difficult for the seed to receive sufficient oxygen for germination. River saltbush bracts are about 0.8 mm thick, whereas wavy leaf saltbush bracts are only 0.2 mm thick. When these fruits are

placed on the surface of saturated soil, capillary action draws water into the cavity between the bracts (Figure 5.3). Under these conditions, the shortest path for the diffusion of oxygen to the germinating seed is through the water-filled intercellular spaces of the bracts. This barrier to oxygen diffusion is greater in the 'thick-bracted' river saltbush than in the 'thin-bracted' wavy leaf saltbush. Not surprisingly therefore, the levels of germination under waterlogged conditions with river saltbush are lower than with wavy leaf saltbush.¹⁸

These observations on the effects of waterlogging on the germination of saltbush fruits have important implications for the method of testing germination ability. Many workers test saltbush germination on waterlogged filter papers in petri-dishes. For the reasons outlined above, this method will give inaccurate results for many species. However, the weighed replicate test (see box on p. 86) overcomes this problem by germinating the fruits at a tension (height above water) of about 15 cm.

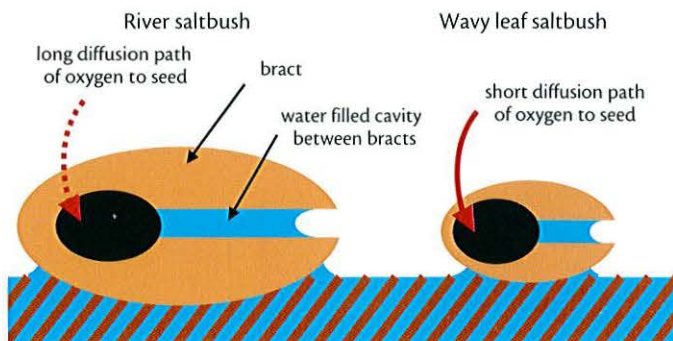


Figure 5.3 Waterlogging saltbush fruits has a more detrimental effect on the germination of river saltbush (thick bracts) than wavy leaf saltbush (thin bracts).

5.2.3 Seed burial

Some salt tolerant plants, including many saltbushes, require sunlight during germination.¹⁹ Seed burial can therefore decrease establishment. In a nursery experiment, Steve Vlahos found that covering fruits of river saltbush with two millimetres and five millimetres of soil decreased germination by 50% and 95% respectively.²⁰

5.2.4 Moisture deficiencies and weed competition

Moisture may limit establishment at any stage from germination onwards. Moisture deficiencies are exacerbated by weed competition (Photo 5.4).

Saltbush fruits are deposited on the soil surface, making them susceptible to dry conditions during germination and early root growth. Controlling grasses using an appropriate herbicide (such as carbetamide) can improve saltbush establishment under moisture deficient conditions (Photo 5.5).²¹



Photo 5.4 Competition for moisture from annual ryegrass in the foreground has prevented establishment of wavy leaf saltbush and quailbrush (visible where there is less competition in background).



Photo 5.5 Controlling weeds. Carbetamide has been used to control weeds in the river saltbush rows in the centre but not on the left.

5.2.5 Insect attack

Control of insects is *critical* for establishment. Immediately after germination, saltbush seedlings can be killed by red-legged earth mite and killed or weakened by Rutherglen bugs, aphids, grubs and locusts.

5.3 Establishing shrubs on saltland

There are three methods for establishing salt tolerant shrubs on saltland:

- (1) direct (niche) seeding
- (2) planting nursery-raised seedlings
- (3) natural regeneration

The method used depends on the species to be grown, the soil type, site characteristics, climate and financial considerations.

5.3.1 Direct (niche) seeding

Seeds on saltland germinate naturally in protected niches (Photo 5.6). Niche seeders attempt to produce such protected sites artificially.²² In general, establishing shrubs using niche seeders is substantially more effective than conventional cultivation and sowing.²³

Niche seeders deposit saltbush fruits and a covering of vermiculite at 1–3-metre intervals on a raised M-shaped mound (Photo 5.7).



Photo 5.6 Seeds germinate naturally on saltland soils in available niches.

The shape of the mound promotes leaching of salt from the soil around the fruits by rain. The vermiculite acts as mulch; it decreases evaporation, helps retain moisture around the fruits and reduces the movement of salt back into the seedbed. Elevating the seedbed above the surrounding soil reduces waterlogging. Sprays of black paint or bitumen over the placement of fruits and vermiculite can help stabilise the placements and increase seedbed temperatures.²⁴



Photo 5.7 Mound, mulch and black paint spray left by niche seeder.

The keys to successful niche seeding are:

- **Good site selection.** Best results have been achieved in WA using the niche seeder on sandy and deeper duplex soils.²⁵ Areas with extreme salinity and/or waterlogging should not be sown; neither should relatively non-saline sites. In the past, we have recommended that suitable sites grow patchy to continuous barley grass.²⁶ Better predictions of success are achieved by choosing sites *without* the key marker species of non-saline soils (annual legumes and capeweed).²⁷
- **Use seeding rates appropriate to the quality of the seed.** For good establishment, seed germination should be tested in a commercial laboratory or by the farmer *before sowing* (see box on p. 86). Seed should be sown at sufficiently high rates to have 50 *germinable seeds per placement*.
- **Control insects.** Check regularly for red-legged earth mite, Rutherglen bugs and aphids. Red legged earth mite may be killing germinating seedlings even before they have emerged from the placements of vermiculite mulch. Eradicate insects by spraying with Rogor® or Lemat®.
- **Control weeds** by hard grazing in the year before establishment and herbicides in the year of establishment. If weed seeds are available, niche seeding can also encourage the establishment of weeds (Photo 5.8). River saltbush establishment can be enhanced by spraying each seed placement with the grass-specific pre-emergent herbicide, carbetamide. In at least one instance, good post-emergent control of grasses and capeweed has been obtained with a mixture of Verdict® and Lontrel®.²⁸
- **Deep rip** to remove traffic pans in sandy soils (see Chapter 7).
- **Reduce waterlogging and inundation.** Reduce overland flow onto saltland using seepage interceptors, drains and banks. Remove surface water from saltland using W-drains (see Chapter 7). Plan niche seeding so mounds and furrows direct excess water into surface drains.
- **Cultivate sites** before niche seeding to improve leaching of salt from the soil (see Chapter 7) and break up large clods.
- **Sow sufficiently early** to increase the likelihood of follow-up rain. Delay seeding until early spring if winter waterlogging is likely.
- **Control grazing** by farm and feral animals until plants are well established.



Photo 5.8 Weeds in the niche competing against the establishment of saltbushes. (a) ice plant, (b) annual ryegrass.

Photo 5.8 (a)



Photo 5.8 (b)

Testing the germination of saltbush fruits – the weighed replicate test²⁹

Take a weighed sample of seed material. Spread it in a line onto thick paper towel and cover this with another sheet of paper towel. Roll these sheets up and stand them on end in a beaker of water with the line of fruit/seed 15 centimetres above the water level. This provides a good gaseous exchange for the seed within the bracts and promotes germination.

Count the number of germinated fruits at seven, 14 and 21 days. Most saltbush fruits germinate between the seventh and 14th day, but the test lasts longer to account for late germination. The results are expressed as the numbers of germinants per gram of material tested.



Photo 5.9 Successful establishment of mixed saltbush (*Atriplex*) species using niche seeder in South Australia.

Thousands of hectares of saltbush have been successfully established on salt affected land using niche seeders (for example Photo 5.9). One of the best results we have seen was obtained by a farmer with saline sandy soils near Cranbrook WA. This farmer was part-owner of a niche seeder and was able to establish an excellent

20 hectare stand of saltbush for \$155 per hectare. In this case, the sowing of the saltbush was only a small part of the total revegetation process (see box below). Revegetation required planning, site preparation, seeding, post-seeding monitoring and management.

Sequence of events to achieve successful saltbush stand at Cranbrook WA

Date	Activity
May 1989	Soil scarified to promote leaching of salt, weed germination and improve tilth (allowed identification of areas with dense annual ryegrass).
June 1989	Site flooded. Farmer marked lines for W-drains by observing and pegging flow of surface water.
September 1989	Areas with barley grass sprayed with mixture of SpraySeed® (weed control) and Le-Mat® (red-legged earth mite control), then scarified, harrowed and niche seeded with mixture of: <ul style="list-style-type: none"> • wavy leaf saltbush (150 g/km row) • river saltbush (100 g/km row) • grey saltbush (30 g/km row) • quailbrush (50 g/km row) • Old man saltbush (25 g/km row) • WA golden wattle (25 g/km row) Areas with annual ryegrass sown to Tall wheat grass.
December 1989	W-drains installed with plough.
April 1991	Site grazed (21 sheep/ha) for two months.

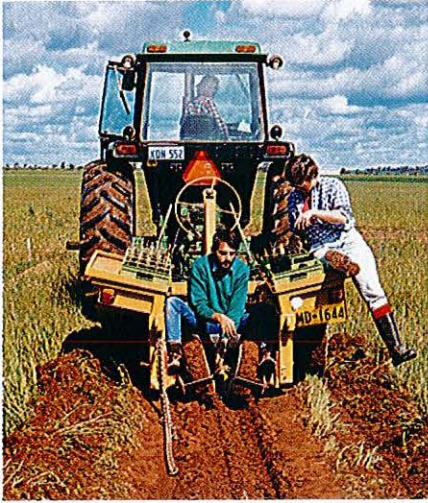


Photo 5.10 Planting saltbush seedlings with a commercial tree planter

5.3.2 Planting nursery-raised seedlings

Nursery-raised seedlings can be planted with a commercial tree planter (Photo 5.10). Our results and farmer experience show increased reliability from nursery-raised seedlings (Photo 5.11).³⁰ Unfortunately, nursery-raised seedlings are relatively costly with most nurseries selling saltbush seedlings for 25–50 cents each. On this basis, a stand of 1000 plants per hectare would cost \$250–500 per hectare, plus transport, site preparation and planting costs.



Photo 5.11 Planting nursery-raised seedlings is relatively reliable. This peat pot was not planted properly but the seedling still survived.



Photo 5.12 Alleys of saltbush at Pingaring WA (Photograph: Michael Lloyd).

Costs can be reduced by:

- **Growing seedlings in a home nursery.** We have met a farmer who propagates saltbushes from cuttings in a simple home nursery at an estimated cost of six cents each. At a planting density of 1000 plants per hectare, this farmer is only paying \$60 per hectare for plants. For information on propagating saltbushes from cuttings see box on p. 89.
- **Planting fewer seedlings per hectare.** This strategy could be linked to alley farming in which rows of saltbush are interspersed with bays of salt tolerant grasses, balansa clover or melilotus (Photo 5.12 – also see Chapter 7).

There has been some interest in the use of bare-rooted seedlings (seedlings without soil around the roots). These have given good results when planted into non-saline soils. However, in our experiments on highly saline soils, establishment of bare-rooted river saltbush seedlings has been poor.³¹ We attribute these failures to:

- **Damage to the roots** during the removal of seedlings from soil in the nursery and during planting. Broken roots allow salt to move into and kill the plant.
- **Lack of salt hardening.** This causes plants to experience a severe osmotic shock when transplanted into saline soils.



Photo 5.13 (a)



Photo 5.13 (c)



Photo 5.13 (b)

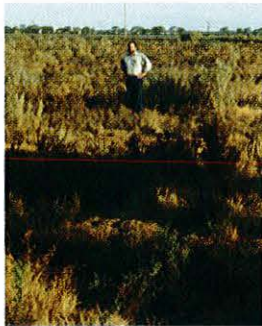


Photo 5.13 (d)

Photo 5.13. Natural regeneration at a saline site over five years at Nangeenan WA, (a) original condition of site, (b) site became stabilised by a stand of ice plant, (c) small leaf bluebush established from nearby sources of seed, (d) condition of site after five years.

5.3.3 Natural regeneration

The lowest-cost method of establishing halophytic shrubs is fencing off the salt-affected area, restricting grazing and allowing the site to regenerate naturally. This is particularly appropriate for bare areas affected by severe valley floor salinity. Once grazing is reduced,

samphire (*Halosarcia* species) will establish provided there are sources of seed close by. Revegetation can also be helped by roughening the soil surface to help catch the seed.

Natural regeneration is also possible with small leaf bluebush (*Maireana brevifolia*) on saline soils not subject to waterlogging (Photo 5.13).

Preparing cuttings of saltbush³²

Parent material. Take cuttings from new shoots of actively growing plants. Use non-woody material. When collecting in the field, prevent wilting of shoots by sealing in plastic bags. Keep shoots cool. Plant within one to two days of collection.

Growth medium. Plant cuttings into free-draining containers of sharp white sand or river sand, at least 10 cm deep. Do *not* use standard potting mixes as organic matter inhibits root initiation and growth. Wet sand thoroughly.

Making cuttings. Cut shoots with stem diameter of two to three millimetres into twigs seven to 10 cm long. Remove leaves from the lower 2/3 of the twig. Dip the leaf-free end of twig in water and then in commercial rooting powder. Shake off excess powder. Place cuttings in sand, leaving three to four centimetres projecting above sand. Place cuttings about five centimetres apart in container.

Caring for cuttings. Cuttings must be kept warm and moist. Cover container with plastic film and keep in warm, semi-shaded environment. Remove film daily to water with gentle mist.

Potting out. Rooting takes two to three weeks. Once roots have formed, pot out into 15 centimetre deep pots or bags filled with free draining potting mixture. Rear in sheltered position for a further four to six weeks then harden seedlings in the open.

5.4 Establishing salt tolerant grasses³³

Two salt tolerant grasses are mainly used for saltland revegetation in southern Australia: Puccinellia (*puccinellia ciliata*) and Tall wheat grass (*Thinopyrum ponticum*). Although a perennial, puccinellia only grows actively in winter and must compete with other winter-growing annuals. Puccinellia can be an excellent pioneer species of bare alkaline saltland. In contrast, Tall wheat grass remains green and grows in summer and winter. It is better suited to less severely waterlogged land and, once established, competes well with other plants; it is suited to areas with a cover of Mediterranean (sea) barley grass and can be planted with legumes and other perennial grasses as companion species.

The keys to successful establishment of salt tolerant grasses are similar to those for the establishment of shrubs.

- **Site selection.** Sites for puccinellia and Tall wheat grass should receive more than 350 mm of annual rainfall and should be dry at the surface in summer. Sites wet in summer should be sown to saltwater couch, marine couch or distichlis (see Chapter 4). Sites for puccinellia should be more severely affected (soil bare) than sites for Tall wheat grass (soil cover with Mediterranean barley grass). Many saline sites are a mosaic of severely and moderately saline land. In these cases, sowing a mixture of Tall wheat grass and puccinellia results in puccinellia colonising the more waterlogged/saline bare land, and Tall wheat grass establishing in the less waterlogged saline areas.
- **Site preparation.** Control mediterranean (sea) barley grass (the major grass competitor). Strategies include:
 - (a) graze hard in the year before sowing
 - (b) spraytop in the spring before seeding
 - (c) burn off dry grass in autumn of the year of seeding.

Extended surface ponding inhibits germination; construct surface water control structures such as W-drains to minimise waterlogging of the surface soil. Cultivate the area roughly before the break of the season, to provide a variety of microsites in which seed can lodge and germinate.

- **Timing of seeding.** If an early break occurs, wait for a germination of Mediterranean barley grass, spray with a knockdown herbicide (e.g. 2 L of SpraySeed in 100 L of water per hectare) and sow. If a late break occurs, seeding should not be delayed; bare saline land should be sown immediately following the opening rains.
- **Sowing.** It is essential that seed is fresh as germination declines rapidly if seed is more than two years old.³⁴ With both grasses, early sowing enhances the likelihood of success. Sow puccinellia before the end of June (later in sites receiving more than 450 mm rainfall). Sow Tall wheat grass before the end of July (later in sites receiving more than 450 mm rainfall). Seed onto the soil surface at rates of 2–4 kg/ha (puccinellia) and 10 kg/ha (Tall wheat grass).³⁵ Covering harrows are not recommended for puccinellia or for mixtures, but can be used for Tall wheat grass.
- **Grazing.** Fence young plants to prevent uncontrolled grazing. Protect stands from heavy grazing for at least 18 months (two winters). If grazing occurs during the first summer many plants will be pulled out of the ground by sheep. Mature puccinellia stands can be grazed as dry feed in the period February to May, when extra grazing is always useful. If required, puccinellia can be grazed after the opening rains, as it produces green feed quite rapidly. Stock should be removed by the end of August to allow for seed development and to ensure stands are thick during spring when salt accumulation on the soil surface is greatest if soil is bare. With Tall wheat grass, the quality of the feed declines rapidly in late summer, so it is important to graze the pasture before the stems are mature. Heavy crash grazing encourages leafiness and helps maintain feed quality. If Tall wheat grass is planted as a companion species with balansa clover, then the grazing should be regulated to allow the balansa to flower and set seed.³⁶
- **Fertilising.** Apply superphosphate (50–100 kg/ha) but not nitrogen at seeding. Fertilise with nitrogen in late winter (see Chapter 7) and graze the following summer/early autumn. Nitrogen application is particularly worthwhile if it is intended to harvest seed during the following summer.

Further reading and notes

- 1 Seed testing laboratories will test the germinability of saltbush fruits for a modest fee. At the time of writing, the test offered by the Western Australian Department of Agriculture costs \$54 per sample.
- 2 Data of Vlahos *et al.* (1991).
- 3 In addition to these factors, there are suggestions that treatment with smoke can improve the establishment of some halophytes. David Millsom (Greening Australia Victoria) has observed improved germination of smoke-treated small-leaf bluebush (*Maireana brevifolia*) (D. Millsom, personal communication). Smoke has been found to improve the germination of many Australian species (e.g. Read and Bellairs, 1999; Roche *et al.*, 1997).
- 4 The following data are indicative.
 1. *Atriplex nummularia* seeds were most germinable within 4 years of storage, but by Year 8 germinability had declined from 92% to 10%. With *A. vesicaria*, germinability declined to zero after five years (Beadle, 1952).
 2. *Atriplex nummularia* fruits stored for more than 8 years had germinabilities of less than 10% (Edwards, 1974).
- 5 Malcolm (1963).
- 6 In our experience, if seeds are present in fresh fruit samples, 80–90% of them will be germinable. Dormant or dead seed appear to be insignificant.
- 7 This point can be illustrated from the study of Strawbridge *et al.* (1997) which considered the effects of changing the ratio of female to male plants on fruit fill in river saltbush (*Atriplex amnicola*). In this study maximum fill (33–36%) occurred where male plants made up 80% or 50% of the plants in the stand. Fill was reduced to 25% and 2% when male plants were 12% or 0% of the stand respectively.
- 8 Strawbridge (1995) reports data for river saltbush at three typical saltland sites where at early stages of development (May–June) 80–90% of developing fruits contain embryos, but the percentage of fruits containing seeds declines to 25–45% by the time the fruits are ripe (November–December).
- 9 In an investigation with river saltbush growing down a slope into a waterlogged valley, fruit fill following fertilisation was initially high (77–92%). However, waterlogging for 30–60 days and 135 days during ripening coincided with declines in fruit fill to 44–49% and 18% respectively (Strawbridge, 1995).
- 10 In one investigation (E.G. Barrett-Lennard and F. Gavelle, unpublished), a sample of river saltbush fruits was divided into three grades according to size. Most (75%) of the sample occurred in the small and medium sized grades which had low germinability. Only the largest fruits had high germinability (see table below).

Grade	Average weight (mg)	Proportion of sample (%)	Fruit fill (%)	Germinability (%)
Large fruits	5.9	25	59	59
Medium fruits	4.4	29	30	22
Small fruits	2.8	46	20	12

- 11 For example, the samphire *Halosarcia pergranulata* subsp. *pergranulata* is a moderately hard seeded saltland species (Malcolm, 1964; Barrett, 2000). Barrett (2000) examined the effects on germination of nicking seeds of this species with a scalpel. Without nicking, germination was 38%. Nicking the seed-coat increased germination to 56% (nicked near plumule) and 79–80% (nicked near the radicle or perisperm).
- 12 For example see Beadle (1952), Twitchell (1955) and Koller (1957).
- 13 Beadle (1952).

Further reading and notes

14 For example:

Malcolm and Swaan (1985) found that washing the fruits of *A. amnicola* and *A. undulata* for two hours under flowing water had no effect on subsequent germination in petri dishes.

Jones (1968) found that the leaching of *A. nummularia* fruits caused a small increase in germination in only one of three fruit samples tested.

15 Germination was tested as follows:

Samphire (*Halosarcia halocnemoides* subsp. *halocnemoides*) was germinated at 5° (night)/35°C (day) for 28 days (Barrett, 2000).

Puccinellia (*puccinellia ciliata*) was germinated at 15° (night)/25°C (day) for 28 days (Barrett, 2000).

Balansa clover (*Trifolium michelianum*) was germinated at 20°C for 24 days (Rogers and Noble, 1991).

16 Vlahos (1997).

17 Reviewed by Ungar (1978).

18 This interpretation is based on the work of Barrett-Lennard and Gavelle (1994) who examined the germination of intact fruits and naked seed of river saltbush and wavy leaf saltbush at two moisture tensions (8 and 1.5 cm). With river saltbush, 80% of fruits germinated at a water tension of 8 cm, but only 50% of fruits germinated at a water tension of 1.5 cm. In contrast, with wavy leaf saltbush, 75–80% of fruits germinated irrespective of the moisture tension.

19 For example, in marine couch (*Sporobolus virginicus*) 73–93% of seeds germinated with a light/dark regime (8h/16h) at 20–35°C for 23 days. However, only 38–70% of seeds germinated under continuous darkness (Frith, 1957). Similarly, in river saltbush (*Atriplex amnicola*) 90–96% of fruits germinated with a light/dark regime (12h/12h) at a range of temperatures over 28 days. However, under continuous darkness, only 27–54% of fruits germinated (H. Runciman and C.V. Malcolm, unpublished).

20 Vlahos (1997).

21 Vlahos (1997) analysed the results of five experiments with river saltbush in which weeds were controlled with the herbicide Carbetamide. He found that the greatest benefits of weed control (80–270% increases in the numbers of successful placements of saltbush seed) occurred in experiments when sowing was followed by 10–18 day periods without rain within the first seven weeks.

22 The prototype of the Mullen niche seeder was developed by Clive Malcolm, a Senior Research Officer in the Western Australian Department of Agriculture, and Richard Allen, a design student (Malcolm and Allen, 1981). Commercial companies rapidly developed their own variations of the machine based on this prototype. The major features of the niche seeder are: (a) two opposed discs (at the front of the machine) which make a mound, (b) a large wheel (in the middle of the machine) which pushes a furrow into the mound, and (c) a mechanism for depositing 'placements' of seed and vermiculite at 1–3 metre intervals along the pressed furrow (termed the 'niche'). Some seeders also have a small press wheel at the back of the machine, which rolls over and stabilises the placements of seed and vermiculite, and a central ripper in front of the discs.

23 One data set that illustrates this point for three halophytic shrubs is tabulated on the page opposite (Malcolm *et al.*, 1980). The sites for this work had saline groundwater (EC = 39 to 51 dS/m) at 0.5 to 1.5 metres depth; they were too saline for cropping, and had a patchy cover of mediterranean barley grass. For each shrub species, the broadcasting of seed onto cultivated ground resulted in *no* establishment. However, the use of the niche seeder (in these cases without mulch or black paint treatments) resulted in the establishment of 0.5–5.0% of germinable seed.

Percentage of germinable seed established after 5–6 months growth (after Malcolm *et al.*, 1980).

