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Artificial watering points are focal points for activity by an invasive herbivore but not native herbivores in conservation reserves in arid Australia

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Abstract The spatial configuration of landscapes can be an important factor influencing the dispersal, distribution and abundance of invasive animals and consequently their impacts. In arid landscapes worldwide, humans have increased the availability of surface water by creating artificial water points (AWP) for livestock and wildlife viewing. The resource subsidy provided by AWP can influence the functioning of arid ecosystems by affecting the density, distribution and activity of water-dependent native and invasive animals and thus facilitate their trophic and competitive interactions. In this study, we used dung count indices to investigate the activity of an invasive herbivore, feral goats (*Capra hircus*), and native herbivores (kangaroos, *Macropus* spp.) in relation to surface water and habitat type in three conservation reserves located in arid Australia. Activity of feral goats showed a strong preference for rocky ranges habitat and decreased with distance from water. Kangaroo activity showed a strong preference for mulga woodlands, but was

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independent of distance from water. Our results suggest that artificial water points may exacerbate the impacts of feral goats by functioning as focal points for their activity. Restricting goats' access to water by closure of water points or strategic fencing, such that the mean distance to water across the landscape is increased, may be an effective strategy to reduce goat grazing impacts in conservation reserves where natural sources of water are scarce but is unlikely to affect the grazing patterns of kangaroos. Our study suggests that there is scope to control populations of water-dependent invasive vertebrates in arid regions by restricting their access to artificial water points.

Keywords AWP · Grazing · Kangaroo · Invasive species · Pest animal management · Resource subsidy · Dung count

Introduction

Reducing the economic and ecological impacts of invasive species is a key goal of invasive species management (Olson 2006), but requires an understanding of factors that influence the spread of invaders and their abundance (Gormley et al. 2011). The spatial configuration of landscapes is an important factor influencing the dispersal, distribution and abundance of invasive species (With 2002). For example, the presence of suitable habitat corridors can focus the movements and dispersal of invaders into some habitats, but not others (Hulme 2009). Likewise, the patchy distribution of resources or habitats preferred by invaders can result in invasive species having spatially structured populations and activity patterns (With 2002; Letnic et al. 2014).

In arid regions, many vertebrates rely upon the existence of refuge habitats where they can obtain reliable access to resources such as food and water (Chamaille-Jammes et al. 2007; Smit et al. 2007; Webb et al. 2014). In the case of invasive vertebrates, such habitats can function as invasion hubs from which the populations of invasive species expand during periods of favourable climatic conditions (Letnic et al. 2014). Once invasion hubs are identified, targeted control efforts at such sites can be an effective way of containing the spread of the invader (Moody and Mack 1988; Florance et al. 2011).

Humans' increased ability to capture and redistribute scarce water has been a key-driver of economic growth in arid regions of the Earth. Livestock grazing, wildlife harvesting and wildlife viewing are important economic activities in rangelands (Packer et al. 2011; Howery et al. 1998; Forsyth et al. 2009), but are constrained by scarcity of surface water because most species of livestock and many wildlife species must drink regularly (James et al. 1999). To increase the number of livestock that can be grazed in arid-lands, pastoralists have created artificial water points (AWP) where water is provided to animals via troughs or earthen dams (James et al. 1999; Dougill et al. 1999; Perkins and Thomas 1993).

By providing a reliable water source, AWP may subsidize some wildlife species with an essential resource for their metabolic homeostasis, growth and reproductive success, and allow "water-dependent" animal species to persist in numbers that would not otherwise be attainable (Florance et al. 2011). For example, the provision of AWP in arid environments has been linked to range expansions and/or population increases of water birds and wild herbivorous mammals (Dawson et al. 2006; James et al. 1999) and has provided previously unavailable habitat for water-dependent organisms (Di Tomaso 2000; Moleele and Perkins 1988). Thus AWP can potentially influence the functioning of arid ecosystems by facilitating the trophic and competitive interactions of water-dependent species (Chamaille-Jammes et al. 2007; Letnic et al. 2014).

In arid landscapes, the foraging patterns of large herbivores reflect a trade-off between obtaining forage and water (Smit et al. 2007). In general, larger herbivores and browsers are more dependent on free water than smaller herbivores and grazers (Redfern et al. 2003). AWP frequently serve as focal points for the activity of livestock and other large herbivores (Lange 1969), and consequently, the landscapes surrounding AWP are prone to overgrazing by over-abundant larger herbivores (Perkins and Thomas 1993; Landsberg et al. 2003). The effect of artificial waters on biodiversity is of particular concern in semi-arid regions of Australia where wild herbivore populations are not effectively regulated by humans or predators such as dingoes (Letnic et al. 2012; Forsyth et al. 2009; Pople et al. 2000). In these areas there is an inherent risk of overgrazing through the combined effects of wild herbivores and livestock (Choquenot and Forsyth 2013; Ludwig et al. 1997; Letnic 2000).

