Predicting the distribution of Eastern Grey Kangaroos by remote sensing assessment of food resources.

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Abstract: This study demonstrates how the distribution of animals can be described using remotely sensed data at a scale in the order of square kilometers. Kangaroo distribution has been monitored at regional scales using aerial surveys and detailed field study. This study attempts to fill the gap between local and regional scales by using Landsat derived vegetation characteristics to provide animal distribution details at local scale. Field surveys of Eastern Grey kangaroos and vegetation biomass were undertaken at the Warrumbungle National Park, New South Wales, Australia. The distribution and abundance of kangaroos and plant biomass were compared with remotely sensed vegetation characteristics taken from Landsat TM imagery. The distribution of green, short (< 5cm) blade grass biomass (the preferred kangaroo food resource) was patchy and positively correlated with kangaroo density and Landsat spectral bands 1, 2, 3 and a principal component combination of bands 1-7 (excluding band 6). Total population density was positively correlated with blade grass biomass and Landsat band 3. The dispersion of kangaroos within habitats was patchy, even though the Landsat image defined habitats as being homogeneous. This study clearly demonstrates the value of Landsat data to environmental management in the past and present.

Keywords: Remote sensing; Eastern Grey Kangaroo; GIS; vegetation cover; vegetation biomass; Landsat TM

Introduction

In most mammals, the dispersion of the female population is governed by the distribution of food resources that are of higher quality[1~~[1~~],2. The males are, in turn, organised by the dispersion of the female population during the breeding season. Larger, dominant males generally control access to females at the time of mating, with smaller subordinate males excluded to the periphery of the female population 3. Outside of the breeding period, males and females may show spatial segregation, preferring different habitat types (e.g., red deer[4], mule deer[5], wood bison[6]. This may give females a greater chance of successfully rearing young, either through access to better food resources or better opportunities to protect young from predation e.g., bighorn sheep[7]. The goats, sheep and deer of the northern hemisphere fit well within this spatial and social framework, although the position of Australia's kangaroos is less understood.

In the large macropods breeding tends to be aseasonal. The opportunities for larger males to dominate smaller males are spread throughout the year e.g., Red Kangaroos[8]; Eastern Grey Kangaroos[9]; Antilopine Wallaroos[10] and Euros[11]. Females with young-at-foot will isolate themselves from social interaction to protect their young[12], although this separation is by no means complete. The process of habitat partitioning among males and females of varying body sizes and reproductive status may occur at a fine spatial and temporal scale.

The description of wildlife distributions can occur at different spatial scales, ranging from several, to thousands of square kilometres. Scale will govern the how one can assess species habitat requirements, the detail that can be extracted from the data and the limits to the predictions that can be made about that species. Field studies of mammalian herbivore populations traditionally involve surveying and then calculating the density of animals within discrete habitat types e.g., African buffalo[13]. Male and female dispersion and social grouping patterns have also been described according to the relative availability and spatial arrangement of the different habitat types e.g., kangaroos[14]. Mapping of wildlife distributions is increasingly undertaken with the aid of a Geographic Information Systems (GIS) e.g., Florida Scrub Jay[15]; waterfowl [16]; kangaroos[17,18]; Red Squirrel [19]; Leadbeaters

Possum[20]. These involve the large scale and often patchy survey of animals across a landscape of habitats. Regional distribution of Individuals can be related to broad habitat types but, more importantly, local distribution of individuals is driven by variation in the distribution and abundance of resources within habitat types. At this scale, the use of GIS habitat-use models is constrained more by the accuracy of the data collected during animal surveys, than by the description of the underlying habitat.

It is very difficult and time consuming to monitor the distribution and abundance of food resources at the local scale. Vegetation surveys that can be completed within the confines of time and budget will result in data at a spatial and temporal scale that is inappropriate for such studies. A remote monitoring technique that can be used to ‘scale down’ (i.e., operate at a finer scale) coarser field data to a local scale would seem appropriate. Remote sensing can collect data at a variety of temporal and spatial scales and would therefore seem to be an obvious choice to satisfy this requirement.

A greater understanding of habitat quality within habitat types, would offer new understanding on the behaviour of kangaroos that could then be useful to gain insight into population distributions at landscape scales. Theoretically, it is inadvisable to assume a simple linear relationship between models at different scales although Stewart et al. (1998) reported some success in linear scaling with hydrological models[21]. Work by Maselli[22,23] found validity in linearly scaling vegetation parameters acquired from high-resolution satellite imagery, to coarse resolution imagery. This is an important point when scaling from local to regional levels. Mapping local dispersion patterns will allow us to identify the importance of local scale if we define habitat use from an animal-centred perspective. A greater understanding of what drives social grouping patterns and dispersion from the animal’s ‘perspective‘ can improve the detail incorporated within models that work on a broader landscape scale. Importantly, better management and conservation predictions regarding future habitat use and population dynamics could be made when the data are coupled with remotely sensed vegetation data.

