Moving from Discrete to Continuous Landscape Metrics Using Remote Sensing: The Ecological Significance of Paddock Trees for Bird Richness

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EXTENDED ABSTRACT

Isolated trees and small patches of trees – paddock trees – are very common within the agricultural landscapes of Southern Australia. These paddock trees potentially represent important natural habitat elements within the agricultural matrix for a variety of fauna, in particular birds. However, the numbers of paddock trees are declining rapidly in many areas which threaten the biodiversity values of these landscapes.

To study the importance of these trees for bird species richness (sampled in 120 sites), we mapped isolated trees and forest cover from Landsat7 and SPOT 5 images using a combination of the normalized difference vegetation index (NDVI), spatial filtering and threshold values. The results of the isolated trees map were verified visually using measures of omission and commission based on a high resolution (2.5m) pseudo natural colour SPOT image on which individual trees could be clearly distinguished. A high level of accuracy (80%-90%) was achieved in deriving a layer of trees represented as point objects in areas with low-medium tree cover. The overall percent cover of isolated trees and forests as mapped from the combined map of isolated trees and the classified Landsat image explained 60% of the variability of the foliage projective cover (FPC) as digitized from the high resolution (2.5m) SPOT images.

Various discrete and continuous landscape metrics were calculated based on the tree and forest mapping. These included traditional landscape metrics available within Fragstats software, as well as continuous landscape metrics which were based on spatial filtering and distance from and within patches. The relevance of both types of metrics for bird richness was analysed according to functional groups of birds (woodland and non-woodland). Remotely sensed forest cover at spatial scales between 0.03 and 0.28 km^2 was found to explain almost 50% of the variability in overall bird richness and 60% of the variability in woodland bird richness. However, paddock trees and small patches of trees or forest did not contribute to the explanation of the spatial variability in overall avian richness. The work provides a novel approach to investigating the ecological relevance of small and isolated landscape features, such as paddock trees, for bird species richness.

Figure 1: Photographs of a paddock tree and a small patch of trees

1. INTRODUCTION

Isolated trees and small patches of remnant trees are very common within the agricultural landscapes of Australia, where they are known as paddock trees (Reid and Landsberg, 2000). Remnant trees potentially represent important natural habitat elements within the agricultural matrix for a variety of fauna, in particular birds and bats (Harvey and Haber, 1999; Daily et al., 2001; Fischer and Lindenmayer, 2002a,b; Gibbons and Boak, 2002; Lumsden and Bennet, 2005). However, the declining numbers of paddock trees in many areas is threatening the biodiversity values within these landscapes (Dorrough and Moxham, 2005).

Assessing the use of paddock trees by birds in an agricultural landscape in New South Wales (Australia), Fischer and Lindenmayer (2002a,b) found that some bird species appeared to be more likely to be detected at sites more than 200 m from woodland, and concluded that paddock trees have the potential to enhance landscape connectivity by acting as stepping stones to assist movement. Working with the same data as in our study, Kavanagh et al. (2007) found that more birds were recorded in all vegetation types (planted and remnants) compared with paddocks, and that only one bird species (from a total of 138) was restricted to paddocks.

Both studies by Fischer and Lindenmayer (2002a,b) and by Kavanagh et al. (2007) relied on field mapping and manual interpretation of habitat characteristics in the field and from a visual interpretation of aerial photographs to map discrete patches of vegetation (Kavanagh et al., 2005). However, the use of discrete landscape metrics may not be appropriate here, as these landscapes represent "a habitat continuum, so that some birds did not distinguish between patches and paddocks as perceived by humans" (Fischer and Lindenmayer, 2002a, p. 822). Therefore, the use of discrete landscape metrics may not be appropriate here and may not give us a complete understanding of the interaction between birds and tree and forest cover (Li and Wu, 2004). In recent years there has been an increasing awareness of the need for using continuous data for land cover modelling and fragmentation, however few studies have attempted to develop and apply continuous landscape metrics, which are usually based on remotely sensed images or image based maps of continuous variables (but see Pearson, 2002; Southworth et al., 2004).

