

Watering points and domestic livestock grazing: indicators of pressure on rangeland biodiversity

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Abstract The requirement for livestock to drink regularly makes watering places foci of livestock activity in the rangelands. Thus they are one of the major influences that give spatial expression to grazing behaviour. Using research results from the Goldfields of Western Australia we show how distance-from-water can be incorporated in models of grazing history at different sites within paddocks. Two surrogates of grazing activity are illustrated: one relying on a commercially available model and one developed from measures of track density. Application of these models shows that numerous interactions need to be considered in addition to distance from long-lasting sources of drinking water. Furthermore, responses in biodiversity to different patterns of grazing behaviour may vary greatly, both within groups of similar organisms and according to hierarchical landscape stratification. We analyse this complexity in terms of implications and opportunities for monitoring biodiversity. Finally, we synthesise information gained from these models and other sources to outline key implications for monitoring rangeland biodiversity of the relationships between grazing activity, distance-from-water, and other regionally specific factors.

Running title: water points, grazing and biodiversity

Key words: monitoring, landscape stratification, modelling grazing activity, grazing gradients, track density, benchmarks

INTRODUCTION

Artificial sources of long-lasting (generally permanent), potable, surface water have been established to support livestock across most of the Australian rangelands. This provision of water has enabled pastoralism to spread from limited areas of reliable natural surface water, often associated with rivers and major creeks, across most of the developed pastoral country today. Indeed, few areas remain unwatered (Landsberg & Gillieson 1996).

The proliferation of artificial watering places occurred because most livestock need to drink water on a regular basis, and long-lasting natural surface water is generally scarce. The physiological dependence of livestock on water results in activity being concentrated in the vicinity of long-lasting water, and dissipating rapidly with increasing distance from it (Valentine 1947; Lange 1969; Andrew & Lange 1986; Ludwig *et al.* 2000). Therefore, watering places play an important role in structuring spatially how livestock behave and impact on rangeland ecosystems.

The spatial structuring of grazing behaviour and impacts has profound importance for managing and monitoring biodiversity. Some of the most important of these include:

1. Many aspects of biodiversity are sensitive to livestock grazing and require water-remote areas to persist (Hunt 1995; Landsberg *et al.* 1999).
2. Other species may require complete protection from livestock grazing, and hence may persist only in undeveloped remnant areas (Landsberg *et al.* 2002).
3. Heavily impacted areas are often desirable habitat for invasive exotic species to establish and then spread (Landsberg *et al.* 1999).
4. Locating ground-based monitoring at particular distances from water sources can allow spatial interpretation of local changes (Ludwig *et al.* 2000).
5. Areas remote from water sources can provide benchmark areas indicative of maximum biological integrity (*sensu* Angermeier & Karr 1994), to provide context for interpreting change in grazed landscapes. ("This is what it can be like").

Evidence of strong influences of water location on patterns of livestock behaviour and impact abounds. James and colleagues (James *et al.* 1999) have conducted a comprehensive review on this subject in Australia. However, other factors need to be taken into account when considering how to manage and monitor aspects of biodiversity at paddock to regional scales; the more important of these are summarised in Table 1.

Many of these factors are likely to interact, further confounding a simple approach to predicting grazing activities and impacts. The implications of these findings are that livestock behaviour and pressure differed historically, and will continue to differ in their spatial impacts on ecosystems within paddocks, across pastoral properties, and between regions. Yet despite these interactions, an

understanding of broad, water-centred patterns is possible within regions of reasonably similar grazing history and landscape composition (Ludwig *et al.* 2000; Landsberg *et al.* 2002; Pringle 2002).

USING DISTANCE-FROM-WATER TO MODEL HISTORIC GRAZING ACTIVITY: A CASE STUDY

In PhD studies in the north-eastern Goldfields of Western Australia (Fig. 1), Pringle (2002) used a combination of multiple regression modelling and spatially explicit habitat suitability indices (Coughenour 1991) to model grazing history, expressed as the total number of sheep years per hectare. The study involved seven paddocks containing long, continuous grazing gradients out from watering points. Four paddocks contained gradients in mulga sheetflood plains and three in chenopod depositional plains adjacent to salt lakes (Pringle 1994a; Pringle 1994b).

