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Catastrophic drought-induced die-off of perennial chenopod shrubs in arid Australia following intensive cattle browsing

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Abstract

Cover and survivorship of perennial chenopods, *Atriplex vesicaria* and *Maireana astrotricha*, declined markedly during a prolonged dry period at Roxby Downs in arid South Australia. Despite their resilience to browsing in favourable seasons, only 2% of the *A. vesicaria* shrubs browsed heavily by cattle survived the drought. *M. astrotricha* exhibited greater drought survivorship, although the post-drought cover retention in browsed shrubs was only half that of unbrowsed controls. Survivorship was highest for unbrowsed chenopods growing in moisture-enhanced run-on or dune-base environments. Maintenance of these patchy areas with reduced water-stress is hence important for the persistence of browsed chenopod shrublands. Light browsing by either European Rabbits (*Oryctolagus cuniculus*) or Greater Stick-nest Rats (*Leporillus conditor*) had no measurable impact upon chenopod survivorship.

Keywords: Chenopod; *Atriplex*; *Maireana*; Cattle browsing; Water stress; Plant death; Survivorship; Drought

1. Introduction

Long-lived chenopod shrubs, such as *Atriplex vesicaria* and *Maireana astrotricha*, are the dominant plant species over much of the southern Australian arid zone (Wilson et al., 1982). These perennial shrubs enhance soil water infiltration, restrict soil erosion, trap humus and seeds and provide habitats for other plants and animals (Graetz and Wilson, 1984). Chenopods also provide important stock feed in the rangelands of both

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southern Australia (Leigh and Mulham, 1967) and western North America (Shoop et al., 1985), particularly in dry times when ephemeral grasses and forbs are scarce. Therefore, the broad-scale death of chenopods, which has been recorded several times since pastoral occupation of the Australian rangelands (Clift et al., 1987), has considerable environmental and economic implications. Although caterpillars and boring insects have been implicated in some die-offs of *A. vesicaria*, the principal causative agents are thought to be water stress and heavy browsing (Clift et al., 1987).

Redistribution of scarce water and nutrients is integral to the survival of chenopod shrubs and the persistence of these shrublands. Run-on zones, lower elevation areas where water and nutrients concentrate, permit more shrubs to grow within the landscape than if the rainfall is not redistributed (Dunkerley and Brown, 1995; Ludwig et al., 1997). Plants in water-yielding zones are more vulnerable to water stress than plants in water-accumulating areas. Likewise, chenopod survival during dry times is lower in those soil types that are relatively impervious or desiccate rapidly (Clift et al., 1987).

Browsing pressure upon Australian chenopods prior to the introduction of stock was probably light, because kangaroos, the dominant native herbivores, feed mainly on grasses (Dawson, 1995). Stick-nest rats (*Leporillus* spp.), which were driven to extinction on the Australian mainland, would have historically browsed chenopods (Ryan et al., 2004) throughout much of the arid zone. Light browsing by domestic stock may enhance the recruitment and vigour of chenopod shrubs, thus improving their resilience to drought or subsequent severe browsing (Osborne et al., 1932; Leigh and Mulham, 1971; Clift et al., 1987). However, prolonged or severe over-grazing can severely damage or eliminate chenopod shrubland on a broad scale (Fatchen and Lange, 1979; Wilson et al., 1982; Oxley, 1987; Eldridge et al., 1990). Sustainable management of chenopod shrublands therefore requires maintenance of browsing pressure at a level which does not inhibit the long-term survival of *M. astrotricha* and *A. vesicaria*.

Most of the studies on the resilience of Australian chenopods to browsing and drought have been conducted in semi-arid areas grazed by sheep, which browse *M. astrotricha* more intensively but *A. vesicaria* less intensively than cattle (Graetz and Wilson, 1980). A previous experiment at Roxby Downs, in arid South Australia, showed that *A. vesicaria* and *M. astrotricha* were resilient to intensive spates of cattle browsing during favourable seasons (Read, 1999). The onset of a severe drought following this trial provided an excellent opportunity to compare the long-term survivorship of these heavily browsed shrubs with unbrowsed controls. Furthermore, this natural experiment permitted comparison of the drought resilience of chenopods in landscape elements with different water accumulation and storage properties.

