

# TREE PERFORMANCE AND ROOTZONE SALT ACCUMULATION IN DISCHARGE PLANTINGS IN THE 400 – 600 mm RAINFALL ZONE OF WESTERN AUSTRALIA

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## ABSTRACT

Doubts exist about the effectiveness of establishing trees near saline discharge areas as part of the solution to dryland salinity. These centre on low rates of water uptake from saline water tables, salt accumulation in tree root zones and consequent poor growth and survival of trees. Despite this, trees still survive in many plantations established on or adjacent to saline discharge areas. Similarly, land-holders often favour such plantings, as they do not compete for arable land.

Tree performance and salt accumulation were thus assessed in three experimental plantations (Popanyinning, Boundain and Dryandra) established near discharge areas 20-25 years ago. These were all in the 400-600 mm rainfall zone of south-western Western Australia, with texture contrast soils formed on lateritic pallid zone clays. Mean soil salinity (0-100cm depth) ranged from 218 to 629 mS m<sup>-1</sup> between sites. Permanent ground-water occurred within 2 - 5 m of the surface and had electrical conductivities ranging from 175 to 4150 mS m<sup>-1</sup>.

Within the limitations of this study – three sites and a limited range of species, the findings confirmed the low growth rates expected for trees established over shallow, saline water tables. *Eucalyptus cladocalyx*, *E. spathulata*, *E. sargentii*, *E. occidentalis* and *E. wandoo* were found to be the most productive species across the sites. Estimated wood volume production was highest for *E. cladocalyx* at Popanyinning (3.5 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>) where soils were generally only slightly saline. Most tree species produced between 0.5-1.5 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>.

Soil salinity was measured using an EM38, laboratory analyses and Wenner array readings. Significant increases (p<0.05) were found within the plantation area at all sites. Although soil salinity had more than doubled since plantation establishment, high survival rates (>70%) were maintained for a range of species. The excellent survival of a number of species despite substantial increases in soil salinity, indicates discharge plantations comprising suitable species can persist in the presence of increasing soil salinity. However, the longer term sustainability of such plantings (50-100 years), without broader landscape treatment of leakage, must be questioned.

## INTRODUCTION

Plantations near saline seeps are often established with the expectation that they will halt rising saline water tables and protect adjacent land with either production or conservation values. Additional potential benefits of the trees include shelter for stock, erosion control, fauna habitat

and wood products. The strategy of planting on or adjacent to discharge sites is often favoured by land-holders over that of wide-spread recharge area plantings, as less arable land is lost.

Commercial forestry in the 400 – 600 mm rainfall zone is restricted by distances to market, lack of forestry related infrastructure (Zorzetto and Chudleigh, 1999) and generally poor growth rates compared to higher rainfall areas. For example, at the lower rainfall limit of commercial *Eucalyptus globulus* Labill. plantations for pulp in Western Australia (600 mm), a growth rate of  $10 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$  is achieved at 10 years (Harper *et al.*, 1999), and lower growth rates are expected in areas with <600 mm of rainfall. Higher growth rates may be achieved in agroforestry configurations and by planting in non-saline areas with enhanced run-on (Stirzaker and Vertessy, 2002). Future development of systems that produce multiple products (for example, biomass for electricity generation, activated carbon, eucalyptus oil and environmental credits) could lead to the expansion of forestry in lower rainfall areas (Zorzetto and Chudleigh, 1999). In general, plantations with high growth rates will have a larger influence over water tables and provide greater opportunities for farmers to obtain income from tree products.