Because of the potential for overgrazing in areas near water, the provision of AWP in arid conservation reserves is a contentious issue for conservation managers (Redfern et al. 2005). This is the case in the arid lands of Australia where sources of natural permanent water are scarce (Fensham and Fairfax 2008). Most conservation reserves in arid Australia were previously pastoral properties used for grazing sheep (*Ovis aries*) or cattle (*Bos taurus*) and thus usually possess many AWP. These conservation reserves are typically managed so that they can benefit biodiversity conservation and provide public recreation. The provision and ongoing maintenance of AWP is frequently a problematic issue for reserve managers because overgrazing in their vicinity has been identified as a driver of biodiversity loss (James et al. 1999). However, AWP are also often perceived to be important foci for wildlife species (Smit et al. 2007; Redfern et al. 2005). Thus managers may be faced with making a decision to either maintain or close artificial watering points, but with little or no quantitative information to assist those decisions.

The major large herbivores in conservation reserves in arid Australia are kangaroos, feral goats, feral horses (*Equus caballus*), feral donkeys (*Equus asinus*) and feral camels (*Camelus dromedarius*) (Fensham and Fairfax 2008). All of these animals frequently drink surface water, but little information is available on how their patterns of activity and grazing reflect the distribution of water in conservation reserves where livestock have been removed (see Fukuda et al. 2009; Russell et al. 2011). In the case of feral goats they need to drink daily when temperatures exceed 38 °C (Norbury 1993). If habitat use by feral goats is focal around AWP, exclusion of feral goats from AWP could potentially be used as a management strategy to reduce their activity and hence grazing impacts in arid conservation reserves of Australia.

In this study we investigate the habitat use of feral goats and kangaroos in relation to landscape type and sources of water in three semi-arid and arid conservation reserves. Our specific aims were firstly to determine if the activity of feral goats, and native herbivores (kangaroos) decreased with distance from water. Because our analyses indicated that goat activity decreased with distance from water our second aim was to quantify how the removal of AWP would change the percentage of each reserve's area in categories defined by distance to water and predict how water closure would alter the activity patterns of goats.

Study sites

The study was conducted within three conservation reserves located in western New South Wales (Fig. 1). The study areas were, Mutawintji National Park, the Peery Section of Paroo-Darling National Park and Nocoleche Nature Reserve. The climate of the region is semi-arid. Rainfall in the region is erratic and may occur throughout the year. Temperatures are high in summer and mild in winter with average daily maximum of 35 °C in January and 17 °C in July and average daily minimum of 21 °C in January and 4 °C in July (Australian Bureau of Meteorology: http://www.bom.gov.au/). Kangaroos and feral goats are abundant in western NSW (Pople et al. 1996; Melville et al. 2008). Rabbits (*Oryctolagus cuniculus*) are present in each of the study areas but occur in relatively low numbers.

Mutawintji National Park covers 747 km^2. Mean annual rainfall of Mutawinjti National Park is approximately 254 mm (Australian Bureau of Meteorology: http://www.bom.gov.au/). The national park contains three major habitat types, rocky ranges, mulga woodlands and stony downs (Fig. 4a). Vegetation of the Rocky Ranges is dominated by *Acacia aneura* and *A. tetragonaphylla* with an understorey dominated by *Aristida contorta* and *Maireana tormentosa*. The vegetation of the low-land stony downs habitat is dominated by *Atriplex vesicaria*, *Maireana sedifolia* and *A. aneura*. Mulga woodlands occur on plains of sandy red-soils dominated by woody-shrubs including *A. aneura*, *Dodonaea viscosa* and *Eremophila longifolia*.

The Peery Lakes Section of Paroo-Darling National Park covers 921 km^2 (NPWS 2009). Mean annual rainfall of Paroo-Darling National Park is approximately 248 mm (Australian Bureau of Meteorology: http://www.bom.gov.au/). Paroo-Darling NP contains three major range-types, stony hills with mulga, red soil plains and lakes and swamps associated with the Paroo River floodplain (Fig. 5a) (Walker 1991). The vegetation consists predominantly of open and shrubby "mulga" woodlands dominated by mulga *A. aneura*, red box *Eucalyptus intertexta,* leopardwood *Flindersia maculosa*, black oak *Casuarina pauper*, whitewood *Atalaya hemiglauca* and beefwood *Grevillea striata*, with gallery woodlands along creeklines and around Peery and Poloka lakes dominated by river red gum *Eucalyptus camaldulensis,* black box *Eucalyptus largiflorens,* bimble box *Eucalypts populnea* spp. *bimble,* Yapunyah *Eucalyptus ochrophloia* and river cooba *Acacia stenophylla* (Westbrooke et al. 2003).

Nocoleche Nature Reserve covers 760 km^2. Mean annual rainfall of Nocoleche Nature Reserve is approximately 261 mm (Australian Bureau of Meteorology: http://www.bom.gov.au/). The nature reserve contains three major range types, lakes and swamps associated with the Paroo River and its floodplain, mulga woodlands and stony downs (Fig. 6a) (Walker 1991). Lakes and Swamps comprise seasonally inundated wetlands on cracking clay soils with vegetation dominated by *Muehlenbeckia florulenta*, *E. ochrophloia* and *Eucalyptus coolibah*. Mulga woodlands occur on sandy red-soils dominated by woody-shrubs including *A. aneura*, *D. viscosa* and *E. longifolia*. There are also small areas of stony downs. This habitat type comprises areas of stony soils that support chenopod shrublands dominated by *M. sedifolia* and the shrubs *A. hemiglauca* and *A. aneura*.

