Effects of Woodland Fragmentation on Tree Diversity in the Northern Province, South Africa
Effects of Woodland Fragmentation on Tree Diversity in the Northern Province, South Africa

by

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Abstract

Fragmentation affects the structure of the landscape and causes loss of suitable area for species to live in. Diversity and composition of species may be affected by fragmentation and it may cause various changes leading to the segregation in different fragments as well as to an edge-interior stratification. In the woodlands of the Bushbuckridge region in South Africa, the type of management (Communal lands and Game reserves) causes fragmentation of the original ecosystem. In the present study, the effects of fragmentation on tree density and diversity were analysed. Tree diversity was analysed using $\alpha$ (Tree richness and Shannon index) and $\beta$ (Jaccard index) diversity measures. Two fragments were identified; a fragment with low human intervention (LI) and a fragment with a high human intervention (HI). Tree density and tree richness were lower in the HI fragment (from 565 to 367 trees/ha and 10 to 8 species/1000 m$^2$ plot respectively), while the Shannon index did not show a significant difference per fragment type. A negative edge effect for tree density (20% lower at the edges) and tree richness (50% lower at the edges) was found. Tree density was asymptotically related with tree richness. Differences in species composition due to fragmentation were not significant. The proximity to human infrastructure such as roads, settlements and agriculture was positively correlated with tree density and tree diversity. In regards to these results, it was concluded that fragmentation negatively affects tree density and tree richness, and that the best option for the conservation of the tree diversity is the type of management carried out in game reserves.
# Table of Contents

1. Introduction ................................................................................................................................. 1
   1.1. Background ......................................................................................................................... 1
   1.2. Objectives .......................................................................................................................... 4
   1.3. Research Questions ......................................................................................................... 4
   1.4. Hypotheses ....................................................................................................................... 4

2. Study Area .................................................................................................................................. 4
   2.1. Study area ......................................................................................................................... 4

3. Methods ...................................................................................................................................... 6
   3.1. Data Collection ................................................................................................................. 7
      3.1.1. Sampling .................................................................................................................... 7
      3.1.2. Diversity Data Processing ....................................................................................... 8
      3.1.3. Spatial Information ................................................................................................. 9
   3.2. Data Analysis and statistics .............................................................................................. 9
      3.2.1. Fragmentation Pattern ............................................................................................ 9
      3.2.2. Fragmentation Effect on Tree Density, Richness and Diversity ......................... 9
      3.2.3. Effect of tree density on the tree richness ............................................................ 10
      3.2.4. Species similarity between fragments ................................................................. 10
      3.2.5. Relationships of Tree Diversity and Richness with the Human Influence ......... 10

4. Results ..................................................................................................................................... 10
   4.1. Fragmentation Pattern .................................................................................................... 10
   4.2. Effect of Fragmentation on Tree Density ....................................................................... 11
   4.3. Effect of Fragmentation on Tree Diversity ................................................................... 12
      4.3.1. Tree Richness .......................................................................................................... 13
      4.3.2. Tree Diversity (Shannon index) ............................................................................. 13
      4.3.3. Effect of tree density on the tree richness ............................................................ 16
      4.3.4. Species similarity between fragments ................................................................. 16
   4.4. Relationships Tree Diversity & Richness with Human Activities ............................... 18

5. Discussion ................................................................................................................................. 21

6. Conclusions ............................................................................................................................... 24

7. Suggestions for further research ............................................................................................. 25

8. References................................................................................................................................. 26
List of Figures

Figure 1. Location of the study area ................................................................. 5
Figure 2. Research approach .............................................................................. 6
Figure 3. Sampling design .................................................................................. 7
Figure 4. Map of the study area ........................................................................... 11
Figure 5. Tree density per fragment type .............................................................. 12
Figure 6. Tree density per fragment type and location within the fragment ............... 13
Figure 7. Tree richness per fragment type ............................................................. 14
Figure 8. Tree richness per fragment type and location within the fragment .............. 14
Figure 9. Tree richness distribution map ............................................................... 15
Figure 10. Tree diversity per fragment type .......................................................... 16
Figure 11. Tree diversity (Shannon index) distribution map ..................................... 17
Figure 12. Tree diversity per fragment type and location within the fragment ............. 18
Figure 13. Relationship between tree richness and tree density ............................... 19
Figure 14. Tree species composition in the study area .............................................. 19
Figure 15. Relationship of tree density and diversity with distance to Human Infrastructure 20

List of Tables

Table 1. Fragments area and edge proportions ...................................................... 12
Table 2. Nested ANOVA for tree density ............................................................... 13
Table 3. Nested ANOVA for tree species richness ............................................... 14
Table 4. Nested ANOVA for tree diversity ............................................................ 16
Table 5. Linear regression between log (Tree Density) and Tree Richness ............... 18
Table 6. Tree density and diversity correlated with Human Infrastructure ............... 21
1. Introduction

1.1. Background

Since fragmentation affects the structure of the landscape it is essential to place the present study into the context of the landscape ecology and nature conservation. Additionally, because it is thought that biodiversity is threatened when fragmentation occurs we need to be aware of the “side effects” or its inherited ecological consequences (Bustamante and Grez, 1995). Finally, it is important to take into account the relevance of fragmentation and species diversity in the area where the study was carried out since the majority of the original savannah woodlands had been disturbed and changed by human activities among other forces (Belsky, 1995).