Effects of salinity and waterlogging near saline seeps are also likely to impose restrictions on growth and survival (Marcar *et al.*, 1995), reducing possible returns from plantations sited in lower rainfall areas. Recent research by George *et al.* (1999) concludes that discharge plantings are relatively ineffective in controlling water tables. They suggest that instances whereby water tables are lowered are generally limited to cases where the salinity of the groundwater is  $<1000 \text{ mS m}^{-1}$ . Similarly, the sustainability of plantations over shallow saline water tables has been challenged due to the accumulation of salts in the soil and groundwater that occur as trees grow (Thorburn, 1996; Stolte *et al.*, 1997; Vertessy *et al.*, 2000). Together, the exclusion of salts by roots in the process of water uptake and the reduction in recharge and (therefore leaching) as plantation leaf area increases, are considered responsible for the increasing concentration of salt in the root zone. Much of the salt affected land in the <600 mm rainfall zone of Western Australia is characterised by conditions which are not conducive to leaching of salt from the soil – low rainfall, low gradients and heavy textured soils (Clarke *et al.*, 2002), thus it has been concluded that discharge plantings have poor long term prospects for survival.

Several multi-species experiments have been established on or adjacent to saline land in the last 20-25 years, and provide a means to test this hypothesis. This study thus assessed growth, survival and salt accumulation in three such experiments, established by Agriculture Western Australia and CSIRO. Results from each site have been previously reported, these being Boundain (Stolte *et al.*, 1997; Scott and Crossley, 1996), Dryandra (Greenwood *et al.*, 1995) and Popanyinning (Greenwood *et al.*, 1994). In each experiment the level of salt accumulation in the soil was examined and inferences were drawn on the impact of this accumulation on tree growth and survival over the medium to long term. An additional objective was to continue the investigation undertaken by Greenwood *et al.* (1994; 1995) in selecting the best tree species for plantations over shallow saline water tables.

## METHODS

### Sites

The sites were located in the Narrogin region of Western Australia. All were situated on gently sloping, cleared farmland with sand over clay duplex soils. Climatic and trial establishment details are listed in Tables 1 and 2. The Dryandra and Popanyinning sites were planted by CSIRO in 1976 and research continued at the sites until 1991 (Greenwood *et al.* 1994; 1995). The main trial area at both sites comprises a number of species (Table 2) arranged in

randomised block designs with five blocks. The trial at Boundain was established by the Department of Agriculture Western Australia in 1981 and consists of species planted in two densities and order of salinity tolerance from more saline land to less saline land.

**Table 1:** Study site characteristics. Climatic data sourced from Bureau of Meteorology.

| Site         | Rainfall<br>(mm) | Evaporation<br>(mm) | Planting Year | Density<br>(stems/ha) |
|--------------|------------------|---------------------|---------------|-----------------------|
| Dryandra     | 509              | 1675                | 1976          | 816                   |
| Popanyinning | 442              | 1680                | 1976          | 816                   |
| Boundain     | 424              | 1640                | 1981          | 80 and 160            |

**Table 2:** Species (examined in this study) at Dryandra (D), Popanyinning (P) and Boundain (B) trial sites. Shading indicates species established at site listed.

| Species                                      | D | P | B |
|--|---|---|---|
| <i>Eucalyptus astringens</i> Maiden (Maiden) |   |   |   |
| <i>E. cladocalyx</i> F. Muell.*              |   |   |   |
| <i>E. camaldulensis</i> Dehnh.               |   |   |   |
| <i>E. flocktoniae</i> Maiden (Maiden)        |   |   |   |
| <i>E. leucoxydon</i> F. Muell.               |   |   |   |
| <i>E. occidentalis</i> Endler                |   |   |   |
| <i>E. platypus</i> Hook.*                    |   |   |   |
| <i>E. redunca</i> Schauer                    |   |   |   |
| <i>E. sargentii</i> Maiden                   |   |   |   |
| <i>E. spathulata</i> Hook.                   |   |   |   |
| <i>E. wandoo</i> Blakely                     |   |   |   |
|  |   |   |   |

\* In Greenwood *et al.* (1994), these species were given varietal status at Dryandra: *E. cladocalyx* F. Muell. var. *nana* Hart; *E. platypus* Hook var. *heterophylla* Blakely.