Methods

Dung counts are a correlate of herbivore activity and abundance (Landsberg and Stol 1996; Forsyth et al. 2007; Forsyth in press) and were used in this study to assess the habitat preference of feral goats and kangaroos. An index of herbivore activity was determined by counting all fresh black dung along 100 m × 2 m belt transects. All fresh black dung within the transect was identified to species according to Landsberg et al. (1994). Dung transects were conducted adjacent to roads and were conducted at survey points located every 3 km from a random starting point in Nocoeleche NR and Mutawintji NP. In the case

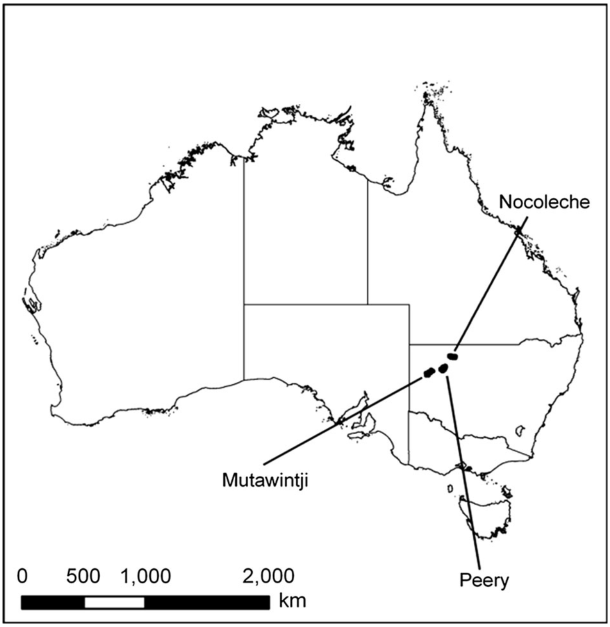

Fig. 1 Map of Australia showing the locations of the three study sites, Mutawintji National Park, the Peery Lakes section of Paroo Darling National Park and Nocoleche Nature Reserve within Australia. The *lines* represent state boundaries. The study was conducted in New South Wales

of Paroo-Darling NP, survey points were situated at 1 km intervals from a random starting point. The sampling strategy of each reserve was designed to provide complete coverage of the roads within each reserve and ensured that some sites were sampled near water, including water on neighbouring properties, and other sites away from water and in the full range of habitats within each reserve. At each survey point between 1 and 3 dung transects were undertaken. An index of herbivore activity was calculated as the mean number of dung groups observed at each survey point for both feral goats and kangaroo. Dung counts were then rounded to the nearest integer. A dung group was defined as a single depositional event, where pellets of the same size, species and freshness occurred within a distinct group. Red kangaroo *Macropus rufus*, eastern grey kangaroo *M. giganteus*, western grey kangaroo *M. fuliginosus* and euro *M. robustus* dung could not be reliably differentiated and so the results for these four species were pooled. For each survey point, the coordinates were recorded using a global positioning system (GPS). Surveys were conducted in June 2006, March 2007 and October 2007 at Nocoleche, Mutawintji and Paroo-Darling, respectively. The conditions were dry preceding each sampling period and thus there was little surface water present except for artificial water points and major water-courses.

We mapped the distribution of water available for drinking by goats and kangaroos that were located within each reserve and on neighbouring properties within 15 km of the boundary of each reserve. The coordinates of all permanent water features (natural and AWP) indicated on 1:250,000 maps published by the Australian Government (Geoscience Australia, 2005) were entered into a geographic information system (ArcGis 9.0). At the time of the dung surveys, we conducted on-ground surveys of the reserves and neighbouring properties to verify the presence of the water sources indicated on maps and also added the locations of water sources that were not indicated on maps and removed those that were not present or did not contain water at the time of the sampling. Using this information, we created a 100 × 100 m grid of each reserve and surrounding properties and then used the Spatial Analyst extension of ArcGIS to calculate the distance from water of each grid cell. We used the package Hawth's tools to intersect GIS layers for the distance from water grid and dung survey locations and thus calculate the distance from water of each dung survey point within each conservation reserve. We used Hawth's tools to intersect a GIS surface for rangetype using the classification of Walker (1991) with each dung survey point and thus allocate the rangetype for each dung survey point.

Analysis of the distribution of herbivore dung

Preliminary examination of scatterplots suggested that the relationships between distances to water and the quantity of goat and kangaroo dung observed on the survey transects were non-linear. Consequently, we used Generalized Additive Mixed Models (GAMMs) to assess the relationships between distances to water and goat or kangaroo dung density. A smoother (from penalized regression splines) was fitted to the effect of distance from water and, to investigate habitat effects, habitat was added as a fixed factor. The survey location (Mutawinjti NP, Paroo Darling NP, Nocoleche NR) was a random factor in the analysis (random intercept). To best model the over-dispersed dung count data, the negative binomial distribution, with a log-link function was used. Plots of fitted values against residuals were inspected to confirm model assumptions. Examination of variogram plots of the residuals indicated no spatial autocorrelation, so it was not incorporated into our models (Zuur et al. 2009). Wald Tests were used to test the fixed factors, Zuur et al. 2009 type and distance from water in the descriptive models of feral goat and kangaroo dispersion. Analyses were performed in R 2.10.1 (R Development Core Team 2009), with the package mgcv 1.6.1 (Wood 2004).

