THE EFFECT OF FOREST FRAGMENTATION ON TREE SPECIES ABUNDANCE AND DIVERSITY IN THE EASTERN ARC MOUNTAINS OF TANZANIA

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Abstract. Habitat fragmentation is considered a threat to biodiversity conservation. Uluguru forest block, a section of the Eastern Arc Mountains in Tanzania remains highly vulnerable to fragmentation. However, to date, fragmentation effects on species abundance and diversity have not been investigated. This study aimed at investigating effects of fragmentation on species abundance and diversity in Uluguru forest block, Morogoro region, Tanzania. A RapidEye satellite image was analyzed using the maximum likelihood classifier (MLC) to map the fragmented forest. Remotely sensed variables with data on species diversity were modelled using the Generic Algorithm for Rule-Set Prediction (GARP) algorithm while fragmentation parameters were extracted using Fragstats software, which were then linked to species and edaphic factors. Results showed that species diversity was predicted better with customized environmental variables which recorded an Area Under Curve (AUC) of 0.89. The Poisson regression results showed that individual tree species responded differently to patch area dynamics, habitat status and soil nitrogen. Generally, the abundance of dominant species like *Mytenus undata Thunb* ($p < 0.001$), *Zenkerella capparidacea* (Taub.) *J. Leon* ($p < 0.001$) and *Oxyanthus specious* DC. ($p = 0.023$) decreased with a reduction in patch area. The present study suggests the need to integrate comprehensive plans and other intervention measures into long-term intervention initiatives.
Keywords: *RapidEye, habitat fragmentation, soil, species abundance*

Introduction

Species abundance and richness are important measures of biodiversity (Gould, 2000). They vary from one spatial range to another, which is a function of habitat heterogeneity (Kerr et al., 2001) fragmentation (Murcia, 1995; Benítez-Malvido and Martínez-Ramos, 2003; Echeverría et al., 2007; Hobbs et al., 2008) and modification (Osborne et al., 2001). Habitat modification interferes with ecosystem configuration (Stoms and Estes, 1993), species distribution and numbers (Griffiths and Lee, 2000), structural complexity of ecosystems and their functioning (Debinski et al., 1999), patch and landscape ecosystem processes (Didham, 2001) and alters the biological trait of individual species (Helm et al., 2006). It also interacts synergistically with anthropogenic threats (Laurance, 2007) interrupting species occurrence, composition and density (Stoms and Estes, 1993). Literature shows that habitat fragmentation also condenses habitat area coverage enhancing the species extinction debt (Bogich et al., 2012). By reducing the total habitat area requirements of species (Murcia, 1995; Fahrig, 2003; Echeverría et al., 2007), the rate of species extinction and endemism is enhanced

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(Burgess et al.; Burgess et al., 2001; Burgess et al., 2002; Adams et al., 2003; TØTTRUP et al., 2004). In low montane ecosystems, fragmentation is known to affect species loss due to deforestation (Hall et al., 2009). Various studies indicate significant variability in the abundance of alien invasive plant species, due to fragmentation. For instance, Mumbi et al. (2008b) showed that fragmentation affects the abundance of coprophilous fungi and algal blooms as a result reduction in the population of Podocarpus and Psychotria tree species.

The intensity of fragmentation is dependent on different factors (Benítez-Malvido and Martínez-Ramos, 2003; Fahrig, 2003; Echeverría et al., 2007). For instance, dynamics in land use and elevation has an effect on individual species (Murcia, 1995; Benítez-Malvido and Martínez-Ramos, 2003; Fahrig, 2003; Burgess et al., 2007b; Echeverría et al., 2007). It may also be a function of varying patch sizes (Echeverría et al., 2007) and structural complexity (Murcia, 1995; Benítez-Malvido and Martínez-Ramos, 2003; Fahrig, 2003; Fischer and B. Lindenmayer, 2006; Burgess et al., 2007b; Echeverría et al., 2007). However, the effect of fragmentation on tree species at local scales is not widely explored (Ylhäisi, 2004; Zotz and Bader, 2009). Whereas a series of studies have used bioclimatic variables to ecologically model species diversity (Pearson and Dawson, 2003; Martínez-Meyer et al., 2004; Thuiller et al., 2006), the validity of this approach, particularly at local scales, remains unresolved (Araújo and Luoto, 2007).