### Tree measurement

At Dryandra and Popanyinning, nine tree spots (ie planted locations) were selected from the centre of each plot for measurement such that at least one row of edge trees existed to the perimeter of the measurement trees. At Boundain, the two trees on either side of each piezometer in the main trial area were selected. The piezometers had been installed on equally spaced, parallel transects, and thus a grid sampling system was employed here. However, insufficient numbers of *E. sargentii* or *E. camaldulensis* at 80 stems ha<sup>-1</sup> could be sampled using this system and these species at this density were not therefore included in the analysis of productivity. *Casuarina glauca* Sieb. and *E. globulus* were planted, but also not assessed due to their location outside or on the fringe of the main trial area. Due to the poor early survival of *E. robusta* Smith and *E. patens* Benth. at Dryandra (Greenwood *et al.*, 1994) and Popanyinning (Greenwood *et al.*, 1995), these species were also excluded.

Measurements were taken in July 2001. Diameter over bark at 1.3 m for all stems was measured and converted to basal area (BA) per tree. The sum of BA per tree for each plot was converted to BA ha<sup>-1</sup> using the plot area. Top height, as represented by the height to the highest green leaf, was measured using a “Vertex” hypsometer. Wood volumes (m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>) were estimated using the conical volume formula:

$$\text{stem volume (m}^3 \text{ tree}^{-1}\text{)} = (\text{basal area} \times \text{height}) / 3 \quad (1)$$

## Survival

Survival counts were based on the nine tree spots located centrally within plots in the case of Dryandra and Popanyinning. At Boundain, the sample population consisted of all tree spots within the main trial.

## Soil salinity

### EM-38 surveys

Readings of apparent soil electrical conductivity (ECa) were taken at the base of all measurement trees using a “Geonics” EM38 meter. However, the electrical conductivity (EC) of a saturated soil paste (ECe) is the standard way of reporting soil salinity with regard to plant response (Bennett *et al.*, 1995). ECa was converted to ECe using the technique of Bennett *et al.*, (1995). Soil samples were collected at 25 cm intervals and analysed for EC in the laboratory using the 1:5 (soil: water suspension) method (EC<sub>1:5</sub>) (Rayment and Higginson, 1992). EC<sub>1:5</sub> was converted to ECe using the formula developed by George and Wren (1985) for southwestern Western Australian soils:

$$\text{ECe} = \frac{(364 \times \text{EC}_{1:5})}{\text{SP}} \quad \text{Where SP} = \text{Saturation Percentage} \quad (2)$$

Texture of the <2 mm soil fraction was determined by the hydrometer method (Gee and Bauder, 1986). SP was estimated from soil texture using George and Wren (1985) where:

| <u>% clay*</u> | <u>Texture</u>               | <u>Saturation percentage</u> |
|----------------|------------------------------|------------------------------|
| <20            | sand – sandy loam            | 25                           |
| 20-30          | sandy loam – sandy clay loam | 32                           |
| >30            | sandy clay – clay            | 45                           |

\*from Moore (1998)

### Drilling

Auger coring was used to sample soil near (<0.3 m) piezometer four at Dryandra in May 2001. Samples were collected at 50 cm depth intervals from 0-350 cm. Chloride concentrations of the <2 mm fraction were determined (Rayment & Higginson, 1992) and compared to historical data (Greenwood *et al.*, 1994) collected following the original drilling of this piezometer site in 1975. Drill rig access problems precluded the extension of this method to other sites at Dryandra or Popanyinning.

At Boundain, soil samples were taken near (<0.3 m) seven piezometers. Five were located under trees planted in 1981, one under a small remnant clump of trees within the plantation area and one in adjacent pasture. Samples were collected at 75 cm intervals by rotary air drilling in October 2001. An additional collection tray was positioned downwind to ensure the fine

fraction of the spoil was reasonably represented in the sample. Each sample of the 75 cm depth interval was bulked and mixed thoroughly before analysis. The <2 mm fraction was analysed for EC<sub>1.5</sub> in the laboratory at 25°C (Rayment and Higginson, 1992) and results compared to those obtained in 1981 and 1988 by the Department of Agriculture.

