DO KANGAROOS EXHIBIT WATER-FOCUSED GRAZING PATTERNS IN ARID NEW SOUTH WALES? A CASE STUDY IN STURT NATIONAL PARK

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Montague-Drake R and Croft DB, 2004. Do kangaroos exhibit water-focused grazing patterns in arid New South Wales? A case study in Sturt National Park. *Australian Mammalogy* **26**: 87-100.

The density of kangaroos (*Macropus* spp.) within 5 km of current and former artificial watering points in Sturt National Park (NSW) was studied over a two-year period using the line transect method. Kangaroo densities were not significantly related to water proximity and did not significantly differ between open and closed watering points. Infrared sensors detected and counted kangaroo movements to and from artificial watering points and these were positively correlated with temperature. However, line transect counts did not reveal a shift in kangaroo distributions to water-proximate areas in warmer seasons. The results suggest that kangaroos travel to drink and then return to relatively stable home ranges that take advantage of sites offering the best grazing and resting opportunities. Vegetation surveys, using a wheel point device, revealed that the biomass of *Atriplex* spp. decreased significantly with increased proximity to artificial watering points, but the biomass of Poaceae spp. and numerous forbs did not. Vegetative diversity was unrelated to water proximity. Low vegetation biomass near artificial watering points in Sturt National Park may be more correctly attributed to the effects from past sheep-grazing pressure, than to any current grazing pressure. The implications of artificial watering point closure on conservation values and nature-based tourism are discussed.

Key words*:* artificial watering point, piosphere, red kangaroo, grazing pressure, arid rangeland, Sturt National Park, line transect, Trailmaster.

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SINCE the advent of pastoralism in Australia's rangelands, artificial supplies of water have increased dramatically, such that now, the average distance between such resources is only 10 km (Landsberg *et al*. 1997). Such increased water availability has been cited as causing marked ecological impacts in a wide range of arid and semi-arid environments.

The 'piosphere' (Lange 1969) is perhaps the best-studied manifestation of impacts caused by artificial watering points. The term 'piosphere' describes the zones of attenuating stocking impacts that extend out from watering places (Andrew and Lange 1986a). The patterning of impact is a function of the stock's need to drink, and thus their limited capacity to travel far to graze, as well as basic geometry, which dictates that stocking density decreases with increasing distance from watering points because individuals are dispersed over a larger area. Many studies (e.g., Osborn *et al.* 1932; Valentine 1947; Andrew and Lange 1986a,b; Tolsma *et al*. 1987; Fusco *et al*. 1995; Thrash *et al*. 1995; Navie *et al*. 1996; Jeltsch *et al*. 1997; Thrash 1997, 1998a,b) have proved the correlation between water-focused grazing by domestic stock or wild African ungulates and one or more abiotic or botanic impacts. However, in Australia no such study has isolated the relative contribution of kangaroos to the development of any piospheric effect in the rangelands nor proven that kangaroos exhibit water-focused grazing patterns.

Rangeland kangaroos are dependent on free water (Dawson *et al*. 1975), and thus regularly drink at watering points especially when temperatures are hot and forage is dry. However, food is probably a more important determinant of kangaroo dispersion than water (Newsome 1965). This fact, together with the high mobility potential of kangaroos, means that kangaroo dependence on free water, does not necessarily equate to the development of a water-focused grazing pattern.

Some studies have shown increased concentrations of kangaroos around watering points either by excluding kangaroos from a watering point (e.g., Hacker and Freudenberger 1997) and watching kangaroo concentrations consequently increase in the area surrounding that watering point, or through demonstrating increased dung around watering points (e.g., Gibson 1995). Whilst informative, such studies do not reveal whether kangaroos exhibit water-focused grazing patterns. They only show that a certain number of kangaroos visit watering points to drink. In comparison, the conduct of line transects at times when kangaroos are actively grazing allows for direct visual determination of the spatial organization and density of kangaroos with reference to distance from a watering point, which more effectively determines whether kangaroos exhibit water-focused grazing patterns.

Kangaroo populations are often assumed to have increased since European settlement because of provision of artificial watering points and such ‘large’ populations of kangaroos are claimed to hinder rangeland regeneration after de-stocking (Norbury and Norbury 1993). Consequently, land managers are advised to remove artificial watering points wherever possible to control and reduce kangaroo numbers. Following publication of Landsberg *et al.*’s (1997) report many conservation agencies initiated programs of decommissioning artificial watering points in their reserves (e.g., Bennett 1997).

If kangaroos do exhibit water-focused grazing patterns, then not only may elevated kangaroo grazing pressure near artificial watering points have negative flow-on effects for other native biodiversity, such as decreased vegetative cover, but artificial watering point removal may also result in a shift in kangaroo grazing pressure to the area around the next available watering point. Graziers may oppose closure of artificial watering points on conservation reserves, believing that kangaroos will move onto their properties. Alternatively, in the absence of proof that kangaroos exhibit water-focused grazing patterns, which are leading to the development of piospheric effects and inhibiting rangeland regeneration, the reasons for leaving artificial watering points in the landscape, such as for use in nature-based tourism and community education, can be explored. Thus, for many reasons, it is imperative to examine kangaroo densities across a landscape with reference to distance from water.

This study aimed to determine whether kangaroos exhibit water-focused grazing patterns by examining kangaroo densities with reference to distance from water, kangaroo presence at open and closed watering points and vegetative biomass and diversity at varying distances from artificial watering points. If kangaroos do exhibit water-focused grazing patterns, then it was expected that:

- The density of kangaroos would be significantly higher in areas surrounding open watering points compared to areas surrounding closed watering points;
- The density of kangaroos would be higher in areas close to an open watering point than areas far from that same (and any other) watering point;
- The density of kangaroos around artificial watering points would increase with increasing temperature;
- Vegetative biomass and diversity of grazing-sensitive plants would decrease with increasing proximity to an artificial watering point; and
- Kangaroo presence would decrease following artificial watering point closure.

METHODS

Study species

Four species of kangaroos occur at the study site (*Macropus rufus*, *Macropus giganteus*, *Macropus fuliginosus* and *Macropus robustus*). Ninety-nine percent (n = 3602) of all ‘kangaroos’ observed during line transect counts were *M. rufus*. One *M. robustus* and 35 *M. giganteus* were recorded on line transects. No *M. fuliginosus* were recorded for line transects, but cannot be discounted from having contributed to counts of ‘kangaroo’ presence using the infrared sensor systems (see Trailmasters below).

Sturt National Park

Sturt National Park (330,000 ha) is situated in the far north-west corner of New South Wales (NSW), adjacent to the town of Tibooburra (29º 26’ S, 142º 1’ E). It forms the only true arid-zone national park in NSW (NSW National Parks and Wildlife Service 1996). The long-term mean annual rainfall for Tibooburra is 223 mm (1887-2000 Bureau of Meteorology), the mean annual temperature is 27.4ºC and maximum temperatures can be as high as 49ºC (Denny 1975). Sturt National Park was progressively formed from six pastoral leases in the early 1970s, and consequently, prior to declaration as a national park, had experienced over one hundred years of grazing by domestic stock, predominantly sheep. Eighty-four artificial watering points, comprising both earthen tanks and bores, were installed across the six properties.