As aforementioned, habitat fragmentation is a threat to biodiversity and conservation (Achard et al., 2002; DeFries et al., 2002; Benítez-Malvido and Martínez-Ramos, 2003; Fahrig, 2003; Fischer and B. Lindenmayer, 2006; Burgess et al., 2007b; Echeverría et al., 2007; Hobbs et al., 2008). This is the case for the Eastern Arc Mountains in Tanzania, a highly ranked global biodiversity hotspot (Olson and Dinerstein, 1998), Hall, 2009). They host approximately 100 endemic vertebrates (10 mammals, 20 birds, 38 amphibians, 29 reptiles) and approximately 1500 plant species including, 68 tree endemics (Burgess et al., 2007b). Despite their global importance, the region remains highly vulnerable to anthropogenic influence (Burgess et al.; Erik Bjørndalen, 1992; Burgess et al., 2002). The extent of habitat loss and fragmentation has been deleterious (Newmark, 1998; Fjeldså, 1999; Hall et al., 2009; Swetnam et al., 2011). Key threats include settlements, logging, farming and urban sprawl (Burgess et al., 2007b), consequently, approximately 80% of forest cover has been lost in recent years (Hall et al., 2009). A substantial area and the highest number of extinct species were recorded in lowland montane forest between 1975 and 2000 (Hall et al., 2009).

A shift in an ecosystem's stability transforms it to an undesired state, compromising its capacity to support normal functions and increasing the rate of endemism and extinction (Şekercioğlu et al., 2004). Although species vary in their geographic occurrence, distribution and response to dynamic environmental conditions (Fischer et al., 2004), modelling their diversity is a prerequisite in conservation monitoring, planning and management (Carlson et al., 2007). This forms a basis for knowledge generation, specifically on species-habitat relationships in space, time and future risk management (Olson et al., 2014). To date, this subject remains unexplored in natural fragmenting ecosystems in Morogoro region, Tanzania (Hall et al., 2009).

In this context therefore, this study aimed at investigating how forest fragmentation affects species abundance and diversity in a heterogeneous landscape in the Uluguru forest block. Edaphic factors such as NPK, Ph and C were used as indicators to soil health (Solomon et al., 2000; Fageria, 2010).

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Materials and methods

Study area

Uluguru tropical forest is located at ($7^o2'$ - 7^o $16'$S) and (38^o $0'$ - 38^o $12'$E) in Tanzania (*Figure 1*) and forms part of the Eastern Arc Mountains blocks, which is a series of crystalline mountains in Kenya and Tanzania (Burgess et al., 1998; Olson and Dinerstein, 1998). The mountains range from lowland rain forests to elfin montane forests and are separated by lowlands whose origin is said to have been caused by faulting (Munishi et al., 2007). The area experiences bimodal rainfall in April and November, ranging from 2900-4000 mm on windward slopes and 1200-4000 mm on the leeward (Munishi et al., 2007). The Uluguru forest block (*Figure 1*) hosts approximately 135 plant species (Fjeldså, 1999; Burgess et al., 2007b), however, the forest cover has declined from 300 km2 in 1955 to 220 km^2 2000 from. Consequently, Uluguru montane forest ecosystem is regarded to be highly vulnerable to fragmentation, negatively affecting species abundance and increasing risk of extinction of rare species like the Uluguru Bush Shrike (Burgess et al.; Bjorndalen, 1992; Erik Bjørndalen, 1992; Burgess et al., 2001; Burgess et al., 2002; Fuchs et al., 2005).