Proximity to water with and without artificial water points

Our GAMM models (see results below) showed that goat activity declined with distance from water. The scatterplots of goat dung counts vs distance to water (Fig. 2) showed that the highest values for goat dung occurred within 3 km of water within each habitat type. Consequently, to investigate the effect that removing artificial waters from the 3 study areas would have on the area of land available for grazing by feral goats, we quantified the area within 3 km of water within each conservation reserve at the time of the study. We then quantified the area within 3 km of water that would be available if all the AWP were removed. The area of land surrounding waterpoints before and after closure was calculated by placing buffers around individual waterpoint locations at 1–5 km distances (see Figs. 4, 5, and 6) using ArcGIS 9.3 (ESRI 2008).

The predictive GAMM for the abundance of goat faecal pellets was applied to each 100 m × 100 m grid cell in each of our study areas to produce a map of the predicted abundance of goat faecal pellets. We then simulated the effect of removing AWP on the abundance of goat faecal pellets by applying the GAMM model to each 100 m × 100 m grid cell in each of our study areas using a distance from water surface from which AWP had been removed within each conservation reserve. We compared the results obtained for the before AWP removal and after AWP removal goat dung abundance surfaces by calculating the difference in predicted goat dung abundance for the post AWP removal and before water removal goat dung abundance surfaces.

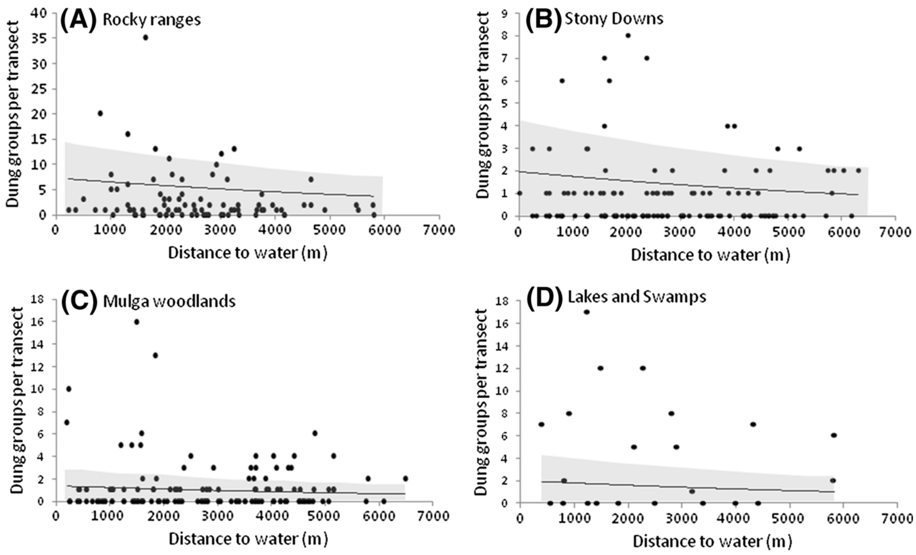

Fig. 2 The abundance of goat dung in relation to distance from water at **a** rocky ranges habitat, **b** stony downs habitat, **c** red soil habitat and **d** lakes and swamps. The *smoother lines* in each panel represent the fitted relationship between goat dung and distance from water in each habitat type from the generalized additive mixed model. The *shaded region* in each graph shows the 95 % confidence region of the generalized additive mixed model

Results

Distribution of herbivore dung

As evidenced by the fitted GAMM line in Fig. 2, the abundance of feral goat dung differed significantly between habitats ($F = 19.68$, $P \ll 0.001$, $df = 3$) and was highest in rocky range habitat, followed by stony downs (Fig. 2; Table 1). Rocky range habitat was not present at Nocoleche NR where goats made extensive use of riverine woodlands. In comparison to other habitats, goat dung abundance was relatively low in mulga woodlands. The abundance of feral goat dung was negatively correlated with distance to water (Fig. 2; Table 1). The highest abundances of goat dung occurred within 3 km of water in each habitat type (Fig. 2).

The abundance of kangaroo dung differed between habitat ($F = 9.02$, $P \ll 0.001$, $df = 3$), but did not significantly differ with distance to water (Table 2). The abundance of kangaroo dung was highest in mulga woodland habitat (Fig. 3; Table 2).

Proximity to water with and without artificial water points and effect of removing AWP on the predicted abundance of goat dung

Prior to simulated AWP removal, 51.36, 47.53 and 33 % of Mutawintji NP, Paroo Darling NP and Nocoleche NR occurred within 3 km of water (Figs. 4b, 5b, 6b). Permanent waters in each of the study areas are few as evidenced by the maps showing the location of water after the removal of AWP (Figs. 4c, 5c and 6c). Removal of AWP would substantially reduce the areas of each reserve within 3 km of water at Mutawintji NP and Paroo Darling

Table 1 Model parameter estimates for fitted model ($R^2 = 0.0361$) predicting the relationship between the abundance of goat dung with habitat type and distance from water

Model term	Parameter	SE	df	*t* value	*P*
Intercept	0.385	0.606	375	0.635	0.526
Rocky ranges	1.292	0.396	375	3.266	0.001
Mulga woodlands	−0.379	0.358	375	−1.059	0.290
Stony downs	−0.025	0.389	375	−0.066	0.948
Water	−0.173	0.0856	375	−2.022	0.044

