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Roads increase woody cover under varying geological, rainfall and fire regimes in African savanna

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ABSTRACT

Roads extend throughout savannas, yet few studies have quantified their effects on adjoining woody vegetation structure. Airborne LiDAR imagery collected over 168 experimental fire plots in the Kruger National Park, all bounded by graded firebreak roads, provided an opportunity to study if, and to what extent, roads influence woody vegetation structure under different rainfall, geologic and fire conditions. In 91.7% of the plots, woody canopy cover was higher on the edges of roads compared to areas farther away. The increase was most pronounced within 5 m of the road edge, but was detectable 10–15 m from the edge. On average, the area within 15 m from the road had approximately 6% and 2% higher woody vegetation cover than areas further than 15 m from the edge on wetter granitic and drier basaltic savanna landscapes, respectively. Increased edge effects on woody cover were observed even in fire exclusion plots, suggesting that non-fire processes, likely altered hydrological regimes, may be the underlying reason for woody encroachment. This study illustrates that roads cause selective woody plant thickening in savannas, even in areas without road edge management, and therefore careful consideration should be paid on how road edges are managed and when roads are planned.

1. Introduction

Roads, and their associated edges, have numerous impacts on biodiversity patterns and processes. In a review, Trombulak and Frissell (2000) identified seven general negative effects of roads on biodiversity: mortality from road construction, mortality from collision with vehicles, modification of animal behaviour, alteration of the physical environment, alteration of the chemical environment, spread of exotics, and increased use of areas by humans. However, other papers have shown that road edges can also have several positive effects, especially in highly transformed landscapes, where they act as refugia and/or movement corridors (Eversham and Telfer, 1994). Foreman and Alexander (1998) proposed that road impacts operate at two primary levels, namely (i) the individual, species and population level (e.g. road kills, disturbance, etc.), and (ii) the ecosystem process and landscape level (e.g. hydrology, erosion, sedimentation, etc.).

In 2003 it was estimated that there were approximately 8000 km of roads in the Kruger National Park (KNP), South Africa (Freitag-Ronaldson and Foxcroft, 2003). Considering the extent of roads and their potential impacts, surprisingly few "road ecology" studies have been conducted to understand potential impacts of roads in the KNP. The only published study we could find for KNP was a qualitative description of road impacts based on personal observations of a resident scientist (Pienaar, 1968). Beyond KNP, we found that studies focussing on the effects of roads on adjoining woody vegetation structure in savannas seem to be lacking from the literature. This study aims to address that gap by determining if, and to what degree, woody vegetation structure is influenced on the edges of low-maintenance graded firebreak roads under different rainfall, geological and fire management regimes (in the absence of road-edge management like scraping or mowing). Graded firebreak roads refer to linear strips that are created when bulldozers and/or scrapers denude an area of vegetation (woody and herbaceous) to leave a rudimentary road (Fig. 1). These graded areas act as firebreaks and serve as management roads for very low volume traffic, such as game ranger patrols and research vehicles. Here we addressed the following questions: Is there a difference in woody vegetation structure in areas closer to edges of roads compared to areas further from the edges? If so, how consistent is the edge effect, and how far from the edge of the road is the effect measureable? How does the edge effect differ between different geologically- and rainfall-defined landscapes? Do different fire

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Fig. 1. Graded firebreak roads of approximately 6 m wide delineate Experimental Burn Plots (EBPs) in the Kruger National Park. Different fire management regimes are practiced on each side of the road.

management regimes lead to different edge effects on woody vegetation structure?

2. Materials and methods

2.1. Study site

KNP covers an area of almost 20,000 km^2 in the north-eastern corner of South Africa, bordering Zimbabwe to the north and Mozambique to the east. The Park contains a north-south rainfall gradient with rainfall increasing from the north (~350–420 mm yr^{-1}) to the south (~680–750 mm yr^{-1}). The western part of the Park is mainly underlain by granite-derived soils and the east by soils of basaltic origin, with some other geologies covering smaller sections of the Park. This abiotic template gives rise to 35 major vegetation types which are dominated by knobthorn (*Acacia nigrescens*), marula (*Sclerocarya birrea*), leadwood (*Combretum imberbe*), red-bush willow (*Combretum apiculatum*), silver cluster leaf (*Terminalia sericea*) and mopane (*Colophospermum mopane*) (Gertenbach, 1983).