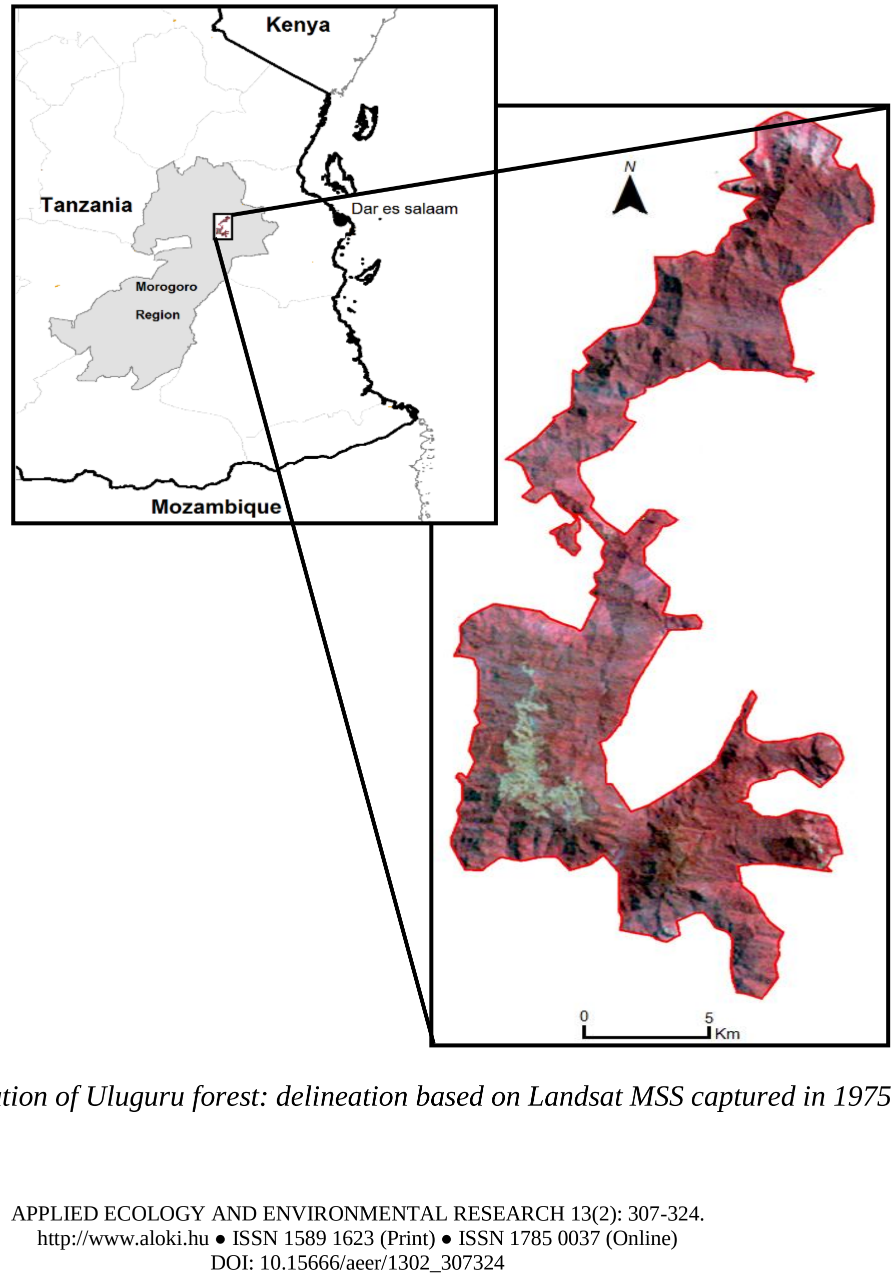

Figure 1. *Location of Uluguru forest: delineation based on Landsat MSS captured in 1975*

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Field data collection

Tree measurements were collected randomly within10 m × 10 m plots in August 2012, in the same month of image acquisition. Data was collected from 80 plots located in the field using a Global Positiong System (GPS) of submeter accuracy. Major tree species with more than five centimeters diameter at breast height (dbh) were sampled. Data on species names, genera, families, density, basal height, and canopy cover were recorded. Additionally, elevation for each plot was taken. Soil data (C, N, P, pH and K) was collected within the 0-15cm depth. The status of the habitat in Uluguru forest blocks was categorised into two classes; fragmmented and intact (82 data ground data points were used).

Image acquisition and pre-processing

RapidEye satellite imagery for the Uluguru forest block was acquired on 23/10/2012. RapidEye has a spatial resolution of 5 metre and 5 bands centered Blue: 440-510 nm, Green: 520-590 nm, Red: 630-685 nm, Red Edge: 690-730 nm and NIR: 760-850 nm. The image was first geometrically corrected (Universal Transverse Mercator: UTM, zone 37 South projection) using 30 identifiable ground control points (GCPs) distributed across the image. The GCPs were recorded on 1:50000 topographic maps of various years. A nearest-neighbour algorithm and first order polynomial transformation were applied to resample the image to its original pixel size. The root mean square error of less than half a pixel was obtained, indicating a reliabe geometric correction. The imagery was then atmospherically corrected using ATCOR module built in Earth Resources Data Analysis System software (Erdas Imagine 2013) and digital number values converted to surface reflectance.