### Ground resistivity survey

Ground resistivity from 0-50cm depth was measured at Dryandra and Popanyinning in October 2001 using a combined electrical current generator and resistance meter (“ET5 Megger Earth Tester”) connected to four electrodes (Wenner array) positioned on the soil surface (Rhoades and Miyamoto, 1990). With the aid of CSIRO field records, sampling points were located in approximate positions where past readings were taken. Past sampling was more extensive in the Dryandra than the Popanyinning plantation.

Resistivity readings (both historical and 2001) were converted to EC<sub>a</sub> (mS m<sup>-1</sup>) assuming a soil temperature of 25°C using the formula from Loveday (1980):

$$EC_a \text{ (mS m}^{-1}\text{)} = 100\,000 f_t / 2\pi a R_t \quad (3)$$

Where “ $f_t$ ” is the factor for correcting EC<sub>a</sub> to 25°C, “ $a$ ” is the distance between electrodes and “ $R_t$ ” is the resistance reading in ohms.

$f_t$  were taken from Bennett *et al.* (1995).

### **Groundwater salinity**

Piezometer installation for Dryandra and Popanyinning is outlined by Greenwood *et al.* (1994; 1995). Eight functional piezometers remained within the plantation areas at Dryandra and Popanyinning in 2001, and these were sampled for groundwater conductivity, along with 21 of the piezometers installed at Boundain. A minimum of one (and where possible two) times the volume of piezometers was baled before collecting water samples in order to remove stagnant water (Department of Natural Resources, 1997). Samples were collected in June and August 2001 and analysed for EC in the laboratory at 25°C with a “TPS” conductivity meter.

### **Statistical analysis**

Significant differences ( $p < 0.05$ ) in means for soil and groundwater salinity between sites were determined by ANOVA and Fisher’s least significant difference tests (LSD). Paired T-tests (Boundain) and Wilcoxon sign-rank tests (Dryandra and Popanyinning) were employed to detect significant differences ( $p < 0.05$ ) between mean soil salinity with time.

Significant differences ( $p < 0.05$ ) between mean productivity for different species were assessed at each site. ANOVA and Tukey’s pairwise comparisons were used for Dryandra and Popanyinning. T-tests were applied in the case of Boundain; however productivity of *E. camaldulensis* at 160 stems ha<sup>-1</sup> was not comparable to that for *E. sargentii* or *E. occidentalis* due to the trial design. Examination of residual plots generated from the ANOVAs for Dryandra and Popanyinning highlighted a number of outliers with high positive values. With only one row of trees buffering the plots in most cases, plots located on the edge of the trial would have been particularly subject to growth enhancement. The more extreme outliers were found to be associated with plots where a significant edge effect was likely; that is, the plots were exposed to an edge effect on two or more sides. These plots were removed from the analysis. Three plots

(*E. occidentalis*, *E. cladocalyx* and *E. sargentii*) at Dryandra and one plot at Popanyinning (*E. cladocalyx*), were excluded for this reason. Plots where no surviving trees were present were not included in the ANOVA but were used to calculate means and standard errors

## RESULTS

### Salinity of soil and groundwater

Surface soil salinity was greatest at Boundain with extremely saline land ( $>1600 \text{ mS m}^{-1}$ ) existing on a proportion of the site (Table 3). The mean salinity of the groundwater in the permanent aquifer at this site was  $>2000 \text{ mS m}^{-1}$  (very saline). Soil at Dryandra was predominantly moderately saline (mean  $427 \text{ mS m}^{-1}$ ) and Popanyinning, slightly saline (mean  $218 \text{ mS m}^{-1}$ ). The mean salinity of the main aquifer at these sites were  $<1000 \text{ mS m}^{-1}$ . Depths to the main aquifer at the three locations were 2 m and greater across each site.