Study sites

The position of past and present artificial watering points and all known natural waterholes was entered into the geographical information system package, Idrisi for Windows V2.0 (Clark Labs, Ma.), and a ‘distance function’ was performed. This showed the distance of every area in the park from a past or present water source. Six operating (open) tanks and three bores (closed approximately 20 years ago) were then selected (Fig. 1), from which a five km transect could be demarcated, such that each km along that transect represented one incremental km from that, and any other, past or present water source. Vegetation monitoring sites were set up along that transect adjacent to the watering point and at 1, 3 and 5 km distances (Fig. 2).

The study sites were located on the Olive Downs land system, which is comprised of gently undulating gibber plains. The areas have bare, stony brown desert loams along with stone-free deep brown clays. Areas of highly gypsic yellowish-brown calcareous loams and clay loams with mudstone outcrops also occur. This land system is often abutted by the 'Jump-Ups'. These mesa formations are outcrops of early Tertiary sedimentary rocks capped by silicified duricrust.

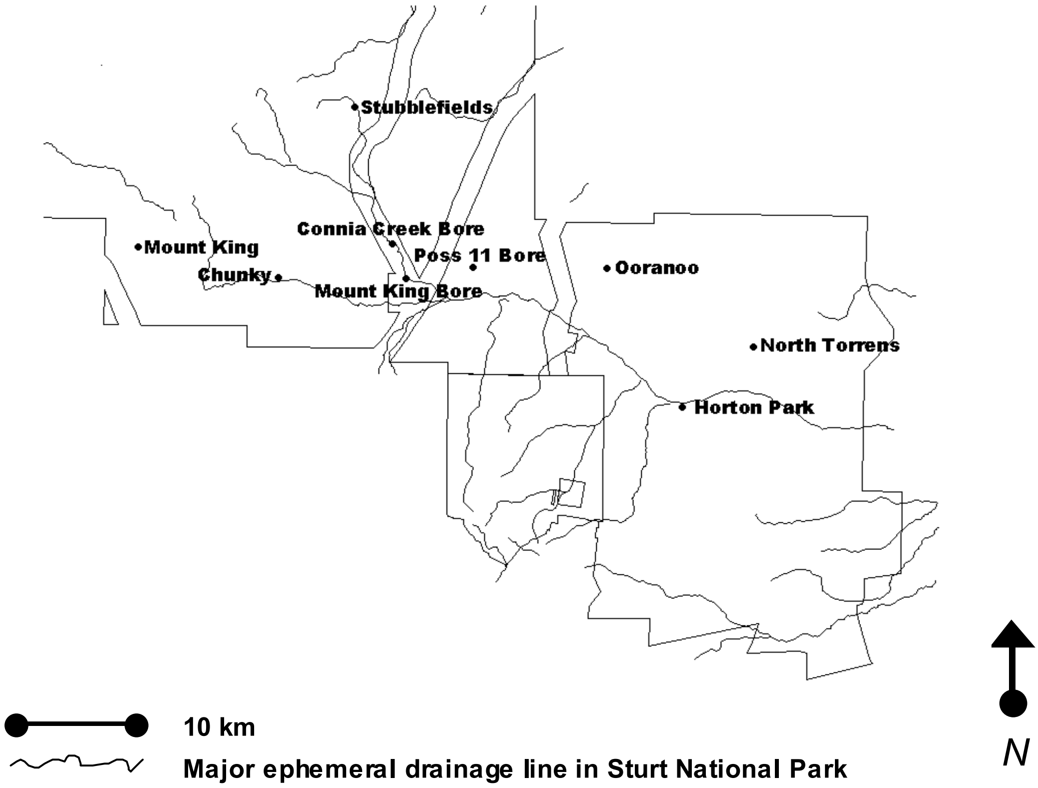

Fig. 1. Location of study sites and major ephemeral creek-lines in the eastern section of Sturt National Park. Watering points around which study sites were based are labelled. Mount King Bore, Poss 11 Bore and Connia Creek Bore are the 'closed' watering points and have not contained water for ~ 20 years. Mount King, Chunky, Ooranoo, Stubblefields, North Torrens and Horton Park are the open watering points (all earthern tanks, with the latter three being used for comparison with the closed watering points and for vegetation diversity and biomass analysis). Chunky tank was closed in the second year of the study, and had gone dry by January 2001.

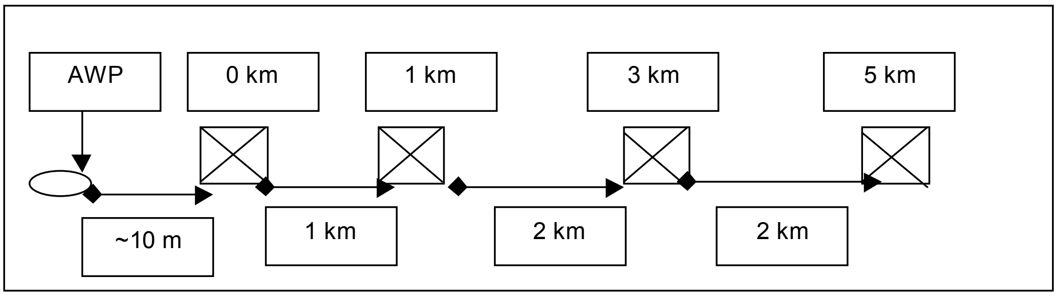

Fig. 2. Line transects were conducted by walking the five km transect from the artificial watering point (AWP) to the area five km distant from that, and any other, watering point. The layout of sites used for monitoring vegetational attributes along transect is shown. Sites were located 0 km, 1 km, 3 km and 5 km from any watering point. The fixed wheel point path for vegetation analysis at each site included both diagonals and all edges of each site, giving a total path of approximately 1.5 km.

The vegetation supported by the Olive Downs land system has undergone dramatic change since European settlement, whereas once the community would have been dominated by perennial *Atriplex* spp., it is now largely dominated by Mitchell grass *(Astrebla pectinata*) with numerous grasses and copperburrs (Milthorpe 1991). The area is mostly treeless except for ephemeral creeks, which are predominantly lined *by Eucalyptus camaldulensis*, *E. coolabah* and *Acacia cambagei*.

Line transects

Kangaroo densities were estimated using the line transect method. Line transects were conducted on foot over five km marked transects (see Fig. 2). The sighting angle and radial distance of each kangaroo observed was recorded. Sighting angle was measured with a Datascope (KVH Instruments, USA) and radial distance was estimated by eye, aided by marker posts at 100 m intervals along the transect as a reference distance. The observer's position along each transect was determined by a Global Positioning System receiver (Garmin GPS 45, USA). Dawn transects commenced at sunrise and dusk transects commenced 2 to 2.5 h before sunset. Transects generally required two hours for completion. Two dawn and two dusk transects were undertaken for each watering point for each season, except summer, for which pilot studies revealed that the high temperatures ensured kangaroos were resting, and thus less visible, throughout daylight hours. Thus summer transects would have produced biased estimates of kangaroo numbers with distance traversed.

Perpendicular distance was calculated from sighting angle and radial distance. Histograms of perpendicular distance indicated that reactive movement away from each transect was common, thus data were truncated at 100 m. The largest 5% of distances were also truncated to ensure better model fit. Replicated transects for each watering point for each season were pooled prior to analysis.