Soil chemical analysis

A total of 80 samples of soil taken at 0-15 cm depth were collected from 10 m by 10 m plots. Samples were air dried and sieved using a 2mm sieve prior to analysis. Scanning of soil samples was conducted using atomic absorption spectrometer to get soil reflectance values. The spectrometer was then used to extract reflectance values for each of the elements (N, P, K, Ph, C) which were then taken for wet chemistry analysis. The contents of nutrient elements were used to correlate bands with actual mineral values. These were then used to estimate for the rest of the samples.

Data analysis

Image classification

Maximum Likelihood (ML) supervised classifier, one of the most commonly used methods for classifying remotely-sensed data (Strahler, 1980; Conese and Maselli, 1992; Foody et al., 1992; Wei and Mendel, 2000; Bruzzone and Prieto, 2001; Seto and Liu, 2003) was used to delineate the fragmented and intact forest classes. Based on the developed class signatures, a thematic map was produced and smoothed using the majority filter rule. A total of 82 ground truth points were used to generate a confusion matrix to determine the overall (OA), producer’s (PA) and user’s (UA) accuracies.

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Modelling fragmentation

Fragmentation in the Uluguru forest block was modelled using Fragstats metrics. Fragstats is a spatial statistics program useful in computing metrics at patch, class and landscape level (McGarigal and Marks, 1995). It is distinct in nature and has the capacity to estimate landscape behavior characteristics (Millington et al., 2003; Saikia et al., 2013). In this study, the classified RapidEye image was converted to ASCII format and analyzed to get different patch parameters. According to Didham (2001) patch metrics are valuable in characterizing fragmentation, consequently, patch metrics were combined with species data for further analysis.

Statistical analyses

Poisson regression was used to investigate significant differences in species abundance between fragmented and intact habitats. Student t-tests were used to determine differences between intact and fragmented habitats in relation to elevation, patch area and soil nitrogen content. Relationships between patch area and soil nitrogen content and patch area and elevation were investigated. Elevation and patch area are considered important estimators of habitat heterogeneity and fragmenting landscape respectively (Kerr et al., 2001).

Calculation of species diversity

Species diversity was calculated from field measurements using the Shannon-Weaver diversity index. The analyses were performed in R version 2.10.0 (R Development Core Team, 2009) for field data collected from the Ulugurus. Shannon-Weaver diversity index is a measure of the diversity index of a species community and combines richness and evenness. It is a non-parametric statistical parameter based on the proportion of species relative (qi) to the total number of species (Q) (Chao and Shen, 2003). Species diversity was calculated, taking into account the number of species per family present in the forest ecosystem and was computed using the equation:

$$H' = -\sum_{i=1}^{S}\left(\frac{qi}{Q}\right)\log\left(\frac{qi}{Q}\right) \qquad \text{(Eq.1)}$$

Where: H' is the Shannon-Weaver diversity index, qi is the fraction of individuals belonging to the i species, Q is the total number of individual species in the sample, and *S* is the species richness (Shannon and Weaver, 1963). Species diversity was then categorized in two groups: low and high values, which were converted to readable text file format with geographic co-ordinates for processing in GARP.

Species niche modelling Using GARP Algorithm

GARP is a genetic algorithm that creates ecological niche models for species. The models describe environmental conditions under which the species are able to maintain populations. For input, GARP uses a set of point localities where the species is known to occur and a set of geographic layers representing the environmental parameters that might limit the species' capabilities to survive. The algorithm applies the best subsets

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procedure using the new open modeller implementation in each GARP run. Remote sensing variables were extracted based on the high resolution RapidEye satellite data and measurements linked to species habitat requirements. Kriging was applied to the rest of variables i.e. N, P, K, C then converted into ASCII format, a format accepted by GARP model. An Aster Digital Elevation Model (DEM) was also converted to the ASCII format. This was used to establish relationships between species diversity and other environmental variables including N, P, K, C, pH, DEM, and RapidEye satellite data. All variables used in the model were screened to test for highly correlated variables using the Pearson correlation tests. With values $r<0.7$ shows no correlation (Olson et al., 2014). A Pearson correlation test was employed to assess relationships between Shannon wiener index and each of the environmental parameters.