The launching of the Landsat program in 1972 and the subsequent series of Landsat satellites provided scientists with an unparalleled opportunity to map and monitor the environment [24]. In particular the launch of Landsat 4 and the Thematic Mapper instrument in 1986 provided ecologists with new ways to measure and monitor ecological processes [25,26]. The Landsat programme has provided near continuous data to date. With the launch of Landsat 8 this source of imagery represents an unprecedented archive that can be used in support of geographic analysis. The use of remote sensing for mapping and monitoring vegetation characteristics is well documented [27]. Traditional classification methods can be used to derive thematic maps of habitat type while quantitative vegetation characteristics such as biomass and percentage cover can also be derived from remotely-sensed imagery. Such methods are based on spectral indices such as; band ratio models (e.g., simple ratio [28], normalized difference vegetation index (NDVI) [29], linear transformations (e.g., Tasselled Cap Transformation [30] or band regression against field-mapped variables [31]. These techniques have received attention in remote sensing research despite inconsistencies and problems in their application [32,33,34,35]. It is now well established that remote sensing can provide timely data on vegetation characteristics including cover and biomass estimates [36,27]. The temporal and spatial scales offered by remote sensing systems are also appropriate to derive vegetation variables at the scale required for this project [37].

This paper reports a project that integrates wildlife space-use patterns with that of remotely sensed vegetation data coupled with GIS analysis. It describes the field measurement of Eastern Grey Kangaroo (Macropus giganteus) food resources and their relationship to Landsat TM spectral signatures relating to vegetation. This relationship is then used to test whether kangaroo dispersion can be correlated with remotely sensed vegetation data. This paper further tests the following hypotheses that:

- the spatial distribution of vegetation parameters can be predicted from Landsat spectral signatures,
- the distribution of vegetation parameters correlates with that of kangaroos,
- kangaroo dispersion is correlated with Landsat spectral signatures.

Study site

This study was undertaken at the Warrumbungle National Park (149° 00’ E., 31° 15’ S., area 215 km^2), 33 km west of Coonabarabran on the north-west slopes of New South Wales. The Park’s average annual rainfall varies locally with topography, ranging from 700-900 mm, with heavier falls in winter. The study site (altitude 480 m, area about 4 km^2) comprises an open, flat and cleared grassland towards the centre of the park. This area was cleared of nearly all trees, and then farmed intensively for cropping and stock grazing until the late 1960s. These conditions promote high Eastern Grey densities as they prefer broad-leaved grasses[38] growing in open areas adjacent to forest cover. The eradication of dingoes and the cessation of commercial culling of kangaroos in the late 1960s further promotes population growth. Rocky volcanic mountains (altitude up to 1200 m) surround lower areas of woodland (altitude about 540 m) dominated by White Gum (Eucalyptus rossii), Narrow-leafed Ironbark (E. crebra) and White Cyprus Pine (Callitris glaucophylla). This woodland surrounds the study site where dark basalt soils support vegetation dominated by a mix of both native (e.g., Bothriochloa decipiens, Chloris truncata, Themeda australis) and introduced (e.g., Cynodon dactylon, Bromus cartharticus) grasses, sedges (Juncus sp.) and forbs (e.g., Vittadina sp., Medicago sp.). The weeds Fleabane (Conyza bonariensis), St Barnaby’s thistle (Centaurea solstitialis), Blue heliotrope (Heliotropium amplexicaule), and Paterson’s curse (Echium plantagineum) dominate the disturbed areas. Sparse Yellow box (Eucalyptus melliodora), Rough-barked apple (Angophora floribunda) and Western Golden Wattle (Acacia decora) are scattered across the study site. River Oak (Casuarina cunninghamiana) and River Red Gum (E. camaldulensis) dominate creek lines.

Common Wallaroos (Macropus robustus robustus), Swamp Wallabies (Wallabia bicolour) and Red-necked Wallabies (Macropus rufogriseus) also occur in and around the study site at low densities, occupying the rocky hills, scrubby woodlands and open woodland areas respectively. Rabbits (Oryctolagus cuniculus) also occur in the cleared area, however, their densities are very low. It is unlikely that there is any significant competitive interaction with the macropods.

Methods

Field data were collected during a six day period from February 6th to February 12th 1997. This was coincident with the acquisition of the Landsat scene (February 8, 1997) that was used in this study.

Kangaroo Survey

Transect lines were positioned at approximately 400 m intervals giving an effective kangaroo sighting distance of 200 m either side of the transect (Figure 1). The ability to detect animals in this environment declines substantially beyond this distance. Transects were marked every 200 m and the location of these posts was known with an accuracy of +/- 1 m.

Counts of the location of kangaroo groups were conducted on foot using line-transect methodology. These commenced at sun-up and were restricted to a 2 hour duration as this is when most kangaroos had moved out from under forest cover to feed and were visible. All transects were counted twice and the survey was completed within 6 days. Counting in this area is easy because of tree clearing while the animals are accustomed to the presence of humans due to tourism in the National Park.

Animals were observed using binoculars and scored as being in a ‘group’ if individuals were within 50 m of each other. Females were classed according to the presence of young and males and juveniles were classed according to estimated body mass:

- Juveniles (5-15 kg),
- Adult Females (15-35 kg): without or with Young-at-foot (< 5 kg and maintaining a < 5 m distance proximity to mother) and/or Pouch young (indicated by bulge in pouch).
- Adult Males: small (25-39 kg), medium (40-59 kg), and large (>60 kg)
- Unknown - same size as female and small male class but sex unidentifiable.

AMG84 coordinates for each animal group location were calculated from the following:

- the observer’s distance from previous transect marker post (measured using a rangefinder accurate to +/- 5m),
- whether the group was east or west side of transect line,

- the angle to animal (estimated relative to transect line), and
- the distance to animal in metres (using rangefinder).

All data were incorporated into a spreadsheet and imported into ArcGIS as a point shapefile. An inverse distance squared algorithm was used to produce an interpolated surface of kangaroo density. Density surface datasets were produced for; total population, female population, females with young-at-foot, large male population, and proportion of females with young-at-foot.