The landscape is a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout (Forman and Godron, 1986). Note that the scale and description of a landscape will depend on the scale of movement and habitat associations (respectively) of the organisms under consideration (Grez et al., 2000). Fragmentation affects the characteristics of a landscape, of which in particular, it is the spatial relationship among its component ecosystems or its structure. There are two components to landscape structure, "composition" or the amounts of the various types of habitat in the landscape and "configuration" or the spatial arrangements of those habitats (Dunning et al., 1992; Turner, 1989).

Often, the destruction of vegetation cover is a major factor in the structural change of landscapes, causing a direct loss of habitat and an increase in the fragmentation of the remnant habitat patches (Hyde, 2000). Land cover fragmentation, or the subdivision of a continuous vegetation cover into smaller patches, has three components: direct removal of suitable habitat, reduction in patch size, and increasing isolation of the remaining patches (Andren, 1994). A fragmented vegetation cover such as a fragmented forest can be described by its attributes like number, size or shape of patches, and for the isolation of patches and for the type of surrounding matrix that generates an edge effect (Bustamante and Grez, 1995), and therefore patches may vary in their suitability as habitat for various organisms (Hyde, 2000). The creation of habitat edges profoundly affects the environment close to the edge (Harris and
Silva-Lopez, 1992; Lovejoy et al., 1986; Ranney et al., 1981). At the edges, some species increase in abundance close the edge, whereas others decrease (Noss, 1983; Yahner, 1988). Moreover, an edge effect is related to shape and size of fragments and is more important in complex-shape fragments than in the more isodiametric ones.

Landscape fragmentation usually originates from some type of natural phenomena, either physical (storms, fires, collapses or winds) and/or biological (predation or foraging) (Williams-Linera, 1991). But, much more important and greater for their impact are the human activities such as agricultural industry, forest industries, cattle raising and urbanization (Bierregard et al., 1992).

Considering studies in forest areas, it has been observed that forest fragmentation causes abiotic and biotic changes in the remnant patches. Abiotic changes are related to microclimatic variations from the edge to the interior (Bustamante and Grez, 1995; Forman and Godron, 1986; Saunders et al., 1991). For example, light intensity, litter moisture, humidity, temperature and wind speed change towards the interior of fragments (Matlack, 1993). Biotic changes refer to direct and indirect effects. Direct biotic changes are alterations of the diversity of forests because species populations can either, reduce its number by increasing mortality and emigrations (Bustamante and Grez, 1995) such as the increase in tree mortality at the edge, or increase its number in the case of proliferation of shade intolerant species (Lovejoy et al., 1986), which means changes in tree density. Diversity can also be directly affected by changes in the composition due to the arrival of new species (Williams-Linera, 1990). Alternatively, indirect biotic changes affect the intensity and quality of animal-plant relationships (Bustamante and Grez, 1995). Intensity when population size of species increase (Roland, 1993), and quality by changing one species for another (Aizen and Feinsinger, 1994).

Recently, habitat fragmentation is one of the most serious causes of diminishing biological diversity (Harris and Silva-Lopez, 1992), where its main consequence - habitat loss - is the responsible for biodiversity loss and the ultimate extinction of species (IUCN, 2002). Although it has been studied theoretically, only a few empirical observations on the relationship fragmentation and species richness have been made. Because of that, more additional information about the effect of habitat fragmentation on species diversity are
needed for conservation and management purposes (Iida and Tohru, 1995). Moreover, landscape ecology of sub-Saharan savannas has seldom been investigated ((Belsky, 1995).

Species diversity has been identified as one of the key indices of sustainable land use practices, and considerable resources are expended to identify and implement strategies that will reverse the current declines in biodiversity at local, regional and international scales (Shackelton, 2000). Historically, diversity has been equated with species richness also known as \( \alpha \)-diversity, or the number of different species in an area (Peet, 1974). However, this concept fails to consider the relative abundance, or evenness of species; two communities with the same number of species but with different relative abundances would have the same level of species richness (Peet, 1974). Therefore, several indices that represent both issues were developed to measure \( \alpha \)-diversity (e.g. Shannon index, Simpson index), but there is little consensus on the best diversity measure to use (Magurran, 1988). Diversity can also be measured in terms of species similarity between habitats belonging to the same geographic area, which is also known as \( \beta \)-diversity. High \( \beta \)-diversity is the result of low similarity between the species composition of different habitats or different locations along a gradient (Huston, 1994).