Jack Knife Tests

Jack Knife tests were used to assess the importance of the variables used in running the model (Saatchi et al., 2008). This test is in-built in the GARP model which is important in testing the significance of each of the environmental variables used. It generates a model that estimates the accuracy for the entire layer set. Then for each layer, a new model is generated without that particular layer and the accuracy determined. All models were trained with similar points randomly selected from given occurrence points, and the accuracy calculated with the rest of the test points using 75% of the data. The area under curve (AUC) was used in assessing the level of significance of the curve. According to Bell, (1999) values less than 0.5 are regarded as uninformative, between 0.7 and 0.8 as acceptable and above 0.8 signify a good fit.

Further model validation

The model was further validated using the partial receiver operating curve (ROC). We integrated species presence data and area dependent suitability file generated as an ASCII file in GARP. This was then converted as a grid format and points extracted in ArcGIS 10.2. The two data sets were run in partial roc setup and run with a proportion of points set at 50.

Results

Figure 2 shows a thematic map obtained using ML classifier. An overall classification accuracy of 84% was obtained with individual accuracies for both classes more than 80%, except the producer’s accuracy for intact forest (*Table 1*). The classifications show that North Uluguru has relatively more intact forest than south Uluguru (*Figure 2*).

Table 1. *Classification accuracy measures for the thematic map*

Class name	Correctly classified	Misclassified	Total	PA (%)	UA (%)
Fragmented forest	54	2	56	96.43	83.08
Intact forest	15	11	26	57.69	100.00
OA (%)	84.15				

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Abundance of tree species

A total of 1,394 trees, comprising 55 different species categories were found in Uluguru forest block. The species discovery curve (*Figure 3*) shows relations between discovered and sampled species.

The *Syzygium cordatum Hochst.ex C.Krauss* was the most dominant tree species, constituting 18% of the total trees measured (*Figure 4*). On average, elevation for Uluguru forest was 1,951.63 m. There was no significant difference ($p \geq 0.05$) in elevation status between intact (1901 m) and fragmented (2056 m) habitats in Uluguru forest (t = -1.515, $p = 0.134$).

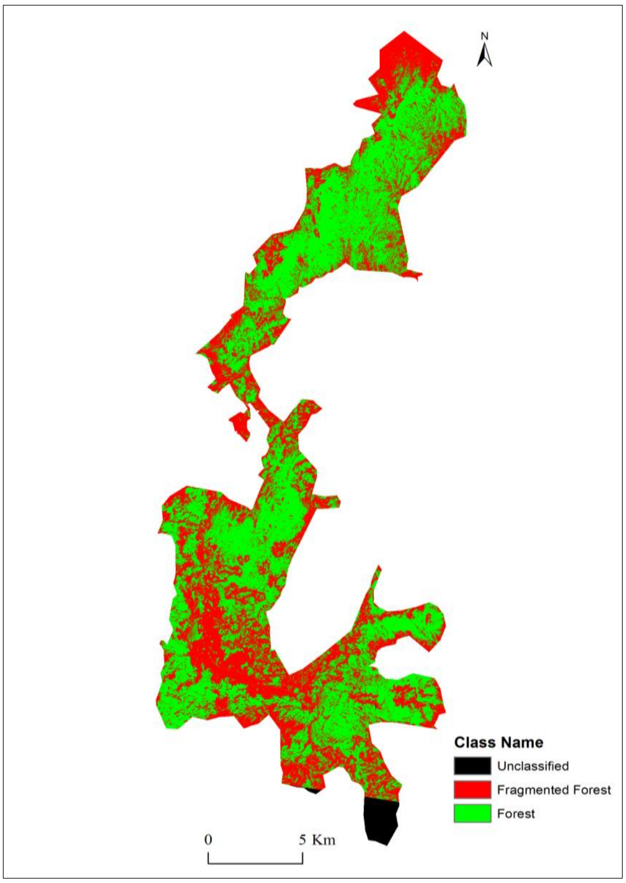

Figure 2. *Fragmented and intact forests in the study area*

Impacts of forest fragmentation on patch area and soil health

The mean patch area was 41,108 m^2, which varied significantly (t = 2.781, $p = 0.007$) between intact (52,665m^2) and fragmented (17,106m^2) habitats. There was no significant difference in nitrogen content between intact and fragmented forests (p=0.242). The average soil nitrogen level for Uluguru was 0.50 mg/g, which was relatively similar in intact (0.53) and fragmented (0.45) habitats.