Shrub species	Establishment method	Non-waterlogged site (planted before break of season)	Waterlogged site (planted after break of season)
Bluebush (<i>Maireana brevifolia</i>)	Niche seeder (no mulch)	3.0	0.9
	Seed spread on cultivated ground	0	0
Wavy-leaf saltbush (<i>Atriplex undulata</i>)	Niche seeder (no mulch)	0.5	0.5
	Seed spread on cultivated ground	0	0
River saltbush (<i>Atriplex amnicola</i>)	Niche seeder (no mulch)	5.0	4.4
	Seed spread on cultivated ground	0	0

24 Malcolm and Swaan (1985) report a dataset (tabulated below) illustrating the interactive effects of vermiculite mulch and a black latex paint on germination of *Atriplex amnicola*. Two grams of seed were evenly spread over 2 metres of niche made with the niche seeder. The data reported here are the average numbers of germinants 33 days after sowing.

	No Vermiculite	Vermiculite
No paint	0.4	14
Paint	1.4	23

- 25 We have recently heard of a new seeder developed by David Millsom (of Greening Australia Victoria) and Bob Cleland (of Kerang Engineering) which may have solved the problems with direct seeding into the heavy clay soils in the Murray-Darling Basin. This seeder creates a seedbed profile, similar to that of the Mallen niche seeder, by driving a tyne (rather than a wheel) through the top of the mound created using double opposed discs. The new seeder is reported to overcome the problems of clay adhering to the wheel, and of the smearing of the clay surface in the niche (which can create a hard crust). Few results are yet available for this machine but we are intrigued by the new design features.
- 26 For example see Malcolm (1986b).
- 27 Results of Vlahos (1997) from a survey of 63 niche seeded plots at 23 sites.
- 28 The recommendation of carbetamide is based on the results of Vlahos (1993). Our recommendations of Verdict and Lontrel are based on personal observations. Note that these are presently non-registered uses of these herbicides. We accept no liability for damage to plants, stock or people through these recommendations. If carbetamide is used to control weeds during saltbush establishment it would be prudent to observe a stock withholding period of 6 months.
- 29 After Vlahos *et al.* (1991)
- 30 Comparisons have been made of the reliability of niche seeding and the use of nursery-raised seedlings for the establishment of river saltbush (Barrett-Lennard *et al.*, 1991). At seven sites over two years, the median result with nursery raised seedlings was 90% of seedlings successfully established. In contrast, with niche seeding the median result was only 18% of seed placements successfully established. It should be added that in this study, the niche seeding was conducted with what would now be regarded as inadequate definition of site suitability and control of weeds and insects. Notwithstanding this, the results show that the use of nursery-raised seedlings is a more resilient method of establishment than direct seeding.
- 31 Barrett-Lennard *et al.* (1991).
- 32 After Strawbridge and Barrett-Lennard (1993).
- 33 After Negus (1985, 1988), McCarthy (1992) and Nichols (1998).
- 34 Nichols (1998, 1999).
- 35 Recommended seeding rates for Tall wheat grass and companion species in NSW are as follows (Nichols, 1998):
 Sites with EC_e values in the top 10 cm of 5 dS/m: 10–15 kg/ha Tall wheat grass, 2 kg/ha phalaris, 1 kg/ha strawberry clover, 0.5 kg/ha balansa clover.
 More severely salinised soils: 15–20 kg/ha Tall wheat grass, 2 kg/ha strawberry clover, 1 kg/ha balansa clover.
- 36 Nichols (1998, 1999).

Chapter 6

Grazing value of saltland pastures



Sheep will do well on saltbush-based pastures provided they can also access other fodders as sources of energy (Photograph: Brett Ward).



In this Chapter

Nutritive value of saltland pasture species

- Metabolisable energy
- Crude protein
- Salt (soluble ash)

The value of mixtures

– adequate energy, protein and dilution of salt

- Evidence from pen-feeding trials
- Evidence from field trials
- Achieving mixtures in the field

Saltland pasture 'wild cards'

- Saltbush in the diet increases wool growth
- Potassium increases the intake of saltbush leaf

Southern Australia experiences hot dry summers and cold wet winters, causing a large variation in the quality and quantity of feed (pastures, fodder crops and crop stubbles) available to livestock throughout the year. At one extreme, in the spring flush, fodder is of *high quality and quantity* and often left to waste. In autumn, fodder is of *low quality and quantity*.

During autumn, the decrease in feeding value relative to the requirements of grazing animals tends to create a 'feed trough'. Withstanding the autumn feed trough is difficult for lactating ewes with high energy demands in the weeks immediately after lambing. Spring-lambing flocks receive some compensation from the spring flush, but winter-lambing flocks experience severe shortfalls and require supplementary feeding.

Saltland pastures present an opportunity to increase feed supply, especially during autumn when other sources of feed are limited. This leads to increases in profit through combinations of:

- Lower supplementary feeding costs
- Higher average stocking rates over the whole year.

The adoption of saltland pastures is attractive because they:

- Fit readily into existing farming systems
- Do not require large up-front investments in plant and equipment.

Factors affecting the profitability of saltland pastures are discussed in more detail in Chapter 8.

This chapter focuses on the grazing value of saltland pastures.¹ The feeding value of saltland pastures can be enhanced by using them in ways that capitalise on their strengths and minimise their weaknesses. For example, halophytic shrubs have high crude protein concentrations but low metabolisable energy and high salt concentrations. Their feeding value is maximised when fed in mixtures with other feed sources of higher energy and lower salt concentration.

Many research questions remain, regarding the use of saltland pastures. Two of these have been scoped at the end of the chapter.

6.1 Nutritive value of saltland pasture species

Key point

• Ruminant animals need metabolisable energy and protein in their diets. Saltbushes and small leaf bluebush (major components of many saltland pastures) contain high concentrations of crude protein, but low concentrations of metabolisable energy. They require supplementation with higher energy material to be an adequate diet.

The feeding value of a forage is determined by the level of feed intake by the sheep and the nutritive value of the feed (Figure 6.1). For maintenance of liveweight, a mature dry sheep requires forages that will provide 7.5–8.5 megajoules of metabolisable energy per day, 1.2–1.5% nitrogen (7–10% crude protein) and an adequate and balanced level of minerals and vitamins.² These requirements may change if high concentrations of salt or toxins affect feed intake or the metabolic efficiency of the animals.

6.1.1 Metabolisable energy

Metabolisable energy is the amount of energy available for absorption by the animal after digestion and fermentation of the feed consumed. It is generally the main constraint to sheep production from pastures. The amount of energy a sheep derives from a fodder is related to the *digestible organic matter in the dry matter* (see page 97).

The energy value of a feed is often predicted from the dry matter digestibility of the feed. However, halophytes growing on saline land can have very high salt concentrations in the leaves; this component *appears* to be digested in the standard digestibility tests, but has no energy value. To correct this problem, energy value estimates for halophytes are based on the *digestibility of the organic matter*.³

High salt concentrations also affect the yield of metabolisable energy a sheep derives by fermenting organic matter in the rumen (discussed further in Section 6.1.3).

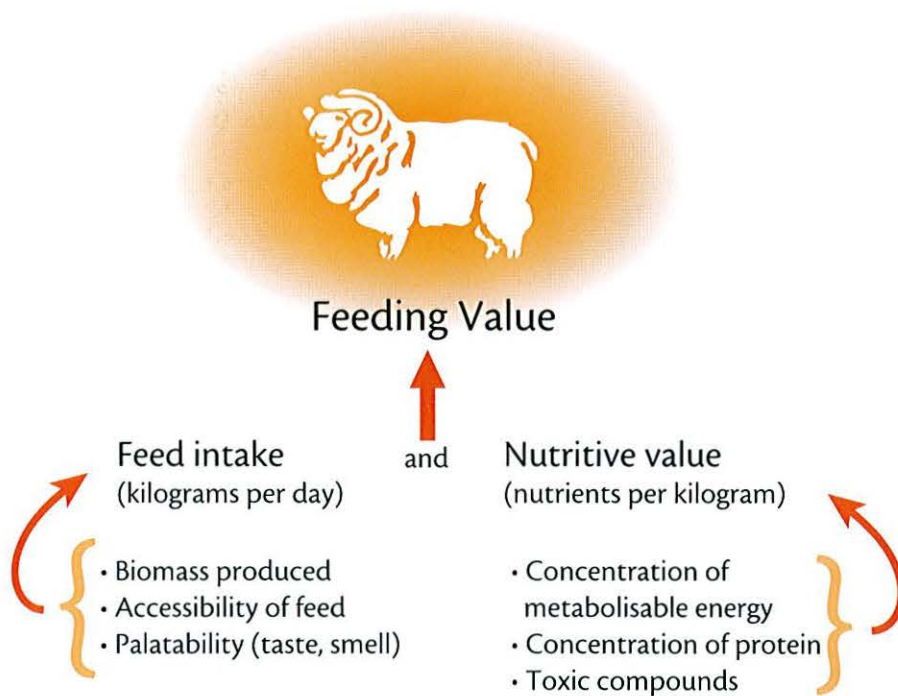


Figure 6.1 Key drivers of feeding value in saltland pastures.

Feed quality, digestibility and metabolisable energy: a few principles⁴

Energy requirements for maintenance

A 50 kg wether requires about 7.5–8.5 megajoules (MJ) of metabolisable energy per day to maintain liveweight.

Digestible organic matter intake and yield of metabolic energy

A 50 kg wether, in a paddock with an unlimited supply of green feed with a digestible organic matter in the dry matter of 70% will eat about 1.7 kg of dry matter per day. This feed will provide the sheep with about 18 MJ of metabolisable energy per day and will support a liveweight gain of about 100 grams per day.

When the pasture has senesced and has a digestible organic matter in the dry matter of 50%, the same 50 kg wether can only eat up to 1.0 kg of dry matter per day. This feed will only provide about 7.2 MJ of metabolisable energy per day and the sheep will lose liveweight.

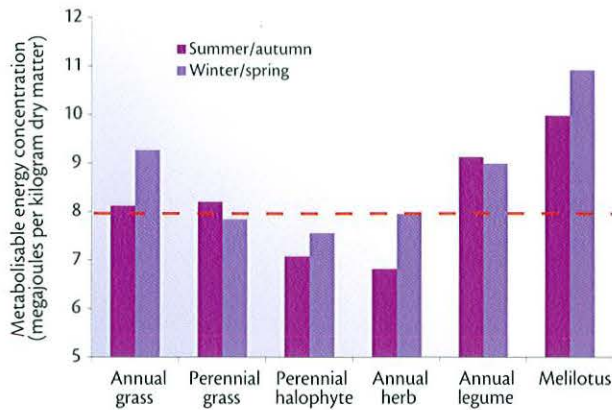


Figure 6.2 The concentration of metabolisable energy in a range of plant species found on saltland in southern Australia.⁵ The dotted line indicates the approximate critical level for the maintenance of a 50 kg sheep.

Figure 6.2 shows the typical concentration of metabolisable energy in a range of plant species grown on saltland, and relates these to a daily requirement of metabolisable energy of 8 megajoules per day required for the maintenance of liveweight. The graph indicates that for perennial halophytes and annual herbs, intake would need to be in excess of one kilogram of dry matter per day for liveweight maintenance. This is not likely to be possible for feeds with such low energy and high salt concentrations. Interestingly during the summer/autumn feed trough, melilotus and annual legumes contained high energy concentrations; with an intake of one kilogram of dry matter per day these would have caused gains in liveweight.

The data in Figure 6.2 for saltbush (a perennial halophyte) indicate its concentration of metabolisable energy *at best*. For such plants, the bulk of the shoot consists of thicker twigs and branches (Photo 6.1). Furthermore, plants become woodier with time.⁶ Even fine twigs (5–6 mm in diameter) have a far lower digestibility than leaves.⁷ There is also a lower intake of stems by grazing sheep.⁸ Sheep must be removed from saltbush-based pastures before they are compelled to eat woody twigs (cf. Photo 6.2).

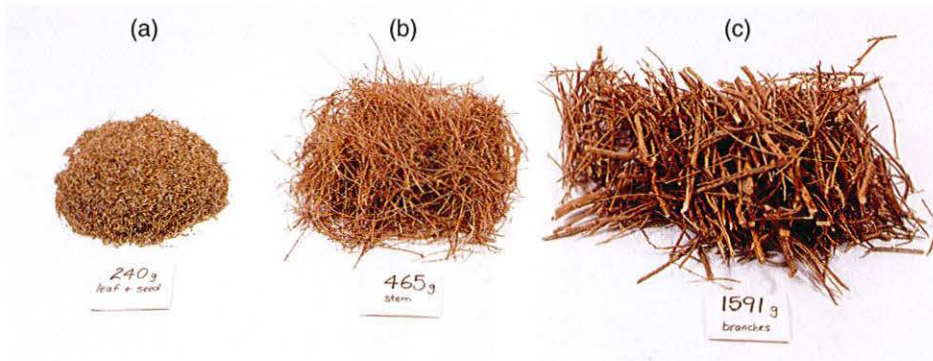


Photo 6.1 The useful sheep feed from saltbush is a small proportion of the total shoot biomass. This river saltbush plant with a shoot dry weight of 2.3 kilograms had: (a) 10% leaf, seed and fine stems, (b) 20% thicker stems, (c) 70% branches⁹ (Photograph: Simon Eyres).



Photo 6.2 With an absence of understorey and saltbush leaf, sheep grazing this pasture would be deficient in metabolisable energy.

6.1.2 Crude protein

To get enough protein to maintain liveweight, a 50 kg dry sheep eating a diet with an organic matter digestibility of 55% needs feed with a crude protein concentration of more than 7–8%. Figure 6.3 shows the crude protein concentrations (in winter/spring and summer/autumn) in a range of plant species found on southern Australian saltland. In winter/spring, fulfilling the crude protein requirement was relatively easy; all species tested except the perennial grasses had crude protein concentrations greater than 9%. The situation was different during the summer/autumn feed trough. During this time, the perennial halophytes, melilotus, and annual legumes fulfilled this requirement, whereas perennial grasses, annual herbs and annual grasses did not.

Crude protein is estimated by analysing a tissue for nitrogen, expressing this as a percentage dry weight, and multiplying the resulting figure by a factor of 6.25. However, this kind of calculation may overestimate the protein in the analysed tissue; many halophytes contain a range of small molecular weight nitrogen compounds, such as glycinebetaine and proline (essential for the osmotic adjustment of plant tissues) and nitrate that are not proteins. These compounds may be converted into microbial protein in the rumen, but the extent to which this occurs depends on the availability of metabolisable energy. In the absence of energy, these compounds are converted to ammonia in the rumen, which is absorbed by the animal, converted to urea and excreted in the urine.¹¹

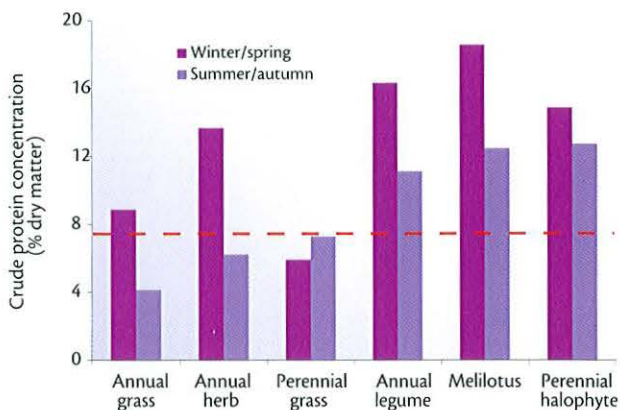


Figure 6.3 Crude protein concentrations in a range of plant species found on saltland in southern Australia.¹⁰ The dotted line indicates the critical level for the maintenance of a 50 kg sheep (see text).

6.1.3 Salt (soluble ash)

Salt concentrations in fodders are determined by burning away the organic material in a muffle furnace, leaving the ash residue. For saltbushes, about 75% of the residue is common salt (sodium chloride – Figure 6.4).

Ash concentrations in the leaves of typical saltland plants vary substantially. The values in Figure 6.5 are indicative.

High concentrations of dietary salt cause animals to drink more water. Figure 6.6 shows data from a pen-feeding study in which sheep were fed six different diets (four saltbush species, hay alone, or a 50:50 hay/saltbush mixture). There was a strong relationship between the daily intake of salt and the daily intake of water. At the highest

levels of salt intake, the sheep drank more than nine litres of water per day (Figure 6.6).

Sheep grazing saline pastures must receive good quality water. In a pen-feeding trial, the intake of Old man saltbush forage decreased by more than 50% when fresh drinking water was replaced by water containing 0.9 or 1.2% sodium chloride.¹⁵

High dietary salt concentrations are undesirable because:

- *They decrease feed intake.* This means that the concentrations of metabolisable energy and crude protein in the forage must be even higher than the thresholds previously described (Figures 6.2 and 6.3) if the sheep are to maintain liveweight.

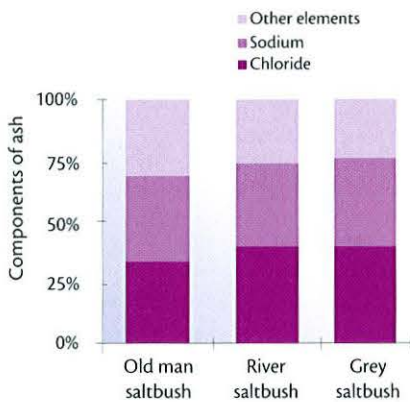


Figure 6.4 Components of the ash in leaves of three saltbush species at Tammin WA in summer/autumn.¹²

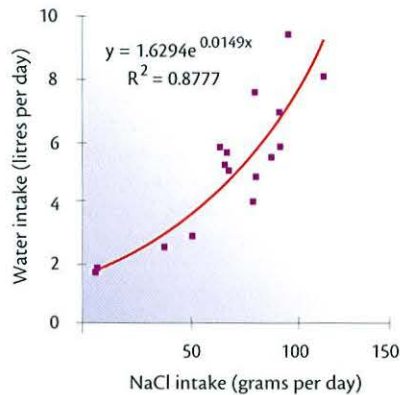


Figure 6.6 Relationship between the water intake by sheep and salt intake in the diet.¹⁴

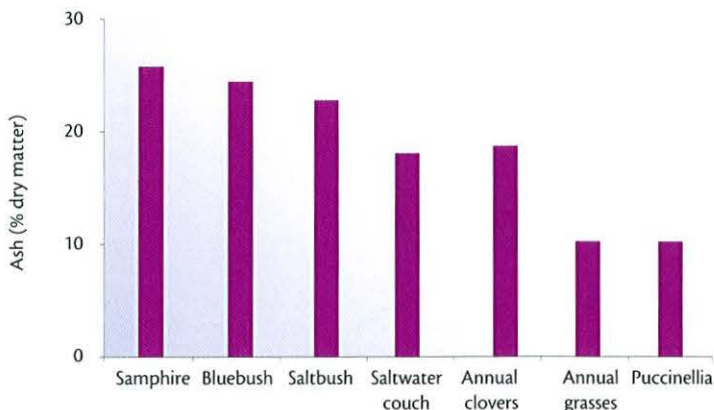


Figure 6.5 Typical ash concentrations in the leaves of a range of saltland plant species.¹³

- They decrease the energy a grazing animal can get from the forage. This occurs because salt increases the volume of water needed by the animal; this flushes the forage more quickly through the digestive tract, decreasing the time available for digestion and the amount of energy obtained from the forage.

- They increase the animal's requirement for energy. Animals with a high salt intake have an increased requirement for energy to fuel salt absorption and excretion from the kidneys.¹⁶ They may also need to walk more frequently to watering points.³⁷

When presented with a choice, sheep will generally consume fodder of lowest salt concentration first. Here are two documented examples:

- *Mixed species saltbush pasture on saltland* – At Lake Grace WA, researchers measured the use of a saltland pasture comprising capeweed and balansa clover (with a leaf salt concentration of about 0.4% dry weight), and old man and wavy leaf saltbush (with concentrations of salt in the leaves of 8 and 13% dry weight respectively), 19 and 74 days after sheep were introduced. The sheep did not start to use the saltbush in this pasture until the capeweed and balansa had been consumed (Figure 6.7).

- *CLONE2 trial* – This trial at Katanning WA examined the palatability of 71 river saltbush clones. The plants were scored weekly for palatability on a scale of one (no evidence of grazing) to six (complete defoliation). Leaf salt concentrations were sampled 14 months before grazing. The most heavily grazed plants (high scores) also had the lowest concentrations of chloride in the leaves (Figure 6.8).

Halophytes use salt in the leaves for osmotic adjustment.²⁰ Research shows ash concentrations in leaves of Old man saltbush vary between about 19% in spring and 30% in late summer/early autumn.²¹ Given that salt concentrations in leaves reflect salinity in the root medium when the leaves were formed, lower winter salt concentrations must be due to *formation of new leaves* with lower salt concentration, and not to reduced salt concentrations in *existing leaves*. These results suggest there is little capacity to decrease salt concentrations in halophyte leaves through the timing of grazing, particularly if the bulk of fodder is to be used to fill the autumn feed trough.

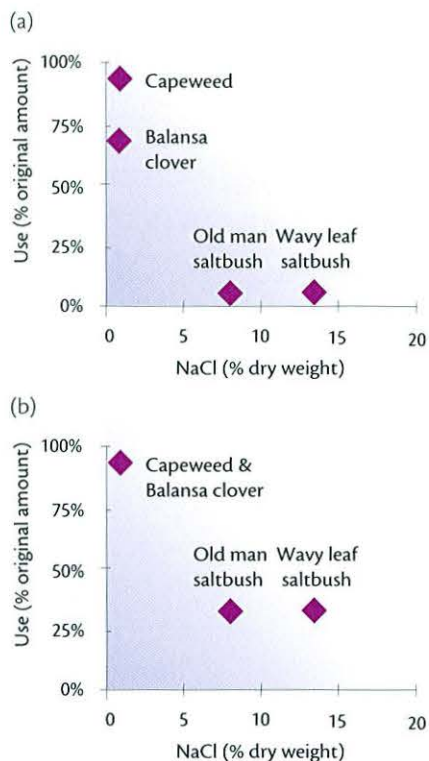


Figure 6.7 Use of major saltland pasture components at Lake Grace during (a) 0–19 days of grazing, and (b) 0–74 days of grazing.¹⁸

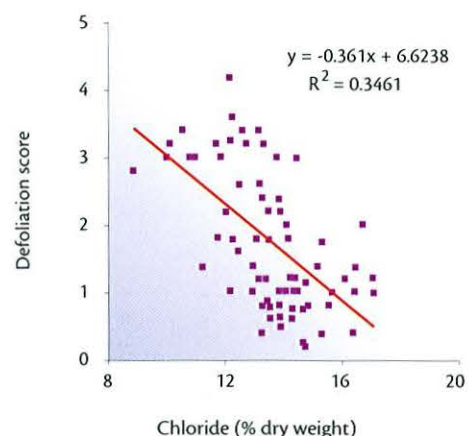


Figure 6.8 Palatability of clones of river saltbush and chloride concentration in the leaves.¹⁹ Low defoliation scores denote little evidence of grazing (see text).

6.2 The value of mixtures – adequate energy, protein and dilution of salt

Key point

• *Pen feeding studies show sheep increase feed intake and maintain liveweight if saltbush leaves are mixed with hay or wheat straw as a source of metabolisable energy. Unfortunately, in the field, animals tend to graze plants from most- to least-palatable, and ingest inconsistent, inadequate levels of energy and protein for maintenance. This may be overcome by:*

- *Intensifying grazing pressure so sheep are more inclined to simultaneously eat the saltbush leaves and the higher energy understorey*
- *Supplementing the saltbush with equally unpalatable sources of metabolisable energy (such as wheat straw).*

Results from pen-feeding studies suggest the key to successfully using saltbush fodders with high crude protein but low metabolisable energy and high salt concentrations is to mix them with other fodders (hay or straw) of complementary properties. Mixing saltbush leaf with hay or straw:

- increases voluntary feed intake and helps maintain liveweight
- improves retention of nitrogen (crude protein).

6.2.1 Evidence from pen feeding trials

Two pen feeding trials illustrate the potential for saltland pasture mixtures to maintain sheep condition in autumn.