2. OBJECTIVES

Our research objectives were therefore three-fold: (1) To develop and test methods for mapping isolated trees in agricultural landscapes from medium-high resolution satellite images (2.5 – 30 m); (2) To develop continuous landscape metrics and examine their ability to understand spatial patterns in bird richness in comparison with traditional discrete landscape metrics; (3) To examine the role of paddock trees and small patches of remnant trees for bird richness

3. METHODOLGY

3.1. Study area

The 'twin cities' of Albury-Wodonga are located on the New South Wales–Victoria State border at the upper reaches of the Murray River. The region was first visited by Europeans in the 1820s and settlement followed shortly afterwards. By 1900, most of the original forest and woodland had been cleared, and grazing by sheep and cattle became the dominant land use. Remnants of the original forest and woodland vegetation now scattered throughout the region (approximately 10% cover). The climate is characterized by hot, dry summers and cold, wet winters. Mean annual rainfall for Albury Airport during 1973–2004 (31 years) was 737 mm, with mean daily maximum and minimum temperatures of 30.9°C (January) and 2.6°C (July), respectively (Australian Bureau of Meteorology).

3.2. Research design

Our research design included a total of 12 'treatment' classes (representing different vegetation types and patch area categories), each of which was replicated 10 times, providing a total of 120 sites for sampling. All 120 sites were located between Holbrook (35°37′S, 147°34′E) in southern NSW and Wangaratta (36°23′S, 146°25′E) in northern Victoria. Within this landscape, almost all planted sites were located within 5 km of a forest remnant >0.10 km^2 in size. Additional details on the sampling design are given in Kavanagh et al. (2005, 2007).

3.3. Field sampling

Sampling was conducted along a transect 200 m long in each study site (n = 120 sites). Systematic (fixed-time, fixed-area) counts were made for birds at two sampling points in each study site. A point-based, 10 minute count at each of the two 7850 m^2 circular plots (radius of 50 m) was employed as the basic sampling unit for diurnal birds in this study. Two counts were made at each point, on different days and by different observers, during November–December 2002. Birds flying through the area were not recorded on the plots unless they were regarded as making some use of that vegetation type, for example, foraging above. We used the classification of Kavanagh et al. (2007) to distinguish between woodland bird species (n=62) and non-woodland bird species (n=49).

A range of variables was recorded at each site to describe aspects of its vegetation and physical structure (e.g. log and rock cover), topography, grazing history and landscape connectivity. Each attribute was assessed on one plot 20 m × 50 m (1000 m^2) per site. All cover and height variables were visually estimated. Of particular interest in this study are the estimates of percent cover of overstorey and shrub, as well as tree counts. Tree species were recorded along with their diameter at breast height (dbh) in categories of <10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-60 cm and >60 cm. Additional details on the field sampling are given in Kavanagh et al. (2005, 2007).

3.4. Satellite images

Satellite images covering the study area were chosen according to criteria of cloud cover, seasonal dynamics and spatial resolution. Two Landsat 7 Enhanced Thematic Mapper (ETM+) images (path 92, row 85) at a spatial resolution of 28.5 m (for the spectral bands) and 14.25 m for the panchromatic band were used (Data available from USGS/EROS, Sioux Falls, SD). The Landsat scene covers all of the study area except for two sites in the north-east. The Landsat image from August 16, 2002 corresponded with the peak of the rainy season, when the understorey vegetation of the agricultural fields was green, making it more difficult to map isolated trees within the fields. We therefore used another Landsat image from February 8, 2003 corresponding with a minimum rainfall period, when only irrigated fields had green vegetation cover (99% of the irrigated fields were located at distance greater than 10km from the nearest study sites). The Landsat image was used to map the large patches of plantations and remnant forests.

Although some of the large trees can be identified on the pan-sharpened Landsat image, we used higher resolution SPOT 5 images to map the isolated trees. We used two SPOT 5 images at a spatial resolution of 10 m (for the spectral bands) and 2.5 m for the panchromatic band. These SPOT images covered most of the sites, and were acquired on May 5th, 2005, and January 5th, 2005. For half of the Victoria sites we only had a SPOT 5 pan-sharpened pseudo-natural colour image at a spatial resolution of 2.5 m. The date this image was acquired was not provided, but it appears to be sometime between March and May.