2. Methods

2.1. Study site

The principal study site was located 15 km north-east of Roxby Downs in the arid zone of northern South Australia (Fig. 1), on the boundary of the Olympic Dam

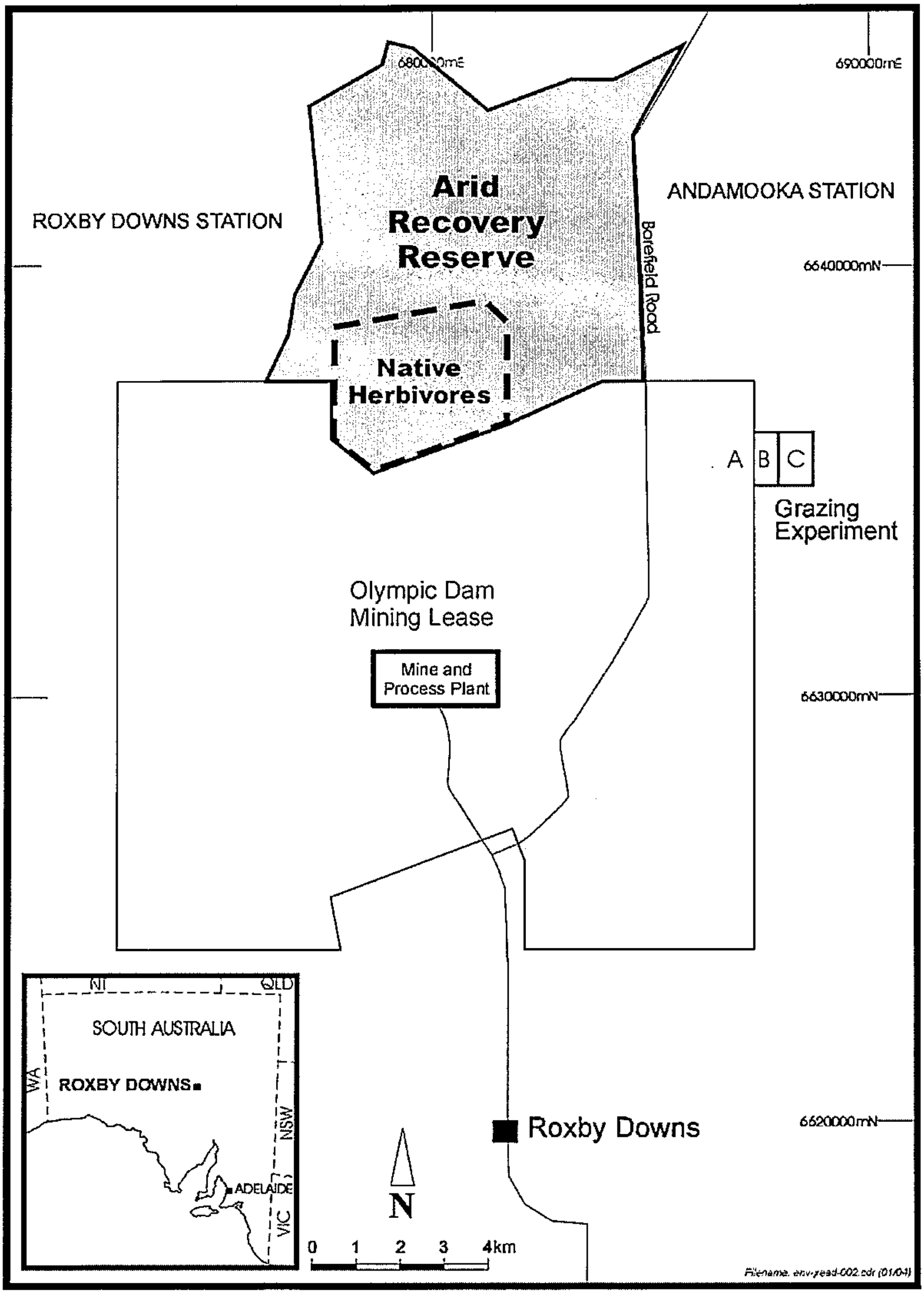

Fig. 1. Location of study sites.

mine lease and the Andamooka Pastoral Station. The landscape was inter-dunal plains, or swales, of chenopod shrubland vegetation overlain by longitudinal sand dunes approximately 500 m apart. Full details of the climate, vegetation and soils of the principal study site are provided in Read (1999). Rainfall, measured at a weather station 10 km west of the main study site, was below the long-term annual average of 166 mm for the period from March 1997 to January 2000, particularly during 1999 when less than 70 mm was recorded for the entire year (Fig. 2).