All line transects were analysed using the computer program DISTANCE V3.5 (Buckland *et al.* 1993). Data were treated as clusters. Pilot studies determined that the choice of model did not greatly change the estimated density but a Hazard Rate Reduction model with a cosine adjustment factor was ultimately selected because of consistently low Akaike's Information Criterion scores. The Hazard Rate Reduction model is also useful as it attempts to model the detection process, accounting for the fact that the observer has more time to see, and thus more probability of seeing, an object at large distances. Large viewing distances were common at the study sites given the gently rolling treeless plains.

Vegetative characteristics

The wheel point technique (Tidmarsh and Havegna 1955) was used to give a frequency estimate for each plant species of the percentage foliage cover, height and greenness (measured as a proportion of the total plant that was green) within each site. The frequency scores for the plant species were pooled into classes on the basis of similar growth form and height classes. Classes included copperburrs (mainly *Sclerolaena* spp. and some *Dissocarpus* spp.) flat-leafed chenopods (mainly *Atriplex* spp. and some *Chenopodium* and *Rhagodia* spp.), round-leafed chenopods (mainly *Maireana* spp. and some *Enchylaena* spp.), forbs (a diverse group of mainly ephemeral herbs) and grasses (Poaceae spp.) or life-cycle classes (i.e., perennial or annual). Categories also included bare ground. The scores were 'corrected' for sampling overestimation because of the diameter of the spoke versus the diameter of a real point using the correction estimates derived by Moss (1995) and these were converted to a percentage cover of the points taken per site. Using regression equations established by Moss and Croft (1999) for similar plant communities on Fowlers Gap (220 km south), the cover estimates were converted into a biomass estimate (kg dry matter ha^{-1}) for each plant class for each site. Wheel pointing was conducted over a 1.5 km fixed path at each of the four sites along each transect (see Fig. 2) over autumn, winter and spring.

Vegetative diversity was assessed for each site across all four seasons using timed searches. Two observers each searched half a site for half an hour (yielding a total search time of one hour per site). Species were either recorded, if their identity was certain, or collected for later identification. Botanists at the John T. Waterhouse Herbarium (University of NSW) identified voucher specimens. Each plant was assigned to a plant class similar to biomass estimates. Classes included copperburrs, flat-leafed chenopods, round-leafed chenopods, forbs (divided into prostrate and erect species), daisies (Asteraceae spp.), grasses and a category 'Malvaceae' which included combined *Abutilon* spp. and *Sida* spp.

Infrared Sensors

A Trailmaster (Model TM550: Goodson & Associates, USA) was placed approximately 100 m from each bank of three earthen tanks (Ooranoo, North Torrens and Chunky) (Fig. 1) perpendicular to a major kangaroo pad coming to that bank. Trailmasters are infrared sensors, which record the date and time that a warm-blooded animal movement is detected within the unit's area of sensitivity that included only the well-defined pad. The Trailmaster unit was set to the least sensitive setting, due to the large size of kangaroos and the high background temperatures, and with a delay to prevent double counting of a hopping kangaroo. Most daylight hours were excluded from analysis because local convection currents of hot air and emus (*Dromaius novaehollandiae*) produced false counts. Analysis was confined to the period from an hour before dusk to an hour after dawn each day (data on dawn and dusk time from the Bureau of Meteorology).

Temperature

Data on average, minimum and maximum daily temperatures were obtained from the Bureau of Meteorology's Tibooburra station.

RESULTS

Kangaroo density

Kangaroo densities around watering points were compared using the estimates from 'DISTANCE V3.5' (Buckland *et al.* 1993) for each watering point for each season.

Variation amongst individual watering points

The densities of kangaroos surrounding six open watering points (Fig. 3) were estimated over three seasonal samples (winter and spring 1999 and autumn 2000). Densities were similar at each watering point (Friedman test, $S = 7.38$, $df = 5$, $P = 0.19$) even though the Twelve Mile Creek naturally divides the westerly watering points (Chunky, Mount King, Stubblefields) from the easterly ones (Horton Park, Ooranoo, North Torrens). Thus kangaroos were relatively homogeneously distributed on the stony downs.

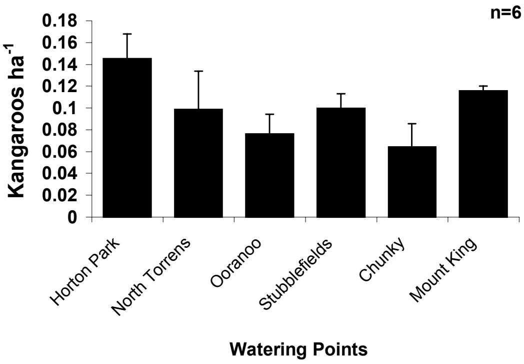

Fig. 3. The mean density of kangaroos (± SE) in areas surrounding each open watering point. Densities were derived from transects performed at each of six open watering points in winter and spring 1999 and autumn 2000.

Effect of watering point status (open or closed)

The densities of kangaroos surrounding three open and three closed watering points was compared across three seasonal samples (winter and spring 2000 and autumn 2001) (Table 1) by Two-Factor ANOVA. Kangaroo densities did not differ significantly ($F_{1,17} = 0.38$, $P = 0.55$) in areas surrounding closed and open watering points nor was there any seasonal effect on kangaroo density ($F_{2,17} = 0.55$, $P = 0.59$) or interaction between seasonality and watering point status (i.e., open or closed) ($F_{2,17} = 0.55$, $P = 0.59$).

Season	Closed watering point	Open watering point
Winter 2000	0.15±0.03	0.07±0.02
Spring 2000	0.22±0.07	0.06±0.02
Autumn 2001	0.18±0.13	0.25±0.22

Table 1. Kangaroo densities (mean ± standard error at closed and open watering points for winter and spring 2000 and autumn 2001.

Effect of distance from water

Kangaroo densities were estimated at 1-km intervals from both open and closed watering points and means across all seasons (winter and spring 2000 and autumn 2001) calculated for each watering point and used as sample values. Watering point status had no significant effect on kangaroo density ($F_{1,107}$ = 0.02, P = 0.88), but there was a trend for density to decrease with distance from the watering point ($F_{5,107}$ = 1.89, P = 0.10) (Fig. 4). This trend was non-linear and so contrast analysis was used to determine homogeneous sets within the distance categories. Densities were significantly greater 1 - 4 km from water than 5 - 6 km (t_{30} = 2.42, P = 0.02). However, there was an interaction with watering point status with no difference for open watering points (t_{12} = 1.3, P = 0.22) but significantly more kangaroos near a closed watering point than far from it (t_{12} = 2.6, P = 0.02). There was no interaction between season (autumn, winter, spring) and kangaroo densities at 1 km intervals from open watering points ($F_{10,53}$ = 0.56, P = 0.83).

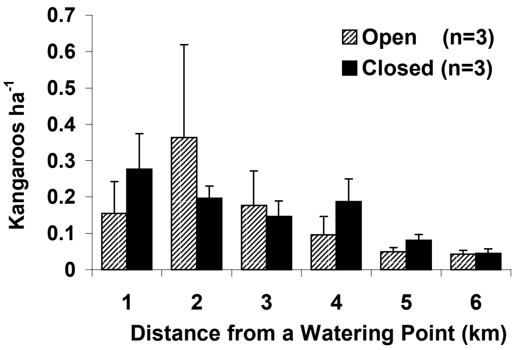

*Fig. 4.*The mean density of kangaroos (± SE) for increasing kilometre increments from watering points (e.g., '1' is the area up to 1 km from a watering point). Densities were derived from transects performed at three open and three closed watering points in winter and spring 2000 and autumn 2001.