3.5. Mapping forest and trees from satellite imagery

All the SPOT images were provided in the Geocentric Datum of Australia 1994 (GDA94), zone 55. The Landsat image was rectified to the SPOT images using a first order polynomial transformation (n = 50, RMSE = 13.4m). Forest patches were classified from the Landsat image using the Mahalanobis (1936) Distance classifier (maximum distance error of 4). This classifier was applied to Landsat's six spectral bands and an additional band of the normalized difference vegetation index (NDVI; Tucker, 1979).

Working in the same area, Gibbons and Boak (2002) mapped woody vegetation and isolated trees using threshold values from a SPOT panchromatic band. However, when using images of a high spatial resolution, individual trees may be detected using more sophisticated methods based on spatial filters (Pitkanen, 2001; Culvenor, 2002). For the study sites where only a pseudo natural colour pan-sharpened SPOT image was available, we could not apply traditional vegetation indices to map the isolated trees, because pseudo natural colour products are not necessarily radiometrically correct: they have been optimized for visual interpretation - not for digital analysis. Proprietary, non-disclosed algorithms, are used to generate commercial pseudo natural colour products from various sensors (Knudsen, 2003). Instead, we took advantage of the fact that this image was acquired when the agricultural fields were mostly without green vegetation, and that the sun elevation was low so that trees cast shadows towards the south-west. We developed a "shadow technique" for mapping isolated trees based on the adjacency of a green canopy area and a shadow area that are smaller than a user defined threshold area size (Figure 2). Applying the shadow technique to the 10 m multispectral SPOT images had poor results, and we therefore used a different method for those images, taking advantage of the availability of the near-infra red band to calculate NDVI, which has been shown to be correlated with percent tree cover as well as with plant and bird richness in recent studies (Levin et al., 2007; Bino et al., in press). The "NDVI technique" for mapping isolated trees was based on a combination of high-pass filters and user-defined threshold area size.

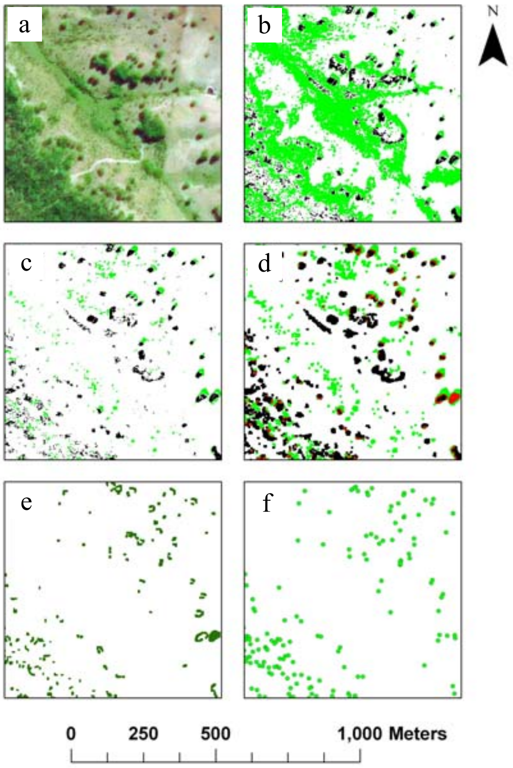

Figure 2: Steps used in the "shadow technique" for mapping isolated trees from a pseudo-natural colour 2.5 m SPOT image of March 2004: (a) The SPOT image; (b) a parallelepiped classification for green (trees) and dark (shadows) areas, using a maximum threshold of three standard deviations; (c) after removing all classified patches whose area was greater than 0.1 ha; (d) after applying a maximum filter of 3×3 pixels separately for the tree and shadow patches (in red – areas where tree and shadow patches overlap); (e) the overlap polygons (f) the centres of the overlap patches were identified as trees, and exported as a point layer.