Three chenopod-dominated sub-habitats, run-on swale, runoff swale and dune-base were selected to represent different soil water accumulation and storage properties. Run-on areas were readily identified as the relatively small patches that supported dense grass and shrub cover (Read, 1999) within the predominantly water shedding, or runoff, areas of swales. Dune-base sites were characterized by 10–100 cm of sand overlain upon the clay swale soils. Sandy substrates facilitate greater water infiltration and storage and reduced evaporation compared with finer grained clay soils (Sperry and Hacke, 2002). Three replicate sites in each sub-habitat were situated in each of two experimental paddocks (Paddock B & C) and an adjacent control region that had been ungrazed for over a decade. The two 20 ha experimental paddocks were each browsed by 80 cattle for 18 days in June 1995 and again by 70 cattle for six days in December 1995. The experimental design, which minimized natural heterogeneity in soils, vegetation and rainfall whilst providing satisfactory site replication and independence, are discussed in detail in Read (1999, 2002) and Read and Andersen (2000).

The number and percentage cover of live *A. vesicaria* and *M. astrotricha* on 60 m of fixed line transects at each site was measured prior to the grazing of the experimental paddocks in February 1995, 1 year after the heavy grazing in February 1997 and 2 months after drought-breaking rains in April 2000.

The line-intercept method is a useful technique for monitoring changes in cover in chenopod shrubland (Friedel, 1990) but is not as accurate as quadrat counts for monitoring plant survival. Therefore quadrat counts of chenopod survivorship from

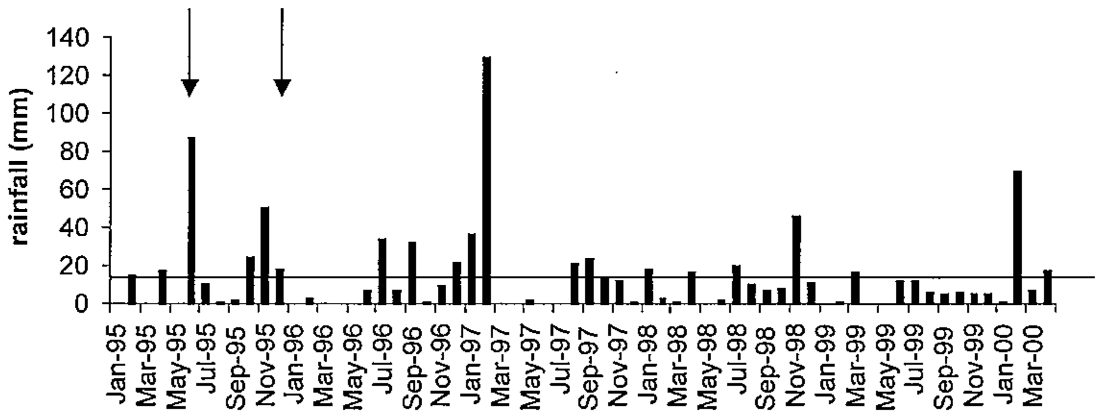

Fig. 2. Monthly rainfall records from grazing periods (marked by arrows) until the final vegetation survey in April 2000. Horizontal line shows long-term average monthly rainfall.

a monitoring program conducted in the Arid Recovery Reserve, within 10 km of the principal study site were used to independently assess shrub survivorship results from the control regions. These additional ten quadrats, monitored within and outside the Arid Recovery Reserve, had been ungrazed by cattle for at least a decade. However, browsing by rabbits and reintroduced stick-nest rats at some of these quadrats also permitted tentative evaluation of the role of light browsing upon chenopod survival through drought. Five quadrats exposed only to stick-nest rat browsing, at densities of approximately 10 individuals km^{-2}, were selected within the Reserve. Two quadrats protected from cattle but exposed to rabbits, also at densities of approximately 10 individuals km^{-2}, were located immediately outside of the Reserve and three quadrats were free from large browsers in areas where rabbits had been removed but rats had not yet been reintroduced. Both stick-nest rat and rabbit densities were considered to be low to moderate during this study period. All chenopods were counted within twenty 2×10 m quadrats at these Arid Recovery Reserve monitoring sites before the drought in October 1997, during the drought in October 1999 and after the drought in April 2000. A distinction was made in the April 2000 count between shrubs that had retained at least a quarter of their foliage and those shrubs that remained alive yet were largely defoliated.