Vegetation Survey

The vegetation survey was conducted along the same transects used to survey kangaroos (Figure 1). The wheel point technique [39] was used to give a frequency estimate of plant species' aerial foliage percentage cover, height and greenness (measured as a proportion of the total plant that was green) for every 200 m 'segment' along each transect. The frequency scores were pooled into 'representative' classes on the basis of similar plant growth form and height (Table 1).

Table 1. The major cover categories and growth forms scored during the wheel point surveys of vegetation cover.

Category	Growth form and species harvested	Height (cm)
Bare ground, Soil, Litter	-	-
Sedge	Juncus sp.	35
Weeds	H. amplexicaule E. plantagineum C. solstitialis	20 25 25
Short forbs	Vittadina sp. Medicago sp.	10 and 20 5

	Helichrysum sp.	10 and 20
Tall forbs	C. bonariensis	100
Stem grass: grass with cylindrical leaves	Stipa sp.	10 and 25
Blade grass: grass with broad blade-like leaves	Cynodon sp. (short) Bothriochloa sp. (tall)	5 10 and 25

The frequency scores were corrected for sampling over-estimation (because of the diameter of the wheel point spoke relative to that of a 'true point' [40] and then converted to a percentage cover of the 200 points taken per 200 m segment. A pilot study showed that 150 points gave a good estimate of plant percent cover.

Plant percentage cover was converted to a biomass estimate for each representative plant growth form. Simple linear regression was used to determine the relationship between six independent cover estimates ranging from 10-50 percentage cover (within a 1 m^2 quadrat) for each plant growth form, and the harvested standing biomass of that same plant growth form. Harvested plants were oven dried at 80 ^oC for two days to give dry biomass. These masses were used in the calculation of percentage cover versus dry biomass regressions. These relationships were then used to extrapolate percentage cover data to biomass estimates for each 200 m segment. Transect locations were surveyed using real-time differential GPS. The points were formatted into Arc/Info "expor" file format for future use in both the GIS and image processing packages.

Remote Sensing

A Landsat Landsat 5 scene acquired on 8th February 1997 was selected for analysis as it was coincident with field work and cloud free. The image was ordered ortho-rectified and resampled to a 25m pixel using cubic convolution. Image processing and analysis was undertaken in Terrascan 3.4-2 and IDRISI for Windows II. Prior to analysis, forest areas were classified using a minimum distance to means supervised classification. This classification was used to mask out forested areas from the Landsat imagery. Bands were corrected for path radiance using the regression intersection method [41] and cross checked by calculating path radiance contribution using an in-house atmospheric spreadsheet model.

Classifying habitat types

Field classification was used to identify relatively homogeneous patches of vegetation that were then qualitatively classified into 11 broad habitat types based on visual comparison. These habitat types were located within the Landsat image using IDRISI. Vector training sites were defined for each habitat type. Spectral signatures were generated and plotted in a two dimensional multi-spectral space to test for spectral separation. The spectral signatures were used to classify the image into 11 habitat categories using a minimum distance top means algorithm. A modal filter was applied to the final classification to remove single classified pixels.

Correlating plant biomass with Landsat Bands

The vegetation transect segments were imported into IDRISI as vector files, each with its own unique identification number. The segment was then used as a training site and an average brightness value was calculated for each of the six bands, for each 200 m segment (this approximates a row of eight 25 m pixels) within all transects. These data were transferred into a spreadsheet. A simple band ratio (Band 4/3, 3/1 and 3/2) and a Normalised Difference Vegetation Index (NDVI) were generated from the data.

Only 200 m by 25 m segment strips known to contain only pasture were used in analyses, leaving 14 of the original 46 segments in the final analyses. Using ‘pasture only segments’ removed the influence of features including trees, breached dams, rocky outcrops and roads on the image data.

Partial correlation coefficients and simple linear regression were used to determine the relationship of plant biomass to each of the six spectral bands derived from the Landsat image and the ratios generated from them. Blade grass forms the basis for kangaroo food resources[38]. Therefore, only total, total grass, blade grass and stem grass biomass (and not cover) were used in these analyses as it better reflected the distribution and availability of kangaroo food resources.

Principal component analysis with Varimax rotation was then used to reduce the 6 bands into simpler combination components (with Eigen values >1). The principal component or spectral band(s) that correlated with total, blade grass, stem grass and total grass (=blade+stem) biomass were then used to generate an image of the distribution of biomass throughout the study area.

All statistical analyses were performed using SPSS (vers. 7.5 1997). All data sets were tested for normality and Log10(x+1) transformed when required and means are presented with +/standard errors (S.E.). Analyses were deemed significant for $P<0.05$.

Correlating plant biomass with kangaroo density

Partial correlation coefficients were used to determine the direct relationship of total, total grass, blade grass and stem grass biomass to the density of the female, female with young-at-foot, large male and total kangaroo population. Animal density was calculated for each 200 m segment. Segment width was truncated to include only those animals that were counted 75 m either side of the transect line. This restricted counted animals to within the same broad habitat type that was measured along the transect.

Correlating Landsat image spectral signatures with kangaroo density

Two methods of analysis were employed. The first was the correlation of female, female with young-at-foot, large male and total kangaroo density with the spectral signatures (using only the 14 pasture segments). This allowed- a complementary analysis that matched the previous vegetation-spectral signature analyses. In the second, the density of the female, female with young-at-foot, large male and total kangaroo population was mapped in ArcView using a 100 m grid with contours interpolated using the twelve nearest neighbours groups to each group of animals. This gave each group and 'area of occupation' rather than a single point of influence. In this environment, Eastern Grey Kangaroos probably shift the daily centre of their foraging home range centre 100-200 m, foraging over only a few hectares [42]. Hence, using an 'area of occupation' better reflects habitat use over that period of time.

