The survival and early growth of perennial halophytes can be predicted using measurements of soil salinity and depth to the watertable

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Introduction

Australia has a substantial area of land affected by salinity because of the presence of shallow watertables: 5.66 Mha are presently at risk of salinity and this area is forecast to increase to ~17 Mha by the Year 2050 (National Land and Water Resources Audit 2001). Soil conditions in affected soils are highly seasonally variable: surface soil salinity varies in response to the movement of salt to and from the soil surface by capillarity and leaching, and waterlogging may occur in winter as seasonal rainfall leads to the development of shallow watertables (Malcolm 1983; Barrett-Lennard *et al*. 2003). Despite this variation, plants tend to display zonation in saline landscapes. It has been suggested that this is a result of the interaction between salinity and waterlogging (Barrett-Lennard 2003). However, confirmation of such effects has been difficult to demonstrate in the field.

Understanding how salinity and waterlogging affect plant zonation on saltland has become an issue of considerable importance. Saltland varies substantially in its capacity for economic production (Masters *et al*. 2006); some saltland can be highly valuable to the farming enterprise, some has lower value, and some will be best allowed to revegetate naturally but not put to any economic use. Farmers require the development of criteria for saltland capability assessment so that plants can be targeted to saltland locations where they will have greatest productive, environmental and economic benefits. These criteria need to be sufficiently robust to offer predictive solutions even in the situations of inherent variability that occur on saltland.

The aim of this work was to examine zonation of saltland pasture plants in the field and relate it to levels of measured salinity and depth to watertables to provide practical advice about saltland capability to farmers. A companion paper (Bennett and Barrett-Lennard 2008) discusses the zonation of typical indicator species found on saltland.

Materials and methods

Sites. Experiments were conducted across ecological “transects” on three sites in south-western Australia in the low – medium rainfall wheatbelt zone. The sites varied by ~0.3 m in elevation, with more severely saline/waterlogged land on the lower side, and less saline/waterlogged land on the upper side. Rainfall was determined from the nearest Australian Bureau of Meteorology Station to each site.

Species. Sites were planted with six perennial plant species: samphire (*Halosarcia* sp.), river saltbush (*Atriplex amnicola* Paul G. Wilson), small leaf bluebush (*Maireana brevifolia*), saltwater couch (*Paspalum vaginatum*), Rhodes grass (*Chloris gayana* cv. Pioneer) and lucerne (*Medicago sativa* cv. Sceptre).

Layout. Plants were established in 0.3 L plastic pots in the glasshouse and transplanted into the field at marked locations in 5 x 5 m ‘quadrats’ running down the transects. There were ten quadrats per row and five rows across the direction of slope at each site. The first planting was in late Spring (mid-September/early October) 2003. Monthly monitoring after the summer of 2003/04 showed that there was considerable mortality in some species. All surviving plants were therefore defoliated by hand stripping the leaves in June 2004 and locations at which plants had died were then replanted with the original species.

Measurements. Soil salinity was measured on four occasions (November 2003, June 2004, June 2005 and September/October 2005) using an EM38. Calibration curves were established between EM38 readings in the vertical and horizontal positions and sampled soil (7–12 holes per site/time) at a depth of 0–25 cm. Optimal calibration curves were single or multiple linear regressions with P values between <0.001 and 0.036. It was assumed that the bulk conductivity of a 5 x 5 m plot could be calculated from the ECe values at its four corners. Depths to the watertable were measured at monthly intervals from nine 3 m deep bores (3 rows of 3 over each site) and these data were used to calculate an interpolated watertable depth in each quadrat in the transect. Plant survival and plant size (based on measurement of shoot dimensions) were determined at monthly intervals.

Relating survival and growth to soil conditions. At each site, quadrats were stratified into five groups based on the order (lowest to highest) of: (a) average ECe of the quadrats (0-25 cm; averaged across 4 times of measurement), and (b) time-weighted average depth to watertable (determined for each cell by linear interpolation) in spring/summer 2003/04 or spring/summer 2004/05. The percentage plant survival in each stratified group was then related to the average ECe or average depth to the watertable in spring/summer of that group. 'Good survival' was defined as 70% survival or greater within each stratified group. The 99% confidence interval (CI) associated with good survival was then calculated for depth to watertable and ECe (after square root transformation to normalise the data). For each species, the 15 largest individual plants across sites were identified based on plant dimensions in April 2004 and April 2005. For the quadrats containing these plants the 99% CI was also calculated for depth to watertable in summer and average ECe (after square root transformation).