2.2. Analyses

Repeated measures ANOVA was considered to be the appropriate statistical test for comparing survivorship and cover in different treatments. However, due to the extremely low survivorship of shrubs following the drought, the data were not normally distributed, which precluded the use of analyses of variance. However, the clear trends supported by non-overlapping error bars around the means for different treatments suggests that the differences between control and treatment paddocks were significant.

3. Results

Only 2% of the monitored *A. vesicaria* plants that were browsed heavily by cattle (Paddocks B&C combined) survived the 1999–2000 drought, whereas post-drought survivorship of *M. astrotricha* in browsed paddocks was 73% (Fig. 3). By contrast, drought survivorship in the unbrowsed control region was 44% for *A. vesicaria* and 88% for *M. astrotricha* (Fig. 3). Post-drought decline in cover was even more apparent than the reduction in survivorship, with a 98% reduction in *A. vesicaria* cover and 90% reduction in *M. astrotricha* cover in browsed Paddocks B&C combined, compared to a 48% and 47% reduction, respectively, in the unbrowsed control sites (Fig. 4).

Only 11%, of the *A. vesicaria* plants from unbrowsed runoff sites at the principal study site survived the drought, whereas survivorship was 49% at run-on and 78% at dune-base sites in this control region (Fig. 5). Likewise, survivorship of *M. astrotricha* shrubs was considerably lower at runoff sites compared to run-on and

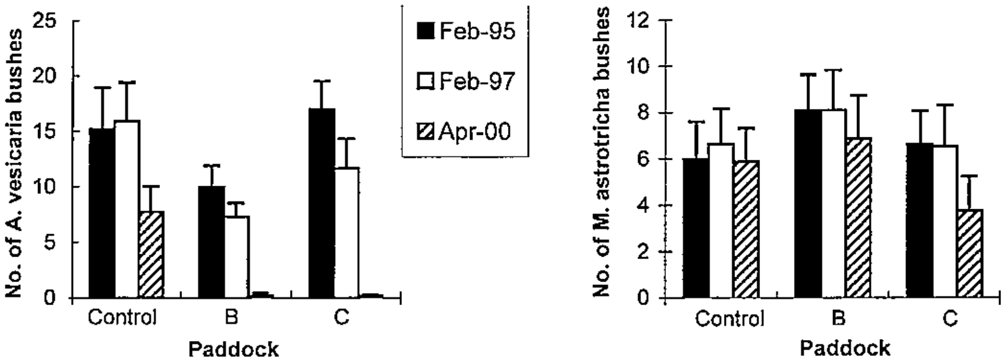

Fig. 3. Number (Mean + 1 s.e.) of live *A. vesicaria* and *M. astrotricha* bushes following grazing (February 1997) and drought (April 2000) in the ungrazed control (12 replicates) and grazed paddocks B&C (nine replicates).

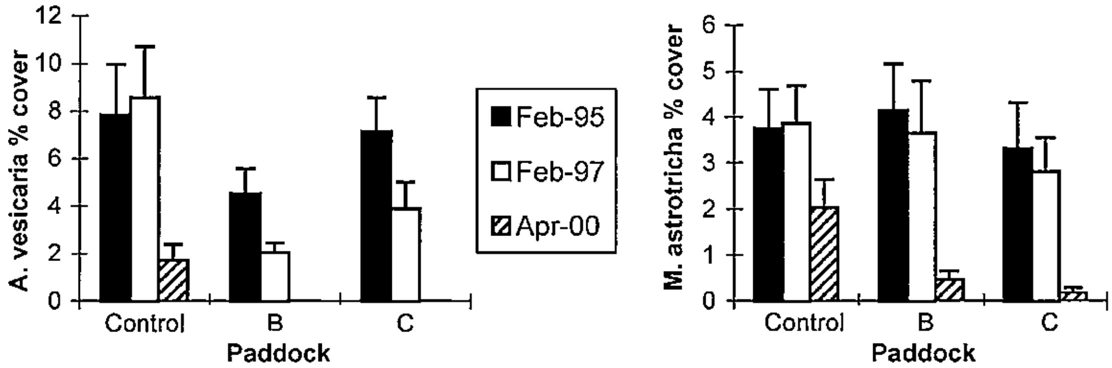

Fig. 4. Cover (mean + 1 s.e.) of *A. vesicaria* and *M. astrotricha* following grazing (February 1997) and drought (April 2000) in the ungrazed control (12 replicates) and the grazed paddocks B&C (nine replicates).