The maps of kangaroo density were compared with that Landsat spectral signature that correlated best with plant biomass. This permitted a visual assessment of the correlation between kangaroos and the spectral interpolation their food resources.

Results

Kangaroo Survey

A total of 1703 kangaroos in 372 groups were counted within the study site in 2 surveys across 6 days. The dispersion of animals across the study site did not appear to change across the survey period. Females and juveniles dominated the observed population (Table 2).

Table 2. Relative proportions and density of each size/sex class in each transect segment after adjustment for unknown animals.

Size/sex class	Proportion of Population	Proportion of adult population	Density (ha +/- S.E.)
Juveniles	0.43	-	3.7 +/- 0.5
Females	0.17	0.30	1.5 +/- 0.3
Female with young-at-foot	0.23	0.40	2.0 +/- 0.3
Small + medium males	0.13	0.23	1.1 +/- 0.4
Large male	0.04	0.07	0.3 +/- 0.5

Vegetation Survey

Plant percentage cover and biomass estimates were derived from wheel point data for each of the 46 segments within the study site. The regression equations used to convert percentage cover to biomass are shown in Table 3.

Table 3. Regression equations for the relationship between vegetation % cover (x) and the dry vegetation biomass (y) for the plant growth form categories measured during wheel point surveys. n=6 in each case All regressions were significant with P<0.01.

Category	Growth form	Height (cm)	Regression equation	r^2
Sedge	Juncus sp.	35	y=11.43x	0.95
Weeds	H. amplexicaule E. plantagineum C. solstitialis	20 25 25	y=0.96x y=16.71x y=12.2x	0.98 0.99 0.91
Short forbs	Vittadina sp. Medicago sp. Helichrysum sp.	10 and 20 5 10 and 20	y=0.51x y=2.65x0.947 y=1.62x1.02	0.89 0.98 0.85
Tall forbs	C. bonariensis	100	y=16.708*x0.8	0.91
Stem grass	Stipa sp.	10 and 25	y=3.13x1.039	0.97
Blade grass	Cynodon sp. (short) Bothriochloa sp. (tall)	5 10 and 25	y=0.46x y=0.61x	0.95 0.96

The distribution of plant percentage cover and biomass across the study site varied considerably for the various plant categories (Table 4). Virtually all plants were green during this survey as rainfall had been high for the 12 months prior to this survey.

Table 4. Range in transect segment biomass estimates for representative plant groups.

Category	Growth form	Mean segment biomass (g m^2 +/-S.E.)	Mean segment cover (% +/- S.E.)
Sedge	Juncus sp.	53.4 +/- 12.9	8.3 +/- 1.7
Weeds	H. amplexicaule	7.2 +/- 1.0	14.81 +/- 1.55

	E. plantagineum	+/- 1.8	0.24 +/- 0.11
	C. solstitialis	22.5 +/- 3.6	16.6 +/- 1.5
Short forbs	Vittadina sp.	18.4 +/- 2.3	20.2 +/- 1.7
	Medicago sp.	9.9 +/- 1.4	11.0 +/- 1.0
	Helichrysum sp.	0.3 +/- 0.1	3.2 +/- 0.4
Tall forbs		41.7 +/- 4.8	9.1 +/- 1.7
Total forb		35.6 +/- 2.2	28.87 +/- 1.18
Stem grass	Stipa sp.	10.5 +/- 3.8	16.4 +/- 0.8
Blade grass	Cynodon sp. (short)	37.3 +/- 3.3	29.3 +/- 1.5
	Bothriochloa sp. (tall)	3.1 +/- 0.5	7.5 +/- 0.6
Total grass		50.9 +/- 3.3	53.2 +/- 1.1
Total biomass/cover		218.4 +/- 12.9	60.9 +/- 0.8

Classifying habitat types

The cleared pasture area of the study site is clearly distinguishable from the surrounding woodland in the Landsat image (Figure 1). Eleven habitat types were identified within the study site (Figure 2). These were patchily distributed throughout the area, with Juncus and weeds predominating along creek lines and short-forb pastures dominating towards the centre of the study site. Forb-grass pastures showed extensive coverage while patches of green grass dominated habitat were contained within these. These grass pastures occupied a relatively small area. The green grass-forb pastures best represent high quality kangaroo food resources. Areas of wooded habitat stand out as discrete patches, particularly along the creek line, at the tops of hills, and encompassing the study site.