Table 2 Model parameter estimates for fitted model ($R^2 = 0.0681$) predicting the relationship between the abundance of kangaroo dung with habitat type and distance from water

Model term	Parameter	SE	df	*t* value	*P*
Intercept	0.867	0.319	375	2.72	0.007
Rocky ranges	0.768	0.271	375	2.832	0.005
Mulga woodlands	1.065	0.248	375	4.291	<0.001
Stony downs	0.619	0.261	375	2.375	0.018
Water	−0.002	0.052	375	−0.031	0.975

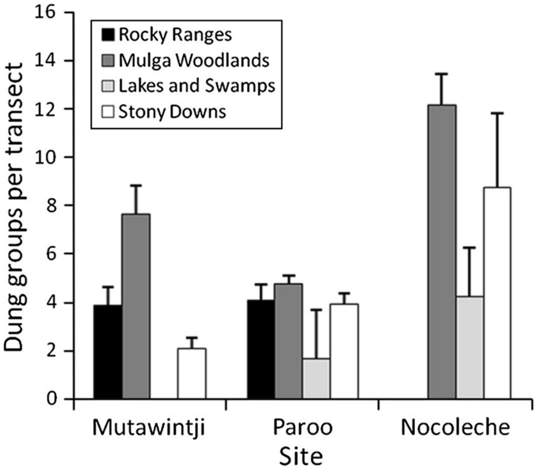

Fig. 3 The mean abundance of kangaroo dung in relation to habitat type in each conservation reserve. The *error bars* represent +1 standard error

NP to 17.87 and 9.69 %, respectively (Figs. 4c, 5c). However, at Nocoleche NR, closure of AWP would only reduce the area of the reserve within 3 km of permanent water from 33 to 30 %. The reason for this is that the channels of the Paroo River bisect the reserve and contain many permanent natural water-holes (Fig. 6c).

Comparison of the predicted abundance of goat faecal pellets in the 100 × 100 m grid cells for each reserve before and after AWP removal revealed that closure of AWP would on average reduce the abundance of goat dung by 20.1 % in Mutawintji NP (with AWP, mean = 3.68 dung groups per transect, SD = 1.68; after simulated removal, mean = 2.94 dung groups per transect, SD = 1.6) and 22.8 % in Paroo DarlingNP (with AWP, mean = 2.06 dung groups per transect, SD = 1.68; after simulated removal, mean = 1.59 dung groups per transect, SD = 1.47). However, AWP removal was only predicted to reduce the abundance of goat dung within the 100 m × 100 m grid cells at Nocleche NR

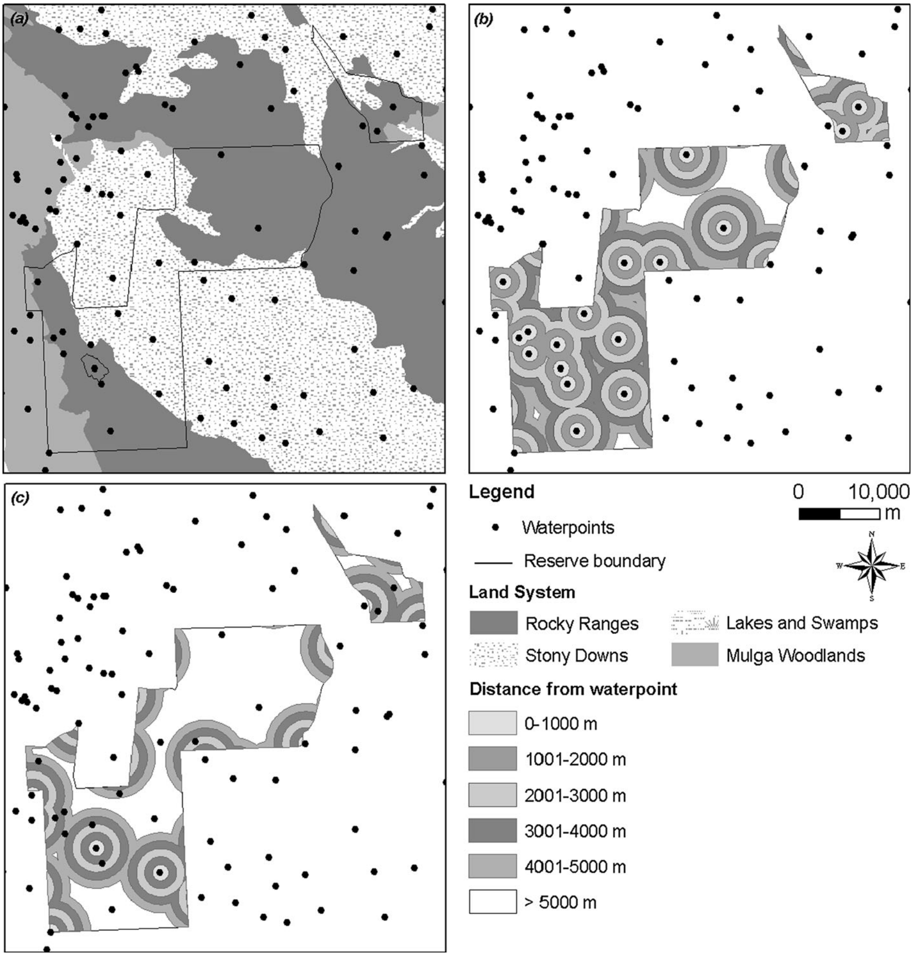

Fig. 4 **a** The distribution of artificial waters and major habitat types within and around Mutawintji National Park. **b** The proximity to permanent water of the landscape at Mutawintji. **c** The simulated proximity to permanent water of the landscape at Mutawintji NP following the closure of AWP within the reserve