In the woodlands of the Bushbuckridge region in South Africa, fragmentation of the vegetation cover is an effect of the establishment of two contrasting land uses: human settlements together with agricultural lands on one hand and game reserves on the other. These activities define two different types of fragments, which are under two different and contrasting management systems. Has been noted that the human impacts external to protected areas have inevitably led to a decrease in biodiversity relative to the nearby protected areas, although many agro-ecosystems are extremely rich in species (Alvarez-Buylla et al., 1989). Despite this concern with biodiversity, there are actually only relatively few studies in southern Africa savannas that have attempted to quantify patterns of alpha and beta diversity, and the relative decline between protected and adjacent areas (Shackelton, 2000). Because of the importance of these issues for the region and the need of studies that provide measures of success or failure of protected areas, the present study contributes to the knowledge about fragmentation and tree diversity of South African woodlands.
1.2. Objectives
- To contribute to the knowledge of habitat fragmentation effects on the biodiversity.
- To describe the fragmentation pattern in the study area.
- To assess the effects of fragmentation on tree diversity in the study area.
- To find out if the fragmentation is a threat for tree diversity in the study area.

1.3. Research Questions
- Which is the fragmentation pattern in the study area?
- Does habitat fragmentation affect tree diversity in the study area?
- Does habitat fragmentation in the study area threat tree diversity?

1.4. Hypotheses
- $\alpha$-tree diversity varies between the types of fragments and between the locations edge and interior.
- $\beta$-diversity (species composition) differs between the types of fragments and between edges and interior locations.

2. Study Area

2.1. Study area
The area where the study was carried out is located in the woodlands of the Northern Province of South Africa. Specifically, it belongs to the Bushbuckridge region neighbouring the Kruger National Park, which belongs to the Lowveld (Fig. 1). The Lowveld is a low-lying area between two mountain ranges – the Drakensberg in the west and Lebombos in the east. A narrow tongue extends through Swaziland to Northern Natal. Northwards the Lowveld and its vegetation patterns persist well into Zimbabwe. Its diverse geology is important because it forms the basis of the Habitats and Ecozones, which influence the distribution of different tree species (Grant and Thomas, 2001). The different geological formations (some of them about 2 billion years old) also contribute to the rich plant diversity and endemism (MELISSA Program, 2000).
According to Grant and Thomas (2001) the area in the Lowveld where the study area was located falls into two ecozones: 1) Mixed Bushwillow Woodlands and 2) Pretoriuskop Sourveld. Both ecozones consist of granite domes, intersected by drainage lines, creating undulating crests and valleys. The rainfall in the first one varies between 550 to 700 mm, and the altitude between 350 and 500 m. For the second one the rainfall varies from 600 to 1000 mm and the altitude from 550 to 600 m above sea level. The mean annual temperature is 22°C.

Human activities and management systems are the main factors causing fragmentation in the region. The main activities that drive the economy of the Central Lowveld are mining, forestry, nature-based tourism and agriculture (in priority order of their contribution to the GDP of the area) (BMI, 1999). There is, however, a market driven macro tendency shifting land use to nature-based economic activities and in particular towards wildlife tourism (Williams, 2000). This highlights the importance of natural resource protection and the significance of these protected areas towards economic and social development in the Central Lowveld. This bioregion also boasts the largest area of privately owned conservation land in the world (MELISSA Program, 2000). As a result of this process, a landscape divided in two
woodland fragments was identified in the study area: The first fragment is a woodland with Low Human Intervention (LI fragment) where Game Reserves are established or human activities such as burning and firewood collection are seldom and controlled; The second fragment is a woodland with High Human Intervention (HI fragment), which is surrounded by human settlements and agriculture also used for grazing or firewood collection.

3. Methods

In order to measure the effects of fragmentation on tree diversity, data about tree richness and tree species abundance were collected for its analysis. Based on an ASTER image, information about the spatial arrangement of fragments was extracted. Finally, statistical analyses were carried out with the aim of identifying whether or not fragmentation causes changes on tree diversity. The general procedure is illustrated in the following flowchart (See figure 2).

![Figure 2. Research approach](image-url)
3.1. Data Collection

The process to collect data for the current research began with sampling in the field to data processing for calculating diversity measurements as well as the extraction of spatial information from a satellite image.