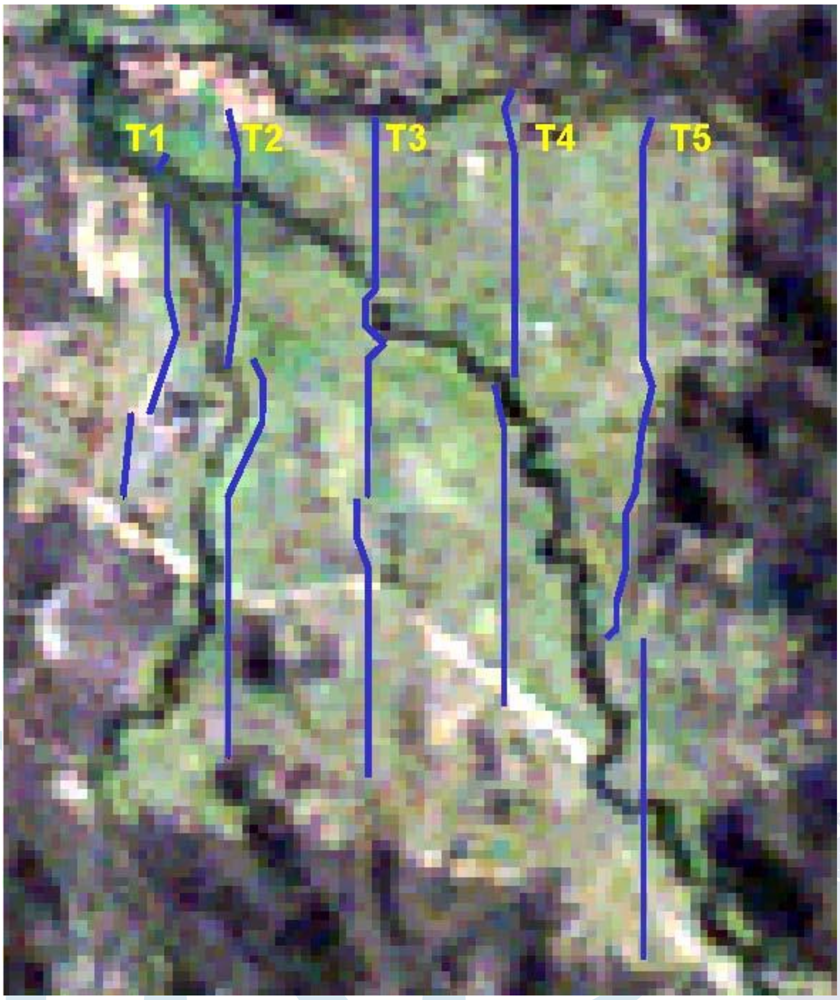

Figure 1. Landsat TM image acquired over study site on 8th February 1997 (B-1, G-2, R-3). The black diagonal band running south-east to north-west is Wambelong Creek dominated by Casuarina and Eucalyptus trees. The white line running south-east to north-west represents a major bitumen road through the study site. Transects are also shown (T1, T2, T3, T4 and T5).

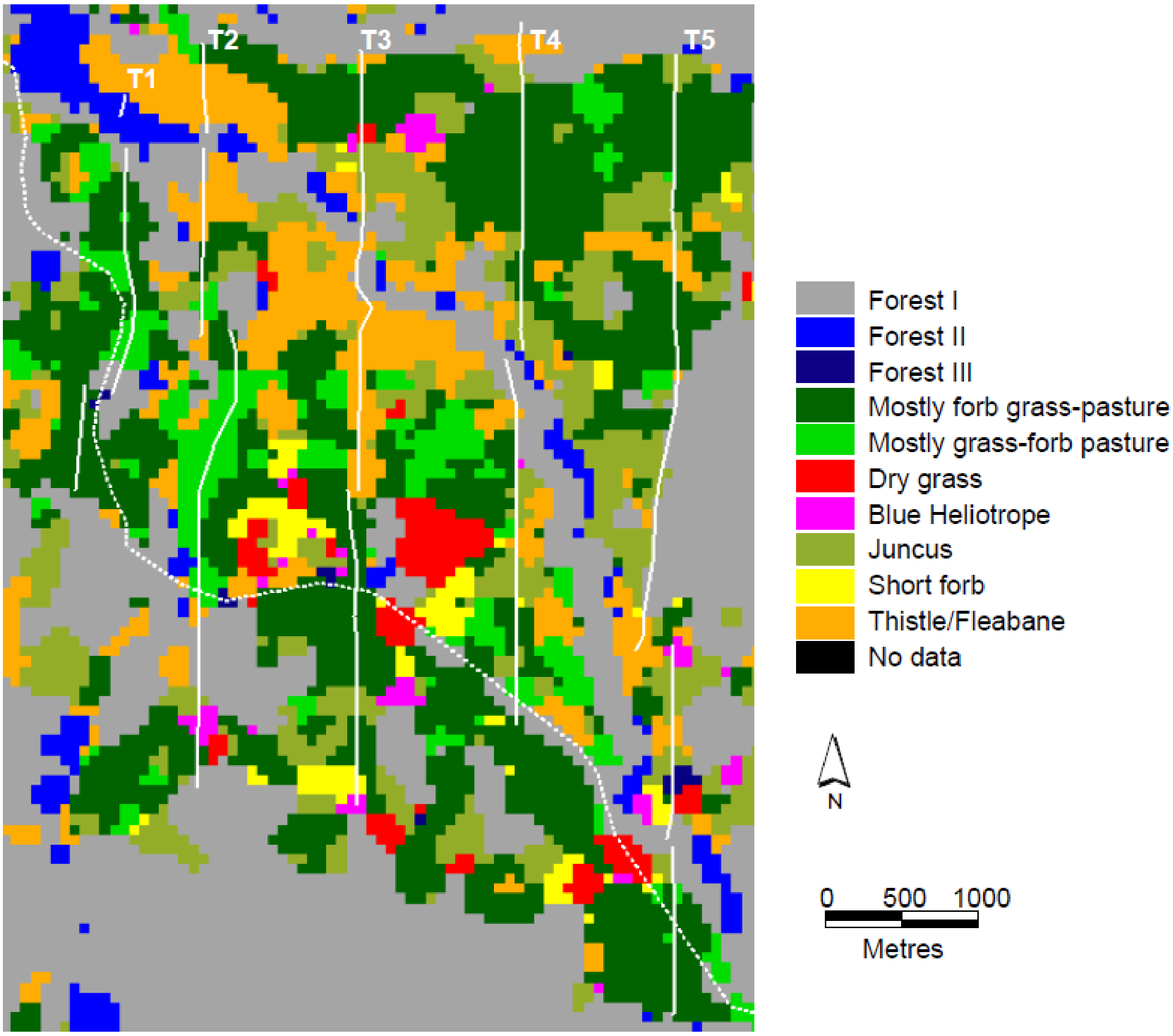

Figure 2. Map of habitat types predicted by supervised classification based on spectral signatures 'trained' in IDRISI from habitat types identified in the field.