by 1.9 % (with AWP, mean = 1.01 dung groups per transect, SD = 0.45; after simulated removal, mean = 0.99 dung groups per transect, SD = 0.46). In Mutawintji NP and Paroo Darling NP the simulated effect of removal of AWP was greatest in rocky range habitat in areas distant from AWP located on surrounding pastoral properties (Fig. 7).

Discussion

Responses of herbivores to habitat type and artificial water

Our study shows how the provision of a resource subsidy by humans can influence the distribution of an invasive ungulate. From dung abundance indices, it was apparent that

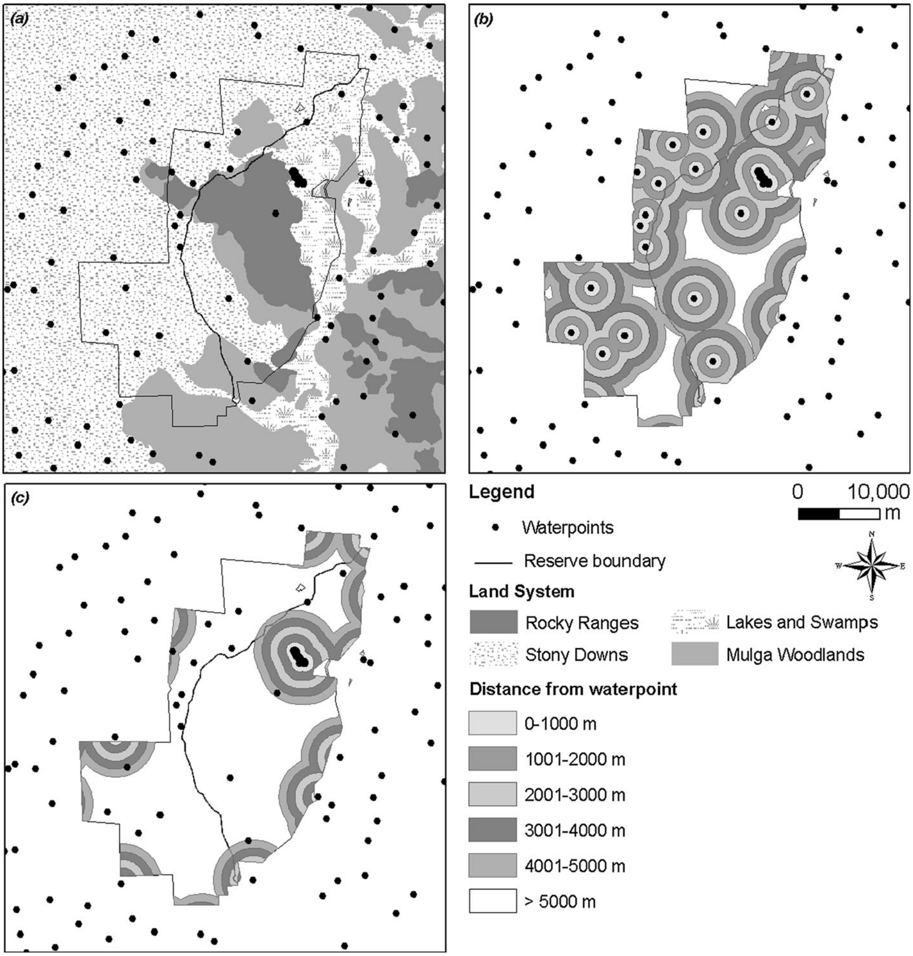

Fig. 5 **a** The distribution of artificial waters and major habitat types within and around Paroo-Darling National Park. **b** The proximity to permanent water of the landscape at Paroo-Darling National Park. **c** The simulated proximity to permanent water of the landscape at Paroo-Darling National Park following the closure of AWP within the reserve

feral goats and kangaroos used different habitat types and showed markedly different responses to the presence of water. Goats showed a strong preference for rocky range habitats. Goat activity decreased with distance from water. Kangaroos on the other hand generally preferred flatter mulga woodland habitats situated on loamy "red soils" and showed no response to water.