3.1.1. Sampling

The data was collected during the end of the dry season, in September of 2002. Tree species diversity was measured in circular sample plots of 1000 m\(^2\) (17.8 m radius) randomly allocated on an ASTER image. The plots were located through the use of GPS. For each plot the present tree species and their abundance were recorded with the purpose to acquire information about tree species richness, diversity (Shannon index) and differences in species composition. Due to the life form of trees in the area and for purposes of this study, a tree was defined as an individual more than 3 meters high with clearly separated stems. For practical purposes stems separated for more than 50 cm were considered being different individuals.

The sampling was stratified according to the aspects of fragmentation that were considered: Type of fragment and Edge effect. The two types of fragment (LI and HI) were considered. Within each fragment two categories were recognized: 1) Edge, at the boundary of the woodland fragment and 2) Interior, inside the patch at a distance of more than 100 m from the edges to a few kilometres. In order to keep a balanced sampling design, 50 samples were taken into the LI fragment and 50 in the HI fragment. From every set of 50 samples, 25 were at the edge and 25 at the interior (Fig. 3). Riverine habitats were not sampled.

![Figure 3. Sampling design](image-url)
3.1.2. **Diversity Data Processing**

To find out if the fragmentation has effects on tree diversity two \( \alpha \)-diversity quantitative measures were used: 1) Richness, which is the number of species and 2) Shannon index. Also a \( \beta \)-diversity measure, the Jaccard index was used to find out if there were differences in species composition between sites.

For the analysis, the data collected in the field was processed into an MS ACCESS Database from which diversity indices (Shannon index and its pseudo-values); species richness; species composition and density were extracted.

The Shannon index was calculated using the formula:

\[
H' = \sum p_i \log p_i
\]

Where \( p_i \) is the proportional of abundance of the \( i \) species in the sample.

The Shannon index was used because it highlights the relative abundance of rare species vs. the dominant ones, which is important to consider in an ecosystem where not too many species are found in 1000 m\(^2\).

The Shannon index pseudo-values were calculated using the following formula:

\[
VP_i = (nV) - [(n - 1) (VJ_i)]
\]

Where \( n \) is the number of samples; \( V \) is the Shannon index and \( VJ_i \) is the Jackknife estimate of the Shannon index.

The procedure to obtain the Jackknife estimates consists in the repeated recalculation of the index missing out each sample in turn. That is, every Jackknife estimate is calculated based on the rest of the samples. For this study, it was recalculated for each sample class of 25 observations.

The Jackknife technique is applied to the Shannon index in order to improve the estimation of the measure of diversity for the further comparison between sites using an analysis of variance. Jackknife is a technique that allows the estimate of virtually any statistic to be improved, such as diversity indices; it makes no assumptions about the underlying distribution and a series of Jackknife estimates and pseudo-values are produced instead (Magurran, 1988).
The Jaccard index was calculated using the following formula:

$$C_j = j / (a + b - j)$$

Where $j$ is the number of species common to both sites; $a$ is the number of species in site A and $b$ is the number of species in site B.

### 3.1.3. Spatial Information

With the purpose of identifying fragments and measuring the extent of edges and interior, an ASTER image dated 02/05/2000 was classified based on field observations by an object-oriented approach. Regarding the objectives of the study three main classes were identified: 1) The LI fragment; 2) The HI fragment and 3) Human Settlements and Agriculture. To classify the image, the principal components of bands 2 and 3 of the visible and near infrared bands and bands 3 and 4 of the short wave infrared were used. To compute the principal components Erdas IMAGINE was used and the classification was performed with e-cognition. GIS analysis, area and perimeter measurements and map composition were made with ArcGIS.

### 3.2. Data Analysis and statistics

In this section the procedures carried out to achieve the results will be explained. ArcGIS was used for GIS operations and SPSS for statistical analyses.

#### 3.2.1. Fragmentation Pattern

After the classified raster map was obtained it was vectorized and the area covered per class and its perimeter were determined. The relationship between perimeter and area was derived in order to estimate the importance of the edges relative to each fragment. Then, with a statistical test for two proportions it was tested if there is any significant difference between these proportions.

#### 3.2.2. Fragmentation Effect on Tree Density, Richness and Diversity

To find out if there are any significant differences on tree density and tree diversity (Shannon index pseudo-value and tree species richness) due to fragmentation, a Two Way Nested Analysis of Variance was used. The factors considered were: 1) Fragment Type and 2) Edge Effect nested into the former. Each Factor contains two classes; Fragment Type with LI and HI classes; within fragment type two classes were distinguished, Edge and Interior.
3.2.3. **Effect of tree density on the tree richness**
According to Shackelton (1993), structural changes precede changes in species composition. Since fragmentation causes structural changes and because of that some species may disappear, therefore, it is important to explore the relationship between density and tree richness. The statistical analysis carried out for this purpose was a linear regression between tree species richness as the dependent variable and the logarithm of tree density as the explanatory variable.