2.2. Experimental Burn Plots (EBPs)

The aim of the KNP Experimental Burn Plots (EBPs) is to study the effects of fire (frequency and season) on the vegetation under the grazing pressure of indigenous herbivores (Van der Schijff, 1958). The EBP experiment consisted of the application of fires at varying return intervals and seasons, and protection from fire, on a series of ~7 ha plots in four of the major vegetation landscapes of the Park (Table 1). The treatments were replicated four times in each of these landscapes (replicates are called “strings”).

The treatments originally included annual winter fires in August, and biennial and triennial fires in August, October, December, February and April. In 1976, further treatments to examine the effects of fires every 4 and 6 years in October were added to selected landscapes (Satara & Mopane) by subdividing the February treatment plots. This resulted in 48 plots (4 replicate strings × 12 treatments) in the Skukuza and Pretoriuskop landscapes and 56 plots (4 replicate strings × 14 treatments) in the Satara and Mopane landscapes. One string in each of the Skukuza, Satara and Mopane landscapes was not included in this study because local soil differences made them unrepresentative of the particular landscapes (Venter, 2004), leaving 48 plots in the Pretoriuskop landscape, 36 in the Skukuza landscape and 42 in the Satara and Mopane landscapes. Full details and history of the experimental design and application of treatments are available from Biggs et al. (2003).

Table 1
Description of the four studied landscapes (based on van Wilgen et al. (2007)).

Landscape	Vegetation type	Dominant tree species	Geology	Mean annual precipitation (mm)
Pretoriuskop	Sourveld	*Terminalia sericea, Dichrostachys cinerea*	Granite	705
Skukuza	Combretum	*Combretum collinum, Combretum zeyheri*	Granite	572
Satara	Knobthorn-Marula	*Acacia nigrescens, Sclerocarya birrea*	Basalt	507
Mopane	Mopane	*Colophospermum mopane*	Basalt	451

2.3. LiDAR derived top of canopy dataset

Airborne Light Detection and Ranging (LiDAR) data were acquired in April 2008 using the Carnegie Airborne Observatory (CAO) (Asner et al., 2007). The CAO was mounted in an aircraft which flew over the 168 EBPs at an altitude averaging 2000 m above ground level. The CAO LiDAR was operated at 50 kHz pulse repetition frequency and a 34° scanning configuration cross-track of the aircraft direction.

Global positioning system (GPS) and Inertial Motion Unit (IMU) data were combined to determine the 3-D location of the laser returns. From the laser “point cloud” data, a physical model was used to estimate top-of-canopy and ground surfaces (digital elevation models; DEM) using the Terrascan/Terramatch (Terrasolid Ltd., Jyväskylä, Finland) software package. Vegetation height was subsequently estimated by subtracting the ground DEM from the top-of-canopy layer. The CAO generated a laser spot spacing of 1.12 m. Since the beam diameter at ground level was also 1.12 m, this laser spot spacing configuration resulted in a 50% overlap between LiDAR observations, decreasing the likelihood of missing vegetation canopy. The resulting canopy DEM had a spatial resolution of 1.12 × 1.12 m, such that a surface was generated where each 1.24 m^2 contained the estimated vegetation height in that particular pixel. The absolute vertical resolution of the CAO LiDAR is 15 cm, but following digitization and application to porous tree canopies, the effective vertical resolution is 0.2–0.5 m. All further analyses were based on these top of canopy surfaces created for each EBP, which is an estimate of woody vegetation cover. Woody vegetation cover is a widely used variable to quantify how horizontal woody structure varies across space and time (e.g. Fensham and Fairfax, 2003). Other variables like tree density can also be used to characterize woody structure, but these parameters were not directly available from the LiDAR dataset employed here.

Due to the lack of late summer rains in 2008 (http://www.sanparks.org/parks/kruger/conservation/scientific/weather/) (accessed 30 May 2011), some woody vegetation already started dropping leafs in April when the LiDAR survey was conducted. This resulted in decreased leaf area, especially on the drier northern basaltic landscapes (Satara and Mopane). Lower leaf cover, together with the spatial resolution employed, resulted in some woody vegetation, especially smaller and sparse individuals, not being detected. However, as we do not compare sites over time but over space, the effect of underestimation on the emerging structural patterns was small. That is, since we are comparing edges to core areas of each EBP, the systematic underestimation would be consistent across and between plots, and therefore would not affect the overall patterns and trends (Smit et al., 2010).