In Trial 1, sheep were fed 100% wavy leaf saltbush, a 50:50 mixture of saltbush and hay, or 100% hay.²² Sheep grazing the saltbush alone had a low feed intake (0.6 kg of dry matter per day – Figure 6.9a) and lost liveweight at a rate of more than 200 g/day (Figure 6.9b). Sheep on an unsupplemented hay diet also had low feed intake and lost liveweight. However, when saltbush leaf was mixed with oaten hay, feed intake increased by more than 100% (Figure 6.9a), and the sheep gained liveweight at a rate of about 70 g/day (Figure 6.9b).

The mixed diet was clearly of higher nutritive value (9% ash, 7% crude protein, 60% digestibility) than the diet based on saltbush alone (15% ash, 10% crude protein and 50% digestibility).

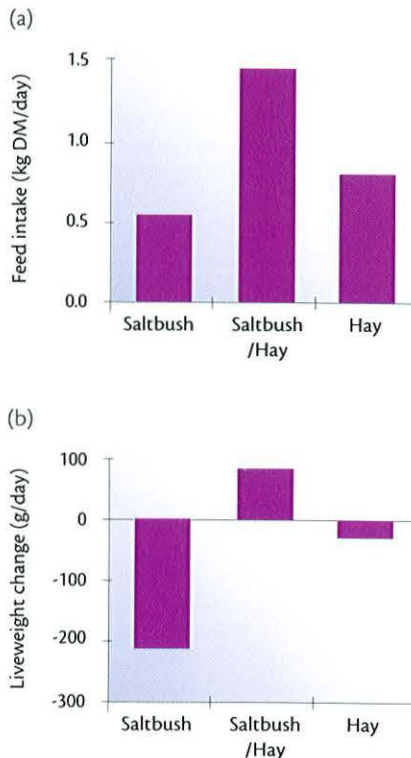


Figure 6.9 Effects of mixtures of wavy leaf saltbush and oaten hay on sheep: (a) feed intake, and (b) liveweight change. Average of three weeks' data.

Trial 2 illustrates the way in which saltbush protein can be retained by sheep if the diet contains adequate metabolisable energy. In this trial, sheep were fed diets varying (in steps of 25%) from 100% wheat straw to 100% river saltbush leaf. The sheep fed the diet of 0% saltbush (100% wheat straw) lost nitrogen at more than three grams per day. However, the inclusion of only 25% saltbush leaf in the diet virtually overcame this loss (Figure 6.10).

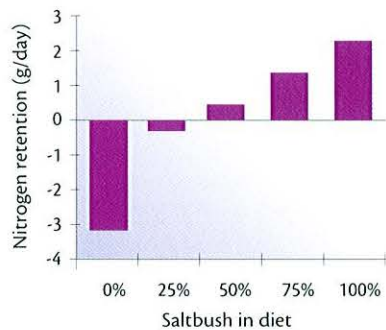


Figure 6.10 Nitrogen retention by sheep fed diets of saltbush leaf mixed with wheat straw. The animals were fed these diets for four weeks. The data reported here are from the last nine days of the experiment.²³

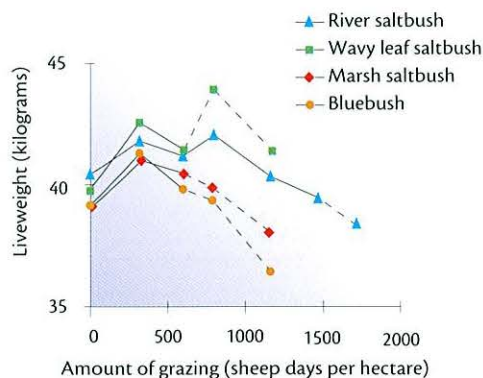


Figure 6.11 Liveweight changes in sheep in a saltbush grazing trial near Wongan Hills. Values are the mean of four (solid lines) or less (dotted lines) plots.²³

6.2.2 Evidence from field trials

The pen-feeding data suggest sheep should do well on saltbush-based pastures provided they can access fodder containing two to three times as much straw (as an energy source) as saltbush leaf.

Measurements have now been made on the effects of saltland pastures on sheep liveweights in field studies at six locations.²⁴ In all of these studies, liveweights increased for a period and then began to decline as the fodder was consumed.

Malcolm and Pol first stated the case for saltbush-based saltland pastures as fodder to fill the autumn feed trough, based on a field trial near Wongan Hills WA. In their trial, sheep were grazed in autumn on stands of halophytic shrubs (river saltbush, wavy leaf saltbush, marsh saltbush and bluebush) for six successive years, and weighed weekly. They were removed from the plots when their liveweights began to fall rapidly.

The final year's results (Figure 6.11) showed sheep gained weight immediately after introduction to the pastures, and maintained liveweight for a considerable time.

However, in the mid-1990s, new data questioned the view of the saltland pasture as a source of autumn fodder. In 1992, Brian Warren and Tess Casson conducted grazing trials with saltbush-based pastures on a clay-textured saline flat on the Great Southern Agricultural Research Station near Katanning WA. Their initial results appeared similar to the previous results of Malcolm and Pol – sheep increased in liveweight following their introduction to saltland pastures and liveweights were conserved for about 500 sheep grazing days per hectare (Figure 6.12). They showed the liveweight of sheep grazing saltbush was higher than that of animals grazing unimproved pasture.

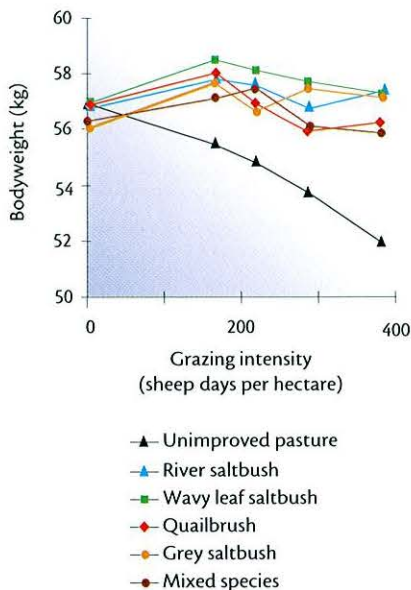


Figure 6.12 Liveweight changes in sheep in a saltbush grazing trial at Katanning WA.²⁶

However, in a clever body-water-labelling experiment, they showed the increases in liveweight in animals grazing saltbush was an artifact: the animals grazing saltbush weighed more mainly because the increased salt load in their diet caused them to drink more water. When the effect of this water was removed from the measurement by calculating the water free liveweight of the animals, it was found that the condition of those sheep fed saltbush was *poorer* than that of animals fed unimproved barley grass pasture. This result highlights the importance of measuring condition score in assessing animal performance on saltland.²⁷

The release of these data, coinciding with the decrease in the market value of wool from the mid-1990s, largely ended the establishment of new commercial saltbush pastures for a period of about five years.

6.2.3 Achieving mixtures in the field

The data discussed above present a quandary: when presented with a variety of feed components, sheep clearly do not eat these in the proportions necessary for their adequate maintenance. Although little research has been conducted, two approaches appear to have potential for resolving this:

1 *Change sheep grazing behaviour by increasing grazing pressure*

At low grazing pressures, sheep preferences for pastures components are influenced by their perceptions of the relative palatability of the components. However, as grazing pressure increases, competitive behaviour ensures the animals become less discriminating and consume all pasture components simultaneously.²⁸ This suggests a new approach to managing saltland pastures, in which pastures are divided into more paddocks of smaller areas, grazed in sequence for brief periods at high stocking rates. Under these conditions, we expect the metabolisable energy/protein ratio to remain relatively constant, and as the animals move from one portion of the pasture to the next, their liveweight and condition will be maintained.

2 *Supplement with metabolisable energy sources of low palatability*

The correct ratio of metabolisable energy/protein in the diet may be achieved by supplementing the unpalatable saltbush with an equally unpalatable energy source such as wheat straw. Farmers are beginning to use 'chaff carts' in their wheat harvesting operations to collect herbicide-resistant weed seeds. This 'cocky chaff' waste product is relatively unpalatable. In a brief (13-day) investigation of the feasibility of cocky chaff as a complement to Old man saltbush, sheep fed a 3:2 mixture of cocky chaff/saltbush leaf had a voluntary feed intake 25–100% higher than animals fed cocky chaff or saltbush leaf alone.²⁹ Sheep on the mixture lost liveweight at about 50 g/day, whereas sheep on cocky chaff or saltbush leaf alone lost liveweight at 190 and 220 g/day respectively.

Further paddock-scale research is required to confirm the value of these approaches.

6.3 Saltland pasture 'wild cards'

Potential exists for two speculative wild cards to affect the utilisation and profitability of saltland pastures. These are: (a) saltbush in the diet increases wool growth, and (b) potassium increases the intake of saltbush leaf.

6.3.1 Saltbush in the diet increases wool growth

The salt concentration in saltbush forage may have beneficial effects on wool growth. This is supported by:

1 *Pen-feeding trial with saltbush/barley mixtures*

Comparisons were made of wool growth in sheep fed a 60:40 'Old man saltbush/barley diet' or a 'control diet' (composed of lupins, barley and oaten hay) of similar value in metabolisable energy and crude protein. Over 10 weeks, sheep fed these two diets had identical liveweight gains (62 g/day). However, sheep on the Old man saltbush/barley diet had 20% higher rates of wool growth than the control group.³⁰

2 *Pen-feeding trial with saltbush/cocky chaff mixtures*

In the study referred to in Section 6.2.3 (sheep fed Old man saltbush leaf, cocky chaff, or a 3:2 mixture of cocky chaff/saltbush leaf), sheep fed the mixture or the saltbush diet had 25% higher wool growth rates than sheep fed cocky chaff alone.³¹

The beneficial effects of saltbush on wool growth are likely caused by increased salt in the diet. The first experiment reported above had a 'control plus salt' diet in which salt was added to the 'control diet' to the same concentration as in the 'saltbush/barley' diet. Animals fed the 'control plus salt' diet also had increased wool growth.

In a pen feeding experiment, salt in drinking water (1% w/v) of sheep fed a linseed meal diet increased rates of wool production by 14–22%.³² This appeared due to increased rates of flushing of the rumen, which decreases breakdown and loss of nitrogen in the rumen and increases the movement of protein into the lower parts of the digestive tract.³³ No satisfactory experiments have been conducted to determine the relationship between saltbush leaf in the diet and wool growth in the field.

6.3.2 Potassium increases the intake of saltbush leaf

Potassium concentration in the leaves appears to affect the palatability and intake of saltbush by sheep. Many southern Australian soils are potassium-deficient. Potassium concentrations in the leaves of saltbush growing on Australian saltland vary from 0.2% to about 3% dry weight, and values less than 2% dry weight are common.³⁴ Of 24 observations in the literature, the median potassium concentration in saltbush leaves was 1.3% dry weight.

Short- and long-term pen-feeding trials suggest potassium concentrations in saltbush leaves affect utilisation by sheep.

• *Short-term preferences*

The preferences of sheep for different feeds can be determined by offering the choice of a pair of fodder samples for brief periods. Atiq-ur-Rehman compared the preferences of sheep for seven saltbush fodders against one standard. The preference for each feed was calculated as the intake of that fodder as a percentage of the combined intake of both fodders. In this experiment, the concentrations of potassium in the leaves varied from 0.2 to 1.2% dry weight. In general, sheep preference for saltbush increased with the concentration of potassium in the leaves (Figure 6.13).

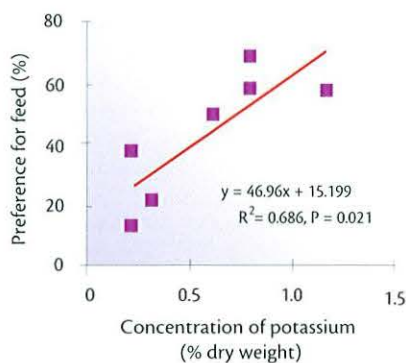


Figure 6.13 Effect of potassium concentration in the leaves on the preference of sheep for saltbush leaves.³⁷

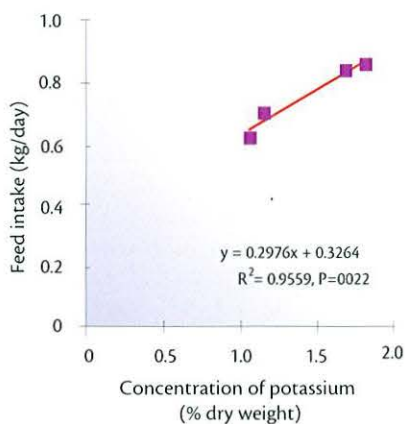


Figure 6.14 Effect of potassium concentration in the leaves on the intake of saltbush leaves by sheep.³⁸

• *Feed intake in longer-term trials*

The influence of potassium on longer-term feed intake can be seen in an experiment in which penned sheep were fed four different saltbush species for two to three weeks. In this experiment, harvested saltbush leaves had potassium concentrations of 1.1 to 1.8% dry weight. Average feed intake was proportional to the potassium concentration of the leaves (Figure 6.14).

There may be limits to the increases in saltbush intake that can be conferred by increasing the concentrations of potassium in the leaves. In a sheep grazing experiment in South Africa, the 20 most accepted plants had leaf potassium concentrations of about 2.6% dry weight, but the 20 least accepted plants had leaf potassium concentrations of 3.6%.³⁵

There appears to be increased utilisation of saltbush forage as the concentration of potassium in the leaves increases to about 2% dry weight.

It is possible the value of some saltbush pastures might be improved by the use of potassium fertilisers. In a glasshouse study, river saltbush grown under saline conditions at low levels of potassium had high selectivity for potassium over sodium.³⁶

Further reading and notes

- 1 Relevant literature includes:

Animal use. Recent publications: Norman *et al.* (2002a,b), and Masters *et al.* (2001). Older papers and reviews include: Malcolm and Pol (1986), Leigh (1986), Warren *et al.* (1990), Ayoub and Malcolm (1993), Wilson (1994), Warren and Casson (1992a, 1994, 1996), Casson and Warren (1994), and Morcombe *et al.*, (1996).

- 2 After Warren and Casson (1996), and Freer *et al.* (1997).
- 3 Correlations have been developed for grasses and halophytic shrubs of the relationships between digestive organic matter in the dry matter and dry matter digestibility (Norman *et al.*, 2002b).
- 4 Estimated using the nutritional simulation model GrazFeed (Freer *et al.*, 1997).
- 5 David Masters, personal communication, 2003. Based on data of Norman *et al.* (2002b), collected from six 'Animal Production from Saline Land Systems' sites across southern Australia involved in a benchmarking study in 2000–01. Metabolisable energy has been estimated from *in vitro* measurements of digestible organic matter in the dry matter and may change following the development of better calibrations to *in vivo* digestibility in the future.
- 6 Le Houérou (1986).
- 7 For example, Atiq-ur-Rehman (1995) studied the digestion in the rumen of fistulated sheep of wheat straw, saltbush leaf and saltbush stem (5–6 mm diameter). After 40 hours there had been digestion of about 45% of both the organic dry weight of the wheat straw and saltbush leaf, but only 9% of the organic dry weight of the saltbush stems.
- 8 Norman *et al.* (unpublished) studied the amounts of leaf, small stem and large stem present on river saltbush and Old man saltbush before and after grazing. All of the leaf and most of the small stem was consumed, but a substantial proportion (45 and 70%) of the large stem was refused.
- 9 Warren *et al.* (1995).
- 10 After Norman *et al.* (2002b).
- 11 Reviewed by Masters *et al.* (2001).
- 12 Norman *et al.* (2002a), Table 12.
- 13 These data are averages calculated from a variety of sources (Malcolm, 1963; Malcolm *et al.*, 1988; Warren *et al.*, 1990; Atiq-ur-Rehman, 1995; Norman *et al.*, 2002a; Warren and Casson, 1996; Smith *et al.*, 1998).
- 14 After Warren *et al.*, (1990). Animals in this experiment were fed one of six diets: hay, hay/wavy leaf saltbush, wavy leaf saltbush, quailbrush, river saltbush or grey saltbush. Sodium intake was calculated from the voluntary feed intake and the sodium concentration in the feed. We have assumed that the sodium (which was measured) was present in the feed as the chloride salt.
- 15 Wilson (1966).

Further reading and notes

- 16 For example, the addition of 12% common salt to a diet of pea hay and barley increased the heat production of sheep by 8%; with a saltbush diet of similar ash concentration the heat production increased by 12% (Arieli *et al.*, 1989).
- 17 Sheep need to drink more than once daily if their diets contain more than 500–600 grams per day of a fodder such as saltbush (Leigh and Mulham, 1967).
- 18 Prior to grazing the stand contained about 240, 100, 90 and 50 kg/ha of balansa clover, capeweed, wavy leaf saltbush and Old man saltbush respectively. Other pasture components (creeping saltbush, pearlwort, plantain, annual ryegrass, bluebush, heliotrope, 'green halophyte' and samphire – not graphed) were at less than 30 kg/ha each, and about 90 kg/ha in total (Norman *et al.*, 2002a).
- 19 R. Galloway, G. Lazarescu and E.G. Barrett-Lennard (unpublished data).
- 20 Sodium and chloride ions are metabolically the least costly means of osmotic adjustment of cell vacuoles which make up about 95% of cell volume (Greenway and Munns, 1980).
- 21 Schulz (1996).
- 22 After Warren *et al.* (1990).
- 23 Atiq-ur-Rehman (1995).
- 24 These are: Wongan Hills (Malcolm and Pol, 1986), Katanning (Warren and Casson, 1994), Pithara (Morcombe *et al.*, 1996), and Lake Grace, Tammin and Meckering (Norman *et al.*, 2002a).
- 25 After Malcolm and Pol (1986). The plots were 0.15 ha in area and there were six sheep per plot. Grazing commenced in the autumn of 1985 and animal liveweights were measured after 0, 8, 15, 20, 29, 37 and 43 days respectively. Feed on offer (t/ha) prior to grazing was:

Pasture	Understorey	Saltbush/bluebush	Samphire	Total
River saltbush	0.48	0.82	0.03	1.33
Bluebush	0.60	0.24	0.05	0.90
Wavy leaf saltbush	0.49	0.30	0.15	0.93
Marsh saltbush	0.53	0.09	0.53	1.15

- 26 After Warren and Casson (1994). The plots were 0.85 ha in area and there were eight sheep per plot. Grazing commenced on 6 April 1992 and animal liveweights were measured on 6 April, 28 April, 5 May, 14 May and 27 May, after 0, 22, 29, 38 and 51 days respectively. Feed on offer (t/ha) prior to grazing was:

Pasture	Understorey	Saltbush	Samphire	Total
Unimproved pasture	1.88	0	0.02	1.90
River saltbush	1.87	0.66	0.25	2.79
Wavy leaf saltbush	1.71	0.93	0.00	2.64
Quailbrush	1.42	0.56	0.03	2.02
Grey saltbush	1.56	0.41	0.20	2.17
Mixed species	1.61	0.26	0.11	1.97

- 27 Condition scoring is done by feel. Accuracy improves with practice. To score, locate the last rib (the 13th) and using the balls of the fingers and thumb, try to feel the backbone with the thumb and the end of the short ribs with the finger tips immediately behind the last rib. Feel the muscle and fat cover around the ends of the short ribs and over the backbone. Feel the fullness of the eye muscle. Body condition scores are as follows (Suiter, 1994).

Score	Comment
0	Animal emaciated, in extremely poor condition and very weak (near death). It has no fat cover, the eye muscle is hollow and there is little tissue between the spinal processes of the backbone or the short ribs.
1	Backbone Prominent and sharp Short ribs Ends are sharp and easy to press between, over and around Eye muscle Thin, tending to have a hollow surface
2	Backbone Prominent but smooth Short ribs Smooth well rounded ends. Can feel between, over and around each smoothly covered bone Eye muscle Reasonable depth with flat surface
3	Backbone Can be felt but is smooth and rounded Short ribs Ends are smooth and well covered. Firm pressure necessary to feel under and between short ribs Eye muscle Full and rounded
4	Backbone Detectable with pressure on the thumb Short ribs Individual short ribs can only be felt with firm pressure Eye muscle Full with a covering layer of fat
5	Backbone Can only be felt with firm pressure Short ribs Cannot be felt even with firm pressure Eye muscle Cannot be felt due to a thick layer of fat.

- 28 B.E. Norton, personal communication.
- 29 Roberts (2001), Roberts *et al.* (2002).
- 30 Pearce *et al.* (2002).
- 31 Roberts (2001).
- 32 Hemsley (1975).
- 33 Hemsley *et al.* (1975).
- 34 References are: Warren *et al.* (1990), Atiq-ur-Rehman (1995), and Norman *et al.* (2002a).
- 35 Jacobs and Smit (1977).
- 36 Aslam *et al.* (1988) examined the selectivity of potassium over sodium uptake in river saltbush grown in solution cultures at a concentration of (Na + K)Cl of 400 mol/m³ (73% of the salinity of seawater), but molar ratios of potassium/sodium varying from 0.0025 to 1.0. At the lowest ratio of potassium/sodium in the trial (0.0025:1), the plants were highly selective for the uptake of potassium over sodium; potassium was 0.25% (molar basis) of the monovalent cations in the external solution but was 5% (molar basis) of the monovalent cations in the expanded leaves. As the ratio of potassium/sodium in the solutions increased to 1.0, the plants ceased taking up potassium in preference to sodium, and potassium became 50% (molar basis) of the monovalent cations in the expanded leaves.
- 37 After Atiq-ur-Rehman (1995).
- 38 After Warren *et al.* (1990).

Chapter 7

Productivity of saltland pastures

Drawing down the watertable using saltland pastures may change a site with a cover of patchy barley grass into one capable of growing ryegrass and balansa clover.



In this Chapter

Measuring pasture productivity

- Shrubs
- Grasses and understorey

Seasonal patterns of growth

Germplasm

- Selection of species
- Selection within species

Soil salinity and the mulching action of plants

Waterlogging

- Effects on halophytes
- Low-cost engineering structures to lower watertables

Soil amendments and growth

- Saltland fertility
- Diagnosing nutrient deficiencies
- Benefits from fertilising saltland pastures

Soil compaction and deep ripping

Layout of saltland pastures

- Lowering watertables
- Producing a balanced mix of fodders
- Reducing plant density and establishment costs
- Design

In much of southern Australia, saltland is wetter for more of the year than adjacent non-saline land and can be more productive than nearby non-saline land. For example, in two case studies in NSW's Boorowa Shire and Pingaring in WA, paddocks revegetated with saltland pastures had ~30% higher stocking rates than annual pasture paddocks.¹ Further improvements in growth may be possible through improved pasture management practices.

Some saltland has low productive potential (only suited to the growth of exceptionally salt- and waterlogging-tolerant species such as samphire), some is of moderate productive capacity (capable of the growth of saltland pastures) and some is of high productive capacity (suited to high value forestry, horticulture etc.).

This chapter focuses on opportunities to improve saltland productivity within these broad categories, through improved management. Our main focus is on ameliorating the major factors limiting saltland pasture growth (Table 7.1): poorly adapted germplasm, salinity, waterlogging, low soil fertility and soil compaction.

7.1 Measuring pasture productivity

The productivity of different components of saltland pastures can be measured using a variety of techniques.

7.1.1 Shrubs

Shrub productivity is expressed as *useable forage dry weight* in units such as tonnes per hectare. In general, leaves are digestible, fine stems have lower digestibility and thicker stems are indigestible. Sheep prefer not to eat twigs greater than 0.9–1.5 mm in diameter.²

The 'Adelaide' technique. This involves measuring biomass on a typical branch of a shrub ('the unit') and estimating the number of units in a series of larger unharvested plants.³ Typically the unit should represent 10–20% of the average size of the shrub to be assessed.