Impacts of forest fragmentation on species abundance and soil health

Individual species responded differently to changes in patch area, habitat status and soil nitrogen content (*Table 2*). The abundance of some species increased (a positive

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estimate value) with an increase in patch area while others decreased (a negative estimate value). For instance, the abundance of *Syzygium cordatum Hochst.ex C.Krauss* ($p < 0.001$), *Allanblackia uluguruensis Engl* ($p < 0.001$), and *Maesa lanceolata Forssk* ($p < 0.001$) increased significantly with an increase in patch area. While the abundance of *Mytenus undata Thunb* ($p < 0.001$), *Zenkerella capparidacea (Taub.) J.Leon* ($p < 0.001$) and *Oxyanthus specious DC*. ($p = 0.023$) decreased significantly. Some tree species were more abundant in intact areas than in fragmented areas, after adjusting for the effect of patch area and nitrogen level and vice versa. *Syzygium cordatum Hochst.ex C.Krauss* ($p < 0.0001$), *Allanblackia uluguruensis Engl* ($p = 0.003$), and *Maesa lanceolata Forssk* ($p = 0.047$) were more abundant in fragmented habitats, while Myt*enus undata Thunb* ($p < 0.001$), *Zenkerella capparidacea* (Taub.) J.Leon ($p < 0.001$), and *Oxyanthus specious DC.* ($p = 0.008$) were more abundant in intact areas (*Table 2).* Results also showed that soil nitrogen content varied with a change in habitat status which also influenced the abundance of species in both fragmented and non-fragmented areas. For instance, adjusting the effect of patch area and habitat status, the abundance of species intensified in some dominant tree species, while others decreased with higher levels of nitrogen (*Table 2*). Species populations also correlated inversely with changes in nitrogen. For instance, the abundance of *Zenkerella capparidacea* (*Taub*.) *J.Leon* ($p<0.001$) and *Psychotria goetzei (K.Schum.) E.M.A* was lowest under low nitrogen conditions ($p = 0.049$).