Effect of distance from vegetated drainage channels

Shelter habitat rather than water availability may attract kangaroos to artificial watering points lying on major drainage lines. Therefore densities along transects (as outlined above) were reclassed into distance (to the nearest km) from a tree-lined drainage channel. Mean density (Y) significantly decreased with increasing distance (x) from a vegetated drainage channel (Y = 0.257 - 0.039x, R^2 = 0.89, $F_{1,5}$ = 31.43, P = 0.005) (Fig. 5).

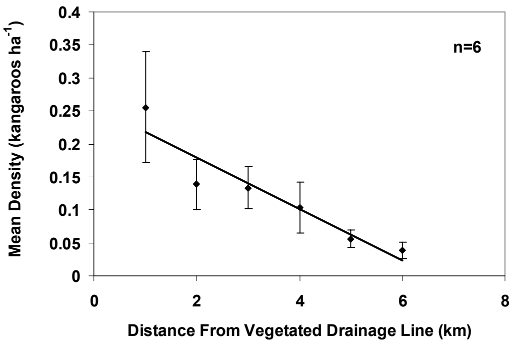

Fig 5. The mean density of kangaroos (± SE) at varying distances from vegetated drainage channels. Densities were derived from transects performed at each of three open and three closed watering points in winter and spring 2000 and autumn 2001 with transects separated into increasing km intervals from a watering point. For each watering point, each interval was then reclassed into approximate distance (to the nearest km of that interval from any tree-lined drainage channel).

Vegetative biomass at open watering points

The biomass of different plant categories (namely flat-leafed chenopods, copperburrs, grasses, forbs, annual plants and perennial plants) was compared using Two-Factor ANOVAs with seasonal replication (winter 1999, 2000; spring 1999, 2000 and autumn 2000, 2001) stratified across the sites at four distances from water (i.e., 0, 1, 3 and 5 km in Fig. 2) and each of three open watering points. Biomass differed significantly between the different open watering points, however such differences are not considered in this paper, which instead focuses on the distance effect (Table 2).

Flat-leafed chenopod biomass generally increased with increasing distance from water ($F_{3,71}$ = 11.33, P << 0.001). Likewise copperburr biomass generally increased with increasing distance from water ($F_{3,71}$ = 6.16, P = 0.001),. In contrast grass biomass decreased with increasing distance from water ($F_{3,71}$ = 5.00, P = 0.004) whereas there was no significant distance effect on forb biomass ($F_{3,71}$ = 0.45, P = 0.72). The biomass of perennial plants increased with increasing distance from water ($F_{3,71}$ = 4.54, P = 0.006) but the biomass of annual plants did not significantly between sites ($F_{3,71}$ = 0.76, P = 0.52).

There were significant differences in the amount of bare ground between sites ($F_{3,71}$ = 8.10, P << 0.001) (Fig. 6). Post-hoc tests using a One-Way ANOVA revealed that sites 5 km from any open watering point had significantly less bare ground than sites 0 and 1 km from any watering point ($F_{1,35}$ = 7.91, P = 0.008 and $F_{1,35}$ = 4.88, P = 0.03 respectively).

Plant Type	0 km	1 km	3 km	5 km
Flat-leafed chenopods	0.45±0.13^{B}	0.86±0.20^{A,B}	1.42±0.24^{A}	1.10±0.18^{A}
Copperburrs	13.09±2.09^{A}	13.40±1.81^{A}	13.57±1.77^{A}	20.76±2.05^{B}
Grass	0.77±0.23^{A}	0.81±0.23^{A}	0.46±0.15^{A}	0.06±0.02^{B}
Forbs	1.53±0.42^{A}	1.79±0.36^{A}	2.09±0.41^{A}	1.96±0.40^{A}
Perennial	15.24±2.69^{A}	16.27±2.09^{A}	17.49±2.25^{A}	24.04±2.17^{B}
Annual	1.14±0.29^{A}	0.80±0.16^{A}	0.82±0.19^{A}	0.85±0.19^{A}

Table 2. Plant biomass (dry g/m^2 (mean ± standard error for vegetation monitoring sites at varying distances from any open artificial watering point. $^{A, B}$ Where two cells in one row posses the same letter, the values are not significantly different as tested by a post-hoc One-Way ANOVA ($P > 0.05$).

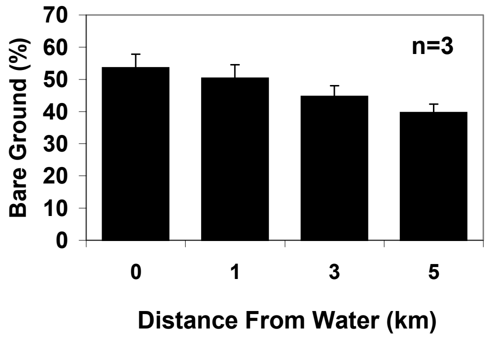

Fig. 6. The mean % of bare ground (± SE) at sites at varying distances from water. Data were derived from the mean of six season's data for three open watering points. Sites 5 km from any open watering point had significantly less bare ground than sites which were 0 km from any open watering point.

Vegetative diversity at open watering points

Total diversity and diversity of different plant categories (i.e., flat-leafed chenopods, copperburrs, grasses, daisies, round-leafed chenopods, Malvaceae and erect, prostrate and total forbs) was compared using Two-Factor ANOVAs with seasonal replication (winter 1999, 2000; spring 1999, 2000; summer 2000, 2001 and autumn 2000, 2001) stratified across the four sites (i.e., 0, 1, 3 and 5 km in Fig. 2) and three different open watering points (Table 3).

Total diversity differed significantly between sites ($F_{3,95}$ = 0.42, P = 0.02), generally peaking at sites 1 km from any open watering point. Likewise copperburr diversity ($F_{3,95}$ = 16.14, P << 0.001) and round-leafed chenopod ($F_{3,95}$ = 4.77, P = 0.004) generally peaked at sites 1 km from any open watering point. In contrast, flat-leafed Chenopod diversity generally decreased with increasing distance from water ($F_{3,95}$ = 2.68, P = 0.05). There was no significant distance/site effect for grass ($F_{3,95}$ = 2.18, P = 0.10), forb ($F_{3,95}$ = 0.41, P = 0.75, $F_{3,95}$ = 0.68, P = 0.56 and $F_{3,95}$ = 0.62, P = 0.60 for erect forbs, prostrate forbs and total forbs respectively), daisy ($F_{3,95}$ = 1.48, P = 0.22) or Malvaceae diversities ($F_{3,95}$ = 1.36, P = 0.26).