Shoot volume measurements as indications of changes in growth. Shoot volume has no value to grazing animals *per se* but can be correlated with leaf biomass. For example, correlations between shoot volume and leaf dry weight of ungrazed river saltbush show this species produces about 400 g of dry leaf per cubic metre of volume.⁴

Table 7.1 Major factors limiting establishment, growth and value of saltland pastures

Limiting factor	Diagnosis	Management response
Poorly adapted germplasm	Inappropriate species planted (Chapter 4); plant death or decreased growth	Better site selection (Chapter 3) Plant better adapted or more productive species (Chapter 4; Section 7.3)
Salinity	Poor establishment	Apply surface mulch (Section 7.4)
Waterlogging and inundation	Shallow watertables; surface inundation; plant death or decreased growth	Better site selection (Chapter 3) Low-cost engineering structures (Section 7.5.2)
Nutrient deficiencies, sodicity and acidity	Decreased growth; visual symptoms of deficiency; low nutrient concentrations in leaves	Apply fertilisers, gypsum and lime (Section 7.6)
Soil compaction	Traffic pan in soil; decreased root growth	Deep rip (Section 7.7)
Poor feed value	Inadequate growth of annuals compared with perennials	Increase spacing between rows of perennials (Section 7.8). Supplement diet (Chapter 6).

7.1.2 Grasses and understorey

Pasture sampling in grazing experiments involves estimating the quantity of herbage (dry weight basis) and its composition (proportions of the different species) by cutting quadrats of the pasture, separating them into pasture components and drying and weighing the components. However, this can be laborious and inapplicable to large-scale experiments. Non-destructive visual estimation procedures, such as the BOTANAL dry-weight-rank method, are a more rapid way of estimating pasture composition. The BOTANAL method is outlined in the box below.

BOTANAL method⁵

In each of a number of quadrats, an observer records the plant species that are ranked as first, second and third (in terms of dry weight). When two or more species contribute similar amounts of dry matter, they are given equal rank.

The species occupying rank 1 is given a value of 8.04, rank 2, 2.41, and rank 3, 1.0. The values for each species are summed over quadrats and expressed as a percentage of the total score of all species.

These percentages are converted to actual component weights by multiplying by the total dry weight estimate for the pasture.

BOTANAL is based on the assumption that:

- At least three understorey species are present in the majority of sample quadrats.
- The order in which species are ranked varies between quadrats.
- No consistent relationship exists between quadrat yield and the dominance of any one species.
- The multipliers of 8.04, 2.41 and 1.0 for the first three species are valid when used in different pastures.

BOTANAL is still in its early days as a way of estimating the composition of understorey in saltland pastures.⁶ The method is simple to use, but there is no clear verdict yet on its accuracy.

7.2 Seasonal patterns of growth

Saltbushes and other summer-active perennials grow most in summer/autumn and little in winter/spring (Figure 7.1), due partly to a temperature response. The plants grow particularly quickly during their first summer, doubling in shoot volume every month or so. River saltbush does not grow at average annual temperatures less than about 15°C, but produces about one cubic metre of shoot volume per degree increase in average annual temperature above 15°C during the first 12 months of growth.⁷ Note the exceptional growth of river saltbush at Peshawar in Pakistan (Figure 7.1); this area has an average annual temperature of 21°C.

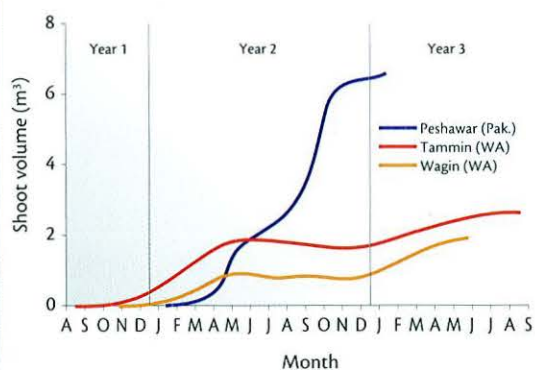


Figure 7.1 Pattern of growth of river saltbush.⁸ Average annual temperatures at Wagin, Tammin and Peshawar were 15, 19 and 21°C respectively. Peshawar is in the Northern Hemisphere with its hot season between July and September.

In contrast, annual understorey plants establish in the early winter months (May–June), but have most rapid growth in the warmer months of spring (September–October, Figure 7.2). *Although the understorey is widely overlooked, in most saltland pastures in most years it will be the major component of the feed on offer for grazing animals.*

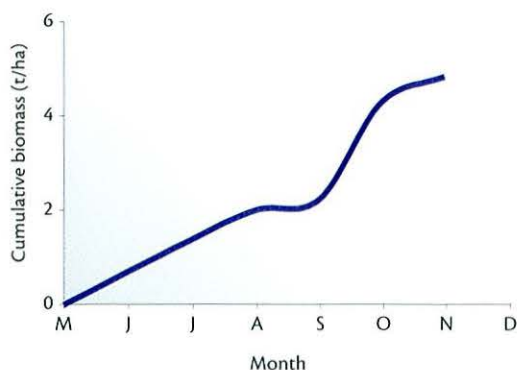


Figure 7.2 Typical pattern of growth of annual understorey plants on saltland.⁹

7.3 Germplasm

Modern databases recognise the existence of about 2,000 true halophytes¹⁰ and a wider range of less salt tolerant understorey species.

Improved germplasm for saltland has developed primarily through selecting adapted species and better-adapted lines from within species.

7.3.1 Selection of species

Similar patterns of events have occurred in selecting herbaceous and shrub species for saltland (Table 7.2). Concern over salinity in WA, the most severely salt affected state, led to farmer experimentation in the 1940s and 1950s, and larger-scale agency-sponsored screenings in the mid 1950s and late 1960s. Adoption occurred as other states became more focused on their salinity problems. In-fill studies (focusing on species for more specialised landscape niches) followed.

Table 7.2 Highlights in selection of germplasm for Australian saltland

Year	Activity
Herbaceous species	
1945–51	Farmers attest to value of Tall wheat grass and saltwater couch in WA. Researchers confirm results. ¹¹
1954–59	Screening of herbaceous germplasm (69 grasses and forbs) at Kojonup WA. Puccinellia and Tall wheat grass are best adapted. ¹²
Mid 1960s – early 1980s	Adoption of puccinellia in WA, NSW and SA. Tall wheat grass strongly adopted in NSW. ¹³
1985–95	Balansa clover released by the SA Department of Agriculture in 1985; its value for waterlogged/marginally saline soils is established in VIC and WA. ¹⁴
1996–99	Screening of perennial grasses (30 genotypes) at six NSW sites. Tall wheat grass, puccinellia, saltwater couch and kikuyu are best adapted. ¹⁵
1995–	Patented clone of <i>Distichlis spicata</i> introduced from US and tested in SA, WA and VIC. ¹⁶
2000–	Melilotus is introduced from Argentina and tested in VIC. ¹⁷
Halophytic shrubs	
Late 1890's	Value of saltbushes noted in pastoral locations. ¹⁸
1959	Planting of small leaf bluebush, Old man saltbush and creeping saltbush advocated for WA wheatbelt saltland. ¹⁹
1966–90	WA Department of Agriculture builds halophyte collection. ²⁰
1968–82	120 halophytic shrubs from five genera screened at three WA sites. ²¹ 25 genotypes selected for further work at 14 WA sites. Outstanding genotypes are small leaf bluebush, river saltbush, samphire, wavy leaf saltbush and quailbrush. ²²
Mid 1980s–1994	Halophytic shrubs from WA program trialled in SA, VIC and NSW with mixed success. ²³
1993–94	83 clones of river saltbush screened at two WA sites and in the glasshouse for productivity, palatability and waterlogging tolerance. Several clones have outstanding growth and tolerance to waterlogging. ²⁴

In general, the selection of species for saltland has been relatively accident-free. An exception was in the early 1990s, when *Kochia scoparia*, introduced by a revegetation company, was declared a noxious weed (Photo 7.1).²⁵ It was eventually eradicated, but the incident serves as a warning to take particular care when introducing exotic germplasm.

The CRC for Plant-based Management of Dryland Salinity's Sub-program Five has national responsibility for improving the productivity of saltland through the introduction of salt and waterlogging tolerant annual and perennial pasture species.²⁵

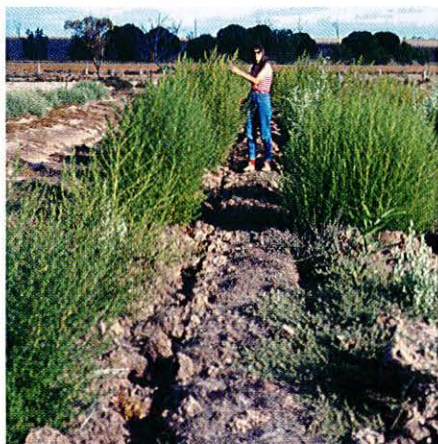


Photo 7.1 (a)

Photo 7.1 *Kochia scoparia* (declared a noxious weed in 1992) in saltland pastures in 1990. (a) while green in spring. (b) at maturity (Photograph: Department of Agriculture Photographic Unit).

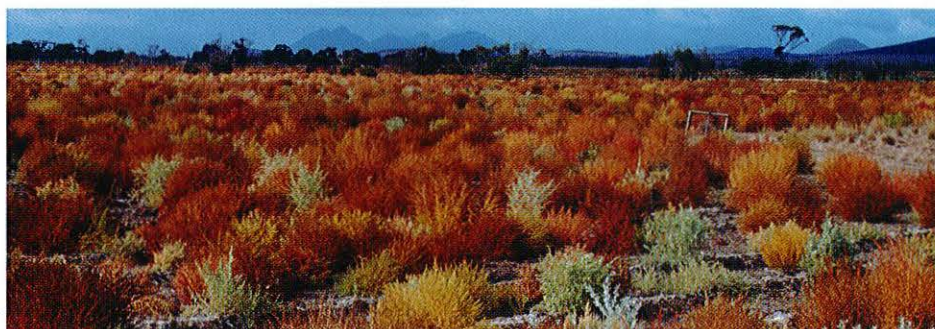


Photo 7.1. (b)

7.3.2 Selection within species

Cross-pollination is a common breeding mechanism in plants that grow in difficult environments. It allows for the generation of genetic diversity that occasionally creates exceptional plants for the diversity of environmental niches found in saltland. This genetic diversity creates opportunities for selection within species to improve genotypes for saltland pastures.

An example is balansa clover, a cross-pollinating species from Turkey. The original balansa cultivar, Paradana, was released by the SA Department of Agriculture in 1985.²⁷ It was suited to higher rainfall areas, but with a relatively long period until flowering, did not persist in drier environments. Frontier (selected out of Paradana for earlier flowering) was commercially released in 2000.²⁸

Considerable genetic diversity exists within halophytic shrub species and many saltbushes can be cloned from cuttings. These attributes have stimulated interest in the selection of saltbushes for increased productivity.

Figure 7.3 shows the variation in shoot growth between 79 clones of river saltbush collected from 14 sites, vegetatively propagated as cuttings and planted at Tammin and Katanning, WA.²⁹ After six months, shoot dry weights at each site were highly correlated, showing much of the variation between clones was genotypic rather than environmental. Clone 28 was most productive and Clones 17, 10, 40, 2, and 3 were highly ranked.



Photo 7.2 (a)

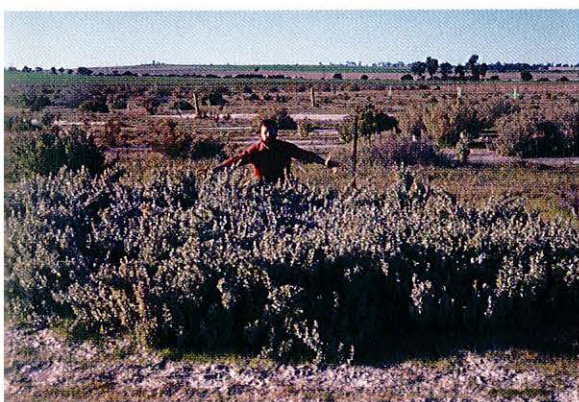


Photo 7.2 (b)



Photo 7.2 (c)

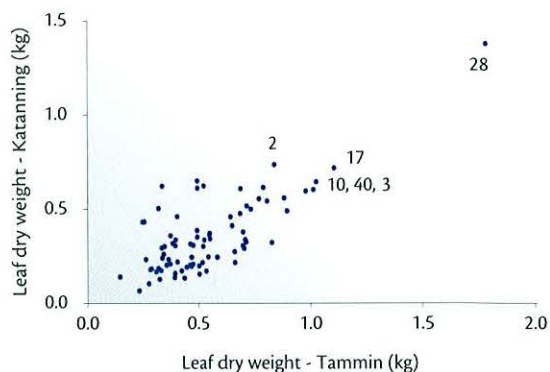


Figure 7.3 Leaf dry weights of 79 clones of river saltbush at Tammin and Katanning after six months' growth.³⁰ Numbers refer to individual clones.

Although Clone 28 was most productive, other characteristics suggest this plant may not be ideal for paddock conditions. Measurements of shoot dimensions showed it achieved its prodigious shoot weights by adopting a prostrate form and producing layering branches that took root where they touched the ground. After six months these plants covered more than twice the soil surface area of the average clone in the trial (Photo 7.2a). This strategy is similar to that used to produce very large shoot weights in grey saltbush (Photo 7.2b).³¹ Unfortunately, it means the shoot architecture is easily damaged. Sheep walk over and break the layering branches to access the forage, and Clone 28 recovered poorly from this damage (Photo 7.2c).

Photo 7.2. Similarities in growth strategy of Clone 28 (river saltbush) and grey saltbush (prostrate form), (a) clone 28 after two years growth, (b) Grey saltbush (prostrate form) after two years growth, (c) clone 28 after 10 years showing grazing damage to centre of plant.

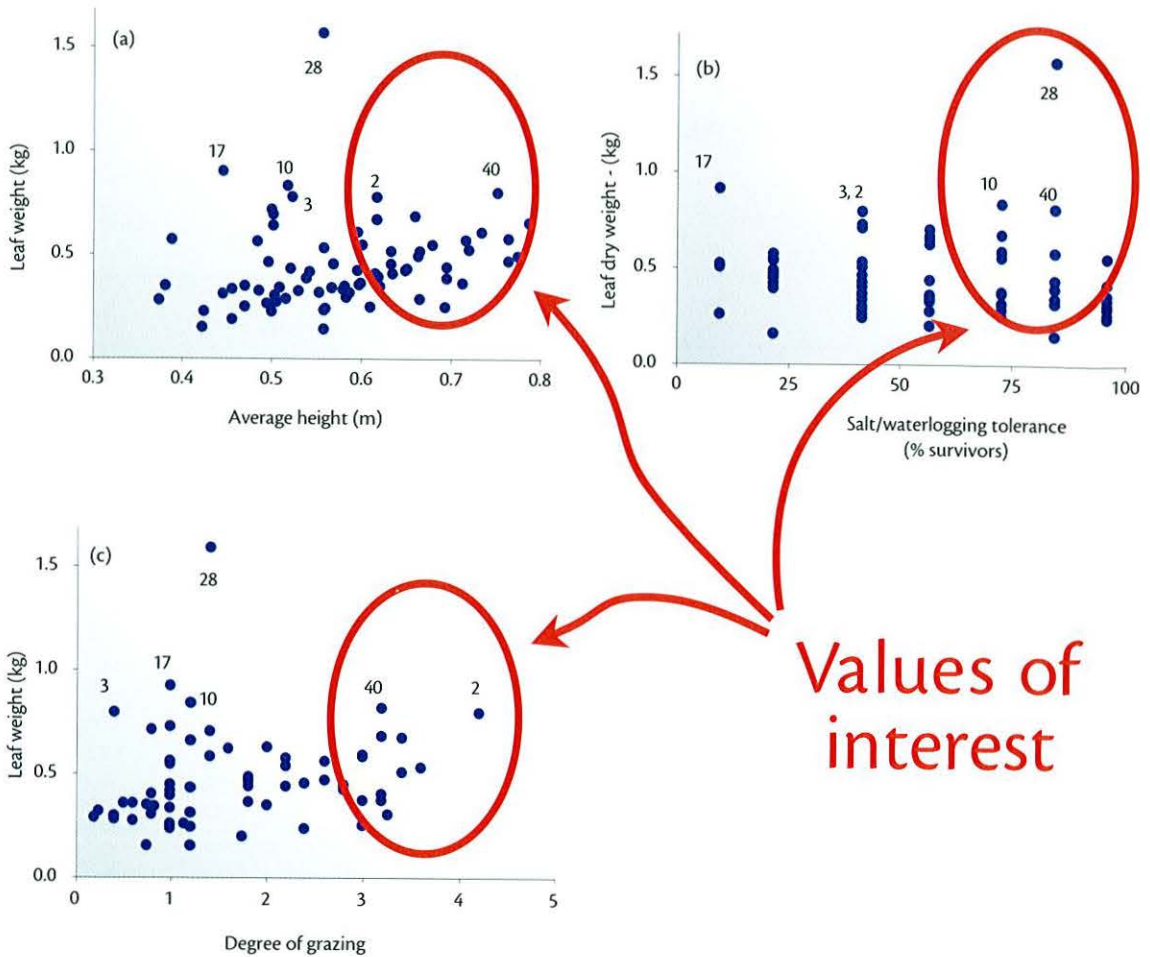


Figure 7.4 shows how the clones performed in terms of leaf production, plant height after six months, salt/waterlogging tolerance and palatability. Considering all criteria, Clone 40 appears to be a better all round performer than Clone 28. It grew higher and would have been less subject to damage by grazing animals than Clone 28 (Figure 7.4a), had similar tolerance to salt/waterlogging as Clone 28 (Figure 7.4b), and higher palatability than Clone 28 (Figure 7.4c).

Figure 7.4 Further criteria in the selection of clones of river saltbush. These graphs relate the amount of leaf weight after six months (average of both sites) to: (a) plant height after six months (average of both sites), (b) survival under conditions of waterlogging and increasing salinity in the glasshouse, and (c) amount consumed by sheep after one week (Katanning site).³²

7.4 Soil salinity and the 'mulching' action of plants

Key points

- *Plant cover helps lower salt concentrations at the soil surface. Maintain plant cover on saltland and on land at risk of salinity. Do not overgraze these areas.*
- *Mulches are critical to revegetation success, especially during the establishment of halophytic shrubs.*

Although soil salinity affects plant growth, plant growth can also affect soil salinity by:

- using groundwater and lowering watertables (Section 7.8.1)
- mulching saltland soils.

Mulches are critical to revegetation success, especially during the establishment of halophytic shrubs (Chapter 5).

Surface salt concentrations vary with the season (Figure 7.5). Typically, winter rain leaches surface salt into the subsoil (Figure 7.5a), while spring evaporation draws salt from the subsoil to the soil surface where it concentrates (Figure 7.5b).

Mulches (materials that decrease the evaporation of groundwater at the soil surface) can significantly reduce the accumulation of salt at the soil surface. Figure 7.6 shows the effects of a mulching layer of sand on salt concentrations in the same soil used in Figure 7.5. By the end of spring (November), the sand mulch had decreased the salt concentration at the surface of the soil profile by 98%.

Plants can act as mulches on saline soils. Figure 7.7 (a) shows the effect of baring a soil using a hormonal spray in a saltland area with a uniform cover of sea barley grass. Removal of the grass caused the concentration of salt at the soil surface to increase by 140%. Figure 7.7b shows the effect of re-establishment of grass cover on a previously bare area. Cultivation and sowing with a mixture of cereals and annual ryegrass for four years re-established plant cover and decreased soil salinities over the upper 30 cm by 50–75%.

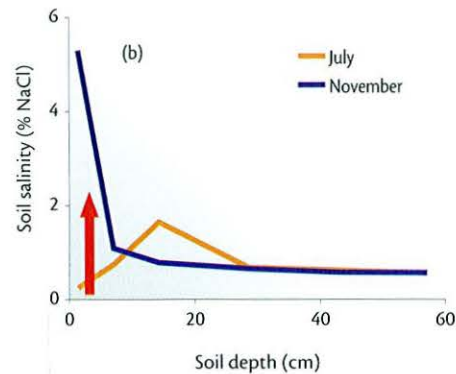
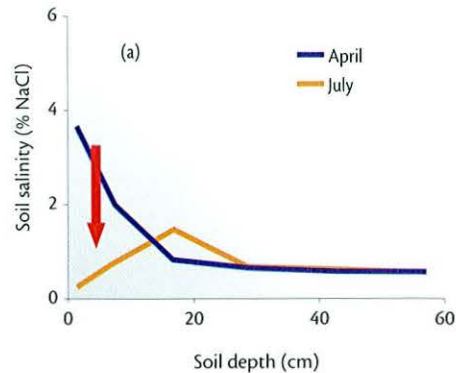


Figure 7.5 Seasonal changes in salt concentrations in a bare saline soil: (a) leaching cycle (April to July), (b) drying cycle (July to November).³³

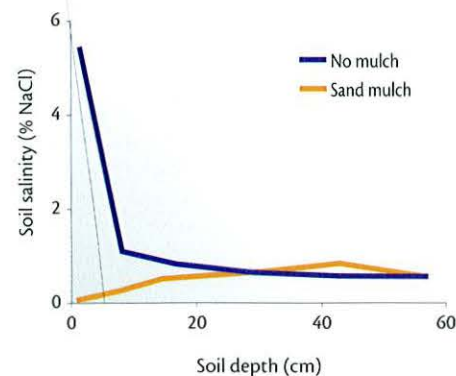


Figure 7.6 Sand mulch decreases the concentration of salt at the soil surface.³⁴

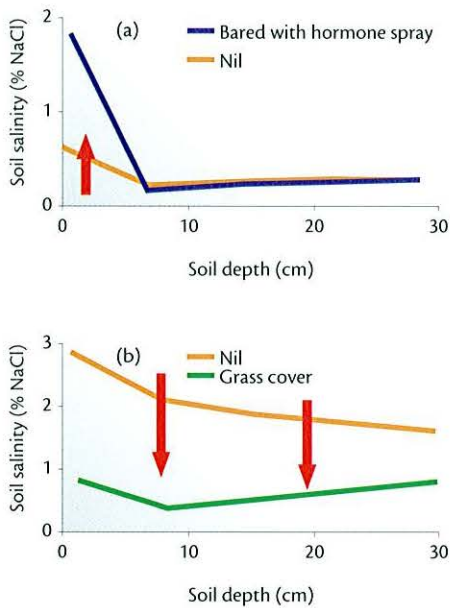


Figure 7.7 Effects of vegetation on the concentration of salt in the soil profile two sites near Corrigin WA. (a) baring a previously grassed saline soil increases salt concentrations, (b) annual cultivation and establishment of a grass cover decreases salt concentrations in a saline soil.³⁵

7.5 Waterlogging

7.5.1 Effects on halophytes

Waterlogging causes an energy deficiency in roots, *decreasing* root growth and survival, and the uptake of nutrients and water, and *increasing* salt uptake.

Although halophytes often grow naturally in waterlogged environments, little is known about the effects of waterlogging on growth. Tests in artificially-controlled waterlogged environments have shown that, although saltbushes are relatively tolerant to waterlogging, there are some differences between species.³⁶ Marsh saltbush and silver saltbush were killed after four weeks of waterlogging. In contrast, Old man saltbush died after five weeks, while river saltbush and a hybrid between Old man saltbush and river saltbush were still surviving after eight weeks of waterlogging. Examination of the root systems of the saltbushes showed that species sensitive to waterlogging like Old man saltbush had deep penetrating root systems, whereas more tolerant species such as river saltbush had a shallow root system (Figure 7.8).