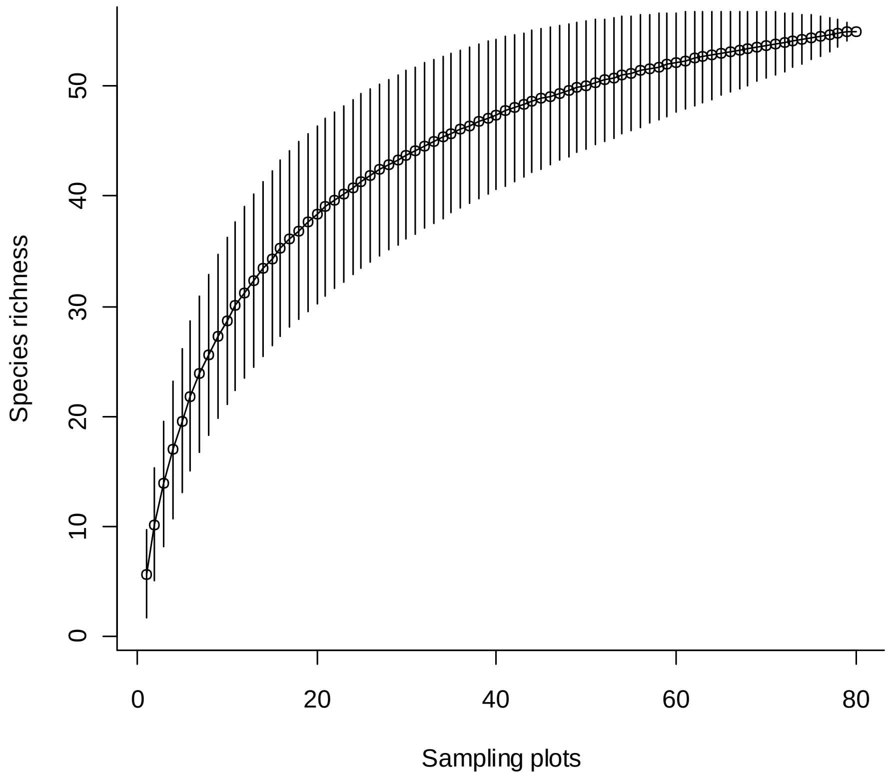

Figure 3. *Species discovery curve (accumulation curve)*

GARP model AUC KAPPA results

The model was run producing a high total area under curve (AUC) accuracy of 0.89, which signifies a good fit of the model. In further validation of the model in Partial Roc,

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a value of 1.27 was generated. This is within the 1-1.5 range which is an indicator of a very good model prediction. The Jackknife test results generated an overall internal test accuracy of 72.31% and a Roc score of 0.89 while the external test accuracy was 81.82% and a Roc score of 0.94. The total area under curve (AUC) was 0.89.

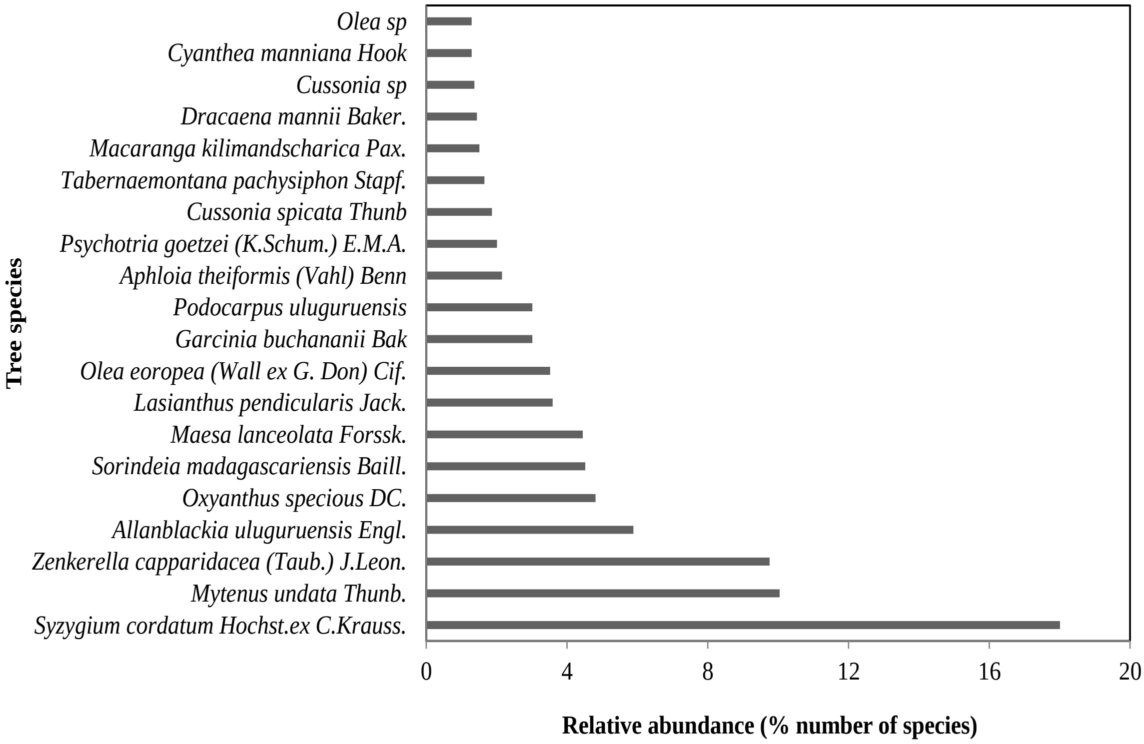

Figure 4. *Rank-abundance curve for dominant tree species*

Species diversity

A total of 1,394 trees, comprising 55 species, were recorded. There was higher species diversity in Uluguru South than Uluguru North (p-value: 6.026e-05). No variables used in the model were highly correlated i.e. r< 0.7. Pearson correlations between the Shannon wiener index and each of the environmental variables showed a positive correlation between most of the variables (C: r=0.26, N: r=0.25, P: r=0.22, DEM: r=0.37) except K: r= -0.25. DEM, C, N, Ph, P had a significant influence on the model. The DEM had the greatest effect on the model.