**Table 3:** Summary statistics for soil ECe ( $\text{mS m}^{-1}$  - derived from the EM38) and EC ( $\text{mS m}^{-1}$ ) of the permanent aquifer within the main trial area at Dryandra (D), Popanyinning (P) and Boundain (B) during winter 2001. The groundwater data were derived from the June and August measurements. Means with the same letter are not significantly different ( $p < 0.05$ ) using Fisher's LSD.

|                    | Soil (ECe) $\text{mS m}^{-1}$ |                  |                  | Groundwater (EC) $\text{mS m}^{-1}$ |                  |                   |
|--------------------|-------------------------------|------------------|------------------|-------------------------------------|------------------|-------------------|
|                    | D                             | P                | B                | D                                   | P                | B                 |
| Minimum            | 46                            | 24               | 51               | 175                                 | 256              | 486               |
| Maximum            | 1113                          | 625              | 2131             | 1106                                | 937              | 4150              |
| Mean               | <sup>b</sup> 427              | <sup>a</sup> 218 | <sup>c</sup> 629 | <sup>a</sup> 856                    | <sup>a</sup> 606 | <sup>b</sup> 2193 |
| Standard Deviation | 207                           | 121              | 502              | 206                                 | 204              | 599               |
| Number             | 522                           | 450              | 191              | 8                                   | 8                | 21                |

### Survival

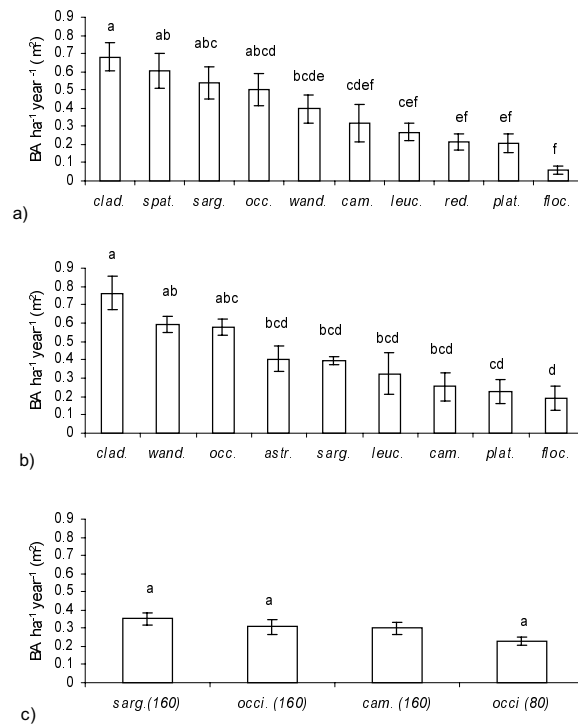
Tree survival rates in 2001 were 80% and above for the three species studied at Boundain, and 60% and above for the majority of species within the main trial areas at Dryandra and Popanyinning (Table 4). Highest rates at each site were 93% (*E. camaldulensis* at Boundain), 93% (*E. cladocalyx* at Popanyinning) and 84% (*E. sargentii* at Dryandra). Past fires had affected survival of *E. sargentii*, *E. platypus*, *E. flocktoniae* and *E. astringens* at Popanyinning (Greenwood *et al.*, 1995).

### Tree productivity

*E. cladocalyx* was ranked highest for productivity (accounting for both growth and survival) at both Popanyinning and Dryandra (Figure 1). Mean rates of productivity for this species were  $0.76 \text{ m}^2 \text{ ha}^{-1} \text{ year}^{-1}$  at Popanyinning and  $0.68 \text{ m}^2 \text{ ha}^{-1} \text{ year}^{-1}$  at Dryandra. However, these figures were not significantly different ( $p < 0.05$ ) from a number of other species at both these sites. Productivity of *E. occidentalis* could not be distinguished statistically ( $p < 0.05$ ) from that for *E. cladocalyx* at Dryandra or Popanyinning. *E. sargentii* at 160 stems  $\text{ha}^{-1}$  in the Boundain trial, had produced a basal area of  $0.35 \text{ m}^2 \text{ ha}^{-1} \text{ year}^{-1}$  by age 20 years. This value was not significantly different ( $p < 0.05$ ) from that for *E. occidentalis* established at either 160 stems  $\text{ha}^{-1}$  or 80 stems  $\text{ha}^{-1}$ .