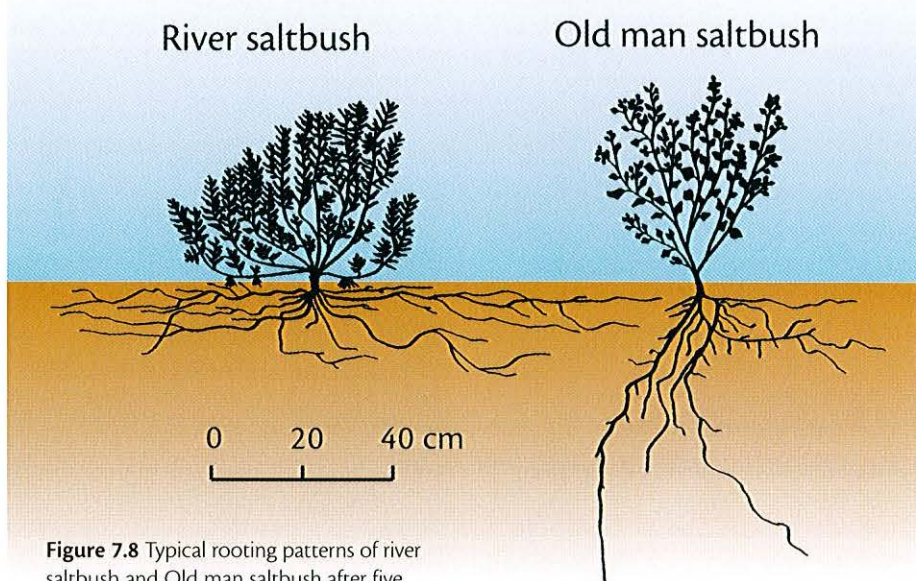


Figure 7.8 Typical rooting patterns of river saltbush and Old man saltbush after five weeks of waterlogging.³⁷

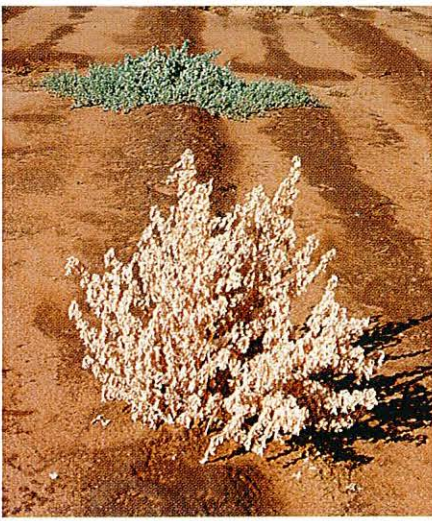


Photo 7.3 Bleaching of saltbush shoots due to waterlogging. The more sensitive Old man saltbush plant in the foreground became bleached and died, whereas the more tolerant grey saltbush plant in the background remained green and survived.³⁸

Prolonged waterlogging in halophytes causes root death, especially at the root tips. Dysfunctional roots take up less water and develop water deficiencies in the shoots. This can lead to a rapid decrease in shoot growth, decreases in transpiration and photosynthesis, leaf wilting and, finally, death of the plant. Sensitive saltbush species can become bleached (lose their chlorophyll) before death (Photo 7.3).

Waterlogging not only increases the uptake of salt by non-halophytic plants (Chapter 3), but also increases the salt uptake by halophytes. In one study, river saltbush was grown in saline nutrient solutions bubbled with air (simulating drained soils) or nitrogen gas (simulating waterlogged soils). With plants grown under saline conditions (40 dS/m), two weeks of simulated waterlogging nearly doubled the concentrations of sodium and chloride in the leaves, due to a combination of increased salt uptake and decreased shoot growth.³⁹

Adverse effects of waterlogging are presumably important for understorey species in halophyte stands, although little information is available. High salt uptake into the shoots of halophytes and understorey species is of concern because it:

- decreases plant growth and survival (cf. wheat plants in Photo 3.5)
- decreases the value of plants to grazing animals (see Chapter 6).

7.5.2 Low-cost engineering structures to lower watertables

Many farmers are adopting various kinds of drainage to lessen the impact of salinity, waterlogging and inundation. Drainage schemes can vary from networks of structures to improve surface water control, to deep drains and groundwater pumping.⁴⁰

Where possible we promote *low-cost* structures to achieve modest drainage and improvements in the growth of saltland pastures (Photo 7.4).

There are two basic strategies:⁴¹

1. *On-site management.* The aim is to decrease waterlogging and increase water movement off the low-lying (saline) land. Low-cost solutions include the use of land-forming and bedding systems to decrease waterlogging, and improved surface drainage into streams using spoon drains and W-drains.
2. *Off-site management.* The aim is to decrease the movement of water onto the low-lying (saline) land. Low-cost solutions include installing grade banks and interceptor drains to direct surface flows from the higher parts of the catchment away from the saltland pasture.

For further details on the construction of surface water control structures contact your nearest Departments of Agriculture and/or Natural Resource Management.



Photo 7.4 Excavation of a surface drain.

Care must be taken when designing surface water structures to ensure water is correctly disposed of. Drainage structures have the capacity to redirect large amounts of water around a catchment. Used appropriately they can make saltland more productive. However, *leakage* from engineered structures can have the reverse effect, making saltland more waterlogged and less productive.

7.6 Soil amendments and growth

7.6.1 Saltland fertility

Plants need at least 14 inorganic nutrients to survive and grow – six macronutrients (nitrogen, phosphorous, potassium, calcium, magnesium and sulphur) and eight micronutrients (copper, zinc, manganese, iron, boron, silicon, nickel and molybdenum). In addition, soil pH values need to be within a relatively narrow range, ensuring the availability of inorganic nutrients and low concentrations of toxic elements such as aluminium.

Little information exists on the nutrient status of saline waterlogged land in Australia. This is unfortunate, as plant growth on much of our saltland is likely to be limited by the availability of one or more nutrients.

(a) Waterlogging, nitrogen and denitrification

Plant nitrogen status is especially vulnerable on soils affected by waterlogging. Waterlogging can lead to denitrification in soils. As soils become oxygen deficient, anaerobic bacteria sequentially convert soil nitrate to nitrite, nitrous oxide, and eventually nitrogen gas. There is increasing evidence of responses by saltland pastures to nitrogen fertilisers, particularly among the grasses.

Waterlogging can also cause nutrient deficiencies by:

- decreasing the energy that plants have for nutrient uptake during the event
- affecting the subsequent depth of rooting, decreasing the ability of roots to forage for subsoil nutrients once waterlogging has ceased.

(b) Sodicity and calcium

As watertables are drawn down and soils are leached of salt, plants can become stressed by sodicity. Soils become sodic when the exchange surface of clays becomes dominated by sodium instead of calcium ions.⁴³ In Australia, soils are defined as sodic if they have an exchangeable sodium percentage (ESP) of 6–15, and highly sodic if their ESP is more than 15.⁴³

Sodicity can be overcome by applying soluble calcium (usually in the form of gypsum). No information is available on the effects of saltland pastures in creating soil sodicity, or of gypsum in improving the growth of saltland pastures. However, yield increases due to gypsum application in cropped systems suggest benefits may be possible.⁴⁴

(c) Phosphorous

Phosphorous may be less deficient on saltland than in other non-saline environments. Literature suggests toxic algal blooms occur in inland waterways at least partly because of the run-off and leaching of phosphate fertilisers from paddocks.⁴⁵ This eutrophication problem has led to phosphate fertilisers with decreased solubility, such as 'coastal superphosphate' in WA.⁴⁶

The up-side to eutrophication is that, being already provided with phosphorous in floodwater, saltland pastures may not have high requirements for phosphate fertilisers. The down-side is, where such fertilisers are necessary, they may need to be used sparingly and incorporated into the soil to prevent further surface water pollution.

(d) Soil pH

Extremes of soil pH can affect plant growth and the availability of nutrients (Photo 7.5). Aluminium can be toxic in soils with low pH values (less than 4.5), and nutrients such as iron and manganese are less available in soils with high pH values (greater than 8.5). Lime can be used to correct soil acidity problems, but it will almost certainly be too expensive to use on extensive areas of acid sulphate soils (see box page 122).

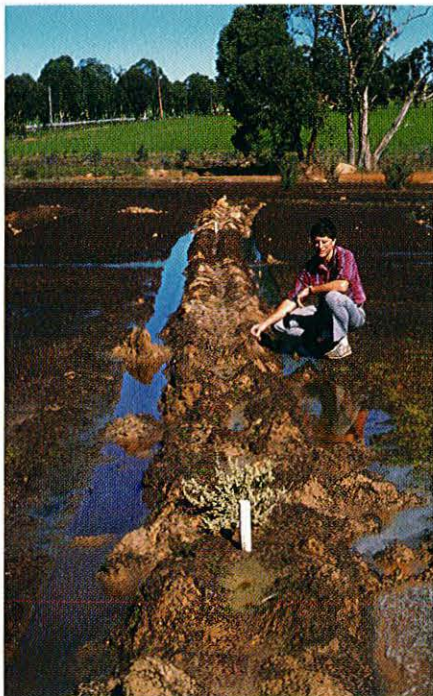


Photo 7.5 Poor growth of saltbush on an acid waterlogged site near Wundowie WA.

The tolerance of halophytes to extremes of soil pH has been poorly documented. However, references include:

- puccinellia established better in spring in soils with pH values in the range 8–9 than in soils with pH values less than 6.5.⁴⁸
- in trials of halophytic shrubs (saltbushes and small leaf bluebush), after five months the second poorest growth occurred at a site with subsoil pH values less than 4.0.⁴⁹

7.6.2 Diagnosing nutrient deficiencies

Nutrient deficiencies may be diagnosed by:

- Identifying visual symptoms
- Analysing plant tissues for nutrient concentrations and comparing the results with the critical concentration for deficiency for that species. The critical nutrient concentration for deficiency is the concentration in the plant tissues just adequate for maximum plant growth. The principle behind this approach is that, for a given plant and nutrient, a relationship can be defined between the concentration of nutrient in the tissues and plant growth (Figure 7.9). At very low nutrient concentrations, growth increases as the nutrient concentration increases; there is then a range in which growth is maximal and not affected by further increases in concentration; finally, as concentrations reach toxic levels, there may be a decline in growth (Figure 7.9).

Although there is extensive information on critical nutrient concentrations for many crops and pasture species, there is little or no information on halophytic shrubs and grasses.⁵⁰ However, in many cases it is possible to gain insights into the nutrient status of saltland pastures by sampling understorey grass and legume components of the pasture.

Acid sulphate soils⁴⁷

Saline groundwater can contain high concentrations of reduced sulphur (sulphide). If discharge areas are drained and exposed to air, the sulphide oxidises to form sulphuric acid. These acid sulphate soils can have pH values less than 4.0. Soil pores may become clogged with clay and various types of iron oxyhydroxides.

Acid sulphate soils are unstable, erode easily and give rise to scalds and erosion gullies. They can discharge water containing toxic aluminium, iron and heavy metals to streams. These soils are difficult to rehabilitate because of their combined problems of acidity, salinity, waterlogging and low fertility.

The key management options are to:

- Recognise sites with potential to form acid sulphate soils. These soils have distinctive black coloured blotches that are often smelly and soggy because of the presence of sulphidic materials.
- Avoid draining or disturbing these sites.
- Allow these sites to retain natural vegetation.

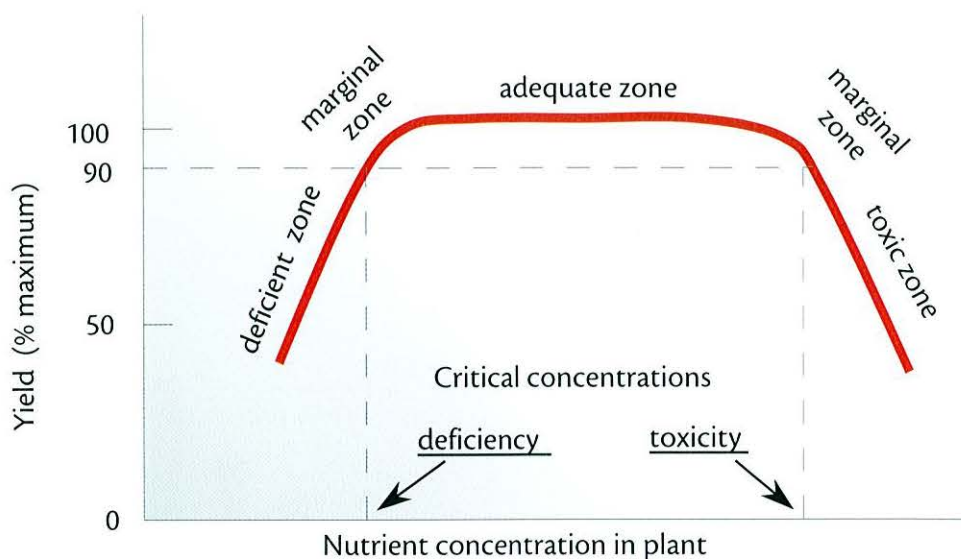


Figure 7.9 Derivation of critical concentrations for diagnosing nutrient deficiency and toxicity in plants.⁵¹

Critical concentrations for deficiency with nutrients such as nitrogen, phosphorous and potassium decrease as plants develop. Figure 7.10 shows for wheat and subterranean clover how the critical concentration for phosphorous on a whole shoot basis decreases from around 0.6% to 0.2% dry weight as the plants grow. Clearly, accurate diagnosis of nutrient deficiency requires precise information about the age or stage of development of the plants sampled.

Many laboratories have a standard form for submitting samples. Check your local laboratory about procedures before beginning a sampling program.

Information essential to accurate diagnosis from plant tissues includes:

1. Details of collection – location, date, person responsible
2. The name of the species sampled within the pasture
3. The tissue sampled – from whole shoots to more specific tissues, such as the youngest expanded leaf (of a grass), or the youngest open leaf blade (of a pasture legume).

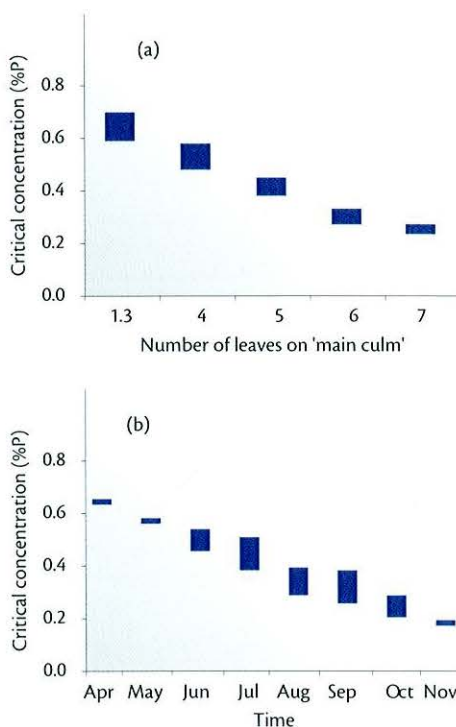


Figure 7.10 Critical nutrient concentrations for deficiency decrease with the age of the plants. The data reported here are for phosphorous (based on the analysis of whole shoots) in: (a) wheat, and (b) subterranean clover.⁵²



Photo 7.6. In the absence of nitrogen, puccinellia can be expected to have exceptionally poor growth.

7.6.3 Benefits from fertilising saltland pastures

Fertilisers can improve saltland pasture establishment and growth. A wide range of experimentation shows that grasses are responsive to nitrogen, and legumes respond to phosphorous and potassium (Photo 7.6). Potassium may also affect the palatability and value of saltland pastures to grazing animals (Chapter 6).

The few case studies on the effects of fertilisers on saltland pasture productivity provide a range of results.

(a) Nitrogen

Saltland pasture plants respond to nitrogen fertilisers, and split fertiliser applications offer a means of ensuring nutrients are available throughout the growing season. These observations are hardly surprising given that denitrification associated with seasonal waterlogging can make saltland soils N-deficient (discussed above), and nitrogenous compounds such as glycinebetaine and proline play critical roles in the osmotic adjustment (and growth) of halophytes.⁵³

Case studies demonstrating the benefits from N fertilisers for plant productivity on saltland include:

- *Puccinellia* at Karkoo on the Lower Eyre Peninsula SA. Without fertiliser, an established stand of puccinellia produced only 2.2 t/ha of fodder. However, production was more than three times greater with a split application of nitrogen (15 kg/ha in June, 50 kg/ha in August – Figure 7.11a). There were also substantial benefits to seed production (Figure 7.11b).

- *River saltbush* at Tammin WA. Application of nitrogen (60 kg/ha) to river saltbush plants had an initial effect on growth, but the effects declined with time. Three months after planting, shoot volumes were more than doubled by the application of nitrogen, but after two years, plants with nitrogen fertiliser were only ~12% larger than non-treated plants.⁵⁴

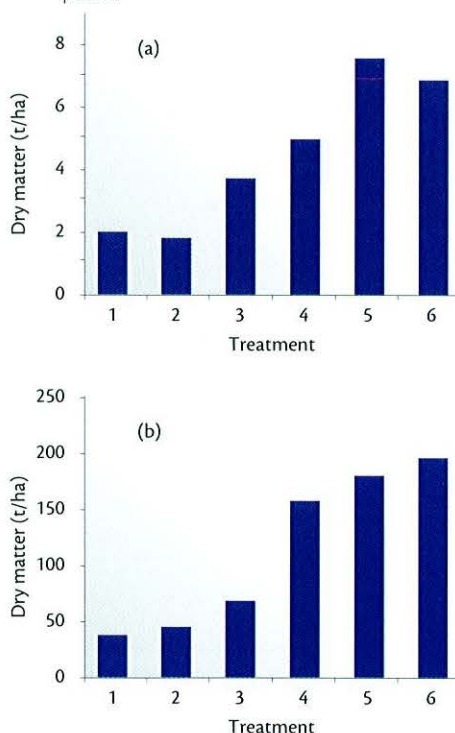


Figure 7.11 Effects of nitrogen fertiliser application on an established puccinellia stand: (a) production of fodder, (b) production of seed.⁵⁵ The fertiliser was applied as a split application in June and August:

Treatment	Nitrogen applied (kg/ha)	
	June	August
1	0	0
2	15	0
3	30	0
4	0	50
5	15	50
6	30	50

(b) Other nutrients

The case for applying other nutrients to saltland pastures has not been well made. At a site at Tammin WA, with high basal levels of phosphorous in the soil (12 ppm in control plots without fertiliser), there was no growth response in river saltbush to superphosphate at rates between 0–96 kg/ha.

In view of the paucity of available information it is recommended saltland pastures be established with modest levels of superphosphate where warranted. The fertiliser should be well incorporated to reduce the risk of waterway pollution.

(c) Mycorrhizas and other plant root associations

Plant growth in nutrient deficient soils can be improved through fungal associations with roots called 'vesicular arbuscular mycorrhizas'.⁵⁶ These associations have been linked to improved phosphorous nutrition in coarse-rooted plant species such as subterranean clover.⁵⁷ Unfortunately, surveys suggest such associations do *not* form with salt tolerant plants.⁵⁸ Other studies suggest root bacterial associations may improve the nutrition of saltland species. High growth rates of two saltbushes on low fertility saltland near Lahore in Pakistan were associated with the presence of the nitrogen-fixing bacterium *Enterobacter agglomerans*.⁵⁹ The significance of bacterial associations has not yet been demonstrated for saltland plants or soils in Australia.

7.7 Soil compaction and deep ripping

Key point

• *Deep ripping increases saltbush growth without substantial cost. At 400 plants per hectare, the cost of establishing nursery-raised seedlings is about \$150 per hectare (\$120 per hectare for seedlings, \$30 per hectare for planting). The use of the Agroplow increases the total cost of re-vegetation by about \$30 per hectare and can increase production of saltbush several-fold.*

Heavy agricultural machinery compacts sandy soils to a depth of about 30–40 cm. In cereals, this inhibits root extension, especially on sands and deeper duplex soils.⁶⁰ Similar problems also occur on saltland.

A river saltbush experiment on a deep duplex soil with a traffic pan at 10–30 cm involved 'no rip', a 'slot rip' treatment (in which soil was ripped to a depth of 40 cm in a band 40 cm wide), and an 'Agroplow' treatment (in which soil was ripped to a depth of 40 cm in a band 4.4 m wide). The experiment also had two rates of fertiliser application (none, or 23 g/m row of diammonium phosphate).

Deep ripping treatments had substantial effects on growth, whereas the effects of fertiliser were slight (Photo 7.7). After two years' growth, plants with no rip had grazable biomass yields of 0.4–0.7 t/ha (Figure 7.12). The slot rip treatment disrupted the traffic pan on 8% of the area, and caused 20–40% increases in leaf growth. The Agroplow treatment disrupted the traffic pan on about 90% of the area, and caused 60–130% increases in leaf growth. Fertiliser application increased leaf growth by 10–60%, with the greatest benefits in the no rip treatment (Figure 7.12).



Photo 7.7 (a)

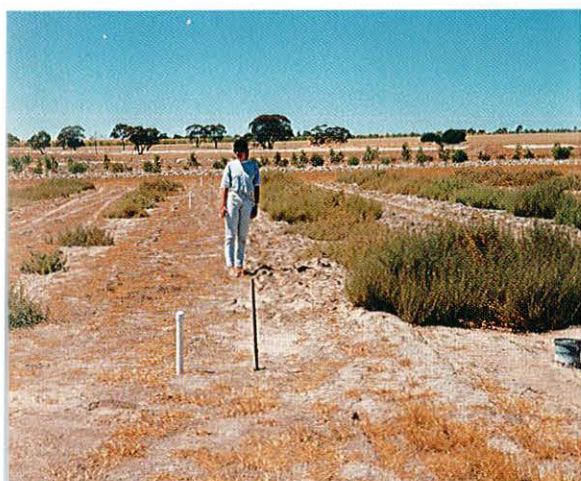


Photo 7.7 (b)

Photo 7.7 Effects of deep ripping a sandy textured soil at Tammin WA. Row on left hand side has 'no rip' treatment. Row on right hand side has agroplow treatment. (a) three months after establishment, (b) two years after establishment.

7.8 Layout of saltland pastures

The layout of saltland pastures is affected by the need to:

- lower watertables
- produce a balanced mix of fodders
- decrease planting density and establishment costs
- fertilise, seed and maintain the pastures.

7.8.1 Lowering watertables

Key point

• Saltland pastures need a substantial perennial component to help lower the watertable.

The use of perennial vegetation (trees and perennial pastures) for lowering watertables is well-established.⁶² Simple drainage theory can be used to estimate the required spacing of rows of trees to achieve drainage in alley-farming systems.⁶³ However, significant lowering of watertables may also be possible using saltland pastures.

Even small decreases in watertable depth on saltland in summer – the time of greatest evaporative demand – could decrease the accumulation of salt at the soil surface. If saline watertables are less than 0.7 metres deep, surface cover of the soil is generally low and accumulation of salt at the soil surface in summer is inevitable. However, if saline watertables can be drawn down by one metre (to 1.7 m) using saltland pastures, the movement of salt to the soil surface in summer is decreased by at least 80%.⁶⁵ This intervention may also be sufficient to change a site with a cover of patchy barley grass into one capable of growing ryegrass and balansa clover, or even a crop of barley.⁶⁵

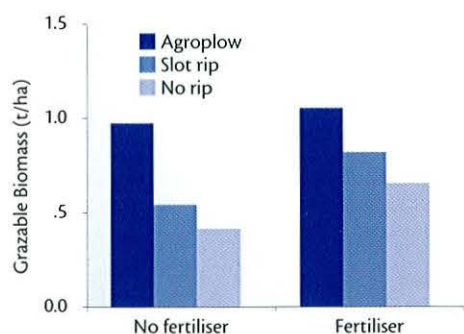


Figure 7.12 Effects of deep ripping and fertiliser application on the growth of river saltbush.⁶¹

The keys to using saltland pastures to lower watertables are:

- (a) Ensuring plants rapidly grow a large leaf area index (leaf area relative to soil surface area). This can only be achieved if the plants are established at sufficient density and on favourable sites. Saltbushes have a remarkable ability to rapidly develop a large leaf surface area. Stands of the clones referred to in Figure 7.3 would have produced average yields of leaf (dry weight basis) of 1.7–0.9 tonnes per hectare *after six months*.
- (b) Managing grazing so pastures still have some leaves during times of highest evaporative demand (summer).
- (c) Choosing sites where watertables are within the active root-zone. Saltbush based pastures can be expected to use considerable groundwater at 1 m depth, but much less at 2 m.⁶⁶

Direct evidence for increased evapotranspiration from saltland with saltland pastures, the lowering of watertables, and the growth of higher value understorey species is summarised below.