Our results were consistent with previous studies of the abundance and habitat-use patterns of kangaroos, which have indicated that the abundances of kangaroos at arid sites and the habitat utilization patterns of kangaroos did not reflect the availability of surface water (Fukuda et al. 2009; Montague-Drake and Croft 2004; Letnic and Crowther 2013). Previous studies suggest that the patterns of habitat use by arid zone kangaroos are dictated primarily by the availability of forage and shade (Fukuda et al. 2009; Montague-Drake and Croft 2004; Newsome 1965). However, we make no conclusions about the activity patterns

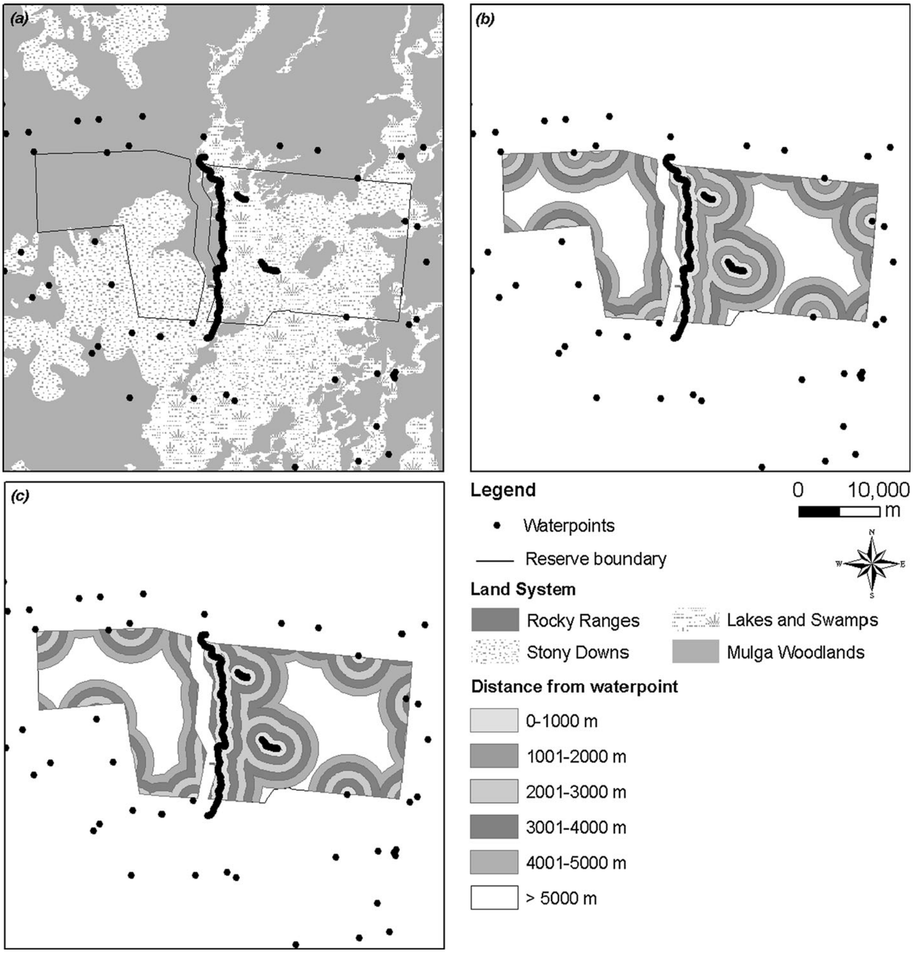

Fig. 6 **a** The distribution of artificial waters and major habitat types within and around Nocoleche Nature Reserve. **b** The proximity to permanent water of the landscape at Nocoleche Nature Reserve. **c** The simulated proximity to permanent water of the landscape at Nocoleche Nature Reserve following the closure of AWP within the reserve

of the different macropods because we could not differentiate the dung of the four kangaroo species that were present in our study areas. Indeed, previous studies suggest that the four macropod species in the study area may have differing water requirements, which could conceivably influence their activity patterns. In particular, the "grey" kangaroos, *M. giganteus* and *M. fuliginosus* are thought to have greater water requirements than the more arid adapted *M. rufus* and *M. robustus* (Dawson et al. 2006).

The results for feral goats were also consistent with previous research from semi-arid landscapes demonstrating that their home ranges are centred around water sources and suggest that AWP function as "invasion" hubs for feral goats (King 1992; Freudenberger and Barber 1999). Our findings and those from previous studies suggest that most of the activity and by extrapolation grazing impact of feral goats in semi-arid rangelands is likely to occur within 3 km of water. However, we caution that further research is required to

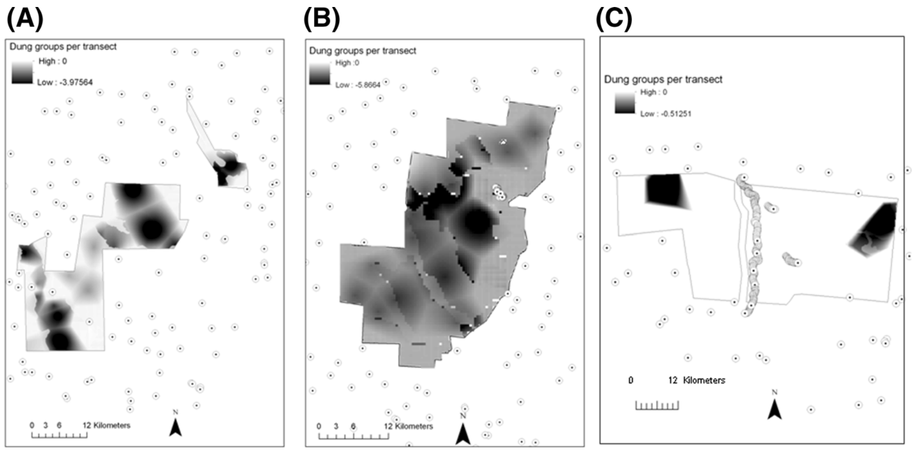

Fig. 7 The predicted difference in the abundance of goat dung before and after the removal of AWP within **a** Mutawintji NP, **b** Paroo Darling NP and **c** Nocoleche NR. The predictions within each reserve were made by applying the GAMM model describing the relationship between the abundance of goat dung, habitat type and distance from water at the time of the study to 100 m × 100 m grid cells within each reserve and subtracting the results for each grid cell using the same model but substituting a distance from water surface generated after removing AWP from each reserve. The circles in each panel represent sources of permanent water after simulated AWP removal on the conservation reserves

obtain more fine detailed information on where goats concentrate their grazing activity, as the dung counts used in this study are a coarse measure of activity only and do not allow partitioning of grazing activity from other activities, such as resting and drinking (Landsberg and Stol 1996).