Effect of watering point status (open or recently closed) on kangaroo presence

Kangaroo passes, along each of four kangaroo pads at each of two open watering points (North Torrens and Ooranoo in Fig. 1), were examined using Trailmaster infrared sensors. Data were analysed for the period July 2000 to May 2001 excluding occasional short periods with no readings as equipment downtime (e.g., memory buffer full) and lack of kangaroo passes could not be reliably distinguished. The mean number of hourly kangaroo passes was calculated for each night for each pad and regressed against average daily temperature. The two watering points were considered independently of each other. At both watering points the mean number of hourly kangaroo passes per pad (Y) (Fig. 7a, b) was significantly positively correlated with average daily temperature (x) (Y = 0.68x- 2.79, R^2 = 0.22, $F_{1,539}$ = 148.12, P << 0.001 for Ooranoo tank and Y = 0.51x – 3.82, R^2 = 0.16, $F_{1,695}$ =132.62, P << 0.001 for North Torrens tank).

The mean number of hourly kangaroo passes per pad per night was also compared between one open (North Torrens tank) and one closed watering point (which had gone dry immediately before the start of the data set) (Chunky tank) (Fig. 8) using a z-test with the various nights for each tank forming paired replicates. There were significantly more passes per pad per night at the open watering point compared to the closed watering point ($Z_{1,73}$ = -6.21, P << 0.001). The mean number of hourly kangaroo passes per night was compared against average daily temperature for both the open and closed watering points using regression analysis. Kangaroo presence was significantly positively associated with increasing temperature for the open watering point (Y = 0.35x – 0.25, R^2 = 0.07, $F_{1,72}$ = 5.50, P = 0.02), but not for the closed watering point (Y = 0.62 + 0.07x, R^2 = 0.02, $F_{1,72}$ = 1.46, P = 0.23).

Plant Type	0 km	1 km	3 km	5 km
Total diversity	34.46±2.39^{A,B}	41.38±2.99^{A}	32.25±2.06^{A,B}	32.46±1.79^{B}
Flat-leafed chenopods	5.46±0.40^{A,B}	5.33±0.28^{A}	4.71±0.15^{B}	4.83±0.16^{A,B}
Copperburrs	6.65±0.26^{A}	7.46±0.40^{B}	4.92±0.25^{C}	6.17±0.32^{B}
Grass	4.29±0.50^{A}	4.67±0.70^{A}	4.17±0.57^{A,B}	2.92±0.44^{B}
Erect forbs	4.97±0.72^{A}	5.67±0.69^{A}	5.58±0.47^{A}	5.42±0.46^{A}
Prostrate forbs	3.18±0.44^{A}	4.21±0.63^{A}	3.71±0.54^{A}	3.5± 0.44^{A}
Daisies	3.14±0.60^{A}	4.96±0.70^{A}	3.92±0.54^{A}	4.21±0.62^{A}
Round-leafed chenopods	2.49±0.21^{A,B}	3.13±0.24^{A}	2.38±0.18^{B}	2.58±0.21^{A,B}
Malvaceae	1.79±0.32^{A}	2.42±0.35^{A}	2.00±0.30^{A}	2.13±0.28^{A}
Total Forbs	8.15±1.05^{A}	9.88±1.19^{A}	9.29±0.90^{A}	8.92±0.78^{A}

Table 3. Vegetative diversity (mean ± standard error for vegetation monitoring sites at varying distances from any open artificial watering point. $^{A, B, C}$ Where two cells in one row posses the same letter, the values are not significantly different as tested by a post-hoc One-Way ANOVA. ($P > 0.05$).

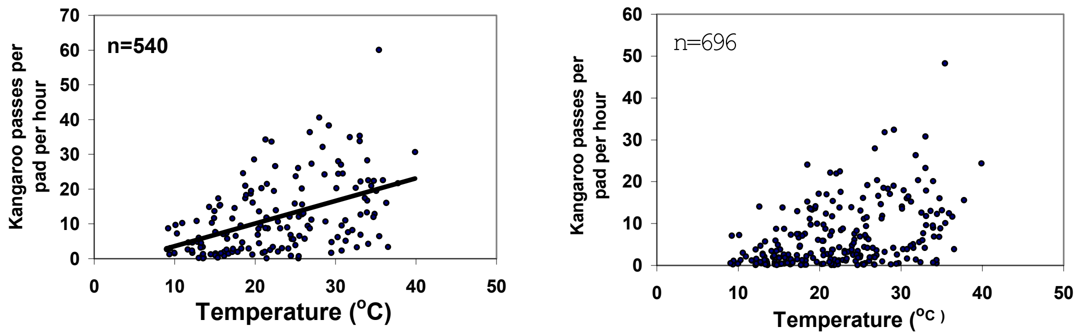

Fig. 7. Mean number of kangaroo passes per pad per hour compared to average daily temperature (°C). Data come from the four Trailmasters along each of four kangaroo pads at (a) Ooranoo tank and (b) North Torrens tank. Data were analysed for the period covering July 2000 to May 2001 excluding occasional small periods.

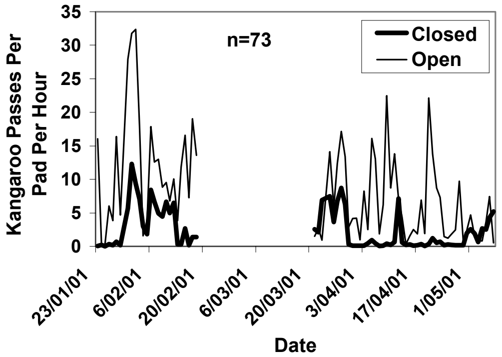

Fig. 8. Mean number of kangaroo passes per pad per hour at one open (North Torrens tank) and one recently closed (Chunky tank watering point). There were significantly more kangaroo passes at the open watering point.

DISCUSSION

Kangaroos on the stony downs in Sturt National Park showed no significant spatial or temporal variation in density with reference to six artificial watering points (tanks). Distance from water did not significantly influence kangaroo density. They were just as likely to be found in areas far from any open watering point as those near to one. Densities were significantly higher within 4 km of a closed watering point than 5 - 6 km. Obviously this was not a contemporary function of water availability. We postulate that habitat along major drainage channels is the determinant since kangaroo density significantly increased with increasing proximity to a vegetated drainage channel. Two of the three closed watering points and four of the six open watering points were located next to tree-lined ephemeral creeks whilst the other remaining closed watering point and one of the other open watering points were next to drainage lines offering small shrubs, such as *Chenopodium* and *Rhagodia spp.* Such drainage lines, because of their run-on position, may offer the first and last 'green pick' in an area, and they provide the only shaded resting locations on the relatively treeless downs.

In a study examining kangaroo distribution around sources of persistent food and water, Newsome (1965: 289) states, "…the kangaroos' distribution and changes in it are controlled primarily by their search for green herbage and shady trees". The trend for higher kangaroo densities near both open and closed watering points highlights the need for caution in interpreting this as an attraction to water. Other correlated factors may be at play in the landscape and so we need to search for these underlying factors (other than water availability) when examining kangaroo densities around watering points.

Kangaroo densities did not vary significantly between open and closed watering points between seasons, nor was there a seasonal interaction in the relationship between kangaroo density and distance from water. This was surprising as extremes of temperature and moisture availability were experienced over the study. Since kangaroos require more water for thermoregulation in warmer weather (Dawson *et al.* 1975), we expected kangaroos to concentrate their activity more intensively around permanent water in hotter weather. However, such patterns were not observed. Priddel (1987) found that the size of *M. rufus* home ranges was positively correlated with temperature, solar radiation and evaporation, suggesting that in warmer, drier times, kangaroos expand their home ranges and so spread their grazing pressure across a wider area, rather than intensively focusing it around one site such as water. Whilst conditions did become dry over our study, an extended severe drought was not experienced, and so further observations will be used to build a long-term picture of kangaroo densities around watering points.