3.2.4. **Species similarity between fragments**
To test for significant species composition differences, the Jaccard index was tested with one-proportion tests. The common number of species of two sites is compared with the expected number of species to be present, which should be the total number of species in both sites. These tests were performed to test differences between fragment types and the edge effect.

3.2.5. **Relationships of Tree Diversity and Richness with the Human Influence**
The main factors causing fragmentation in the area are the establishment of settlements, agriculture and roads. The significance and magnitude of a relationship between distance to these infrastructures and tree diversity was analysed with Pearson correlations. The information about the distance from those infrastructures to the sample plots was extracted from a distance map, which was calculated with ArcGIS.

4. **Results**
Since fragmentation has spatial and ecological consequences, the present study begins by analysing this phenomenon by describing the pattern of fragmentation in the area. Then, the implications of tree density on tree richness were analysed. Followed by an analysis of the effects of fragmentation on species diversity and species composition. Finally, the relationship between tree density and tree diversity was explored.
4.1. Fragmentation Pattern

With regards to the purpose of this study, three main units were identified into the study area: 1) Low Human Intervention woodland (LI fragment); 2) High Human Intervention woodland (HI fragment) and 3) Human Settlements and Agriculture (Fig 4).

Figure 4. Map of the study area
Table 1. Fragments area and edge proportions

<table>
<thead>
<tr>
<th>Fragment Type</th>
<th>Total Area (ha)</th>
<th>Edge Perimeter (km)</th>
<th>Perimeter/Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI fragment</td>
<td>93,270</td>
<td>150</td>
<td>0.0016</td>
</tr>
<tr>
<td>HI fragment</td>
<td>43,182</td>
<td>2800</td>
<td>0.0648</td>
</tr>
</tbody>
</table>

The area covered by the HI fragment (communal lands) is almost the half of the LI fragment, showing that communities use one third of the area while a bigger portion is under protection measures. The relationship perimeter/area of the HI fragment is 40 times bigger than for the LI fragment. These proportions are significantly different ($Z=-53.04; P_{(a=0.05)}<0.001$), revealing that the extent of the edge in the HI fragment is bigger than in the LI fragment (Table 1). This also indicates that the shape of the HI fragment is more complex than the LI fragment.

### 4.2. Effect of Fragmentation on Tree Density

Before analysing the affects of fragmentation on tree diversity, it is important to analyse the affects on tree density, which is affected by the human activities under these two different management systems.

The mean tree density in the LI fragment is 565(SE=55) trees/ha, while in the HI fragment only 367(SE=48) trees/ha can be found (Fig. 5). According to the statistical analysis performed, the tree density in the LI fragment is significantly higher than in the HI fragment (Table 2).

![Figure 5. Tree density per fragment type](image-url)
With regards to edge effects, the mean tree density at the edges of the LI fragment is 401 (SE=76) trees/ha while in the interior is 78% higher, (728 trees/ha, SE=66). In the HI fragment, the density drops in 81% from the interior to the edge, that is from 473 trees/ha (SE=70) to 261 trees/ha (SE=61) respectively (Fig. 6). In this case, the variation around the mean also marks differences between interior and edge in both fragments. However, tree density at the interior of both fragments is significantly higher than at its edges (Table 2).

<table>
<thead>
<tr>
<th>Fragmentation effect</th>
<th>N</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragment Type</td>
<td>100</td>
<td>1</td>
<td>8.312</td>
<td>0.005</td>
</tr>
<tr>
<td>Nested Edge Effect</td>
<td>100</td>
<td>2</td>
<td>8.065</td>
<td>0.001</td>
</tr>
</tbody>
</table>

**Figure 6. Tree density per fragment type and location within the fragment**

### 4.3. Effect of Fragmentation on Tree Diversity

The effects of fragmentation on tree diversity were analysed taking in account tree richness and Shannon index for a quantitative analysis of diversity and the Jaccard index for analysing species similarity between fragment types and edge-interior categories.

#### 4.3.1. Tree Richness

The mean tree species richness in the LI fragment is 10 species/plot (SE=0.7), while for the HI fragment is 8 species/plot (SE=0.75) (Fig. 7). The statistical analysis revealed that these differences are significant (Table 3), showing that tree species richness in the LI fragment is significantly higher than in the HI fragment. This result can also be appreciated when looking
at the sample plots and its distribution throughout the study area, more sample plots in the HI fragment have lower species richness than in the LI fragment (Fig. 9).