A likely reason for the difference between feral goats and kangaroos in their use of habitat relative to water is the higher water requirements of goats compared to kangaroos (Dawson et al. 1975; Munn et al. 2009, 2012). The energetic costs associated with moving to and from water could also contribute to the difference, as kangaroos are able to move between their feeding, resting and watering sites with the higher energy efficiency of moderate speed hopping, relative to the quadrapedal locomotion of ungulates such as goats (Dawson and Taylor 1973; Webster and Dawson 2004).

Management implications

The presence of AWP has substantially increased the availability of standing water and spatial distribution of water in rangelands, particularly during the past century. For example, in Australia, the creation of AWP over the last 150 years means that there are now few places more than 10 km from water across the approximately 70 % of the continent that is used for livestock grazing (Fensham and Fairfax 2008; James et al. 1999). By way of contrast, prior to European settlement, surface water was rare in this low rainfall region and normally occurred only in the channels of major rivers and isolated springs, and was only widespread for brief periods following rain (Fensham and Fairfax 2008). By subsidising the critical resource, water, AWP have facilitated the invasion of water-dependent invasive species such as feral goats and cane toads into arid Australia (Letnic et al. 2014). Because goats' movements and grazing activity are focal around water, there is considerable scope to exploit their attraction to water to control their populations, movements and impacts.

Trapping goats at water sources is a frequently used technique to manage feral goats in both pastoral lands and conservation reserves in semi-arid Australia and can be a particularly effective technique for reducing goat abundance (Edwards et al. 1997). To be successful, trapping of goats requires that AWP be maintained and that goats be allowed access to the water for much of year. Consequently, trapping of water points may only temporarily alleviate goat grazing pressure as new goats will immigrate into the area from surrounding properties and continue to graze there.

Because goat activity decreases with distance from water and kangaroos are more homogenous in their use of habitat with respect to the location of water, restricting goats' access to water could be an effective approach to alleviate their grazing impacts without greatly affecting kangaroo dispersion or abundance. Our results showed that closing AWP would substantially reduce the area within 3 km of water and the predicted abundance of goat dung at Mutawintji NP and Paroo Darling NP. However, AWP closure would have little effect on proximity to water and abundance of goat dung in Nocoleche NR because there were few AWP there and it is bisected by the Paroo River, which comprises a series of waterholes and intermittently flooded wetlands that are impossible to economically fence. These differences between reserves highlight the need for assessment of the likely impact of AWP closures on feral goats before commencing on-ground works.

Reducing the availability of water to feral goats entails a number of strategies including the removal of AWP, exclusion of goats from them and the construction of barrier fences that prevent goats from travelling on direct routes to water (Russell et al. 2011). By preventing access to AWP on conservation areas, the mean distance to water across the landscape should increase and goats would only be able to forage at areas distant from water during relatively brief periods of cool weather or after rain when water is not limiting in the environment and they are not water stressed. The net result of water closure should be a reduction in both long-term goat grazing activity and their impacts on vegetation, ground cover and soils (Graz et al. 2012; Russell et al. 2011).

Although each of the four species of kangaroo in our study area will drink when water is available and otherwise show physiological sign of water stress (Underhill et al. 2007; Dawson et al. 2006), our results suggest that the closure of AWP would have little impact on kangaroo activity because their activity appeared to be independent of water in all habitats. Habitat use varies between species of kangaroo (Pridell 1987) but the methods used here precluded investigation of grazing by each species in relation to AWP. However, our findings are supported by an experimental exclusion of kangaroos from water that did not influence the density or dispersion of kangaroos in a drought-stricken semi-arid landscape similar to our study sites (Fukuda et al. 2009). Although sorting of ungulates to exclude goats from AWP while allowing sheep access has been demonstrated using machine vision (Finch et al. 2006), the applicability of the technology to extensive pastoral lands is untested. However, restricting goat access to water should be a useful strategy in conservation reserves, where there is normally no need to provide water for livestock.

Conclusion

Artificial water points can focus the movements and hence impacts of herbivores in arid landscapes. In our study region AWP act as focal points for the activity of feral goats but not kangaroos. Restricting goats' access to water by closure of AWP or strategic fencing, such that the mean distance to water across the landscape is increased, may be an effective strategy to reduce goat grazing impacts in conservation reserves where natural sources of water are scarce but is unlikely to affect the grazing patterns of kangaroos. Water closures are unlikely to be a viable strategy on pastoral lands because of the need to provide water for livestock, but should be a useful strategy in conservation reserves, where there is normally no need to provide water to sustain commercial livestock grazing.

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