**Table 4:** Survival rates (%) by species at Dryandra and Popanyinning at 25 years, and Boundain at 20 years. Sample size in brackets - = not available.

| Species                 | Survival |      |              |      |          |       |
|-------------------------|----------|------|--------------|------|----------|-------|
|                         | Dryandra |      | Popanyinning |      | Boundain |       |
|                         | %        | (n)  | %            | (n)  | %        | (n)   |
| <i>E. sargentii</i>     | 84       | (45) | 59           | (27) | 93       | (146) |
| <i>E. cladocalyx</i>    | 82       | (45) | 93           | (45) | -        | -     |
| <i>E. spathulata</i>    | 81       | (36) | -            | -    | -        | -     |
| <i>E. camaldulensis</i> | 80       | (45) | 80           | (45) | 98       | (165) |
| <i>E. wandoo</i>        | 71       | (45) | 87           | (45) | -        | -     |
| <i>E. leucoxydon</i>    | 64       | (45) | 58           | (36) | -        | -     |
| <i>E. platypus</i>      | 53       | (45) | 62           | (45) | -        | -     |
| <i>E. flocktoniae</i>   | 33       | (45) | 69           | (45) | -        | -     |
| <i>E. occidentalis</i>  | 60       | (45) | 69           | (36) | 80       | (228) |
| <i>E. astringens</i>    | -        | -    | 47           | (45) | -        | -     |



**Figure 1:** Mean BA ha<sup>-1</sup> year<sup>-1</sup> (m<sup>2</sup>) by species at **a)** Dryandra and **b)** Popanyinning at 25 years of age; and **c)** Boundain at 20 years of age. Bars denote standard errors. Species with the same letter are not significantly different ( $p < 0.05$ ) using Tukey's pairwise comparisons (Dryandra and Popanyinning) or two sample T-tests where applicable (Boundain). Full species names in Table 2. Establishment density (stems ha<sup>-1</sup>) for each species denoted in brackets for Boundain

Simple estimates of productivity on a volume basis revealed the maximum to be 3.5 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> for *E. cladocalyx* at Popanyinning. Mean values for *E. occidentalis* were 2.5 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> at Dryandra and Popanyinning, and 1 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> at the lower density, younger plantation at

Boundain. *E. sargentii*, *E. spathulata* and *E. cladocalyx* also produced  $2.5 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$  at Dryandra. In all other cases, volumes were estimated to lie in the range from  $0.5\text{-}1.5 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ .

### Salt accumulation

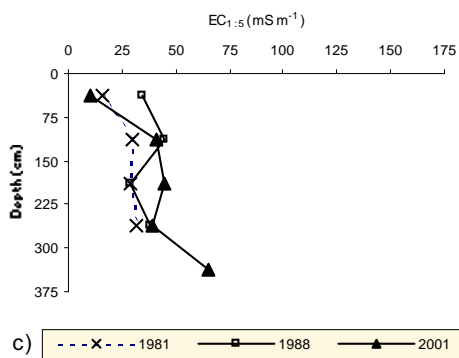
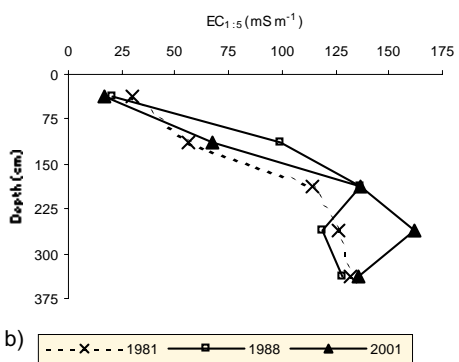
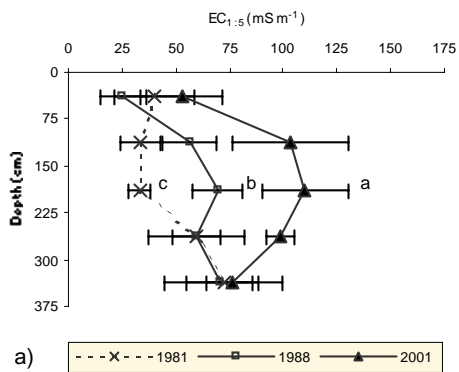
Measurements of soil salinity taken within the plantation areas at Boundain and Dryandra showed a pronounced increase with time. At Boundain, the increase was greatest between 1-2.5 m depth under the plantation (Figure 2).  $EC_{1.5}$  has more than doubled throughout most of this depth interval since the plantation was established. In contrast, there has been little change in the salinity of the soil profile at one nearby position outside the plantation area. At Dryandra, the  $EC_a$  from 0 – 50 cm as measured by a resistivity meter, approximately doubled between 1980 and 2001 (Figure 3a). The increase for the mean of the survey locations at Popanyinning over the same period was even greater (Figure 3b). The salinity of soil samples collected at various depths beneath one location within the plantation area at Dryandra suggested a substantial accumulation of salt (up to  $2000 \text{ mg kg}^{-1}$ ) had occurred to a depth of 2 m between 1975 and 2001 (Figure 4).