Results

Rainfall and groundwater. From the winter of 2003 to the summer of 2004/05, the sites showed a typical mediterranean rainfall pattern with wet winters (121–169 mm) and dry summers (2–62 mm). However, this cycle changed after the summer of 2004/05; compared to long-term average rainfall data, the autumn of 2005 was 20–65% wetter and the summer of 2005/06 was 240–320% wetter at the three sites.

The average depth to the watertable over the period January 2004 to September 2006 was 2.10 m at Wubin, 1.17 m at Pingaring and 0.75 m at Meckering. Variation in depth to watertable with time reflected the pattern of rainfall. Between the summer of 2003/04 and the autumn of 2005, the watertables varied seasonally over depths of 0.8 m at Meckering, 0.65 m at Pingaring and 0.45 m at Wubin. However, after the higher than average rainfall in the autumn of 2005, the watertable at Meckering and Pingaring reached new heights, and following the exceptional rainfall in the summer of 2005/06 the watertable rose at all sites by 0.4–1.0 m.

The variation in watertable depth across transects differed between sites. At Wubin the three bores on the upper side of the transects were 0.41 m deeper on average on the more elevated than on the less elevated sides of the plots, and this variation across transects decreased in the order Wubin > Meckering (0.36 m) > Pingaring (0.27 m).

Plant survival – site, season and species. Mortality was greater at Wubin and Pingaring than at Meckering. Greatest mortality occurred in the spring of 2003 and the summer of 2003/04, and then after replanting, in the spring of 2004 and the summer of 2004/05. The plant species with greatest mortality (assessed by June 2004 and June 2005) was samphire (84 and 89% mortality respectively) and mortality decreased in the order samphire, lucerne (85 and 82% respectively), Rhodes grass (67 and 64% respectively), saltwater couch (61 and 56% respectively), small leaf bluebush (15 and 13% respectively) and river saltbush (8 and 5% respectively). 'Good survival' and optimal growth of the six species was strongly related to average soil ECe and depth to the watertable over the prior spring/summer (summarised in Fig. 1). Further details are given below.

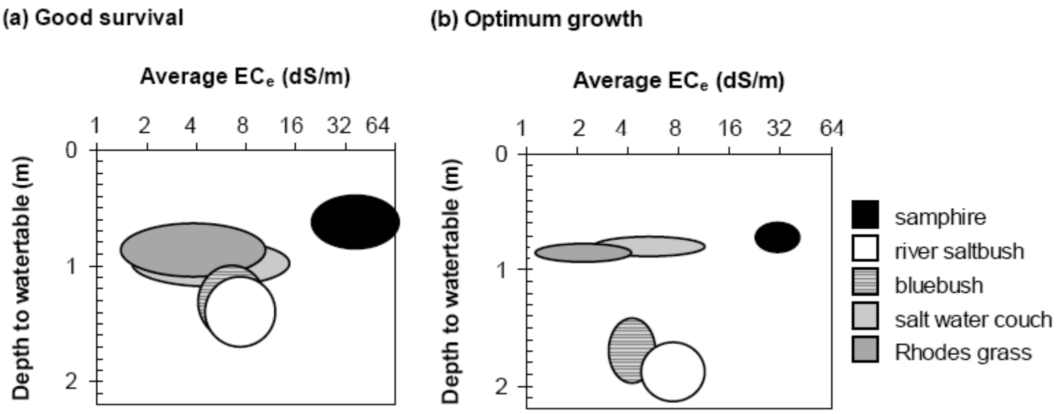

Figure 1 Effects for five species of combinations of average salinity (ECe, 0-25 cm depth, logarithmic scale) and average depth to watertable in summer on: (a) 'good survival', and (b) optimum growth. Lucerne (not shown) did not have 'good survival' where average ECe values were greater than ~4 dS/m.