**Table 3. Nested ANOVA for tree species richness**

<table>
<thead>
<tr>
<th>Fragmentation effect</th>
<th>N</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragment Type</td>
<td>100</td>
<td>1</td>
<td>4.027</td>
<td>0.048</td>
</tr>
<tr>
<td>Nested Edge Effect</td>
<td>100</td>
<td>2</td>
<td>10.255</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

**Figure 7. Tree richness per fragment type**

**Figure 8. Tree richness per fragment type and location within the fragment**

Edge effects either in the LI or HI fragment are significant on tree species richness (Table 3). The mean tree species richness at the edges of the LI fragment is 7 tree species/plot (SE=0.8) while at the interior it is 50% higher with 12 tree species/plot (SE=0.86). In the HI fragment,
the tree richness drops from the interior (10 tree species/plot, SE=0.96) to the edge (6 tree species/plot, SE=1.06) in 4 tree species/plot (Fig. 8).

Therefore, tree species richness at the interior of both fragment types appeared significantly higher than at its edges. The visual interpretation of the distribution of the samples shows that...
the lowest richness values are located mainly at the edges of the LI fragment, while the HI fragment shows a higher variation but it is still distinguishable that the higher values of tree diversity are located mainly in the interior (Fig. 9).

### 4.3.2. Tree Diversity (Shannon index)

The mean value of Shannon index in the LI fragment (3.05, SE=0.05) was not significantly different from the HI fragment (2.86, SE=0.13) (Table 4), although the variation observed shows that in the HI fragment the Shannon index can be much lower than in the LI fragment (Fig. 10). Tree diversity as a variation of tree richness together with the relative abundance of tree species is not affected by fragmentation, but may vary much more when human pressure is higher. As is shown by the statistical analysis, the diversity in the study area is not different between fragments, but a higher variability can be observed in the HI fragment (Fig.12).

**Table 4. Nested ANOVA for tree diversity**

<table>
<thead>
<tr>
<th>Fragmentation effect</th>
<th>N</th>
<th>df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragment Type</td>
<td>100</td>
<td>1</td>
<td>1.823</td>
<td>0.180</td>
</tr>
<tr>
<td>Nested Edge Effect</td>
<td>100</td>
<td>2</td>
<td>0.320</td>
<td>0.727</td>
</tr>
</tbody>
</table>

**Figure 10. Tree diversity per fragment type**

With regards to edge effects within the fragment types, the mean tree diversity value at the edges of the LI fragment is 3.02 (SE=0.08), which is similar to the interior 3.07 (SE=0.06). In the HI fragment, the tree diversity indices between edge (2.94, SE=0.19) and interior (2.79 SE=0.18) are also not significantly different (Table. 4). Although there are no significant differences between edge and interior, the variation around the mean shows that at both edge
and interior of the HI fragment the tree diversity is relatively more variable. Within the LI fragment the Shannon index is more stable (Fig. 12). Therefore, tree diversity at the interior of both fragment types is not significantly higher than at its edges.

Figure 11. Tree diversity (Shannon index) distribution map
Looking at the spatial location of the sample plots in the study area and its Shannon index there is not a clear difference between edge and interior of any of the fragments (Fig. 11).

![Shannon Index Chart](image)

**Figure 12. Tree diversity per fragment type and location within the fragment**

### 4.3.3. Effect of tree density on the tree richness

Since a direct and obvious effect of fragmentation is the loss of vegetation cover and because differences on density and tree richness are both affected by fragmentation, tests were performed to identify if the loss of cover had a relationship with the richness of tree species in the area.

A significant linear relationship between the logarithm of tree density and tree richness was found (Table 5), where tree density explains 71% of the variation in tree richness. However, the tree density is asymptotically related with tree richness (Fig. 13). Moreover, when tree density drops between 200 and 400 trees per hectare tree richness starts reducing at a higher rate. Looking at the dispersion of the observations it can be observed that the highest tree richness observations as well as the lowest do not show a relationship with fragment types neither with their location relative to the edge.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>T</th>
<th>P</th>
<th>R²</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-9.76</td>
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<td>-8.040</td>
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**Table 5. Linear regression between log (Tree Density) and Tree Richness**
4.3.4. **Species similarity between fragments**

Tree species composition is significantly different between LI and HI fragments and also edge and interior share a significant proportion of species (Fig. 14). Seventy-five tree species were found (Appendix 1, Species Table) and 76% were common to both LI and HI fragments. The statistical analysis revealed that these communities were significantly different ($Z=-20.02; P_{(a=0.05)}<0.001$). In the LI fragment 58% of the species were common to both edge and interior but these difference in species composition is significant ($Z=-34.00; P_{(a=0.05)}<0.001$). In the HI fragment edge and interior share 71% tree species, and again these communities are significantly different ($Z=-21.28; P_{(a=0.05)}<0.001$).
4.4. Relationships Tree Diversity & Richness with Human Activities

The main factor causing fragmentation in the area is thought to be the establishment of settlements, grazing lands, agriculture and roads. Therefore the effects of distance to these human activities on tree diversity and density were analysed.