Chenopod paddocks contained five sampling sites spaced approximately two kilometres apart, from near a watering point to successively further away from any water. Mulga paddocks contained three sampling sites similarly arranged and an associated reference site in an undeveloped (remnant) geo-ecological analogue in the same sub-catchment. Rigorous criteria were observed in order to avoid coincidental (e.g. slope/drainage) or confounding (e.g. natural surface water sources) factors. This design was adapted from the CSIRO grazing gradient approach (Landsberg *et al.* 1999).

There were two components to modelling grazing history: selecting a suitable surrogate for grazing behaviour, and determining how this surrogate was affected by a range of biophysical influences. Two surrogates were tested. One relied on RANGEPACK, a commercially available model for estimating grazing behaviour (Stafford Smith & Foran 1990; Cridland & Stafford Smith 1993). Although RANGEPACK predicts grazing behaviour, there was an element of circularity in its use in the study context, because it was parameterised using remotely sensed vegetation cover, which was also a biophysical influence of interest in the study. Hence an alternative surrogate was also tested, based on the density of clearly defined (i.e. persistent) livestock paths ("tracks") as a surrogate of accumulated grazing activity. Track density has a history of successful application as a grazing surrogate (Lange 1969; Squires 1974), including in the study area (Hacker 1978).

Track density was estimated by counting tracks along transects at 42 locations across six of the seven grazing gradients. Transects were located at the study sites and at intermediate sampling locations equidistant between them. The transects were orientated perpendicular to the direction of the nearest watering point, with each transect approximately 45m in length. At each sampling location three transects were walked in each major land unit present (two mulga paddocks contained two major units, but track frequencies did not differ significantly between them). Occasional local topographic features (e.g. low rises or drainage foci), which can influence track patterns (Lange 1969), were

avoided, and minor, local anastomoses were considered single tracks. Only those tracks with clearly recognisable courses were counted. Track counting was conducted in November 1998. The procedure was rapid, with each site generally taking less than ten minutes to complete.

Track density declined exponentially with increasing distance from water (Fig. 2). This indicates extremely intense activity (grazing, trampling, defecation and so forth) near water and a rapid decline in activity away from water. Track definition also declined with increasing distance from water: tracks became shallower and had less clearly defined margins.

The logic underlying track density as a surrogate for grazing behaviour is that areas of higher track should reflect areas that have been used more heavily and for longer periods of time in individual paddocks. In southern Australian rangelands, sheep tracks branch out from water and become less distinct as animals fan out to graze (Arnold & Dudzinski 1978). Areas of high track density reflect areas where grazing activity is likely to have been heavy in the past, but more recent grazing activity may be occurring in areas where well-defined tracks have not yet developed. Therefore, track density is at best a relative, rather than an absolute indication of long-term grazing activity. However, it has advantages over other commonly used surrogates, including animal counts, dung accumulation and sward utilisation. Compared with these surrogates, track density reflects a much longer time-frame, and it is also quicker and easier to sample.

Unlike vegetation cover, track density is less likely to be both a cause and a consequence of grazing activity. However, as all stock grazing patterns partially reflect previous grazing impacts (e.g. favouring or avoiding degraded areas), a totally independent surrogate may be illusory.

The track density measurements were used to develop a density-based model of grazing activity that incorporated paddock parameters likely to influence grazing behaviour. The candidate variables selected for modelling track density and the rationale for their selection are presented below:

D = distance from water: chosen because of its critical importance in arid rangelands as discussed

S = salinity of water: chosen because of its potential to constrain the distance sheep (the predominant livestock in this study) can travel between drinks

A = age of watering point: chosen because of its potential to influence accumulated impact on spatial patterns of forage availability and therefore distance animals must travel along tracks before spreading out to graze

N = average number of sheep using the watering point, which was chosen for the same reason as age.

Most watering points were in the corners of large (>70 km²) paddocks and so paddock configuration was not considered at this stage (but see later). The full model tested was:

$$\text{Ln (TF)} = a + bD + cS + dA + eN$$

where

Ln (TF) = natural logarithm of track frequency (tracks/km)

D = distance from water (km)

S = salinity of supplied water (%)

A = age of paddock (years)

N = average stock numbers (dry sheep equivalents).

The minimal model (*sensu* Crawley 1993) that best reflected variation in track frequency within and among paddocks was:

$$\text{Ln (TF)} = 4.6 - 0.9D - 30.0A^{-1}$$

The percentage of variation accounted for was 83 % and all terms were highly significant ($p < 0.001$).