The maps of isolated trees were first validated in a "training area" of 4.3 km^2 which consisted of isolated trees at various densities (no continuous forest patches), and in which all SPOT and Landsat images overlapped. In that area, we visually identified and digitized 337 isolated trees on the pseudo natural colour 2.5m SPOT image. We then examined this layer to see how many of these trees were identified by the algorithms described above, and how many of the automatically mapped trees were really trees or just "false positives". Based on this step, we determined which SPOT image to use as the source for the isolated trees layer in areas where there is an overlap between the SPOT images. We validated the isolated trees using two additional data sets for the study sites. In 34 of the field sites isolated trees could be visually identified and were therefore digitized for 50 m radius circular plots around each study site. For these sites we compared the number of trees that were counted in the field with those extracted visually and automatically from the SPOT images. In sites were the tree cover was continuous, we did not expect to be able to map isolated trees, only percent tree cover.

The isolated trees were added to the forest cover map to produce a map representing the total foliage projective cover (FPC). This map was validated against field estimates of overstorey and shrub cover, and also against digitized areas of foliage projective cover as estimated visually from the pseudo natural colour images for 50 m radius circular plots around each study site.

3.6. Spatial analysis of landscape metrics

The results of the above analyses yielded two types of maps: a continuous metric (NDVI) and a binary map of FPC (both at a spatial resolution of 28.5 m). We used the FPC map to calculate a variety of discrete and continuous landscape metrics (Table 1). Discrete landscape metrics of patch area, number and isolation were calculated using Fragstats 3.3 (McGarigal et al., 2002) at various buffer distances (50, 100, 200 and 400 m) around the study sites.

Table 1. The landscape metrics used in this study.

Name	Type	Remarks
Percentage of landscape covered by forest and trees (PLAND)	Discrete	
Patch number (NP)	Discrete	
Patch area statistics	Discrete	mean, standard deviation, coefficient of variation
Proximity indices	Discrete	Euclidean nearest neighbour distance
NDVI	Continuous	
Foliage projective cover (FPC)	Continuous	
Distance from patches	Continuous	
Distance within patches	Continuous	

The continuous landscape metrics based on the FPC map included: (1) percentage cover of FPC (%FPC); (2) Distance from patches; (3) Distance within patches from their edges; (4) Combined distances, where distances from patches had negative values, and distances within patches had positive values (Figure 3). These metrics were subsequently passed through a mean filter at various spatial scales (radius of 50, 100, 150, 200, 250, 300, 350 and 400m) to determine the best prediction area, following Bino et al. (in press). To analyse the importance of paddock trees and small patches of trees/forests, we calculated the above continuous variables of % cover and distance for the manipulated versions of the FPC map which included only patch areas greater than a minimum threshold of 1 to 100 pixels, or only patch areas smaller than 1 to 100 pixels. Bird richness was expected to be positively correlated with %FPC and distance within patches, and to be negatively correlated with distance from patches.

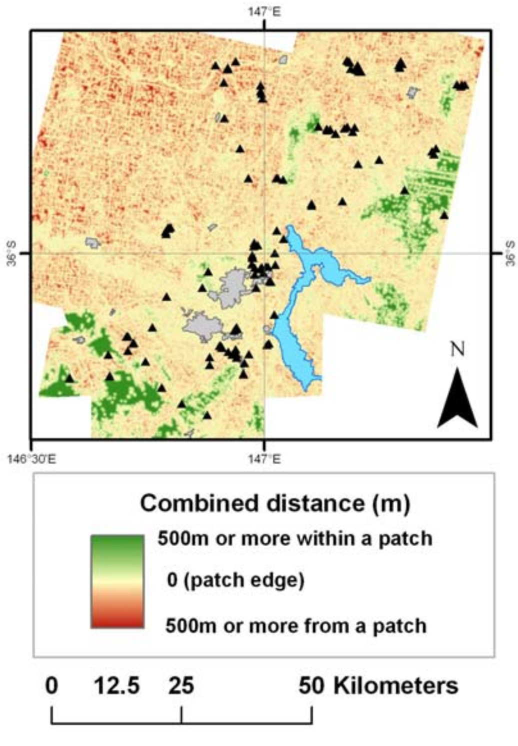

Figure 3: Map showing an example of one of the continuous landscape metrics that were used: combined distances, where distances from patches (a patch may be a single tree or a whole forest or plantation) have negative values, and distances within patches have positive values. The study sites are the black triangles and the built-up areas are shown in grey.