The distance to human infrastructure is positively correlated with tree density; Shannon index and tree species richness (Table 6). Although those relationships are highly significant they are not strong. In general, low values of density and diversity are found not far from human infrastructures. However, high values can be found within close distances to human infrastructures as well as further away from them (Fig. 15).

![Figure 15. Relationship of tree density and diversity with distance to Human Infrastructure](image-url)
Table 6. Tree density and diversity correlated with Human Infrastructure

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5. Discussion

Fragmentation of the north-eastern woodlands of South Africa occurs due to the presence of contrasting management systems. In the area studied in the current research, two clearly recognizable fragments are defined: One with low human intervention (LI fragment) and the other with a high human intervention (HI fragment). In the former, many game reserves are established and human intervention is limited. In the second, human activities such as firewood collection, grazing and burning are more pronounced. The LI fragment has a low proportion of edges compared with the HI fragment, under these conditions the first one persists in keeping a bigger portion in more natural conditions. As will be explained further down, due to differences edge-interior and fragment type on tree diversity, the differences in edge proportions are more relevant for tree density and diversity in the HI fragment.

Tree density in the LI fragment was higher than in the HI fragment suggesting that the pressure in communal lands leads to changes in structure towards more open woodlands. Higgins (1999) found that under high woody tree harvesting levels of communal lands tree biomass reduces compared with private game reserves, thus, it may explain the reduction in tree density. Looking at differences between edge and interior in the LI fragment, it is clear that the lower tree densities at the edge may reflect the preference for harvesting firewood closer to settlements, agricultural fields or roads. In the HI fragment, the lower tree density at the edge may be the product of standing fences at the border, for what clearing, road construction and its maintenance are needed, that means that a constant human intervention takes place at those sites.

Tree richness is relatively lower in the HI fragment showing that under greater human pressure less species are able to survive. It was reported that tree richness was influenced by land use towards a reduction in communal lands (Higgins et al., 1999). In contrast, Shackelton (2000)
found that tree species richness increased in communal lands, but he sampled in the protected areas at a distance not more than 0.75 km from the fences. In the present study, the sample plots at the edge of the LI fragment and those at the interior of the HI fragment correspond to those of protected areas and communal lands for Shackelton (2000) respectively. Looking at the results of the present study, it was found that at the edge of the LI fragment tree species richness is lower than at the interior of the HI fragment (Fig. 8). Comparing Shackelton’s study and this one, it seems that he did not take in account the possibility of an edge effect to occur. Considering the distance of Shackelton’s samples in the LI fragment makes us to think that the edge effect with regards to tree richness could penetrate at least 0.75 km from the LI fragment boundary. This result also highlights the meaning of analyzing diversity from the point of view of the landscape ecology in cases where habitats are being modified.

Human-caused alterations of habitat are recognized as the primary cause of the current species extinction event (WCMC, 1992). In general, the smaller the habitat and/or the lower the quality of habitat within an area, the smaller the local populations will be and this will lower the probability of local populations survival, fragmentation of habitat even without habitat loss also leads to reduced population survival ((Fahrig and Grez, 1996). In the present study it was observed that the number of tree species starts reducing when human influence becomes higher and especially at the edges of the LI or HI woodlands. That means that due to the fragmentation and the consequent habitat loss in the study area, some species disappear and because edges are more altered than the interior of woodlands, less species are found there. It was also observed that tree density and tree richness are related in an asymptotic way (Fig. 13). It is evident that tree richness has a response to structural changes, where tree density may affect tree richness (Palmer et al., 2000). In this study, the disappearance of tree species is more evident when tree densities reduce below 40 by hectare, where no more than 10-15 species can be present.

In contrast to tree richness, Shannon index does not reduce because of human influence, although the variability in tree diversity indicates that fragmentation may affect diversity in terms of richness and evenness of species, but this is not a general rule. This means that although the number of species reduces when human impacts are higher tree diversity is not affected uniformly, and there are still places where the tree diversity is relatively high. Moreover, the large variation of Shannon index indicates that a disturbed environments present more variable diversity (see fig. 10 and 12)
In terms of species composition, fragmentation may change species composition (Williams-Linera, 1990). This study also showed significant differences in species composition between the communities that were studied (Fig. 14 and Appendix 1, Species Table). Some species present in the LI fragment were not found in the HI fragment (14 species; *Acacia gerardii*, *Acacia robusta*, *Balanites maughamii*, *Berchemia discolor*, *Commiphora glandulosa*, *Commiphora phyracantoides*, *Kirkia acuminata*, *Lannea discolor*, *Mundulea sericea*, *Zanthoxylum capense*, Knoble Teak and Morph species B, C and D), while others appeared in the HI fragment but were not present in the LI fragment (5 species; *Acacia tortilis*, *Burkea Africana*, *Ficus sansibarica*, Cotton bush and Morph species A). All of those species were only relatively rare species in the area and they were found in one or two plots and in low densities (from 1 to 3 individuals per plot). There are also some species that were found exclusively in the edge and others only in the interior, showing that the conditions created at the edge also have an impact on the species composition. This means that under human pressure the rare species are more affected by fragmentation and they could be extinct, while others can appear in disturbed areas where previously were not present. Although some species can disappear and others appear depending on the conditions under they develop, it was reported that even with the high pressure due to the cattle grazing and firewood collection, tree species composition appears resilient (Harrison and Shackelton, 1999). This can be attributed to the increased vigour of woody plants in communal lands, which become resistant to the human pressure (Parsons et al., 1997). Thus, even there is a change in the community, considering the proportions of species that are still present in both fragments and knowing that rare species are affected, it is still possible that in disturbed areas the resilience sources for tree species composition remain.