Correlating plant biomass with Landsat image spectral signatures

The average brightness value for all transects for each band is presented in Table 5. There was a significant correlation among all bands except for between bands four and seven.

Table 5. Mean brightness value index (BV) for the pasture segments for each of the six spectral bands from Landsat TM image. (n=14 in each case).

Band	Mean BV index (+/- S.E.)
1	79.22 +/- 1.81

2	32.34 +/- 1.05
3	32.24 +/- 1.28
4	66.26 +/- 4.88
5	99.42 +/- 7.70
7	44.38 +/- 3.92

Table 6. The Varimax rotated component transformation matrix showing loadings for each principal component.

		Principal component (PC)				
Band	1	2	3	4	5	6
1	0.63	0.61	0.37	0.32	0.02	0.02
2	-0.59	0.16	0.79	-0.06	0.06	0.03
3	0.49	-0.68	0.49	-0.22	0.06	0.04
4	-0.13	-0.37	0.06	0.91	-0.15	-0.07
5	0.04	0.03	0.09	-0.16	-0.89	-0.42
6	0.01	-0.01	0.01	-0.01	0.42	-0.91

Table 7. Pearson's coefficients of correlation for biomass against spectral data. Correlation probabilities: * P<0.05, ** P<0.001.

Biomass	Band 1	Band 3	PC1
Total	-0.52	-0.52	-0.31
Blade grass	0.83**	0.74**	0.74**
Stem grass	-0.23	-0.34	-0.16
Total grass	0.77**	0.64*	0.73**

Table 8. Regression equations for the relationship between the two TM bands and PC (x variable) and short blade grass biomass (y predicted variable).

Band/PC	Regression equation	R^2	p-value
Band 1	y = 8.017x -599.382	0.69	<0.001
Band 3	y = 10.1x - 289-871	0.54	<0.01
PC1	y = 16.7x + 38.81	0.55	<0.01

Table 9. Pearson's coefficients of correlation for short blade grass biomass against ratios.

Short blade grass	Ratio of band 3/1	Ratio of band 3/2	Ratio of band 4/3	NDVI
Biomass	0.477	0.425	-0.174	-0.182
% cover	0.479	0.485	-0.198	-0.205

A principal component analysis of these data identified one component (PC1 Eigen value = 4.32) that described 72% of the variance in the spectral data (Table 6). The component loadings for each principal component indicate a heavy bias to the visible part of the spectrum and a minor negative contribution from the infra-red (Table 6).

There was a significant positive correlation of green, short blade grass and total grass biomass against bands one, three and PC1 (Table 7). Stem grass and total biomass both showed negative correlation with spectral data although the correlation was not statistically significant. All regression models showed positive correlation between short blade grass biomass and the two TM bands and PC1 (Table 8). There was no significant correlation of green short blade grass biomass or percentage cover to any of the band ratios or the NDVI (Table 9).

Correlating plant biomass and with kangaroo density

Only the correlation of green, short blade grass biomass against total animal density was significant (Pearson's r=0.61, P<0.05, n=14). This is as expected as it reflects the preferred food that is available to kangaroos.

Correlating Landsat image spectral signatures with kangaroo density

1. Pasture segments

Total, female, female with young-at-foot and large male kangaroo density was correlated with bands one, two and three and PC1. The only significant correlation was that of band three against total animal density (Pearson's r=0.54, P<0.05, n=14).

Given this relationship, the predicted distribution of green, short blade grass biomass based upon Band 3 was generated in the GIS. This then indirectly reflects the distribution of preferred kangaroo food resources, showing a patchy distribution across the study site (Figure 3).