Predicted sheep activity derived from the RANGEPACK grazing activity model was the second surrogate used to model grazing history. The basic model inputs are distance from water (D), water salinity (S) and a variable for relative grazing preferences for different vegetation types (P). These are combined in an exponential decay function to predict relative grazing activity at a point (RGA) thus:

$$\text{RGA} = e^{(C \cdot D)} \cdot P \text{ (where } C = -0.392 \cdot S \text{)}$$

Relative grazing activity is then used to estimate activity per unit area, by summing point scores for the unit area. This is a slight modification of the relative grazing model of Cridland and Stafford Smith (1993), developed in consultation with these authors.

RANGEPACK predicted activity and modelled track density were each used to calculate alternate estimates of total grazing history (sheep years per hectare) for the study sites, using a raster-based GIS and the following procedure. For each hectare pixel within a paddock, the process involved:

- estimating the proportion of the paddock's total grazing activity that had occurred in that pixel, using the decay functions from all watering points and regional livestock habitat preferences based on pastoralists' opinions of pasture productivity (ratings ranged from zero for bare salt lakes to 40 for best favoured land systems),
- multiplying this value by the average number of sheep run per year in the paddock to estimate stocking rate (sheep per hectare per year), and

- multiplying the stocking rate by number of years of grazing to estimate stocking history (sheep years per hectare).

Relative to the RANGEPACK decay function, the track the density model resulted in a considerably more exponential decline in modelled grazing history at successive sites out from watering points at each gradient (Fig. 3). The RANGEPACK approach also tended to predict slightly higher relative grazing activity at greater distances from water, while the track density model predicted substantially higher relative grazing activity near water. The track-based approach appear to better reflect where historic grazing has been concentrated, as opposed to current activity. RANGEPACK probably underestimates historical impacts near watering points but provides a more realistic picture of current activity further from water. However, strong anecdotal evidence was gathered from pastoralists during the study that both models underestimate the distances animals graze away from watering points.

Both the track-based and RANGEPACK models were used to explore ecosystem responses to modelled grazing history. Given the contrast in decay functions of grazing with distance from watering points, some interesting spatial interpretations of responses of various ecosystem variables were possible, because one or other model generally accounted for more of the variation (i.e. a higher R^2 value). These differences are summarised in Table 2. They suggest that responses to grazing history depend strongly on the choice of ecosystem variable.

Table 2 near here

The study also suggested that responses of particular ecosystem variables often contrast in intensity, and occasionally in direction, within different landscape units (e.g. mulga grove versus inter-grove) and between landscapes (e.g. mulga versus chenopod landscapes) (Pringle 2002). For instance, profound degradation was observed near watering points in chenopod landscapes (secondary salinity, erosion, landscape leakiness, loss of numerous decreaser ant and plant species), but this impact zone was limited in spatial extent. In contrast, the impacts of grazing on mulga landscapes appeared to be more diffuse, but also more far-reaching, particularly with respect to decreaser plant species. These results - all pervasive impacts in mulga landscapes, and relatively limited impacts in chenopod landscapes - may be regionally specific, however.

Chenopod landscapes are likely to be far less resilient in the region to the north-west of the study region where one of us (HP) is currently working. This is the region encompassing the Gascoyne and Murchison River catchments, where the chenopod landscapes have higher hydraulic energy (being outward flowing and incised), are more intensely watered and have experienced considerably greater grazing pressure (Wilcox & McKinnon 1972). Hence, although a general understanding of pastoral history and landscape ecology developed in one

region can help develop likely scenarios about pressures on biodiversity in another, there is also a need to take different regional narratives into account.

FACTORS THAT COMPLEMENT DISTANCE-FROM-WATER IN DEVELOPING REGIONAL NARRATIVES

Distance from water is undeniably a critical influence in the relationship between pastoralism and rangeland biodiversity. We suggest the following complementary factors also need to be considered in a holistic, hierarchical approach to monitoring impacts on biodiversity in Australia's rangeland regions:

1. *Watering point location in the landscape.* Personal observations by one of us (HP) during low-level aerial traverses of the Gascoyne and Murchison River catchments suggest that many of this region's watering points are in locations likely to lower local base levels and hence entrain landscape degradation processes. These may include gully and sheet erosion/planation, general landscape dessication, scalding and/or scrub encroachment (Tinley 1982; Pringle & Tinley 2001). These processes, and the patterns they cause, may occur at such broad scales that the spatial impacts of watering points may be nested within them, and relatively minor by comparison.
2. *Other landscape-scale causes of accelerated and/or modified land succession.* The construction of tracks and roads has had profound impacts on landscape function in the rangelands, creating new drainage lines and consequently dessicating landscapes deprived of run-on. Tracks and roads are also common causes of severe, widespread gully-head retreat and landscape dessication (Fanning 1994; Pringle 1994b). Landscape incision effectively lowers local base levels, which in turn accelerate often overlooked but ongoing processes of geomorphic succession that have profound effects on vegetation patterning (Cole 1963; Tinley 1982). These pervasive and profound succession processes potentially confound water-remoteness as an indicator of landscapes minimally affected by human disturbance.
3. *Characteristic landscapes and habitats* Demonstrated patterns of ecosystem responses to distance from water are usually limited to widespread and uniform (or regularly patterned) landscapes, partly reflecting statistical requirements. Small areas or linear features, like those often associated with drainage basins, tend to be ignored or excluded because of lack of regular representation (e.g. Pringle 2002). Yet these drainage foci, billabongs, claypans, remnant duricrusts and so forth often support the most distinctive and restricted aspects of local biodiversity (Pringle 1994a; Pringle 1994b; Pringle *et al.* 1994). They also receive disproportionately heavy grazing pressure (Morton *et al.* 1995). Such focussed impacts on regionally important habitats are particularly pronounced in tropical rangeland areas that rely on natural surface waters, and where local damage to riverine habitats may have magnified downstream impacts.
4. *Feral animals.* The nature and distribution of feral animal impacts vary markedly between species. *Rabbits* are not dependent on surface water for survival and hence areas may be devoid of watering points but still severely

impacted by rabbits (e.g. Mitchell *et al.* 1979). *Feral goats* depend on surface water but they use the surrounding country differently to cattle and sheep. For instance, they camp on remnant duricrusts, extirpating rare flora usually ignored by conventional livestock (Pringle 1994a; Pringle 1994b) and cause massive structural damage to wetland vegetation (personal observations, Hugh Pringle). *Feral pigs* are more reliant on access to water than livestock but their rooting activities cause substantial physical damage to their preferred floodplain and seasonal wetland environments (Choquenot *et al.* 1996).

SYNTHESIS

The relationships between grazing activity, distance-from-water, and other regionally specific factors have many implications for managing and monitoring aspects of biodiversity. Key implications include:

1. Such is the complexity of potential responses of biodiversity to poorly documented grazing histories that pragmatic regional frameworks are needed to provide starting points for monitoring. They should include innovative spatial and temporal patterns of exposure and protection from grazing to develop tentative “best-fit” patterns of rangeland objectives and management, using what we know now (Morton *et al.* 1995; Pringle 1995; James *et al.* 2000; Landsberg *et al.* 2002; Pringle 2002).
2. The limitations of distance from watering points as a surrogate for biodiversity need to be recognised and accommodated at paddock to regional scales in order to develop scale-integrated frameworks for monitoring grazing impacts.
3. Never-the-less, studies of the density and location of watering places, and local impacts along water-centred grazing gradients, provide valuable indications of the degree to which the pressures associated with grazing activity pervade a region. Value can be added if there is a convincing regional narrative regarding the relationships with other potentially important influences.
4. The location of ground-based monitoring sites in paddocks needs to take account of grazing history (or a surrogate such as distance from water) in order to be sensitive and spatially informative of changes (*sensu* Ludwig *et al.* 2000). Furthermore, at least some monitoring sites need to be located in the dynamic part of the sigmoidal response curve.
5. Models of grazing impact, both theoretically based ones such as RANGEPACK and empirical models based on track density or remotely sensed data, can predict or verify where this dynamic zone is likely to be in different paddocks and regions.
6. Sites in the dynamic zone are not sufficient, however. Without benchmarks, monitoring is ungrounded, targets are arbitrary and progress is quantified without rigour. Geomorphically and biological intact benchmarks are critical for developing and improving regional narratives about ecologically sustainable rangeland use. Candidate areas are easily identified, but need to be checked remotely, for landscape context, and on the ground, for biological detail. The future management of remnant benchmarks should be

a community-based priority so that those who manage land have a context for tracking change.