## DISCUSSION

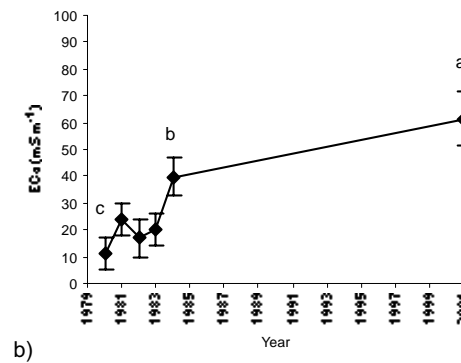
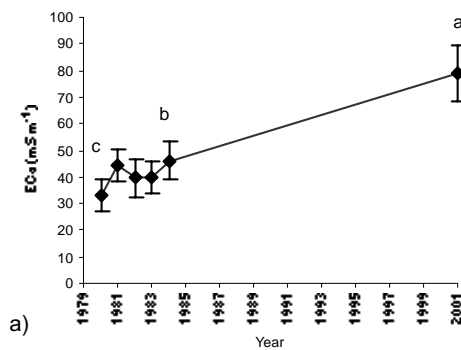
With correct selection of species and planting density, survival can be maintained above 70% to 20-25 years and beyond when trees are planted near saline seeps. *E. platypus* at Dryandra was the only instance where survival substantially declined across the three sites since they were last studied – at 15 years for Dryandra (Greenwood *et al.*, 1994) and Popanyinning (Greenwood *et al.*, 1995), and at 4 years for Boundain (source: Department of Agriculture Western Australia). Losses of this species could be attributed to a combination of competition effects (given the small plot sizes) and the fact that this species was planted outside its natural range\*. Higher survival rates for *E. occidentalis*, *E. sargentii* and *E. occidentalis* at Boundain where salinity was higher, but the planting density was lower ( $80$  and  $160 \text{ stems ha}^{-1}$  vs.  $816 \text{ stems ha}^{-1}$ ), suggests competition for water resources or salt accumulation may have affected survival in the block plantings.

The evidence for a significant elevation of salt in the soil below the plantation areas was strong. At Boundain, increased salinity levels in soil under trees in contrast with those under pasture demonstrates the link between tree growth and salt accumulation. However, from the survival data, an associated decline in tree health was not apparent at the time of the study. As observed in natural systems, long term leaf area, water use and salinity co-evolve and achieve equilibrium (G. Walker pers. comm.). Species that occur naturally in saline environments (for example, *E.sargentii*, *E. spathulata* and *E. occidentalis*) could therefore be expected to persist with increasing concentrations of salt, albeit at a cost to growth. The relatively stable salt profile over time under the remnant trees at Boundain, in contrast to that under the plantation, may be indicative of this mechanism. The accumulation of salt under trees represents a threat to sustainability of these discharge plantings in the longer term (50-100 years) if water tables underlying the plantations rise over that period, and points to the need to manage leakage of water across the whole landscape.