Evidence for the lowering of watertables by saltland pastures

1. **Tall wheat grass pasture in the Upper South East SA** With Tall wheat grass, watertables decreased from 0.1 to 1.4 m over 36 days in the summer of 1994/95. Evapotranspiration was 3.6 mm/day. In nearby areas with a cover of barley grass, watertables decreased from 0 to 1.0 m; evapotranspiration was 2.8 mm/day.⁶⁷
2. **Tall wheat grass stand near Woodanilling WA** Soils beneath a two-year-old stand of Tall wheat grass were 30–40 mm drier in summer and had 70% less waterlogging in winter than in adjacent areas with annual cover. After three years, plots with Tall wheat grass had twice the balansa clover composition of plots with annual pasture and after five years balansa only appeared in association with Tall wheat grass.⁶⁸
3. **Various saltbush species near Kellerberrin WA** Measurements of salt accumulation in the root zone of saltbushes over two years showed evapotranspiration accounted for 60–100 mm of groundwater plus 460 mm of rainfall. The amount of groundwater used was proportional to the weight of saltbush leaf per unit soil surface area.⁶⁹ With bladder saltbush (the smallest species in the experiment), evapotranspiration in summer was between 1.3 and 3.3 mm/day.⁷⁰
4. **Saltbush stand in North Stirlings area WA** An excellent stand of mixed saltbush species was established on a sandy-textured field with a watertable at 1.2 m in summer (Photo 7.8a). Five years later, the watertable at the site had been drawn down to 2.5 m in summer, the saltbush had lost much of its leaf area because of moisture deficiency, and the barley grass-dominated understorey had been replaced by subterranean clover (Photo 7.8b,c). The saltland pasture at this site had therefore used about 25 mm of groundwater per year over the five-year period⁷¹
5. **Saltbush stand near Pingaring WA** A good stand of mixed saltbush species was established on a duplex-textured field with a shallow watertable in April 1998. An adjacent site was not revegetated. After two years, watertables were 0.5 m deeper with saltbushes than at the non-revegetated site (Figure 7.13).⁷² After 30 months, the watertables had been drawn down to levels lower than the capillary fringe.⁷³

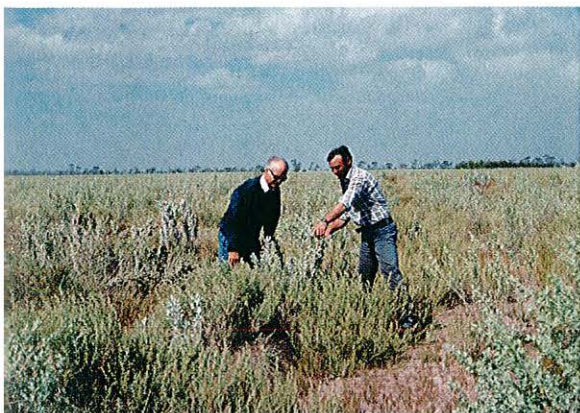


Photo 7.8 (a)



Photo 7.8 (b)

Photo 7.8 Saltbush induces ecological change on stand of mixed saltbush species in the North Stirlings WA. (a) Original stand. Five years later: (b) saltbush loses leaf area because of moisture deficiency, and (c) understorey of subterranean clover develops.

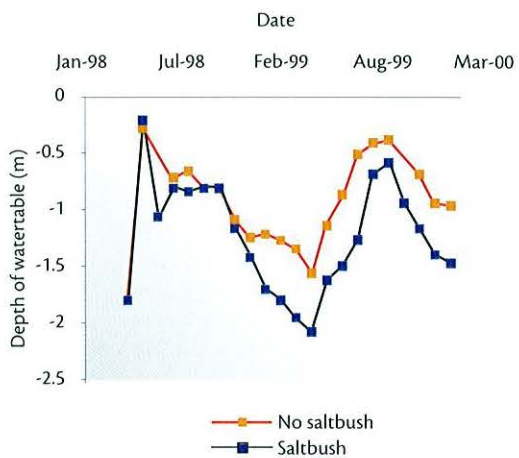


Figure 7.13 Effects of a saltbush stand on watertable depth at a saline site at Pingaring WA.⁷⁴



Photo 7.8 (c)

7.8.2 Producing a balanced mix of fodders

Key point

• Achieving a balance of crude protein and metabolic energy in the saltland pasture requires an appreciation of the way in which perennial and annual pasture components compete with each other for scarce resources – especially water.

Grazing animals need a mixture of saltland fodders to supply their needs for protein and metabolisable energy. Two broad feeding systems could operate:

- *Dense plantations of halophytic shrubs (providing crude protein) and a minimal understorey.* In this system the bulk of the required metabolisable energy would be provided as a supplement of hay, straw or some other energy source.
- *Widely spaced stands of halophytic shrubs (which provide crude protein) and a substantial understorey (which provides metabolisable energy).* In this system, intensive rotational grazing might be required to ensure animals simultaneously graze palatable understorey and unpalatable shrubs.



Photo 7.9 Saltbush suffering severe competition from summer growing perennial grasses near Wellington NSW.

Competition between perennial and annual components of the pasture for soil moisture could affect the ability of the pasture to deliver a balanced diet. Three sets of evidence (see box below) show saltland pastures can rapidly access the surface soil moisture.

Evidence that components of saltland pastures compete for surface moisture

1. Strong competition between different saltland pasture species

Saltland pasture composition (amounts of saltbush, Tall wheat grass and other understorey) were observed on 14 plots at Scadden and Cranbrook, WA (Figure 7.14a). The amount of saltbush leaf decreased exponentially as Tall wheat grass increased (Figure 7.14b). This suggests strong competition, probably for soil moisture, between summer-active components. Similar competition between saltbush and Tall wheat grass has been observed on mixed saltland pastures at Wellington NSW (Photo 7.9).

2. Strong competition between plants within stands

In older stands of saltbush, the largest plants invariably occur on the edges of plots (where competition for water is decreased by about 50%) and at the corners of plots (where competition for water is decreased by about 75% (Photo 7.10).

3. Greater growth of saltland pasture species under irrigated than under dryland conditions

The importance of water for salt-tolerant pasture growth is illustrated by comparing production under dryland and irrigated conditions. In general, irrigation increases shoot dry weight production at least three-fold (Figure 7.15, Photo 7.11). This reinforces the view that growth under dryland conditions is constrained by the availability of moisture. High productivity has been reported in overseas irrigation studies.⁷⁵



Photo 7.10 (a)



Photo 7.10 (b)

Photo 7.10 The largest plants in saltbush stands generally occur on the edges and corners of plots where competition for moisture is lowest. (a) North Stirlings WA, (b) Tammin WA.

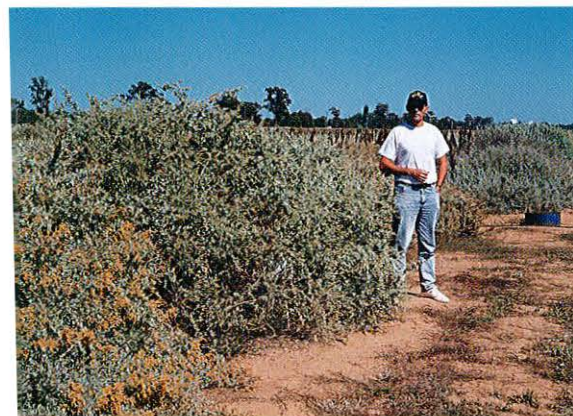


Photo 7.11 High levels of production in irrigated river saltbush at Tatura VIC.

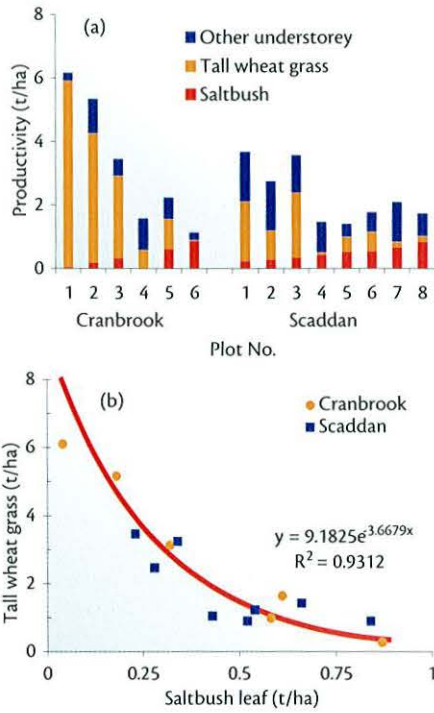


Figure 7.14 Relationships between production of saltbush leaf and Tall wheat grass. (a) Production of saltbush, Tall wheat grass and understorey on 14 plots at Cranbrook and Scaddan WA. (b) Yields of saltbush leaf decreased exponentially as yields of Tall wheat grass increased.⁷⁶

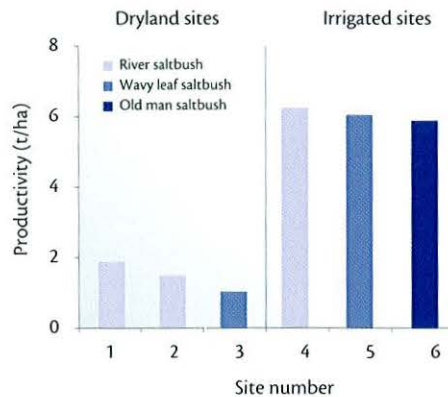


Figure 7.15 Relative yields of saltbush stands under dryland and irrigated conditions.⁷⁷

In exceptional circumstances, understorey can fail to develop even when halophytic shrubs are widely spaced. In the very dry 2002 season, many farmers found their deep-rooted saltbushes produced good fodder using stored soil moisture, but soil surface conditions were too dry to allow for the establishment and growth of annual understorey (Photo 7.12). In this situation, to gain best value from the stands, farmers will need to provide an energy supplement such as straw.



Photo 7.12 Poor production of understorey in saltbush stands at Pingaring WA during the exceptionally dry 2002 season (Photograph: Michael Lloyd).

7.8.3 Reducing plant density and establishment costs

Key point

• *Planting density affects establishment costs. Aim to plant no more perennials than required to achieve the fodder and water-use goals. With large-framed saltbush species (river saltbush, Old man saltbush) this may be possible with 400 plants per hectare.*

Planting density can dramatically affect establishment costs. For example, if saltbush seedlings are to be planted at 1,000 stems/ha, and the nursery sells the seedlings for 25 cents each, establishment will cost more than \$250/ha. On the other hand, if the planting density can be decreased to 400 stems/ha, establishment costs can be decreased by more than 50%.

Saltbush growth generally increases as the plants are more widely spaced. Appreciable leaf production can be achieved at low planting densities. However, two important qualifications need to be made:

- Growth is affected by the genetic potential of the species to be planted – some plants have a lower potential for growth than others.
- Soil texture affects growth. Saltbushes grow larger in lighter (sandy) than heavy (clay) textured soils.

Evidence is available from two trials (summarised in box below).

Planting density and growth – the evidence

Effects of species

A study at Kellerberrin (WA) compared the effects of planting density on saltbushes with differing capacities for growth (Figure 7.16). Bladder saltbush (a small growing plant) reached its maximum size with an area of 4 m² per plant, whereas the larger growing wavy leaf saltbush and river saltbush were still increasing in size with areas of up to 9 m² per plant (Figure 7.16a). Another way to consider these data is in terms of the effects of planting densities (numbers of plants per hectare) on saltbush productivity (Figure 7.16b). At high planting densities (5,000 plants per hectare), river saltbush and wavy leaf saltbush had similar productivity (about 2 t/ha of leaf and twig). At lower planting densities (1,111 plants/ha), river saltbush had 50% higher yields than wavy leaf saltbush, and bladder saltbush had a lower productivity than both river and wavy leaf saltbush (Figure 7.16b).

Effects of soil type

In another study, river saltbush was planted at sandy (Esperance, WA) and clayey (Katanning, WA) sites, each with about 450–480 mm of average annual rainfall. At the sandy site, shoot growth continued to increase as spacing increased up to 80 m² per plant. Shoot volumes were about three times larger at spacings of 80 m² per plant than at spacings of 5 m²/plant. In contrast, at the clayey site, there was no significant increase in shoot volume at plant spacings wider than 40 m²/plant (Figure 7.17).

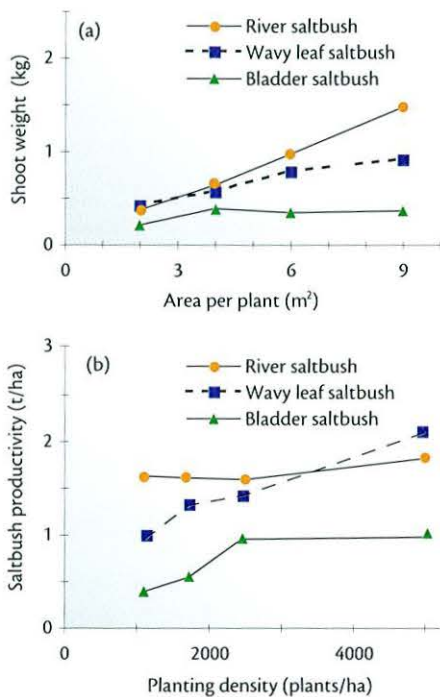


Figure 7.16 Relationships between growth of saltbush species and spacing: (a) area per plant and productivity per plant; (b) planting density and productivity.⁷⁸

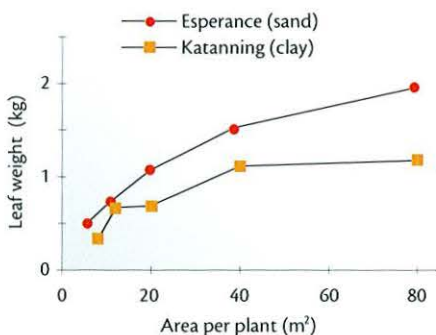


Figure 7.17 Effects of soil texture on the relationship between plant spacing and shoot growth in river saltbush.⁷⁹

7.8.4 Design

One of the keys to saltland pasture profitability lies in pasture planning and layout.

- Assess the area to be planted in terms of its susceptibility to salinity and waterlogging and plant appropriate species (cf. salinity/waterlogging matrix in Figure 4.1).
- Establish an animal feeding system. A number of questions need to be considered. When (during which season) are the plants to be grazed? Which plants will provide the bulk of the metabolisable energy and which the bulk of the crude protein? Will the diet of the animals need to be supplemented with fodder from off-site? Will an intensive rotational grazing system be used? Will plants be established in dense stands or alleys?
- Plan the infrastructure at the site. Drains and banks may need to be constructed to control waterlogging and inundation. Land management and grazing units will need to be delineated using new permanent or temporary fencing. A water delivery system of permanent or moveable water troughs will be required. Vehicular access may be required to bring supplementary fodder to the site. Will the design allow for the fertilising or reseeded of the pastures?

The best answers to saltland pasture design issues will depend on the characteristics of the site and the farmer's needs. Figure 7.18 shows in plan view a typical saltland site with areas of bare saltland, barley grass and poor crop. Figures 7.19–7.21 show three alternative ways that this site could be developed depending on the levels of salinity and waterlogging in the area and the needs of the farmer.

Scenarios 1 and 2 (Figures 7.19 and 7.20). In the first two scenarios, we have assumed that the indicator species are telling us that the bare saltland is severely affected by salinity and waterlogging, and the land with barley grass is moderately affected by salinity and waterlogging (cf. Figure 4.2). The salinity/waterlogging matrix (Figure 4.1) therefore suggests that these zones are suited respectively to the growth of samphire (which we will establish naturally by fencing and the control of grazing – Chapter 5) and saltbushes (which we will establish with a niche seeder or as nursery-raised seedlings – Chapter 5).

In both scenarios, plant growth has been improved by decreasing waterlogging and inundation by:

- capturing run-on with a graded bank and diverting it into a dam
- increasing run-off using W-drains.

These steps also help to ameliorate erosion because there is less inundating water on the site.

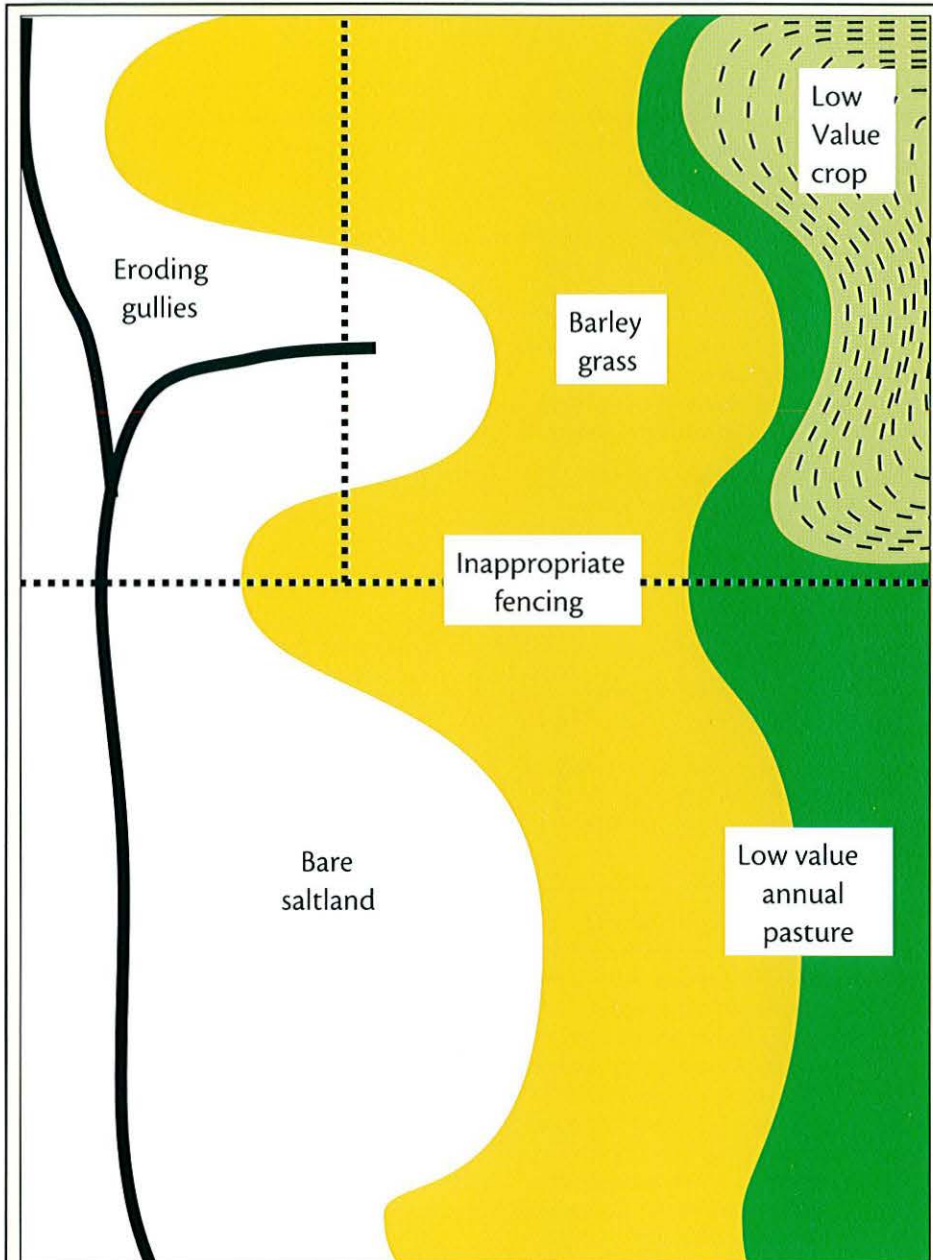
In both scenarios the planting of the saltbush will lower the watertable, enabling the growth of a higher quality understorey than previously available.

The two scenarios differ primarily in the manner in which the pastures are used by grazing animals. In Scenario 1 (Figure 7.19), the stand of saltbush is dense (1,000 stems per hectare), there is only limited understorey as a source of metabolisable energy, and the animals need to be provided with hay or straw as a supplement. The fencing and provision of water reflect this use. In contrast in Scenario 2 (Figure 7.20), rows of saltbush are separated by wide alleys of improved understorey, and having a range of palatability, the feed on offer is intensively grazed. The arrangement of moveable electric fencing and moveable water troughs facilitate this use.

Scenario 3 (Figure 7.21). Scenario 3 assumes the site to have differing susceptibility to salinity and waterlogging; careful examination of the site reveals that the site has low to moderate salinity but high waterlogging. Indeed, the lowest part of the landscape is bare primarily because of extensive inundation. Clearly, improved surface water control is the key to productivity. We have therefore augmented the earlier surface water control steps by adding a tree belt to the edge of the affected land to further decrease run-on. This site is too waterlogged to grow saltbushes, but analysis of soil pH shows that the soils are alkaline, and the bulk of the site is therefore suited to the growth of puccinellia. In the less waterlogged land, Tall wheat grass is sown with balansa clover as a companion legume.

Fertility is a key to productivity – the puccinellia needs to be fertilised with nitrogen, and the balansa clover needs to be fertilised with potassium and phosphorous.

Puccinellia and Tall wheat grass have quite different palatabilities to sheep. This scenario could therefore also benefit from an intensification of grazing, and in a similar manner to Scenario 2, moveable electric fences and water troughs could play an important role in ensuring a more uniform use of the feed on offer.



Major landscape features

- Saline/waterlogged land not productive
- Fencing design not appropriate to saltland management units
- Most saltland subject to unrestricted grazing
- Waterways eroding
- Annual pastures and crops are of low value, being affected by salinity, waterlogging and inundation.

Figure 7.18 Plan of a typical degraded saltland site.