7. Monitoring sites located in heavily used areas can also be valuable for providing an alternative context of “what we don’t want to see”, allowing informal assessments of how good/bad the situation is.
8. There is no universal response pathology (*sensu* Rapport & Whitford 1999) for the impact of grazing history on biodiversity. Different elements of biodiversity do not always respond similarly within, let alone across types of landscape, even within a region, and taxa do not always respond consistently. It is highly likely that the most threatened taxa and functional groups will vary between rangeland regions. Thus a regional approach is needed that recognises the implications of internal heterogeneity. Universality can be expressed in terms of overarching objectives, rather than prescribed monitoring protocols.

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Table 1. Important influences on the distribution of livestock activity and impacts, in addition to distance from watering places.

Factor	Important influences
Species of livestock	Cattle generally travel much further from water than goats, which travel further than sheep. Different species also have different grazing preferences and vertical limits to damage on vegetation (browse lines). Even within species, classes (sex, age, reproductive status) of livestock may differ in behaviour.
Salinity of water	The saltier the water, the more frequently stock need to return to drink; hence stock activity becomes more concentrated around salty water, and attenuates more quickly away from it. Species of stock also show different sensitivity to salinity of water.
Landscape heterogeneity	Preferential grazing is common in rangelands with contrasting landscapes, and hence pasture types. Grazing activity is often focussed on more productive, often lower-lying landscapes. Watering points such as earth dams, which rely on surface run-off, are often located in lower-lying landscapes also, exacerbating the impacts of stock preferences for these areas.
Stocking history	If watering points become surrounded by large areas of degraded pasture livestock need to travel further from water to graze. Degree of degradation is likely to be influenced by <i>paddock age</i> and <i>historic stocking rates</i> .
Paddock configuration	The size and shape of paddocks have strong influences on grazing behaviour. For instance, watering points in corners have only 90 degrees of approach, leading to more concentrated activity close to them and contrasting lightly used (“under-utilised”) areas in the corner furthest away. Centrally located watering points have more angles of approach and so are less heavily impacted in their immediate vicinity, but allow greater dispersion of impact to other parts of the paddock.
Kangaroo competition	Competition from kangaroos serves to accentuate and expand zones of concentrated activity around preferred pasture types and watering points. Because they are not constrained by stock-proof fences, kangaroos may also negate the benefits of resting

	from livestock.
Fire regimes	Areas regenerating after fire tend to attract livestock and other herbivores, but under some fire regimes, particularly fire exclusion, unpalatable woody plants may come to dominate as an unpalatable semi-stable state (Dyer <i>et al.</i> 2001). Patch burning within paddocks can be used to rotate grazing and enhance vegetation diversity. Resting from grazing is usually required to allow accumulation of sufficient grass biomass to fuel a paddock fire.
Grazing management	Emerging management systems, such as higher grazing intensities over shorter grazing periods or wet season spelling, may alter fundamentally livestock behaviour and ecosystem responses.
Configuration of water source	While point watering places, such as troughs, dams and tanks, predominate in many rangeland areas, linear features such as bore drains and rivers predominate in regions such as the mulgalands of Queensland (Noble <i>et al.</i> 1998). Effects on grazing behaviour follow similar principles, but with some differences in spatial expression (Crowley <i>et al.</i> 1999)
Natural surface water	Ephemeral surface waters are common in many rangelands. The loss (breaching) of ephemeral wetlands is likely to simplify grazing behaviour, focusing it on permanent (mostly artificial) watering points. Livestock tracks are a major cause of breaching. Natural surface waters are also common across much of the tropical savannas, and associated riparian areas are particularly vulnerable to physical degradation due to trampling and weed invasion, in addition to the impacts of preferential grazing.
Infrastructure decline	Many southern and central rangeland areas developed substantial infrastructure when prices were high, but are now experiencing declining terms of trade, leading to deteriorating infrastructure and a transition to broader scales of selective grazing consequent of ineffective enclosure. Resting of stressed landscapes is not possible without adequate control of grazing pressure.

Infrastructure intensification	Traditionally, there has been far less infrastructure development in northern Australia, but thriving live-cattle export markets in Asia are driving a trend toward infrastructure intensification to make use of previously under-utilised country. The implications, risks and opportunities for biodiversity management and monitoring are considerable.
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Table 2. Classification of spatial impact on variables with increasing distance from water. Response shape was determined by the nature of the best-fit model (E = Exponential, L = Linear); response direction was determined by visual inspection (D = declining trend with increasing distance from water; I = Increasing trend).