Although not everywhere, tree density, tree richness and Shannon index can be lower when located closer to human infrastructures. It is also obvious that no low tree densities, tree richness or Shannon index are at larger distances from human infrastructures (Fig. 15). This means that tree populations have higher probabilities to be threatened if they are located closer to human infrastructures. Shackelton also found that with regards to plant species richness, it may vary with changes in disturbance related to proximity to human settlements (Shackelton et al., 1994). This shows that far from human infrastructures the human intervention is lower while close to them the human impact on tree density and diversity is higher. Obviously human infrastructure such as settlements, agricultural fields and roads increase accessibility to
resources tree density and diversity thus it is expected that tree density and diversity may reduce close to them.

As it was observed before, the extent (perimeter) of the edge in the LI fragment was smaller compared with the HI fragment. Thus, the fact that there is an edge effect on tree richness and density becomes more prevalent in the HI fragment due to its extent caused by its shape, which is more complex than the LI fragment. In the LI fragment, there is an edge effect but due to its shape, only a smaller portion is affected. Finally, the management type is responsible for the fragmentation of those woodlands where the tree structure (density) and tree diversity are different and also two strata (edge and interior) are recognized into these fragments.

6. Conclusions

- According to the type of management, woodlands in the Bushbuckridge region of South Africa are stratified in two types: 1) The woodland fragment with High human influence (HI fragment) where cattle grazing and firewood collection take place, and 2) The woodlands fragment with Low human influence (LI fragment) where game reserves are established and human activities are controlled.

- Tree density in the LI fragment is higher than in the HI fragment and towards the edges the tree density is lower.

- Tree richness in the LI fragment is higher than in the HI fragment and also a negative edge effect was found, showing relatively lower tree richness towards the edges of both fragments.

- The Shannon index does not differ between LI and HI fragments, but presents a higher variability in the HI fragment.

- There is an asymptotic relationship between tree species richness and tree density. Tree richness is lower where tree densities are lower.
- Tree species composition is affected by fragmentation, either between fragments or between edge and interior. Thus, fragmentation affects β-diversity as well as α-diversity.

- Tree density and tree diversity increased with increasing distance to human infrastructures, while when coming closer to them tree populations have more chances to be threatened. This highlights the importance of maintaining conservation areas far from human infrastructures.

- Due to the extent of the HI fragment perimeter, which is a product of its complex shape, the edge effect becomes more important than in the LI fragment. In this case, the edges are a bigger threat for tree populations in the HI fragment. Also it is important to avoid the development of complex shaped fragments and decreases in size of conservation areas.

- Tree density and tree richness are higher in the LI fragment and also the Shannon index is less variable. However, the current management type that is carried out in protected areas is the better option for conservation of tree diversity.

### 7. Suggestions for further research

- Since fragmentation affects the landscape structure and involves colonization and extinction of species, the succession dynamics might be addressed.

- Not all of the places had been fragmented at the same time and some areas may have the effects of many years of disturbance or land use change, while others are more recent. Then, it is important to know how the time dimension affects biodiversity in a fragmented ecosystem.

- The vegetation has a response not only to human intervention, but also to natural phenomena. Thus, the effect of fragmentation can be analysed including variables such as the hypsometric gradient east-west, variation in soils type due to its catenal variation and also the effect of the herbivores.
- According to the intermediate disturbance hypothesis (Connell, 1978), the intensity, frequency and time of disturbance may explain the variation in biodiversity. Thus, would be important to know if diversity varies according to different degrees of disturbance and which are the main disturbing sources.

8. References


Williams, J. 2000. The environment and development: Discussion document towards the establishment of the Kruger to Canyons Biosphere Reserve.


### Appendix

Tree species and its location per fragment

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<th>Scientific name</th>
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| Only LI species | Only HI species | Only interior species | Only edge species |