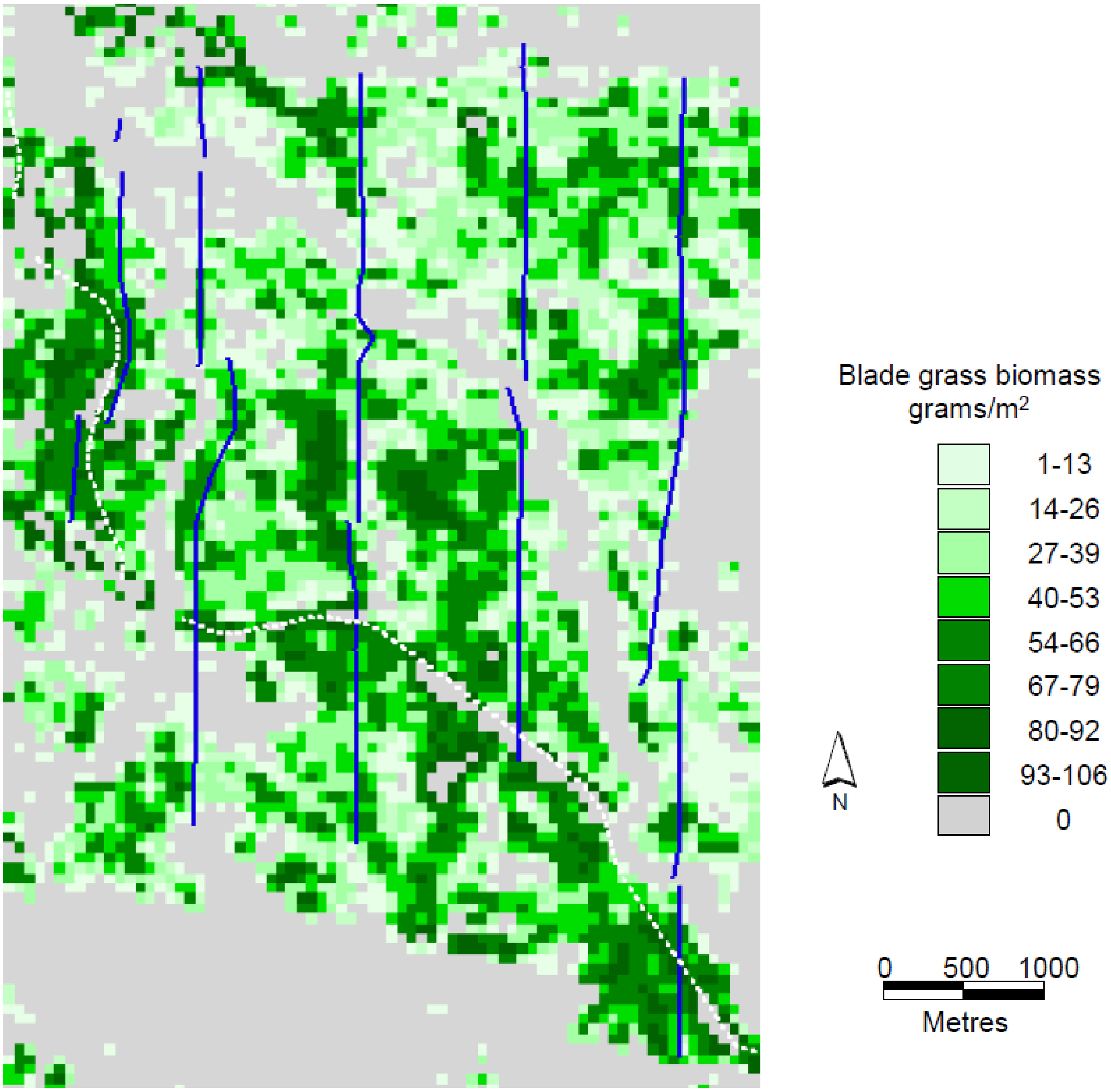

Figure 3. Green, short blade grass biomass as predicted by Landsat TM using regression equation (see Table 8) for Band 3.

2. Total Kangaroo Density

Density was variable ranging from 1-20 animals per hectare and the distribution is patchy (Figure 4). Four distinct areas of intense habitat use are apparent. These areas tend to be small, disjunct, and are often defined by only one or two grid cells. Three of these are close to the forest edge that surrounds the study site.

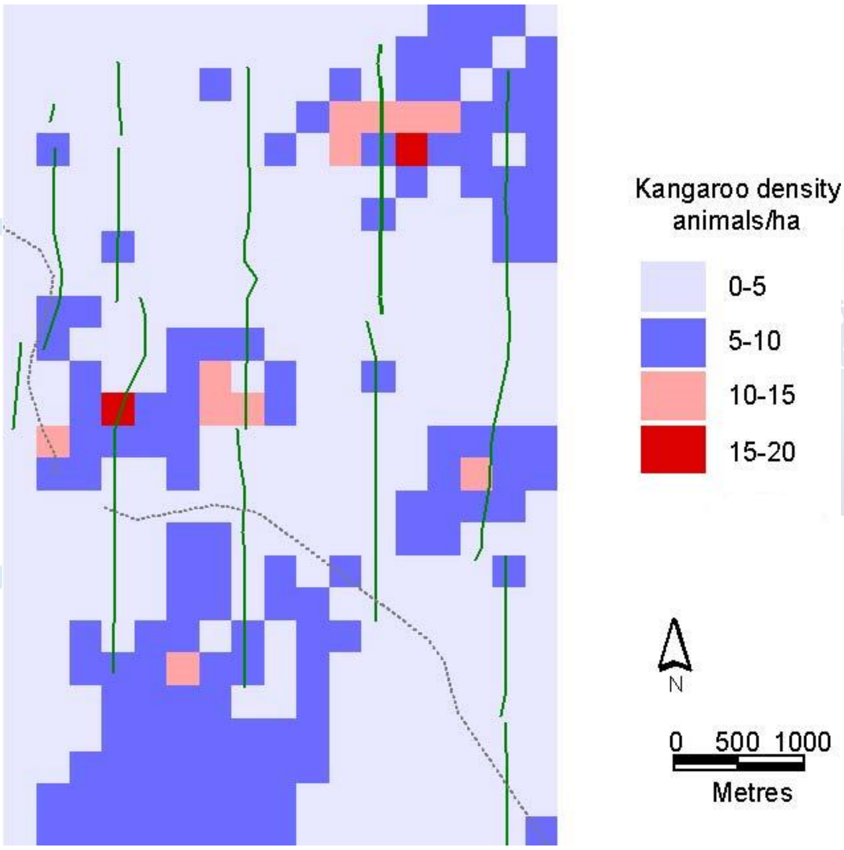

Figure 4. Density distribution of the total kangaroo population (n=1703 individuals, 372 groups) across the study site.