Perspective	Response variable	Response direction	Response shape
Pastoralism	Range condition score (high = worse)	D	L
	Sustainable Carrying Capacity	I	L
	Pastoral Integrity	I	L
Biodiversity	Decreaser plant species richness	I	L
	Increaser plant species richness	D	L
	Ant species richness	D	E
	Decreaser ant species richness	D	E
Ecological integrity	Chenopod shrub cover	I	E
	Size of open areas, chenopod	D	E
	Potentially mineralisable nitrogen, sandy mulga	D	L
	Available phosphorus, mulga	D	L
	Organic carbon	I	E
	Electrical conductivity, chenopod	D	E

Fig. 1. Location of the PhD study region and its largest town, Leonora.

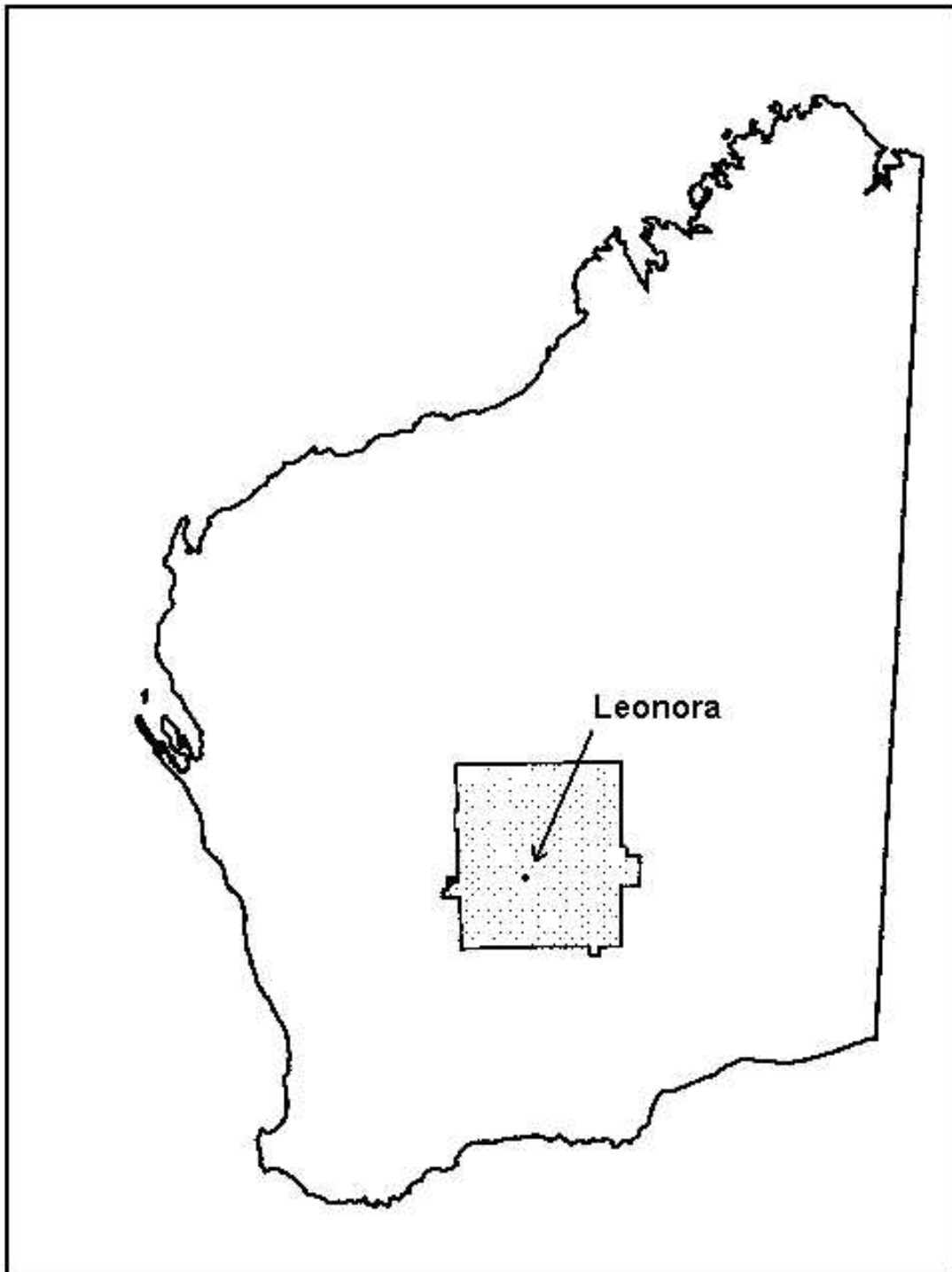


Fig. 2 Influence of distance from water on track density

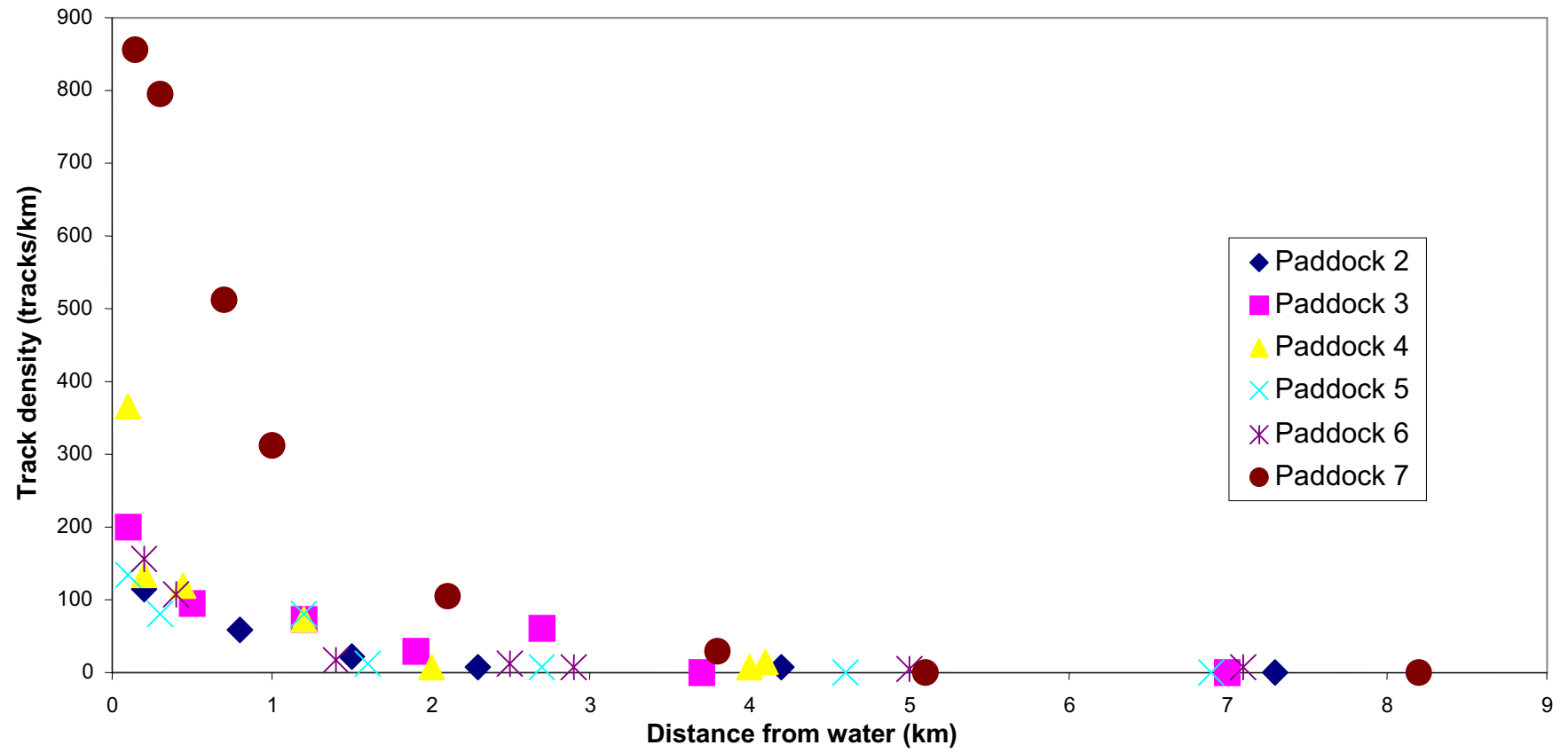


Fig. 3. Comparison of RANGEPACK/Paddock (RP) and track-density based (SH) models of stocking history