Scenario 1 Dense stand of saltbush with little understorey

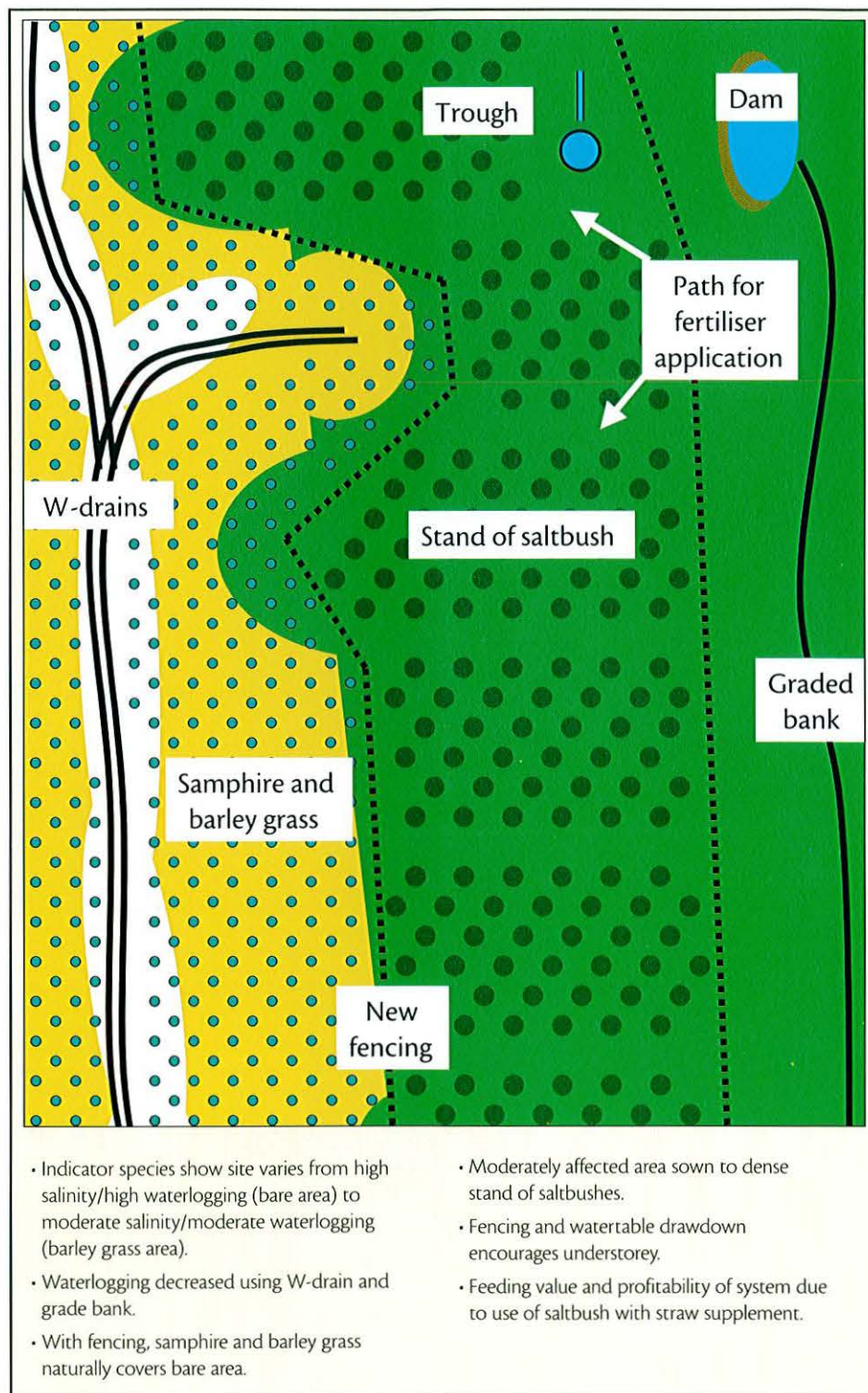


Figure 7.19 One saltland pasture solution to the degraded saltland in Figure 7.18 – Dense stand of saltbush with little annual understorey (Scenario 1).

Scenario 2 Alleys of saltbush with substantial annual understorey

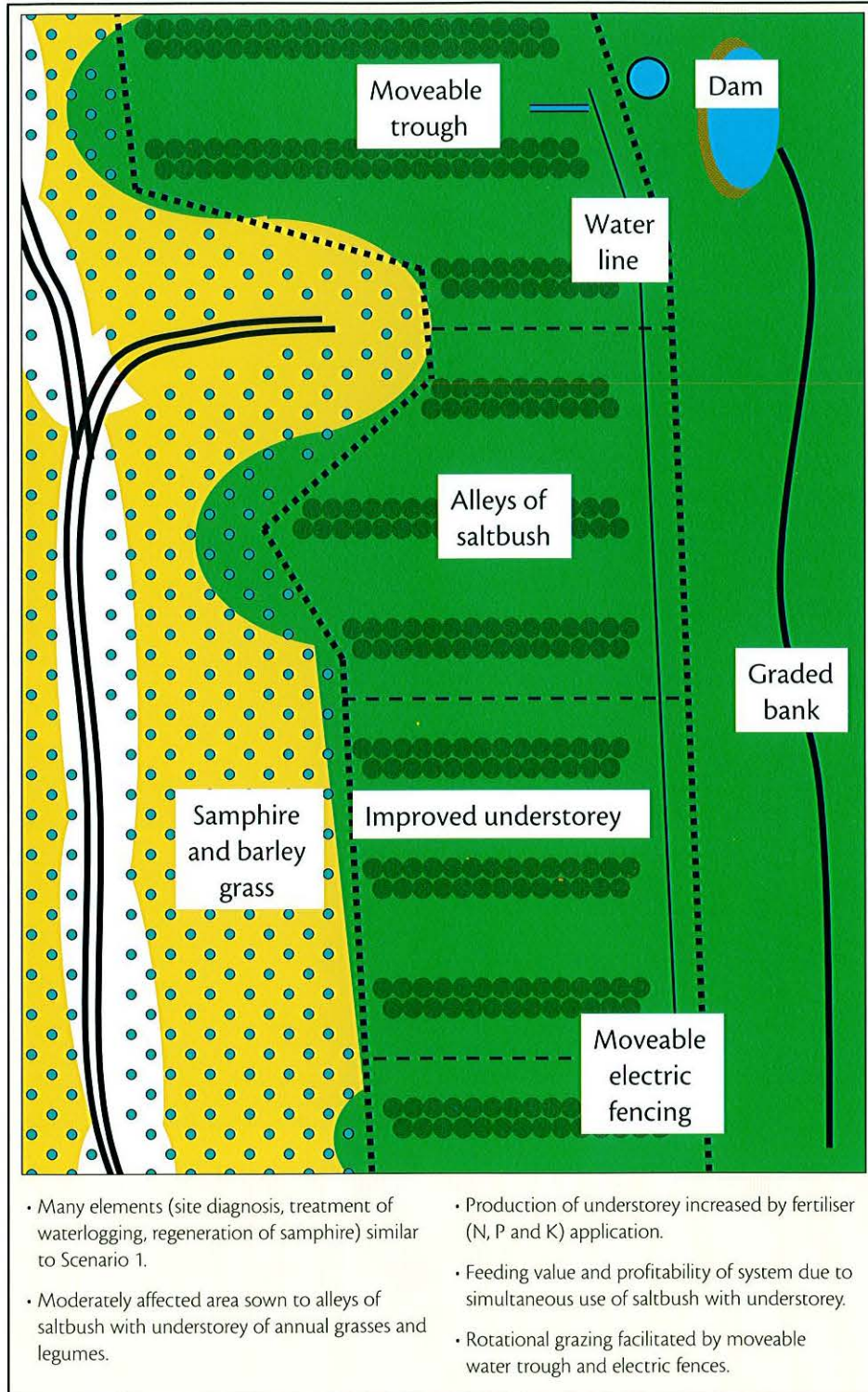


Figure 7.20 Another saltland pasture solution to the degraded saltland in Figure 7.18 – Alleys of saltbush with substantial annual understorey (Scenario 2).

Scenario 3 Range of perennial grasses and annual understorey

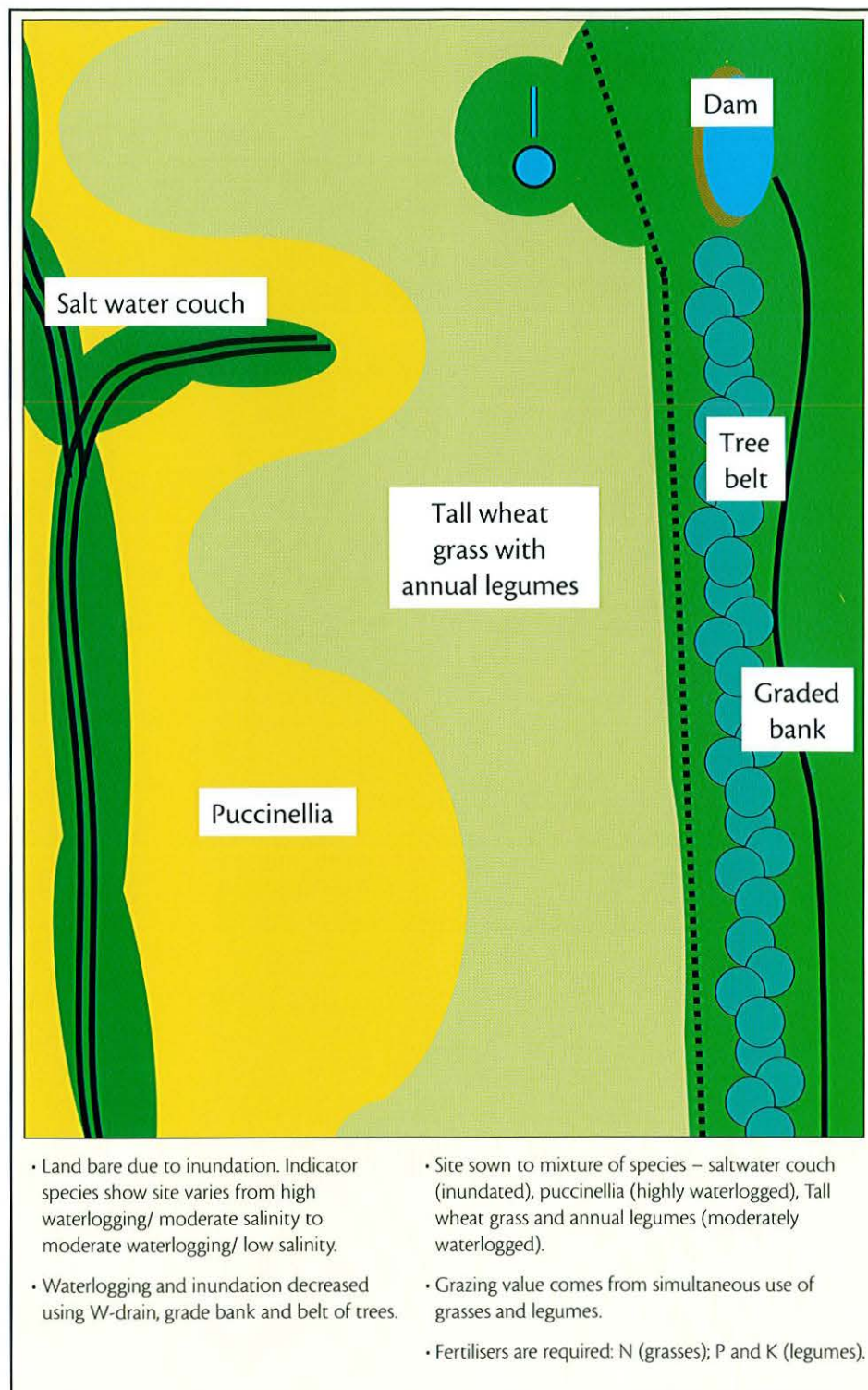


Figure 7.21 A third saltland pasture solution to the degraded saltland in Figure 7.18 – A range of perennial grasses with annual understorey (Scenario 3).

Further reading and notes

- 1 Leech and Southwell (1999), Ghauri and Westrup (2000).
- 2 Atiq-ur-Rehman (1995).
- 3 Andrew *et al.* (1979). Widely used for the measurement of biomass in rangeland environments.
- 4 Based on unpublished data of E.G. Barrett-Lennard and K.C. True for 18–28 month old river saltbush plants tabulated below:

Location	Correlation between shoot volume (m ³ – x-axis) and leaf dry weight (kg – y-axis)	r ²
Esperance	$y = 0.497x + 0.223$ (n = 23)	0.61
Katanning	$y = 0.475x + 0.084$ (n = 21)	0.67
Merredin	$y = 0.442x + 0.452$ (n = 18)	0.56
Tammin	$y = 0.291x + 0.552$ (n = 12)	0.64
Jacup	$y = 0.275x + 0.594$ (n = 11)	0.77
Kamballup	$y = 0.393x + 0.497$ (n = 11)	0.93
Denbarker	$y = 0.459x + 0.385$ (n = 10)	0.50
Gairdner	$y = 0.345x + 1.449$ (n = 10)	0.34

- 5 Based on Tothill *et al.* (1992).
- 6 It was used by Norman *et al.* (2002a) to estimate the composition of understorey in three halophytic shrub/understorey pastures. We are unaware of its use for other saltland pastures.
- 7 Barrett-Lennard and Galloway (1996).
- 8 The data for Peshawar are from the ADAPT2 experiment (river saltbush, accession 949, median of eight plants at 625 plants/ha – Rashid and Khan, unpublished data). The data for Tammin are from the FERT experiment (400 plants/ha – Davidson, Galloway and Barrett-Lennard, unpublished data). The data for Wagin are from the CLONE1 experiment (625 plants/ha – Lazarescu, Galloway and Barrett-Lennard, unpublished data). The final yield of saltbush leaf at Wagin and Tammin was 0.4–0.5 t/ha.
- 9 P. Evans (unpublished data) for the Katanning area.
- 10 Yensen (1999).
- 11 Teakle and Burvill (1945), Burvill and Marshall (1951).
- 12 Rogers and Bailey (1963).
- 13 Malcolm and Smith (1965), Fleck (1967), Hamilton (1972), Lay (1990), McCarthy (1992), Herrmann (1996).
- 14 Rogers and Noble (1991), Rogers and West (1993), Evans (1995).
- 15 Semple *et al.* (1998; 2003).
- 16 Leake *et al.* (2001), Sargeant *et al.* (2001).
- 17 Evans (2001), Evans *et al.* (2001), Thompson *et al.* (2001).
- 18 Turner (1897).
- 19 Smith and Malcolm (1959).
- 20 Accessions in the collection are listed in Malcolm (1971) and Malcolm *et al.* (1984). The collection peaked at more than 1000 accessions. Unfortunately much of this collection is no longer available.
- 21 Malcolm and Clarke (1971).
- 22 Malcolm and Swaan (1989).
- 23 Lay (1990), West (1990), Barson (1994).
- 24 R. Galloway, G. Lazarescu and E.G. Barrett-Lennard (unpublished).
- 25 Agriculture Protection Board of WA (1992).

- 26 CRC for Plant-based Management of Dryland Salinity (2002).
- 27 Rogers and Noble (1991).
- 28 Craig *et al.* (1999).
- 29 Tammin is in the central wheatbelt of WA and is the most salt-affected shire in Australia (about 9% affected, George, 1990). It has an average annual rainfall of 341 mm, 67% of which falls in the months of May to September. Katanning is about 200 km south of Tammin in the Great Southern region. It has an average annual rainfall of about 480 mm, 67% of which falls between May and September. Mean monthly temperatures are 1.5–3.8°C higher at Tammin than at Katanning.
- 30 Unpublished data of R. Galloway, G. Lazarescu and E.G. Barrett-Lennard. Each point is the geometric mean of 4–9 replicates per clone.
- 31 Barrett-Lennard (1993).
- 32 Data of R. Galloway, G. Lazarescu and E.G. Barrett-Lennard (unpublished).
In the glasshouse experiment (Figure 7.4b), clones were grown in sand under waterlogged conditions. NaCl concentrations were initially 50 mol m⁻³ and were increased by 100 mol m⁻³ per week for seven weeks. There were six replicates per clone. To assess the degree of grazing (Figure 7.4c), sheep were allowed access to the shrubs for up to three weeks. The degree of grazing was assessed on a scale of 1 (no evidence of grazing) to 5 (complete defoliation).
- 33 Data from Quairading WA (Smith, 1962). Data are the geometric means of six (April) or eight replicates (July, November).
- 34 Data are from Quairading WA (Smith, 1962). The sand mulch was applied in May to a depth of 5.1 cm. The data here are for November. The 'no mulch' treatment is therefore the same as the 'November' line in Figure 7.5b.
- 35 (a) The site was near Corrigin WA and had a uniform cover of barley grass prior to the commencement of the experiment (Smith, 1962). The soil was bared by the application of a hormonal spray in June. Soil salinities were measured in November of the following year. The data are the geometric means of eight replicates.
(b) The site was on a badly salt-affected soil near Corrigin WA (Smith, 1962). The area was 40% bare when the trial commenced in the autumn of 1954. After four years of treatment, soils which were annually cultivated and sown with a mixture of cereals and annual ryegrass had no bare patches remaining, while adjacent non-treated soils still had considerable bare areas. The soil sampling was carried out in February 1959. The data are the geometric means of 10 replicates.
- 36 Galloway and Davidson (1993b).
- 37 Redrawn after Galloway and Davidson (1993b).
- 38 Barrett-Lennard *et al.* (1990).
- 39 Galloway and Davidson (1993a).
- 40 In a comprehensive review, the National Dryland Salinity Program's 'Engineering Options' project recognised 11 different drainage techniques to improve the productivity of saltland (Sinclair Knight Merz Pty Limited, 2001).

Option	Sub-options
Groundwater pumping	<ul style="list-style-type: none"> • Single bore • Multiple single bores • Bore or spear point • Relief bore
Shallow surface drains	<ul style="list-style-type: none"> • Spoon drains • W-drains
Deep surface drains	<ul style="list-style-type: none"> • Open drains
Sub-surface drainage systems	<ul style="list-style-type: none"> • Mole drains • Tile drains • Biopolymer (deep) drains • Interceptor drains

Further reading and notes

- 41 Nulsen (1986).
- 42 Qureshi and Barrett-Lennard (1998), Moore (2001).
- 43 Northcote and Skene (1972).
- 44 Examples include McKenzie and So (1989) and papers referred therein; also Howell (1987).
- 45 See Kuhn (1993) for the Murray-Darling River System, and Hodgkin and Hamilton (1993) for the Peel-Harvey estuary in WA.
- 46 Yeates *et al.* (1984).
- 47 Fitzpatrick *et al.* (2000).
- 48 Semple *et al.* (2003a).
- 49 Malcolm and Swaan (1989).
- 50 The literature on critical nutrient concentrations has been summarised by Reuter and Robinson (1997).
- 51 After Smith and Loneragan (1997).
- 52 Elliott *et al.* (1997), Bolland *et al.* (1995).
- 53 Flowers *et al.* (1977), Storey *et al.* (1977).
- 54 R. Galloway, N.J. Davidson, G. Lazarescu and E.G. Barrett-Lennard (unpublished).
- 55 McCarthy (1992).
- 56 Reviewed by Abbott and Robson (1982).
- 57 Bolan *et al.* (1983).
- 58 Khan (1974).
- 59 Bilal *et al.* (1990).
- 60 See Crabtree and Jarvis (1988).
- 61 After Barrett-Lennard (1993). The experiment had a randomised block design with six treatment combinations, and four replicate blocks. Replicates within blocks consisted of 10 plants in a row. The seedlings were planted on a 5 x 5 m grid.
- 62 Reviewed by George *et al.* (1999).
- 63 Stirzaker *et al.* (1997).
- 64 This decrease is for clays; more than this would be expected with loams and sands (calculated from Talsma, 1966).
- 65 Based on Nulsen (1981), and our observation that balansa clover grows on saltland associated with annual ryegrass. It should be stressed that a failure to develop a higher value understorey does not necessarily mean that watertables have not been substantially drawn down. Seed may not be present, or the soils may be too nutrient deficient, too sodic or saltbush may be too densely spaced to grown substantial understorey (see Sections 7.6 and 7.8).
- 66 There are few details on the rooting depth of saltbush species in the field. With Old man saltbush in rangeland situations, most roots are less than 0.3 m deep, although there are occasional roots to 4.2 m (Jones and Hodgkinson, 1969). Not surprisingly, water use by Old man saltbush over a watertable at 1.6–2.2 m was less than 0.2 mm/day (below the measuring capacity of the equipment used – Slavich *et al.* 1999).
- 67 Bleby *et al.* (1997).

- 68 Soil moisture was measured using neutron probes; waterlogging was estimated using the SEW30 technique described in Chapter 3 (S.J. Robinson and G.S. Woodall, personal communication, 2000; our observation, 2002).
- 69 Barrett-Lennard and Malcolm (1999). This study had a randomised block design with five plant spacings (1 x 1, 1 x 2, 2 x 2, 2 x 3, and 3 x 3 m), five saltbush species (*Atriplex undulata*, *A. amnicola*, *A. vesicaria*, *A. paludosa* and *A. bunburyana*) and three replicate plots (each consisting of 25 plants in 5 x 5 array). Watertables were between 0.5 and 1.5 m deep.
- 70 Greenwood and Beresford (1980).
- 71 I Walsh, personal communication (reported in Barrett-Lennard and Galloway, 1996; Barrett-Lennard, 2002).
- 72 M.J. Lloyd, personal communication (reported in Barrett-Lennard, 2002).
- 73 Ferdowsian *et al.* (2002).
- 74 M.J. Lloyd, personal communication (reported in Barrett-Lennard, 2002).
- 75 For example, for quailbrush and Old man saltbush, there are reports of biomass yields of 14 and 12 tonnes/hectare in the USA (Watson *et al.*, 1987), and 20 and 18 tonnes/hectare in Israel (Aronson *et al.*, 1988). In the American study the plants were irrigated (water EC 10 dS/m) with overhead sprinklers. Yields were assessed six months after planting. In the Israeli study, the plants were drip irrigated (water EC 56 dS/m). Yields were the sum of three to five harvests of plants between 12 and 24 months old.
- 76 Barrett-Lennard (no date).
- 77 Details of these trials, their locations and the growth conditions are as follows:
- **Sites 1 and 3** Plants were raised in a nursery and planted at Kellerberrin WA at 1111 plants/ha. Biomass (leaves and twigs up to 5 mm diameter) was assessed after 20 months growth (Malcolm *et al.*, 1988).
 - **Site 2** Plants were raised from cuttings in a nursery and planted at Tammin WA at 1,111 plants per hectare. Total plant biomass was assessed after six months growth (unpublished data of R. Galloway, G. Lazarescu and E.G. Barrett-Lennard – CLONE2 experiment).
 - **Sites 4, 5 and 6** Plants were raised in a nursery and planted at Tatura VIC at 10,000 plants/hectare. Plants were irrigated with fresh water during establishment, and with water at 0, 2500, 5000, 7500 or 10,000 ppm during the second and third years of growth. The plants were harvested after establishment and then after a further 12 and 24 months. The data here are the estimated dry weights averaged across all salt treatments at the third harvest (Shulz and West, 1994). Data have been converted to a dry weight basis assuming a fresh weight/dry weight ratio of 4.0 in the harvested material (M. Aslam, R.H. Qureshi, K. Mahmood, S. Nawaz and E.G. Barrett-Lennard, unpublished data).
- 78 After Malcolm *et al.* (1988). Shoot weights are leaves and twigs harvested after 20 months growth. Subsequent results have suggested that the twigs harvested here would not have been used by sheep. There were three replicate blocks. Each block contained 25 plants in a 5 x 5 array; measurements were made of the central nine plants. Plants were at 1 x 1 m, 2 x 1 m, 2 x 2 m, 2 x 3 m and 3 x 3 m spacings. The results from the 1 x 1 m spacings have not reported as they were anomalous for several species.
- 79 Unpublished data of E.G. Barrett-Lennard and K.C. True. Leaf weights are after 20 months growth, and were calculated from shoot volume data using the conversion between volume and weight in Footnote 6. There were four replicates of each treatment. Each block contained 25 plants in a 5 x 5 array; measurements were made of the central nine plants. Plants were spaced at 2.2 x 2.2 m, 3.2 x 3.2 m, 4.5 x 4.5 m, 6.3 x 6.3 m, and 8.9 x 8.9 m, giving respective plant densities of 2000, 1000, 500, 250, and 125 plants per hectare.

Chapter 8

Assessing the value of saltland pastures for grazing

This chapter has been contributed by Andrew Bathgate,
Technical Specialist, Salinity Economics, NSW Agriculture



In this Chapter

Methods for assessing the economic value of saltland pastures

- Sensitivity to change
- Methods of economic analysis

Factors affecting the value of saltland pastures

- Previous studies
- Feed scarcity
- Biomass and nutritive value
- Costs of saltland pasture
- Area of saltland pastures and other perennials
- Wool and meat prices

Concluding comments

A number of enterprises have been proposed to make productive use of saline land (Chapter 2, Table 2.2). Many of these are promising but are yet to be widely adopted. There are many impediments to their adoption, including the identification of markets for products, cost of establishment, lack of knowledge about the management of new enterprises and financial risk. In the medium term it is unlikely that many of these enterprises will be broadly adopted and will only contribute in a minor way to the management of saline land. This is likely to be the case in the longer term also, even in the event that these enterprises become widely adopted. This is because most of the enterprises proposed utilise a small area of saline land relative to the total area. The exception is saltland pastures.

Saltland pastures have the potential to complement existing grazing systems in agricultural regions of Australia. Grazing is usually an extensive enterprise requiring large land areas. As such it is the only option (at present) that

provides a potential management solution for a large proportion of the land that is expected to become saline in the next few decades.