Discussion

The lack of a significant correlation between green, short blade grass biomass and the NIR (or any vegetation based ratio) is, at first, somewhat surprising. These finding are supported, however, by the work of Todd et al. (1998). They found that in grazed environments, a variety of vegetation ratios were not significantly correlated to biomass while the visible red was negatively correlated.

The poor performance of NDVI was similarly reported by Ripple [43] who found linear regression using spectral bands gave superior results albeit at different scales. In a much later study Pople et al. [18] (p 1077) maintained that " more extensive NDVI data may be able to predict movement and the resulting changes in distribution of kangaroos" Even so, if a ratio had proven more successful, it must still be calibrated by regression to biomass variables as no explicit relation exists between band ratios and vegetation biomass [34]. This makes band ratioing less desirable if straight regression is satisfactory. Other work has also shown that the relationship between vegetation cover and ratios (including NDVI) tend to vary according to plant type *34* ~~(Sannier and Taylor 1998)~~, the season [44], annually [45] and geographically (i.e., site specific). However, NDVI has been successfully applied in other situations, particularly in the Northern Hemisphere [35]. NIR models probably do not work at the Warrumbungles due to a less projected area of green leaf matter to the sensor with concomitant enrichment of NIR with respect to red. Variations of NDVI such as the Soil Adjusted Vegetation index (SAVI [46]) have attempted to overcome these issues with limited improvement [47].

Of equal significance is the positive correlation between biomass and the visible blue/red (TM Bands 1 and 3) which permits us to accept the first hypothesis. If pigment absorption is the dominant factor in vegetation colour we would expect a negative correlation between biomass and TM1 and TM3 as found by Todd [32]. Graetz [48] suggested that the visible red was correlated to vegetation cover because the vegetation itself is darker than the underlying bright soil. The relationship is therefore established on percentage light soil versus dark vegetation.

At the Warrumbungles, the soils are derived from basalt parent material and are mostly very dark. The opposite situation to that encountered by Graetz, and confirmed by Todd et al. would explain the positive correlations found in the regressions. At the Warrumbungles, the soil is very dark and the vegetation (and its litter) is brighter than the soil background. More vegetation makes an area brighter, hence the positive correlation. Given this situation it is understandable that vegetation indices based on band ratios were not successful.

The distribution of green, short blade grasses fits that of the kangaroo distribution, both from the correlation with field biomass measurements, and that predicted by the Landsat spectral signatures, and so the second and third hypotheses can be accepted. However, several explanations can be offered as to why these correlations were not tighter.

Firstly, predation threat and proximity to forest cover secondarily influence the distribution of kangaroos [49]. It was anticipated that areas of high density would be in close proximity to the forest cover that surrounds the cleared area, i.e., towards the edge of the study site. This is true for most areas of high kangaroo density, but not all short blade grass areas (Figure 4). Animals were still found in moderate densities towards the centre of the study site, suggesting that there is sufficient lateral cover to provide protection from the weather and predation threat if needed.

Secondly, social and spacing behaviour may play a role in modifying not only the dispersion but also the size/sex class structure of social groups. Smaller males are often found in low density away from the bulk of the female population, females with young may isolate themselves, and large males are often found 'between' habitats as they move in search of females ready for mating [49, 8]. There was no clear evidence of spatial separation of size/sex classes although males tended to be more evenly dispersed than females.

Thirdly, biomass per se is often not a good predictor of herbivore dispersion because more productive areas tend to be grazed more heavily, and so support low food biomass levels [50]. Hence, the productivity of the food resources should determine the density of animals that an area can support, not the amount of food that is there. All areas of high kangaroo density can be visually correlated to high short blade grass biomass apart from one group found half way along transect 5. The correlations with green blade grass biomass reflects kangaroos occupying areas where preferred food types exist. The fact that the correlations are against biomass suggests that these areas must also be able to produce higher biomass more quickly.

Analysis of imagery has successfully interpolated vegetation type and biomass between transects. A good example where the image has provided data not present in the transect data can be found on transect 3. Data collected during the vegetation survey mapped weeds at a point approximately half way along transect 3 (Figure 2). Either side of the transect at this point, the image has mapped areas of high blade grass biomass. Field work has confirmed this prediction. Significantly, an area of high kangaroo density does occur there (Figure 4). In this situation the image has mapped a critical patch of vegetation that the field work missed due to the scale of sampling.

Conclusions

This series of analyses represents an investigation of the relationship of animal dispersion to remotely sensed data. We have shown that the distribution and abundance of kangaroos and plant biomass can be correlated with remotely sensed vegetation characteristics taken from a Landsat TM image. Importantly, this study has shown that the distribution of habitat type and quality is only one governing factor in the distribution of Eastern Grey Kangaroos.

Remotely sensed imagery can be acquired at a variety of scales and is therefore useful to ‘scale’ field data down to fine scales and up to regional scales. Scaling down vegetation data using remotely sensed imagery allows an analysis of vegetation quality within habitats that can then be used to account for animal distribution at a finer scale than was previously possible.

Animal-centred determination of habitat use permitted the definition of preferred kangaroo resource use (green blade grass) at a fine spatial scale. The factors determining the dispersion of male and female kangaroos within these habitat types, and their relationship to remotely sensed vegetation characteristics will be investigated at a finer scale. This has implications for improving models of animal dispersion at the landscape level.

Author Contributions

Both authors collaborated on all aspects of this research. G Moss undertook fieldwork and N Rollings undertook image analysis and GIS work. The manuscript was prepared by both authors.

Conflicts of Interest

"The authors declare no conflict of interest."

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