4. RESULTS

4.1. Validation of forest and tree mapping

Strong relationships were achieved in mapping the isolated trees within the training area, for all of the SPOT images. The shadow method worked well only in the pan-sharpened SPOT image at a spatial resolution of 2.5m. Overall the NDVI method outperformed the shadow method in mapping more trees, with more than 90% of the digitized trees identified, although the spatial resolution used was four times coarser (10m vs. 2.5m). The percent cover of forest and isolated trees combined (as mapped from the satellite images) was highly correlated with digitized areas of foliage projective cover as estimated visually from the pseudo natural colour images within the 50 m radius circular plots ($r^2 = 0.62$).

4.2. Correlation between bird richness and landscape metrics

Remote sensing estimations of %FPC were positively correlated with overall bird richness ($r^2 = 0.45$), and especially so with woodland bird richness ($r^2 = 0.59$). From the various discrete landscape metrics that we analysed, the percentage of landscape covered by forest and trees (PLAND) was the only metric that was strongly correlated with bird richness, whereas the number of patches (NP) and isolation indices were poorly correlated with bird richness. As there was a strong negative correlation between FPC and NP, it seems that loss of habitat had a stronger effect on bird richness than fragmentation *per-se*. Values of NDVI (February 2003) were highly correlated with % of FPC, and accordingly NDVI values were positively correlated with bird richness reaching maximum correlation at a spatial scale of 0.28 km^2 (radius of 300m; $r^2 = 0.58$ for woodland bird richness). As expected, distance from patches was negatively correlated with bird richness whereas distance within patches from their edges was positively correlated with bird richness. No correlation was found between any of the landscape metrics and non-woodland bird richness.

4.3. The role of paddock trees and small patches for bird richness

Removing small patches from the FPC map did not affect the strong correlation between FPC and bird richness, however it did lower the correlation coefficient slightly, as well as it increased the spatial scale in which maximum correlation was reached. Using only small patches, FPC and bird richness were negatively correlated and the best correlation coefficients were much lower (r^2 =

0.16) than when using all patches. Examining the distance from patches, it seems that removing the small patches from the analysis had no real influence on the strong and negative correlation between distance from patches and bird richness. Distance from small patches is positively correlated with bird richness, however the correlation coefficients obtained are weaker than those obtained from distance from all patches.

5. CONCLUSIONS

The high correlation between FPC and bird richness corresponds with other studies where the remnant areas of native vegetation were found to be a good predictor of bird richness (Miller and Cale, 2000; Bino et al., in press) corresponding with the species-area relationship, according to which species richness increases with increasing area size (Arrhenius 1921; Fernandez-Juricic 2000; Lomolino 2000). Our results indicate that habitat loss rather than habitat fragmentation has large and negative effects on biodiversity as reviewed by Fahrig (2003).

The pattern that emerged from the analysis of the landscape metrics was that overall bird richness (especially woodland bird richness) is higher when forest/tree cover is greater and the distance from forest/tree patches is smaller. Continuous landscape metrics were shown to equal or outperform traditional discrete metrics within the framework of this study. Continuous landscape metrics allow for a more realistic representation of gradients which exist in natural landscapes, whereas within the traditional discrete representation of landscape patches, arbitrary decisions of what is a patch are unavoidable. Our mapping of forest patches was based on supervised classification of a satellite image, thus creating discrete patches (the minimum size corresponding to the satellite image resolution), from which we created continuous metrics using spatial filtering and distance calculations. However, a variety of additional continuous metrics can be calculated using satellite images (in addition to the NDVI used here), using techniques such as spectral unmixing (Asner and Lobell, 2000) or spatial autocorrelation (Pearson, 2002).

Although our analysis highlighted the importance of large forest/tree patches for bird richness, paddock trees may represent an important habitat for more specific functional groups of birds than analysed here, as well as for other taxa. We have shown that paddock trees can be reliably mapped using high resolution satellite images. However, the success of our method in identifying individual trees was hampered when foliage projective cover was greater than 50%. New methods are therefore needed to enable mapping of tree characteristics (e.g. canopy size) from passive sensors, as well as to map individual trees within continuous forest patches so that mapping of tree density can become a reality.

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