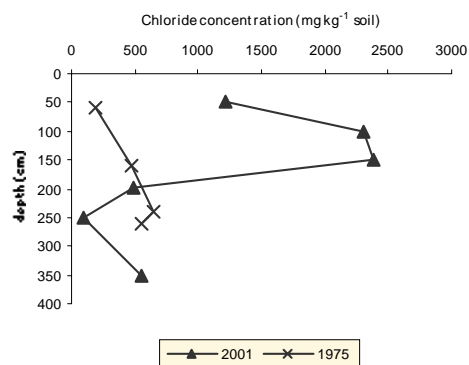
\* *E. platypus* naturally occurs in the south coast region of Western Australia (Brooker and Kleinig, 1990).



**Figure 2:** Changes in EC1:5 at Boundain for three sampling times – January 1981, February 1988 and October 2001 in soil under **a)** plantation, **b)** remnant trees and **c)** pasture. Bars denote standard errors. Means with the same letter for 150-225 cm in a) are not significantly different ( $p < 0.05$ ) using paired T tests. 1981 and 1988 data sourced from Department of Agriculture Western Australia.



**Figure 3:** Change in ECa (0-50 cm) measured using the Wenner array for the plantation area at **a)** Dryandra ( $n = 68-70$ ) and **b)** Popanyinning ( $n = 15-20$ ) from 1980 – 2001. Bars denote standard errors. Means with the same letter for 1980, 1984 and 2001 are not significantly different ( $p < 0.05$ ) using Wilcoxon sign-rank test. 1980-1984 data sourced from CSIRO.



**Figure 4:** Soil chloride concentration at piezometer 4 at Dryandra in 1975 and 2001 ( $n=1$ ). 1975 data from Greenwood *et al.* (1994).

Maximum production of any species in this study ( $3.5 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$  for *E. cladocalyx* at Popanyinning) was low when compared to commercial production for *E. globulus* in the 600 mm rainfall zone. As the Popanyinning site was only slightly saline, such a growth rate may be higher than should be expected from typical land adjacent to saline seeps. Furthermore, *E. cladocalyx* is not renowned as a particularly salt tolerant species, with a reduction in growth and survival expected at  $500 \text{ mS m}^{-1}$  and above (Marcar *et al.*, 1995). Productivity at the higher rainfall but more saline site of Dryandra was lower ( $2.5 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ ), but still comparable to a range of species of greater known tolerance. *E. spathulata*, *E. sargentii*, *E. occidentalis* and *E. wandoo* demonstrated their capacity to grow and survive over shallow saline water tables comparative to a range of other species. The low growth rates at Dryandra and Popanyinning, where the salinity of the permanent aquifer was less than  $1000 \text{ mS m}^{-1}$ , is not encouraging for the prospect of siting commercial plantations over shallow water tables as a means of enhancing tree growth and discharge from shallow water tables. Growth rates of this magnitude are unlikely to attract commercial investment. However, the small number of species, and the fact that provenance variation within species was not tested, should be considered with this finding. Additionally, whether the trees had penetrated the confining layer overlying the aquifer at each site warrants investigation. Greenwood *et al.* (1994; 1995) suggested this was not the case during the initial years of growth.

Productivity at the lower planting density, but more saline site of Boundain, was higher in proportion to that at the planting density at Dryandra or Popanyinning. Some production from pasture also occurs in the alleys between the trees at Boundain. These facts highlight the need for further research into optimal arrangements that address both production (of the combined agroforestry system) and water table control (J. McGrath pers. comm.) Of particular interest is whether the accumulation of salt in tree root zones can be manipulated by plantation density and lay-out, this possibly leading to more stable systems in the long term.

In conclusion, the results support continued tree planting on land adjacent to saline seeps where environmental objectives are the focus. Survival in the presence of salt accumulation should be expected if suitable salt tolerant species are planted at appropriate densities and if water tables are not rising rapidly. Localised recharge reduction, biodiversity enhancement, shelter for stock and erosion control can continue for 20 years and beyond. Future monitoring of these sites, in addition to others located in more saline locations, will increase the understanding of salt accumulation effects on tree growth and survival.

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