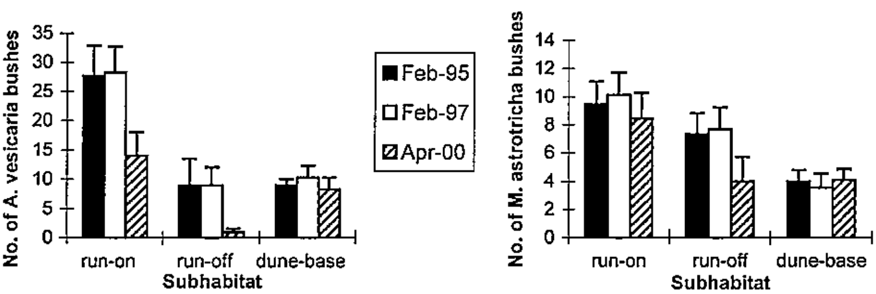

Fig. 5. Number (Mean + 1 s.e.) of live *A. vesicaria* and *M. astrotricha* bushes in each sub-habitat following drought (April 2000) in the ungrazed control (four replicates).

dune-base sites (Fig. 5). Both *A. vesicaria* and *M. astrotricha* experienced severe loss of cover in run-on and runoff habitats but decline in cover was not significant at dune-base sites (Fig. 6).

Consistent with the control region results from the cattle-browsing experiment, post-drought survivorship of *A. vesicaria* within the Arid Recovery Reserve was approximately 50%, irrespective of browsing history (Fig. 7). Very few

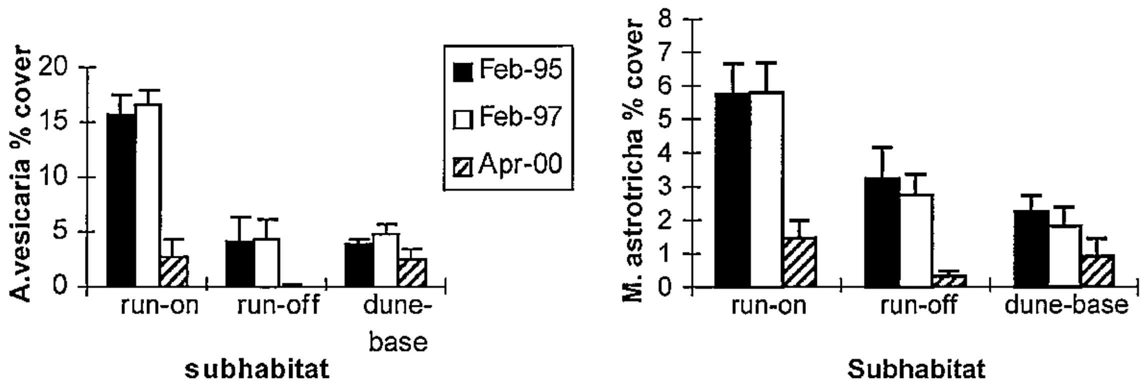

Fig. 6. Mean (+1 s.e.) cover of *A. vesicaria*, and *M. astrotricha* in each sub-habitat following drought (April 2000) within the ungrazed control (four replicates).