Despite the fact that densities of kangaroos did not increase around open watering points in warmer weather, kangaroos visited these watering points (as measured by Trailmaster 'hits') more often with increasing temperature. Such a relationship held true across all seasons, suggesting summer does not create an aberration in the patterns witnessed. Such results suggest that kangaroos travel to drink and then travel back to perhaps relatively stable home ranges (*c.f.* Croft 1991) to take advantage of the best grazing and resting opportunities.

Such home ranges are not necessarily centred on permanent water. If we assume a rectangular range of 8 km^2 or less in a 1 km wide strip, then those individuals living beyond 4 km of a watering point centre their range at some distance from the watering point (Fig. 9). A home range of 8 km^2, is not unreasonable, as Croft (1991) found that in western NSW weekly cumulative movements of *M. rufus* were less than 6 km^2. Frith (1964) sighted a recognisable group of *M. rufus* eight times within a 5 km radius over nearly one year suggesting similar patterns. Denny (1980) found that of 697 *M. rufus* tagged in Sturt National Park, 60% of those sighted after release were at their original place of capture and in Kinchega National Park, Priddel (1987) found that of 22 *M. rufus* sighted 1000 or more days after capture, 17 were within 7 km of the original capture place and that the average *M. rufus* home range was 7.7 km^2. Recognisable individuals have been repeatedly sighted in Sturt National Park at the same location over the study period (pers. obs). Whilst kangaroo home ranges are not centred on an open watering point, it is likely, as stated by Denny (1980), that kangaroos use one or even several watering points that are located in their home range to satisfy water requirements. Examination of the spatial configuration of water in Sturt National Park (Fig. 10) revealed that, hypothetical (randomly placed) *M. rufus* home ranges of 8 km^2, in plains habitat, would indeed often take in one or even several watering points. Home ranges not encompassing an artificial watering point generally only narrowly miss such a resource meaning that excursions from such a home range would not need to be large to satisfy water requirements. Such a spatial configuration of watering points thus means that kangaroo home ranges can currently be spread across the landscape based on food and shelter preferences rather than a necessity to group around water.

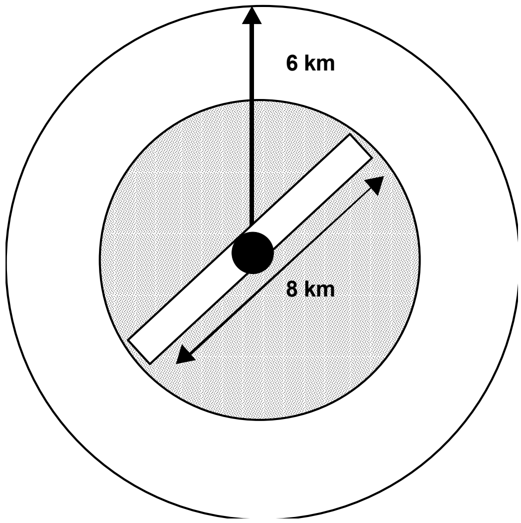

Fig. 9. The shaded area depicts the location of all kangaroos with home ranges (up to 8 km^2) centred around permanent water (assuming a maximum span of 8 km and a width of 1 km). The central solid circle reresents the artificial watering point. The clear rectangle represents a hypothetical kangaroo home-range (8 km^2) centred around the artificial watering point

Thus the effect of watering point closure on kangaroo grazing pressure is scale-dependent. Experimental closure of one watering point in Sturt National Park resulted in significantly less kangaroo presence than at an open watering point. Despite this, some kangaroos did remain present in the area. This kangaroo presence was not related to temperature, suggesting that kangaroos were not looking to drink but were simply present, probably because the area was part of their home range. Therefore turning off artificial watering points at a small scale (at a scale whereby kangaroos still have access to another watering point in or near their home range) may reduce the perceived number of kangaroos in an area (especially during the preferred drinking times of kangaroos) but probably will not reduce total grazing pressure in that area. Similarly, Freudenberger and Hacker (1997) found that water closure, at least over paddock sized treatment areas had no effect on kangaroo grazing intensity in that area.

Priddel (1987) showed that *M. rufus* make regular excursions between their feeding-resting and watering sites. These distances are negotiated with the high energy efficiency of moderate speed hopping relative to quadrupedal stock (Dawson and Taylor 1973). Even so questions remain as to how far and how frequently kangaroos will travel to reach water and such questions should be answered before watering point removal is undertaken at a large scale. Similarly, it is necessary to establish whether kangaroos will perish in existing home ranges should distances become too large for regular travel or whether home range shifts will occur. If the former then the timing and ethics of intentional water closure requires debate. If the latter then a gain for grazing-sensitive plants in one area may come at a cost of intensified grazing pressure at another.

The results of the density-distance relationship around watering points clearly suggest that kangaroos do not exhibit water-focused grazing patterns in Sturt National Park. The analysis of vegetative biomass and diversity around watering points was consistent with no contemporary water-focused grazing. The apparent sparseness of vegetation around artificial watering points is often assumed to be the result of current grazing pressure. However, by examining the relative biomass of different plant types, we were more accurately able to determine the processes operating. Many studies (e.g., Dawson *et al*. 1975; Barker 1987; Short 1987; Dawson and Ellis 1994; Landsberg and Stol 1996) have clearly identified the dietary preferences of sheep and kangaroos and thus the relative impacts of past and present herbivores can be differentiated. Such studies have generally shown that the preferred feed of red kangaroos is grass. Forbs, chenopod sub-shrubs and shrubs do, however, make up small proportions of their diet. Sheep are more variable in their diet, more readily switch between different feed types, and do so even when the biomass of other plants is still reasonably high (Short 1987). Whilst kangaroos always eat more grass than any other plant type, chenopods, shrubs or forbs may at times dominate the diet of sheep (Dawson *et al*. 1975; Dawson and Ellis 1994).

Examination of the different plant categories showed that whilst indeed there was more bare ground around watering points it was the flat-leafed chenopods which showed the most significant decrease in biomass with increasing proximity to a watering point. Such a relationship has been well demonstrated in areas grazed by sheep (e.g., Lange 1969; Andrew and Lange 1986). Dawson and Ellis (1994: 257) state that "…a decline of perennial shrubs in these arid-rangelands was considered probable because of the emphasis of sheep and rabbits on them in the dry times; the dominant chenopod shrubs do not survive persistent grazing" and thus it is most probable that the decrease in flat-leafed chenopod biomass is attributed to the impacts of past, rather than current grazing pressure. *Atriplex vesicaria*, the principal species in the study area, is most sensitive to defoliation amongst the perennial chenopods and may show recruitment only once every five years in a life of about 10 years (Graetz and Wilson 1984). The desert loams on which saltbush grow are also easily degraded (Johns *et al*. 1984) although clays are more resilient. Thus in the 30 years since sheep have been removed there has probably been an only limited recruitment opportunity from remnant shrubs and so insufficient time for full recovery, if any parent stock persisted on degraded soils.