Integrating saltland pastures into a farming system profitably will depend upon careful and considered financial analysis, as profitability will be a major determinant of adoption. This chapter will discuss the role of economic analysis in decision making and the factors affecting the financial viability of saltland pastures.

8.1 Assessing the economic value of saltland pastures

Economic analysis can provide information to assist producers, researchers and advisers make judgements about the costs and benefits of introducing saltland pastures to the farming system. Judgements must be made about trends in external factors, such as commodity prices and interest rates, and how (livestock) production is affected by changes to the system. These trends cannot be known with any certainty.

Bio-economic modelling

Bio-economic modelling integrates the biological and economic components of a system by explicitly representing the production relationships and their economic impacts. There are a number of advantages of this approach. A well-specified model can be used to gain experience about the 'behaviour' of a system very quickly and cheaply which would otherwise take many years to obtain. It imposes more rigour on analyses by reducing the possibility that proposed management plans are biologically infeasible. Analyses that explore the factors affecting the profitability of systems are more easily done and results of such analyses can be made more transparent through auditing the stocks and flows of resources within the model. In this way results are more readily validated. Also, model runs are more easily repeated and results are less subject to the biases of the analyst.

The particular strength of bio-economic modelling is in analysing systems where there are complex interactions between system components. This is especially the case with pasture-livestock systems where the problem is one of matching the supply and demand for livestock feed to maximise profit. Grazing enterprises in agricultural regions of Australia typically have multiple feed sources (with different costs) that provide inputs to a production process that result in joint outputs (e.g. meat and wool). There are links between grazing livestock and pasture growth and pasture quality and both of these factors influence product quality.

Whilst bio-economic models describe the farming system in more detail, and provide a more rigorous approach to analysis, such models can be misused and results misinterpreted. The challenge to the user of such models and indeed all methods of analysis is to provide real life context to results to ensure they are applied appropriately.

8.1.1 Sensitivity to change

This uncertainty can be taken into account by assessing the impact of different economic and seasonal conditions on the results of economic analysis, providing information about the profitability of saltland pasture for different conditions. For example, it is important to know the profitability of saltland pasture at the current wool price, but also at what wool price it ceases to be profitable. An astute decision-maker will then assess the risk of the wool price falling below the break-even price. Repeating the analysis for a range of conditions is known as sensitivity analysis. It provides insight into the robustness of an enterprise for a variety of situations.

8.1.2 Methods of economic analysis

Key point

• There are a number of methods of analysis. They vary in their level of complexity and their data requirements. The most appropriate method of analysis depends on the problem being addressed, data availability and resources available to undertake the analysis. Methods that oversimplify the problem, or exclude important aspects of the problem, can lead to incorrect conclusions about the economic value of a change in management or technology.

There are a number of methods of economic analysis that may be used to determine the profitability of saltland pasture. The most appropriate method depends on the specific questions being addressed, the availability of data and the resources available to undertake the analysis.

Simple methods of analysis, such as gross margins are most appropriate when few data are available and/or few changes to the farming system are required to incorporate new technology or management. More detailed methods are appropriate where changes to an enterprise (or paddock) affect the management of other enterprises (or paddocks) and where data are readily available. These interactions may be difficult to anticipate and are frequently difficult to quantify, particularly in financial terms.

Methods that do not consider these interactions may oversimplify the description of the problem. This may lead to wrong conclusions about the profitability of changing management or technology.

More comprehensive analysis requires a more detailed description of the farming system. However, such analysis has larger data requirements and sometimes requires specialist technical expertise and software. Therefore a detailed analysis is sometimes impractical. However where a suitable model exists it is preferable (and more efficient) to take advantage of it.

A discounted cashflow analysis can examine the longer term financial impact of changing enterprises and can reveal much about the farm level implications of changing management - in the hands of a skilled analyst. However, important interactions within the farming system are easily overlooked. Bio-economic modelling reduces the likelihood that this will occur by describing the biological production relationships of the farm explicitly.

8.2 Factors affecting the value of saltland pastures

Key point

• *Profitability depends on biomass produced and its nutritive value, costs, the area of pasture planted and the prices received for wool and meat.*

8.2.1 Previous studies

A number of studies using bio-economic models were undertaken prior to 1994 to examine the potential value of saltland pastures for wool production¹. The focus of these was to determine the economic potential of halophytic shrubs which were assumed to be the primary source of feed for livestock. Understorey species were assumed to be of no grazing value or not present. These studies indicated that establishing saltbush for animal production was likely to be profitable.

The analyses had a number of important features. All assumed that: saltbush provided 0.8 t/ha or more of dry matter for grazing, metabolisable energy was 7.5 MJ/kg or greater and pasture was available for grazing at any time of year. Also, wool prices were assumed to be much higher than those of the 1990s. Trial work undertaken in WA subsequently indicated that some of the assumptions used in the analyses were overly optimistic and the returns from saltbush would not have covered costs.

This led to a shift in focus of research to explore the potential of understorey species planted with halophytic species. Halophytic shrubs had been shown to lower local watertables in some cases and this enabled understorey species to flourish. These species are usually of higher grazing value, however they also add to the cost of establishment. One such species is balansa clover.

An analysis conducted for the high rainfall region of WA² indicated that balansa clover could increase the profitability of waterlogged, poor producing paddocks by between \$50–80 per hectare.

Other studies have been undertaken more recently.³ They indicate that saltland pasture offers some prospect of improving the profitability of farm businesses, although many of the assumptions of the analyses are yet to be tested. In all of the studies reviewed, the profit increased for three reasons:

- decreased use of costly feed supplements,
- increased stocking rates, or
- deferred grazing of perennial pastures.

However, these studies are useful mainly because they explore the implications of altering assumptions on the profitability of saltland pasture. They provide insights into the components of farming systems that should be considered when making investment decisions on saltland pasture. The following discussion outlines the factors affecting the value of saltland pastures.

8.2.2 Feed scarcity

The cost of carrying sheep through periods of feed scarcity is a major limitation to improving the profitability of livestock production in southern Australia. Feed scarcity is caused by periods of seasonal dry periods and/or low temperatures. During these periods stocking rates need to be low or costly supplements need to be fed. The value of additional pasture (that might be supplied by saltland pasture) for grazing during this period will be higher than the value of additional pasture in periods of greater availability. The value of a small change in pasture availability is known as the marginal value. Figure 8.1 shows the marginal value of pasture at different times of the year for a typical farm in southern Australia.

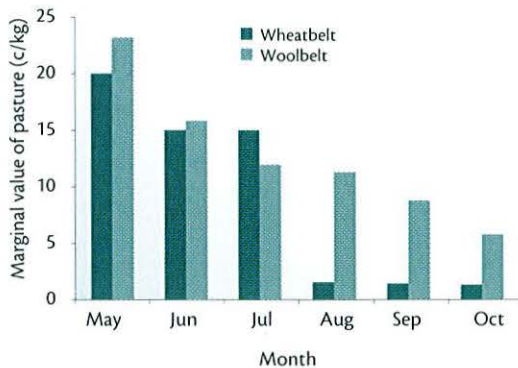


Figure 8.1 Marginal value of pasture during the growing season for two types of farm in a mediterranean environment in WA.⁴

The value of extra pasture production depends on the impact it has on *whole farm* stocking rate and wool production and/or reducing the need for supplementary feeding. During the winter months the marginal value of pasture is high because it is the period when lack of feed most limits the production of meat and wool. Also additional pasture in winter will lead to additional production in the later months if grazing is deferred. In contrast the marginal value of pasture is low in spring when pasture is in greater supply.

As the marginal value of pasture varies during the season gross margin analysis can lead to

incorrect conclusions about the value of different grazing systems. Pasture species that provide a small number of grazing days when the marginal value of pasture is high could be more profitable than a species that provides a relatively large number of grazing days when the marginal value is low. In physical terms providing feed at times of scarcity means the stocking rate on a farm may be able to be increased at low cost, even if out of season feed is available for a short period.

8.2.3 Biomass and nutritive value

The nutritive value of a pasture is affected by the metabolisable energy and protein concentrations, as well as its palatability (see box below). The nutritive value will directly affect livestock production or the need for supplementary feeding.

Saltland may be able to provide feed of higher nutritive value than dry pasture because soil water can be available beyond the end of the normal growing season (due to high watertables), enabling annual species to persist for an extended period. The importance of providing feed of higher nutritive value in summer and autumn depends largely on the cost of providing it. Where the costs are high, large revenues are required to cover the costs. In such cases saltland needs to provide pasture of high nutritive value to be profitable.

Value of improving quality and biomass at different times of the year

The economic value of improving feed quality is illustrated in the analysis of balansa undertaken for the South West of Western Australia. It showed that profit would be increased by as much as \$15/ha for every 5% increase in metabolisable energy in late summer. This compared to a \$5/ha increase in profit for a 10% increase in pasture growth rate in spring⁵. Another study for the South Coast of WA found that a 10% increase in the concentration of metabolisable energy in saltland pasture was worth almost three times the value of a 10% increase in the quantity of pasture over the same period⁶.

8.2.4 Costs of saltland pasture

The economic importance of saltland pastures as a source of high quality feed in summer and autumn will be affected by costs. There are four main components to the cost of saltland pasture:

• Establishment

A large initial cost is incurred to prepare the paddock for seeding, purchasing seed and fertiliser, sowing the pasture and applying fertiliser. Fences may also need to be erected and watering points developed. The up-front cost is perhaps the most critical factor likely to adversely affect the rate of adoption of saltland pasture. Not only does future income need to cover these costs but also farmers need to have the financial capacity to sustain a large debt.

• Longevity

The extent to which income will cover costs depends partly on the longevity of the pasture (the period before re-sowing is necessary). Better longevity will reduce the average annual costs, however it will not affect peak debt or the number of years required to break-even.

• Risk of failure

Re-establishment after a failure will add to the up-front costs. A high risk of failure of establishment could have a profound effect on the risk to the business, depending on the level of debt being carried.

• Opportunity cost

The opportunity cost is the income forgone for the next best investment. Farmers are unlikely to invest in a new enterprise unless the returns to expenditure are sufficiently high to warrant the additional effort. Returns to expenditure associated with a change in practices need to be between 10 and 15% to provide sufficient incentive for widespread adoption.⁷

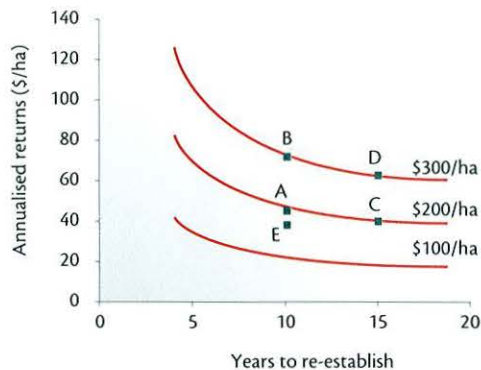


Figure 8.2 Break-even net returns for different establishment costs and duration of pasture stand, assuming a 15% marginal rate of return and 20% chance of establishment failure.

Figure 8.2 shows the importance of each of the components of cost by showing how they affect the annualised returns required to break-even. The curves show the annualised costs of saltland pasture for different time periods. The annualised costs are equivalent to an annuity or annual loan repayments. For example, point A in Figure 8.2 shows that the repayment for a loan of 10-years duration is \$48/ha/year, assuming an establishment cost of saltland pasture of \$200/ha and an interest rate of 15%. It can also be viewed as the annual net return (net of variable costs) required to cover establishment costs if the life of the pasture stand was 10 years and the farmer required a return of 15% on his investment.

An alternative use of the figure is to determine the break-even pasture establishment costs for a given level of annualised income. In this manner the maximum establishment costs for expected returns for saltland pasture can be found. For example, if the estimated net returns of saltland pasture is \$40/ha and the expected life of the pasture stand is 10 years, the cost of establishment would need to be much less than \$200/ha, as shown by point E.

The importance of keeping establishment costs as low as possible can be seen from Figure 8.2. By comparing points A and B it can be seen that if establishment costs increase by \$100/ha (from \$200 to \$300/ha) the net return required to cover the cost is \$24/ha/year higher, assuming the life of the stand is 10 years. Extending the life of the pasture to 15 years makes only a small difference to the increase in returns required to cover establishment costs. In this case the net returns have to be \$21/ha/year higher (compare points C and D) to cover an additional \$100/ha establishment cost.

Not only does this example illustrate the value of low establishment costs it shows that the value of improved longevity of the pasture stand greater than 10 years is small. By improving the longevity from 10 to 15 years the annualised costs are only reduced by \$3/ha/year. However this is only part of the story because the figures also show that extending the longevity of the pasture stand up to 10 years can have substantial benefits. Increasing longevity of the stand from five to 10 years can decrease the net returns required to break-even by \$22/ha/year from \$70 to \$48/ha/year, where establishment costs are \$200/ha.

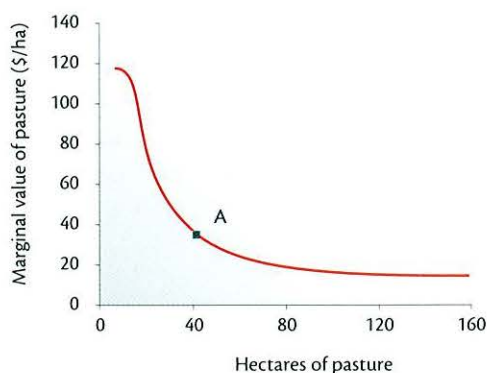


Figure 8.3 Marginal value of saltland pasture with increasing area.

8.2.5 Area of saltland pastures and other perennials

The effect of changing the supply of feed on its economic value has important implications for the optimal area of saltland pasture. Because the value of extra feed declines as more is added the value of additional area of saltland also declines.

An example of how the extra value of saltland pasture changes as the area changes is shown in Figure 8.3. The figure is based on an analysis of saltland pasture in the high rainfall woolbelt of WA (the same study used in Figure 8.2). It shows that the value of additional hectares of saltland pasture is very high (>\$100/ha) when the area of pasture is small (<20 ha). However, the marginal value declines substantially as the area of saltland pasture increases. For this representative farm, if the establishment cost is \$200/ha the optimal area will be less than 40 hectares. This is because the marginal value of pasture is less than \$40/ha/year (Point A) when the area is greater than 40 hectares and we have previously seen that the minimum break-even return required to cover establishment cost of \$200/ha is around \$48/ha/year (Figure 8.2).

It is important to ensure that investment analyses of saltland pasture account for the decline in value of feed as the established area is increased. This can be done by feed budgeting, giving careful consideration to how additional feed will be used and how this affects the cost of production and the productivity of the livestock enterprise.

8.2.6 Wool and meat prices

Wool and meat prices are major determinants of the profitability of livestock enterprises and influence the profitability of saltland pastures. The relationship in Figure 8.3 was derived from an analysis that used prices typical of the early 1990s. It is important that a range of wool and meat prices is used in an analysis to determine how profitability is affected by prices. This will provide an indication of the potential financial risk of the investment.

8.3 Concluding comments

Pasture for livestock production is the only saltland enterprise that is likely to offer a management solution to saline land at the scale required to manage the problem in the foreseeable future. However, determining its role in different farming systems requires a considered analysis. There are a number of factors that will affect the economic value of saltland pastures. Of those discussed, the cost of establishment is likely to be the biggest constraint to adoption. Where the cost of establishment cannot be reduced below \$200/ha saltland pastures will need to provide high quality feed at a time of relative scarcity. Only where this can be achieved will the net returns from grazing cover the cost of establishment.

A number of analyses have been conducted for a range of environments throughout Australia. Many of these indicate that saltland pastures offer some prospect of improving farm profitability by making use of otherwise unproductive saltland. However, many of the analyses are dated and a number of different environments have not been assessed. Further work is required in this area. A number of approaches could be used and some are mentioned above. The most cost-effective approach would be to conduct the analyses using bio-economic models. In the absence of bio-economic models a discounted cashflow analysis is perhaps the most useful method. While gross margins may provide some insights they usually lead to over simplification of the system and spurious results.

Further reading and notes

- 1 Salerian (1987), Howard (1988), Bathgate, Young and Barrett-Lennard (1992), and Bathgate and Young (1993).
- 2 Bathgate and Monjardino (1998).
- 3 Crosthwaite and Malcolm (1998a), Crosthwaite and Malcolm (1998b) and O'Connell and Young (2002).
- 4 Morrison and Bathgate (1990).
- 5 Bathgate and Geisbertz (1998).
- 6 O'Connell and Young (2002).
- 7 Makeham and Malcolm (1986).

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Common names and species names of plants

In general, common names of plants have been used in the text. Latin (species) names of these plants are in the table below.

Common name	Species name
Annual ryegrass	<i>Lolium rigidum</i>
Balansa clover	<i>Trifolium michelianum</i> (also called <i>Trifolium balansae</i>)
Barley	<i>Hordeum vulgare</i>
Beans	<i>Phaseolus vulgaris</i>
Bladder saltbush	<i>Atriplex vesicaria</i>
Boorabbin mallee	<i>Eucalyptus platycorys</i>
Burr medic	<i>Medicago polymorpha</i>
Capeweed	<i>Arctotheca calendula</i>
Carrot	<i>Daucus carota</i>
Comet vale mallee	<i>Eucalyptus cornitae-vallis</i>
Cotton	<i>Gossypium hirsutum</i>
Cotula	<i>Cotula</i> sp.
Creeping saltbush	<i>Atriplex semibaccata</i>
Curly ryegrass	<i>Parapholis incurva</i>
Date palm	<i>Phoenix dactylifera</i>
Distichlis	<i>Distichlis spicata</i>
Flat topped yate	<i>Eucalyptus occidentalis</i>
Goldfields blackbutt	<i>Eucalyptus lesouefii</i>
Grapefruit	<i>Citrus paradisi</i>
Grey saltbush	<i>Atriplex cinerea</i>
Ice plant	<i>Mesembryanthemum nodiflorum</i>
Kikuyu grass	<i>Pennisetum clandestinum</i>
Kondinin blackbutt	<i>Eucalyptus kondininensis</i>
Maize	<i>Zea mays</i>
Marine couch	<i>Sporobolus virginicus</i>
Melilotus	<i>Melilotus alba</i>
Oats	<i>Avena sativa</i>

Common name	Species name
Old man saltbush	<i>Atriplex nummularia</i>
Peach	<i>Prunus persica</i>
Persian clover	<i>Trifolium resupinatum</i>
Phalaris	<i>Phalaris aquatica</i>
Puccinellia	<i>Puccinellia ciliata</i>
Quailbrush	<i>Atriplex lentiformis</i>
Red river gum	<i>Eucalyptus camaldulensis</i>
Rhodes grass	<i>Chloris gayana</i>
River saltbush	<i>Atriplex amnicola</i> (previously called <i>Atriplex rhagodioides</i>)
Salt water couch	<i>Paspalum vaginatum</i>
Samphire	Species from the genus <i>Halosarcia</i>
Sea barley grass	<i>Hordeum marinum</i>
Silver saltbush	<i>Atriplex bunburyana</i>
Small leaf bluebush	<i>Maireana brevifolia</i>
Strawberry clover	<i>Trifolium fragiferum</i>
Sugarbeet	<i>Beta vulgaris</i>
Swamp mallet	<i>Eucalyptus spathulata</i>
Swamp oak	<i>Casuarina obesa</i>
Tall fescue	<i>Festuca arundinacea</i>
Tall wheat grass	<i>Thinopyrum ponticum</i> (also called <i>Agropyron elongatum</i> and <i>Thinopyrum elongatum</i>)
Tomato	<i>Lycopersicon esculentum</i>
WA golden wattle	<i>Acacia saligna</i>
Wavy leaf saltbush	<i>Atriplex undulata</i>
Wheat	<i>Triticum aestivum</i>

Glossary of terms

Aerenchyma – Tissue in roots with large intercellular spaces through which and within which gases may diffuse and be stored. Aerenchyma formation is a frequent adaptation to waterlogging. Its action has been likened to that of a snorkel.

Agroplow – Tractor-drawn implement for loosening traffic pans in soil.

Alley (farming) – A farming system in which belts of perennial vegetation (trees, saltbush) are interspersed with alleys of land for the growth of annual species (crops, understorey).

Bio-economic model – A mathematical model that describes the biological and economic relationships of a system. In a farming system context such a model would describe the relationship between inputs (e.g. fertiliser and pesticides) and outputs (e.g. grain and meat) and the economic consequences of these relationships.

Biomass – The total weight of living material present.

Condition score – A method of assessing animal condition based on the feel of the backbone, ribs and eye muscle.

Culm – Stem of a grass, solid only at the nodes

Dioecious – Male and female flowers occur on separate plants.

Discounted cashflow – Expected flow of money payments to and from the investor. The timing of the flow of payments is made explicit and future payments are discounted to reflect the time value of money. The time value is a measure of the forgone income of an alternative investment.

Ecological zonation – Refers to the distribution of plant species in separate ecological zones because of variations in the environment (e.g. soil salinity, waterlogging and inundation).

Electrical conductivity (EC) – An easily measured indicator of the salt concentration in soil solutions and soil water extracts. Abbreviated as EC, with units of decisiemens per metre (dS/m) or similar.

Genotype – genetic make-up of an organism. This term can refer to groups of plants with the same (or similar) genetic constitution.

Gross margins – Gross income of an enterprise minus the variable costs of production.

Groundwater – Water found in pores, crevices and cavities in soils and rocks.

Halophyte – Plant adapted to living in soil with a high concentration of salt.

Inundation – A condition in which free standing water occurs above the soil surface (sometimes called flooding). Waterlogging usually coincides with inundation, but many waterlogged soils are not inundated.

Leaf area index (LAI) – The ratio of leaf area in a plant canopy to the area of the land beneath that canopy.

Monoecious – Separate male and female flowers occur on the same plant.

Net margins – Gross income of an enterprise minus the variable and fixed costs of production.

Niche seeding – The placement of seed and other soil ameliorants at micro-sites specially engineered to increase the likelihood of germination and establishment.

Osmotic adjustment – Increase by the plant in the concentration of salts or solutes in its tissues. This ensures that water continues to move by osmosis across plant membranes from the soil into the roots and shoots.

Panicle – A flower with a main axis and subdivided branches.

Plasmolysis – Process in which plant cells lose their internal pressure because water moves out of the cells into more saline environments through osmosis. This results in the outer membranes of the cells collapsing away from the cell walls.

Primary salinity – Land which is naturally saline.

Raceme – Part of a flower; the primary unbranched axis onto which spikelets are directly attached by short stalks.

Rachis – Primary axis of a flower.

Rhizome – Underground stem that grows horizontally and, through branching, acts as an agent of vegetative propagation.

Saltbush – Common name for species from the genus *Atriplex*.

Secondary salinity – Land once suited to the growth of crops and pastures, but now too saline for agriculture.

Sodic soils – Soils that have a deteriorated structure due to the absorption of ions of sodium (and to some extent magnesium) rather than calcium on the exchange surfaces of the clay particles. Hence **sodicity** – refers to the degree of this condition.

Soil compaction – Process in which the use of heavy agricultural machinery compacts soils.

Spikelet – Basic flowering unit in grasses; normally consists of two glumes and one or more florets.

Stolon – Horizontally growing stem. Adventitious roots can form from the nodes of stolons where they touch the ground. They are therefore agents of vegetative propagation.

Stomate – Pore at the surface of the leaf through which gases and transpired water pass.

T/E_{pan} – Ratio of annual transpiration (T) by stands of trees to the annual pan evaporation (E_{pan}) at that site. (E_{pan} is an indicator of the dryness of the climate.)

Traffic pan – A compaction of the soil caused by the use of heavy agricultural machinery.

Waterlogging – A condition in which soil pores are filled with water. This inhibits the exchange of soil gases with the atmosphere and ensures that plant roots become oxygen deficient. Waterlogging will occur when the watertable is at or close to the soil surface.

Watertable – Surface below which the soil is saturated with water.

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