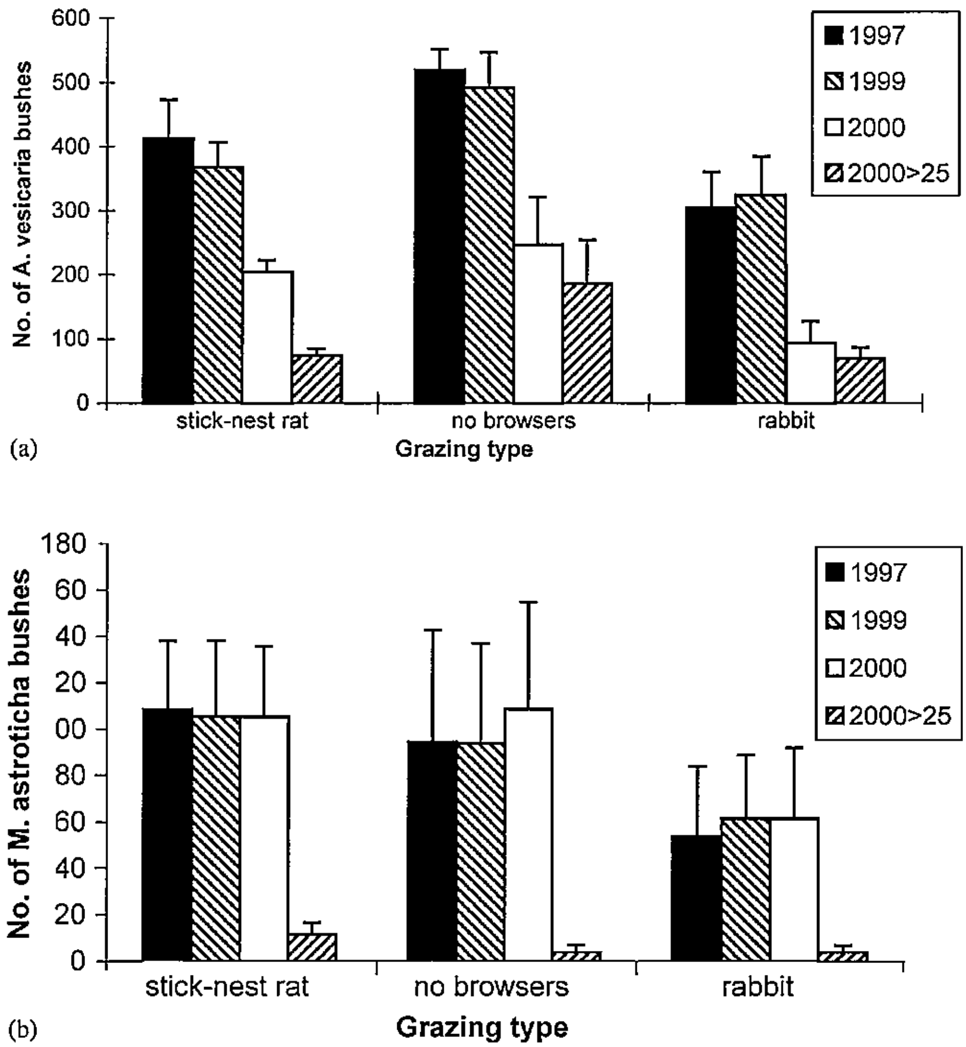

Fig. 7. Mean (+1 s.e.) number of live *A. vesicaria* (a) and *M. astrotricha* (b) in 400 m^2 quadrats in regions browsed by stick-nest rats (five replicates), no mammalian browsers (three replicates) or rabbits (two replicates). 1997 and 1999 counts preceded the drought. The number of bushes with >25% cover following the drought in 2000 are plotted separately.

M. astrotricha died within the Arid Recovery Reserve although only approximately 10% of the shrubs retained greater than 25% foliage cover following the drought (Fig. 7).

4. Discussion

The death of approximately half of the *A. vesicaria* shrubs monitored in areas remote from cattle browsing at Roxby Downs during the drought of 1999–2000 was of a similar magnitude to drought-induced shrub mortality in arid regions of both Australia (Clift et al., 1987) and southern Africa (Milton et al., 1995). Despite this considerable mortality, post-drought survivorship of *A. vesicaria* was over 20 times greater in the unbrowsed control region than in heavily browsed experimental paddocks. Therefore, although *A. vesicaria* bushes may be initially resilient to intensive bouts of cattle browsing (Read, 1999), heavily browsed bushes at Roxby Downs were subsequently far more susceptible to drought than unbrowsed bushes. This reduced drought resilience of heavily browsed *Atriplex*, which has also been recorded for *Atriplex confertifolia* in Utah (Chambers and Norton, 1993), may be caused by inhibited root growth of defoliated plants (Leigh and Mulham, 1971; Earl and Jones, 1996).

Although *M. astrotricha* shrubs experienced severe defoliation following the drought, few shrubs had died at the time of monitoring. *M. astrotricha* is a longer lived plant than *A. vesicaria* and like its congeners *M. sedifolia* and *M. pyramidata*, it is able to recuperate from defoliation (Leigh and Mulham, 1971). Light grazing pressure by rabbits or greater stick-nest rats appeared to have negligible impact on *A. vesicaria* or *M. astrotricha* survivorship.