The strongest evidence to suggest that kangaroos do not exhibit water-focused grazing patterns came from the fact that grass biomass, for at least three of the six open watering points, significantly increased with increasing proximity to a watering point. This favoured food type is not grazed out by an accumulation of kangaroos around water. Rather it is a consequence of hydrology and/or probable degradation of the vegetation community. The watering points are by design in run-on positions to capture run-off. The higher soil moisture may favour the establishment and persistence of grass. This is likely to interact with the competitive release of past grazing out of shrubs near water by stock leading to a 'sub-climax' community. In successionary studies, sub-climax communities are more diverse than the climax community, and indeed there was a trend across various plant types for sites close to the watering point (0 and 1 km) to have more diversity than sites far from the watering point (3 and 5 km). Such results suggest a slow, but steady recovery towards the climax community, which is dominated by *A. vesicaria*. Alternatively, it may simply be that

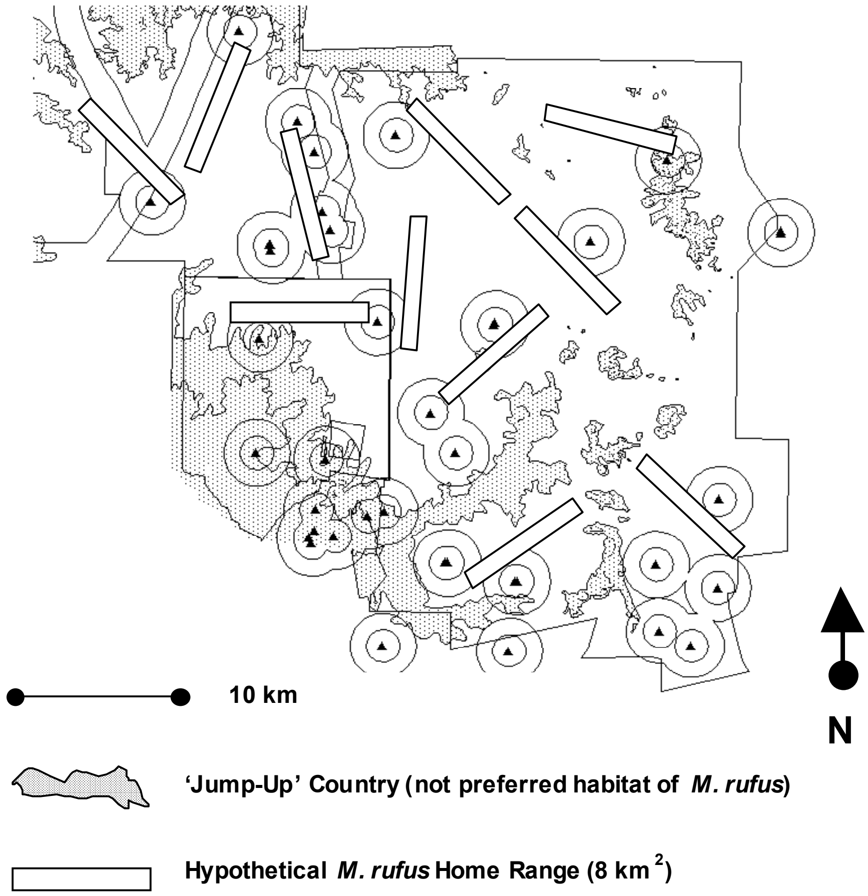

Fig. 10. Artificial watering points, hypothetical *M. rufus* home ranges and general topography in the eastern section of Sturt National Park. Circles surrounding artificial watering points delineate distances of one and two km from that watering point. Rectangles represent hypothetical (randomly placed, but excluding 'Jump-Up' country *M. rufus* home ranges (~8 km^2) and illustrate that home ranges may encompass one, or even several, water sources. Home ranges not encompassing an artificial watering point, generally only narrowly miss such a resource, indicating that home range excursions need not be large to satisfy water requirements.

sites situated next to the watering point in a run-on position favour a complex community of both perennial and annual plants supported by higher soil moisture and water-dispersed propagules. However, a simple hydrological effect does not explain the similar trends experienced for those sites 1 km fromany watering point. Our results therefore favour an explanation based on the residual effects of a stock-induced piosphere of at least 1-km radius and a degraded shrub community around water colonised by mainly annual grasses if vegetated at all.

Meissner and Facelli (1999) found that grazing exclusion of the order of a decade was not enough to reverse the changes produced by long-term grazing in a chenopod shrubland environment similar to that of Sturt National Park. It is probable that in the two and a half decades since the study area was declared as a national park, there has simply not been sufficient time to reverse the changes wrought by one hundred years of grazing by domestic stock, especially if the seed bank has been irrevocably depleted and soil structure lost around water.

Kangaroos are not currently exhibiting water-focused grazing patterns in Sturt National Park, and are instead more evenly distributed throughout the landscape. Whilst small-scale closure may not alter kangaroo grazing pressure, the impacts of large-scale watering point closure are still uncertain. Such large-scale closure must be considered against post-European loss of natural waterholes through sediment infilling and the impacts of closure for a whole suite of species, not just kangaroos. Given such uncertainties, and the possibility that the landscape may well be showing a slow, but steady recovery given the current distribution of artificial watering points, further research is strongly advised before large-scale closures are undertaken. Furthermore a careful historical assessment of changes in landscape function should be made so that contemporary land management is not seen as the cause of landscape dysfunction that has resulted from past malpractices.

ACKNOWLEDGMENTS

We thank all the personnel of the NSW National Parks and Wildlife Service, Tibooburra for their invaluable assistance and continued interest and support. In particular, we wish to thank the Area Manager, Lars Kogge, and Senior Field Supervisor, John Jackson. We also thank the many German volunteers and Dr Udo Ganslosser for organising these volunteers. The assistance of Jan de Naardi and Frank Hemmings (UNSW) was invaluable for identifying the many plant specimens. Funds were provided for this work by a federal government "Strategic Partnerships in Research and Training" (SPIRT) grant with the Western Directorate of NPWS and an Australian Postgraduate Award scholarship. We thank the Kangaroo Management Program, especially Joshua Gilroy, for financial and other support and the Tibooburra Area for significant in-kind support. This work is part of a Ph.D. by R. Montague-Drake entitled 'Strategic management of artificial watering points for biodiversity conservation and nature-based tourism in Sturt National Park'.

REFERENCES

ANDREW MH AND LANGE RT, 1986a. Development of a new piosphere in arid chenopod shrubland grazed by sheep. 1. Changes to the soil surface. *Australian Journal of Ecology* **11**: 395-409.

ANDREW MH AND LANGE RT, 1986b. Development of a new piosphere in arid chenopod shrubland grazed by sheep. 2. Changes to the vegetation. *Australian Journal of Ecology* **11**: 411-424.

BARKER RD, 1987. The diet of herbivores in sheep rangelands. Pp. 69-83 in *Kangaroos: their ecology and management in the sheep rangelands of Australia* ed by G. Caughley, N.C. Shepherd and J. Short. Cambridge University Press: Cambridge.

BENNETT B, 1997. Water points: where pastoralism and biodiversity meets. *Oikos* **92**: 10-14.

BUCKLAND ST, ANDERSON DR, BURNHAM KP AND LAAKE JL, 1993. *Distance sampling. Estimating abundance of biological populations*. Chapman and Hall: London.