'Good survival' and average ECe. Average ECe values for the groups stratified for survival ranged between 0.6 and ~67 dS/m. In general, ECe affected 'good survival' in two different ways across species. With samphire the 99% confidence interval (CI) for ECe values associated with 'good survival' was ~20–70 dS/m, and survival decreased at ECe values *lower* than this range. However, for each of the other species, survival decreased at ECe values *higher* than the 99% CI for ECe range associated with good survival, and these ranges were 4.7–12.4 dS/m (river saltbush), 4.1–11.1 dS/m (small leaf bluebush), 1.6–15.5 dS/m (saltwater couch), 1.4–10.8 dS/m (Rhodes grass) and 0.4–3.8 dS/m (lucerne).

'Good survival' and depth to watertable. Given that plant survival was constrained in the spring/summer of 2003/04 and 2004/05, the survival of stratified groups was related to the timeweighted average depths to the watertable over these two periods. Across the stratified groups, average depths to watertable ranged from 0.5 to 2.4 m. In general, species could be divided into three groups on the basis of the relationship between 'good survival' and depth to watertable. With samphire the 99% CI for average depth to watertable associated with 'good survival' was 0.4–0.8 m, and survival decreased as watertables became deeper than this range. With Rhodes grass, lucerne and saltwater couch, the 99% CI for average depth to watertable associated with 'good survival' was 0.7–1.1, 0.8–1.1 and 0.8–1.2 m respectively, and survival decreased if watertables were shallower or deeper than this range. Finally, with river saltbush and small leaf bluebush the 99% CI for average depth to watertable associated with 'good survival' 1.0–1.6 m for both species, and survival was only substantially decreased by watertables shallower than this range.

Optimal growth, average ECe and depth to watertable. There was a similar pattern to the effects of ECe and depth to watertable across species with optimal growth as there was with 'good survival'. However, with samphire, river saltbush and small leaf bluebush, the depth to the water-table associated with 'optimal growth' was somewhat deeper than the depth to the water-table associated ,with 'best survival'. Clearly for these species, shallow watertables were more damaging to growth than to survival.

Discussion

Our data suggest that the capability of saltland sites for agriculture may be diagnosed on the basis of average ECe values in the upper soil profile and depth to watertable. However, two important caveats need be placed on this suggestion. 1. *The groundwater must be available to plant roots.* Saltland may be subject to groundwater under pressure. If a bore is drilled through a semi-confining layer in the soil profile, then watertables may appear to be shallower than they actually are from the plant's point of view. We suggest that depth to watertable be assessed from an open pit, or a bore hole no deeper than ~2 m lined with slotted pipe. 2. *Soil salinity (ECe values) should not be averaged within sites across bare and grassy* *patches*. Some saline soils can be patchy with bare areas of moderate-high surface soil salinity alternating with grassy areas of lower surface soil salinity. Recommendations for sites with this kind of salinity expression need to be based on separate assessments for bare and grassy areas and not combined average surface soil salinities.

Our current work represents a small start in saltland capability assessment. However, further work is required on the following issues. 1. *More sites, more species.* Our key only gives critical limits for a small number of species collected at three sites. Studies of more sites incorporating a wider range of species are required. 2. *Measuring average ECe values.* We recognise that determining the average ECe in the upper 25 cm of the soil profile is difficult in the field as it necessarily involves taking soil salinity measurements at several times through the year. However, there are grounds for believing that the long-term average surface soil salinity is approximately equal to the ECe of the soil at a depth of ~50 cm (cf. Smith 1962). Further work is required to determine whether saltland capability assessment is possible based on the measurement of deeper soil salinities. 3. *Measuring depths to the watertable in other seasons.* To be useful, a key for saltland capability assessment needs to be able to make predictions at any time of year. Our key based on depths to water-table in spring/summer is clearly of limited value. Further work is required to establish relationships between plant zonation and depth to watertable at other times of the year. 4. *Causes of damage due to waterlogging.* We have been surprised that seasonal waterlogging did not decrease plant survival during winter, but predisposed plants to early death in the subsequent summer. This suggests that winter waterlogging probably damages roots, preventing them from obtaining moisture from greater soil depths in the subsequent summer. Deep pot experiments need to be conducted in the glasshouse to confirm this interpretation.

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