Despite considerable summer rainfall in February 2000 and February 2001, the apparently dead *Atriplex* did not resprout, as has been recorded elsewhere (Osborne et al., 1932), nor was any *A. vesicaria* germination recorded. The drought virtually eliminated live saltbush for at least two years from areas browsed heavily by cattle. Therefore, although moderate browsing can be tolerated by chenopods in some cases without considerable adverse impacts (Yan et al., 1996; Read, 1999), land managers should be mindful of the greater vulnerability of heavily defoliated *Atriplex* to drought stress.

Even in unbrowsed regions, most *A. vesicaria* and many *M. astrotricha* bushes were eliminated from runoff areas during the 1999–2000 drought at Roxby Downs. The role of water-stress in the widespread death of chenopods was further illustrated by the survival and seeding of most *A. vesicaria* in a patch adjacent to the experimental region that was flooded by fresh water from a pipeline leak for several days in late 1998. This localized increase in water availability dramatically enhanced survival over the following two dry years. The greater survivorship and foliage retention of *A. vesicaria* at dune-base and run-on areas compared to those areas that shed water was also attributed to improved water storage or increased water availability at these sites. These sandy or run-on areas, which typically comprise considerably less than half of the area vegetated by local *A. vesicaria* populations, are therefore key sources of seed for post-drought regeneration of this important shrub.

Saltbush populations can be removed by heavy browsing pressure followed by dry conditions (Fatchen and Lange, 1979) because these wetter patches are also targeted by introduced herbivores (Morton, 1990). Furthermore, increased soil compaction and reduced vegetation cover caused by livestock grazing can cause run-on patches to be buried by eroded sediments (Tongway and Ludwig, 1990; Fuls, 1992). The resulting landscape has less vertical relief and hence is less able to concentrate or store water, which contributes to the replacement of perennial shrubland by short-lived colonising plants. Removal of chenopods not only affects the carrying capacity of the rangelands but more importantly it also renders these landscapes vulnerable to erosion (Graetz and Wilson, 1984) and disrupts wildlife communities (Landsberg et al., 1997; Read and Andersen, 2000; Read, 2002).

This study reinforces that despite their resilience to browsing in wet periods (Read, 1999), heavy browsing by domestic herbivores can contribute to catastrophic drought-induced die-off within *Atriplex* populations (Harrington et al., 1990). In order to maintain both pastoral and ecosystem productivity in the long term, browsing pressure should be reduced prior to severe defoliation of *Atriplex* shrubs, particularly in dry times when the shrubs are most vulnerable (Chambers and Norton, 1993).

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References

Chambers, J.C., Norton, B.E., 1993. Effects of grazing and drought on population dynamics of salt desert shrub species on the Desert Experimental Range, Utah. Journal of Arid Environments 24, 261–275.

Clift, D.K., Semple, W.S., Prior, J.C., 1987. A survey of bladder saltbush (*Atriplex vesicaria* Heward ex Benth) dieback on the riverine plain of South-eastern Australia from the late 1970s to 1983. Australian Rangeland Journal 9, 39–48.

Dawson, T.J., 1995. Kangaroos: Biology of the Largest Marsupials. University of New South Wales Press.

Dunkerley, D.L., Brown, K.J., 1995. Runoff and runon areas in a patterned chenopod shrubland, arid western New South Wales, Australia: characteristics and origin. Journal of Arid Environments 30, 41–55.

Earl, J.M., Jones, C.E., 1996. The need for a new approach to grazing management—Is cell grazing the answer? The Rangeland Journal 18, 327–350.

Eldridge, D.J., Westoby, M., Stanley, R.J., 1990. Population dynamics of the perennial rangeland shrubs *Atriplex vesicaria, Maireana astrotricha* and *M. pyramidata* under grazing, 1980–87. Journal of Applied Ecology 27, 502–512.

Fatchen, T.J., Lange, R.T., 1979. Piosphere pattern and dynamics in a chenopod pasture grazed by cattle. In: Studies of the Australian arid zone Proceedings of symposium, CSIRO, Research unit of the Division of Land Resources, Deniliquin, pp. 160–69.