CROFT DB, 1991. Home range of the red kangaroo *Macropus rufus*. *Journal of Arid Environments* **20**: 83-98.

DAWSON TJ, DENNY MJS, RUSSELL EM AND ELLIS B, 1975. Water usage and diet preferences of free ranging kangaroos, sheep and feral goats in the Australian arid zone during summer. *Journal of Zoology*, *London* **177**: 1-23.

DAWSON TJ AND ELLIS BA, 1994. Diets of mammalian herbivores in Australian arid shrublands: seasonal effects on overlap between red kangaroos, sheep and rabbits and on dietary niche breadths and electivities. *Journal of Arid Environments* **26**: 257-271.

DAWSON TJ AND TAYLOR CR, 1973. Energetic cost of locomotion in kangaroos. *Nature* **246**: 313-314.

DENNY M, 1975. Mammals of Sturt National Park, Tibooburra, New South Wales. *Australian Zoologist* **18**: 179-195.

DENNY M, 1980. *Red kangaroo arid zone studies. Final report.* Report to the Australian National Parks and Wildlife Service: Canberra.

FREUDENBERGER D AND HACKER RB, 1997. The effect of temporary closure of watering points on grazing intensity of red and grey kangaroos with related observations on feral goats. *Rangelands Journal* **19**: 157-165.

FRITH HJ, 1964. Mobility of the red kangaroo, *Megaleia rufa*. *CSIRO Wildlife Research* **9**: 1-19.

FUSCO M, HOLECHEK J, TEMBO A, DANIEL A AND CARDENAS AM, 1995. Grazing influences on watering point vegetation in the Chihuahuan desert. *Journal of Rangeland Management* **48**: 32-38.

GIBSON L, 1995. Concentration of eastern grey kangaroos (*Macropus giganteus*), red kangaroos (*Macropus rufus*) and wallaroos (*Macropus robustus*) in the vicinity of artificial waters and differences in artificial water usage. Pp. 75-84 in *Ecological research and management in the mulgalands - Conference Proceedings* ed by M.J. Page and T.S. Beutel. University of Queensland: Gatton.

GRAETZ RD AND WILSON AD, 1984. Saltbush and Bluebush. Pp. 209-222 in *Management of Australia's rangelands* ed by G.N. Harrington, A.D. Wilson and M.D. Young. CSIRO: Melbourne.

HACKER RB AND FREUDENBERGER D, 1997. The effect of short-term exclosure of watering points on the behaviour and harvesting efficiency of grey and red kangaroos. *Rangelands Journal* **19**: 145-156.

JELTSCH F, MILTON SJ, DEAN WR AND VAN ROOYEN N, 1997. Simulated pattern formation around artificial waterholes in the semi-arid Kalahari. *Journal of Vegetation Science* **8**: 177-178.

JOHNS GG, TONGWAY DJ AND PICKUP G, 1984. Land and water processes. Pp. 25-40 in *Management of Australia's rangelands* ed by G.N. Harrington, A.D. Wilson and M.D. Young. CSIRO: Melbourne.

LANDSBERG J AND STOL J, 1996. Spatial distribution of sheep, feral goats and kangaroos in woody rangeland paddocks. *Rangelands Journal* **18**: 270-291.

LANDSBERG J, JAMES CD, MORTON SR, HOBBS TR, STOL J, DREW A AND TONGWAY H, 1997. *The effects of artificial sources of water on rangeland biodiversity*. Final Report to the Biodiversity Convention and Strategy Section of the Biodiversity Group, Environment Australia: Canberra.

LANGE RT, 1969. The piosphere: sheep track and dung patterns. *Journal of Rangeland Management* **22**: 396-400.

MEISSNER RA AND FACELLI JM, 1999. Effects of sheep exclusion on the soil seed bank and annual vegetation in chenopod shrublands of South Australia. *Journal of Arid Environments* **42**: 117-128.

MILTHORPE PL, 1991. *Lands of the north-west corner of NSW*. Technical Report No. 12, Soil Conservation Service of NSW.

MOSS GL, 1995. Home range, grouping patterns and the mating system of the red kangaroo (*Macropus rufus*) in the arid zone. Ph.D. thesis, University of NSW, Sydney.

MOSS GL AND CROFT DB, 1999. Body condition of the red kangaroo (*Macropus rufus*) in arid Australia: The effect of environmental condition, sex and reproduction. *Australian Journal of Ecology* **24**: 97-109.

NAVIE SC, COWLEY RA AND ROGERS RW, 1996. The relationship between distance from water and the soil seedbank in a grazed semi-arid subtropical rangeland. *Australian Journal of Botany* **44**: 421-431.

NEWSOME AE, 1965. The distribution of red kangaroos, *Megaleia rufa* (Desmarest), about sources of persistent food and water in Central Australia. *Australian Journal of Zoology* **13**: 289-299.

NORBURY GL AND NORBURY DC, 1993. The distribution of red kangaroos in relation to range regeneration. *Rangelands Journal* **15**: 3-11.

NSW NATIONAL PARKS AND WILDLIFE SERVICE, 1996. *Sturt National Park, Plan of Management.* NSW National Parks and Wildlife Service: Hurstville.

OSBORN TG, WOOD JG AND PALTRIDGE TB, 1932. On the growth and reaction to grazing of the perennial saltbush (*Atriplex vesicarium*). An ecological study of the biotic factor. *Proceedings of the Linnaean Society of New South Wales* **57**: 377-402.

PRIDDEL D, 1987. The mobility and habitat utilization of kangaroos. Pp. 100-118 in *Kangaroos: their ecology and management in the sheep rangelands of Australia* ed by G. Caughley, N.C. Shepherd and J. Short. Cambridge University Press: Cambridge.

SHORT J, 1987. Factors affecting food intake of rangelands herbivores. Pp. 84-99 in *Kangaroos: their ecology and management in the sheep rangelands of Australia* ed by G. Caughley, N.C. Shepherd and J. Short. Cambridge University Press: Cambridge.

THRASH I, 1997. Infiltration rate around drinking troughs in the Kruger National Park, South Africa. *Journal of Arid Environments* **35**: 617-625.

THRASH I, 1998a. Impact of large herbivores at artificial watering points compared to that at natural watering points in Kruger National Park, South Africa. *Journal of Arid Environments* **38**: 315-324.

THRASH I, 1998b. Impact of water provision on herbaceous vegetation in Kruger National Park, South Africa. *Journal of Arid Environments* **38**: 437-450.

THRASH I, THERON GK AND BOTHMA JDP, 1995. Dry season herbivore densities around drinking troughs in the Kruger National Park. *Journal of Arid Environments* **29**: 213-219.

TIDMARSH GEM AND HAVEGNA CM, 1955. The wheel point method of survey and measurement of semi-open grasslands and karoo vegetation in South Africa. *Botanical Survey South African Memoirs* **29**: 1-49.

TOLSMA DJ, ERNST WHO AND VERWEY RA, 1987. Nutrients in soil and vegetation around two artificial waterpoints in eastern Botswana. *Journal of Applied Ecology* **24**: 991-1000.

VALENTINE KA, 1947. Distance from water as a factor in grazing capacity of rangeland. *Journal of Forestry* 749-754.