Friedel, M.H., 1990. Some key concepts for monitoring Australia's arid and semiarid rangelands. Australian Rangeland Journal 12, 21–24.

Fuls, E.R., 1992. A technique for objective habitat condition assessments in rangelands. Journal of Arid Environments 22, 195–198.

Graetz, R.D., Wilson, A.D., 1980. Comparison of the diets of sheep and cattle grazing a semi-arid chenopod shrubland. Australian Rangeland Journal 2, 67–75.

Graetz, R.D., Wilson, A.D., 1984. Saltbush and bluebush. In: Harrington, G.N., Wilson, A.D., Young, M.D. (Eds.), Management of Australia's Rangelands. CSIRO, Melbourne.

Harrington, G.N., Friedel, M.H., Hodgkinson, K.C., Noble, J.C., 1990. Vegetation ecology and management. In: Harrington, G.N., Wilson, A.D., Young, M.D. (Eds.), Management of Australia's rangelands. CSIRO Publications, Melbourne, pp. 41–1061.

Landsberg, J., James, C.D., Morton, S.R., Hobbs, T., Stol, J., Drew, A., Tongway, H., 1997. The effects of artificial sources of water on rangeland biodiversity. Environment Australia and CSIRO, Lyneham ACT.

Leigh, J.H., Mulham, W.E., 1967. Selection of diet by sheep grazing semi-arid pastures on the Riverine Plain 3. A bladder saltbush (*Atriplex vesicaria*)-pigface (*Disphyma australe*) community. Australian Journal of Experimental Agriculture and Animal Husbandary 6, 468–474.

Leigh, J.H., Mulham, W.E., 1971. The effect of defoliation on the persistence of Atriplex vesicaria. Australian Journal of Agricultural Research 22, 239–244.

Ludwig, J., Tongway, D., Freudenberger, D., Noble, J., Hodgkinson, K., 1997. Landscape ecology: function and management. Principles from Australia's rangelands. CSIRO, Australia.

Morton, S.R., 1990. The impact of European settlement on the vertebrate animals of arid Australia: a conceptual model. Proceedings of the Ecological Society of Australia 16, 201–213.

Osborne, T.G.B., Wood, J.G., Paltridge, T.B., 1932. On the growth and reaction to grazing of the perennial saltbush, *Atriplex vesicarium*. An ecological study of the biotic factor. Proceedings of the Linnean Society of N.S.W., pp. 377–402.

Oxley, R.E., 1987. Analysis of historical records of a grazing property in south-western Queensland 2. Vegetation changes. Australian Rangeland Journal 9, 30–38.

Read, J.L., 1999. The initial response of a chenopod shrubland plant and invertebrate community to intensive grazing pulses. The Rangeland Journal 21, 169–193.

Read, J.L., 2002. Experimental trial of Australian arid zone reptiles as early warning indicators of overgrazing by cattle. Austral Ecology 27, 55–66.

Read, J.L., Andersen, A.N., 2000. Using ants as early warning indicators: responses to pulsed cattle grazing in the Australian arid zone. Journal of Arid Environments 45, 231–251.

Ryan, S.A., Moseby, K.E., Paton, D.C., 2004. Comparative foraging preferences of the Greater Stick-nest rat (*Leporillus conditor*) and the european rabbit (*Oryctolagus cuniculus*): implications for regeneration of arid lands. Aust. Mammalogy 25, 135–146.

Shoop, M.C., Clark, R.C., Laycock, W.A., Hansen, R.M., 1985. Cattle diets on shortgrass ranges with different amounts of fourwing saltbush. Journal of Range Management 38, 443–449.

Sperry, J.S., Hacke, U.G., 2002. Desert shrub water relations with respect to soil characteristics and plant functional type. Functional Ecology 16, 367–378.

Tongway, D.J., Ludwig, J.A., 1990. Vegetation and soil patterning in semi-arid mulga lands of eastern Australia. Australian Journal of Ecology 15, 23–34.

Wilson, A.D., Tupper, G.J., Tongway, D.J., 1982. Range condition assessment in Bladder Saltbush (*Atriplex vesicaria*) communities. Australian Rangeland Journal 4, 41–51.

Yan, Z.G., Holm, A.McR., Mitchell, A.A., 1996. The population dynamics of perennial shrubs in a Western Australian chenopod shrubland in relation to grazing and seasonal conditions. The Rangeland Journal 18, 10–22.