High species diversity was dominant in intact areas located in the central region of the Uluguru forest (*Figure 5A*) while low species diversity was widespread in fragmented areas (*Figure 5B*). Areas characterized by zero values are not well placed to support high species diversity due to the extent of fragmentation beyond the threshold.

Discussion

This study provides important findings on effects of fragmentation on species abundance in the Uluguru forest area based on field measurements and remotely sensed data. The relatively high overall accuracy (see *Table 1*) of mapping fragmented and intact forest in the study area provided an important basis for investigating the impact of

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Table 2. *Poisson regression model results for the relationship between abundance of tree species and mean patch area (ha), habitat status and soil nitrogen content for the dominant species in Uluguru forest area*

	Patch area (ha)		**Habitat Status**		**Nitrogen level (g kg-1)**	
Species	Estimate±se	*P* value	Estimate±se	*P* value	Estimate±se	*P* value
Syzygium cordatum Hochst.ex C.Krauss.	0.00001±0.000001	<0.001	1.17±0.14	<0.001	0.58±0.16	<0.001
Mytenus undata Thunb.	-0.00004±0.000007	<0.001	-2.40±0.33	<0.001	0.76±0.33	0.020
Zenkerella capparidacea (Taub.) J.Leon.	-0.00002±0.000006	<0.001	-0.81±0.21	<0.001	-1.91±0.53	<0.001
Allanblackia uluguruensis Engl.	0.00001±0.000002	<0.001	0.75±0.25	0.003	0.71±0.27	0.008
Oxyanthus specious DC.	-0.00003±0.000015	0.023	-2.74±1.03	0.008	0.28±0.95	0.769
Sorindeia madagascariensis Baill.	-0.00004±0.000013	0.001	-0.92±0.30	0.002	0.74±0.43	0.086
Maesa lanceolata Forssk.	0.00001±0.000003	<0.001	0.61±0.31	0.047	0.79±0.29	0.007
Lasianthus pendicularis Jack.	-0.00004±0.000013	<0.001	-1.89±0.48	<0.001	-0.39±0.69	0.578
Olea eoropea (Wall ex G. Don) Cif.	0.00001±0.000003	0.008	1.22±0.31	<0.001	0.003±0.44	0.995
Garcinia buchananii Bak	0.00001±0.000003	<0.001	2.14±0.37	<0.001	1.16±0.36	0.001
Podocarpus uluguruensis	0.00004±0.000003	0.244	1.84±0.37	<0.001	0.38±0.43	0.382
Aphloia theiformis (Vahl) Benn	0.00011±0.000003	0.002	0.43±0.41	0.301	-0.29±0.61	0.634
Psychotria goetzei (K.Schum.) E.M.A.	-0.00001±0.000007	0.17	0.35±0.38	0.362	-2.08±1.06	0.049
Cussonia spicata Thunb	0.00003±0.000006	<0.001	1.53±0.53	0.004	2.08±0.36	<0.001
Tabernaemontana pachysiphon Stapf.	-0.00001±0.000011	0.235	-1.91±0.74	0.010	-4.48±1.91	0.019
Macaranga kilimandscharica Pax.	0.000018±0.00001	0.066	-2.32±0.76	0.002	-19.21±3.94	<0.001
Dracaena mannii Baker.	0.00002±0.000006	0.003	-0.002±0.69	0.998	-1.02±1.12	0.363
Cussonia sp	-0.00004±0.000033	0.217	0.264±0.46	0.570	-1.562±1.19	0.190
Cyanthea manniana Hook	0.00002±0.000011	0.840	-1.815±0.76	0.017	-10.395±3.07	0.001
Olea sp	-0.000003±0.00002	0.170	-1.667±0.75	0.027	-2.724±1.77	0.123

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habitat fragmentation on species abundance and diversity. Results show that fragmentation is intensive on the outskirts of the Uluguru forest (see *Figure 3*). The results are discussed in the context of how fragmentation affects species abundance and diversity and related conservation implications.

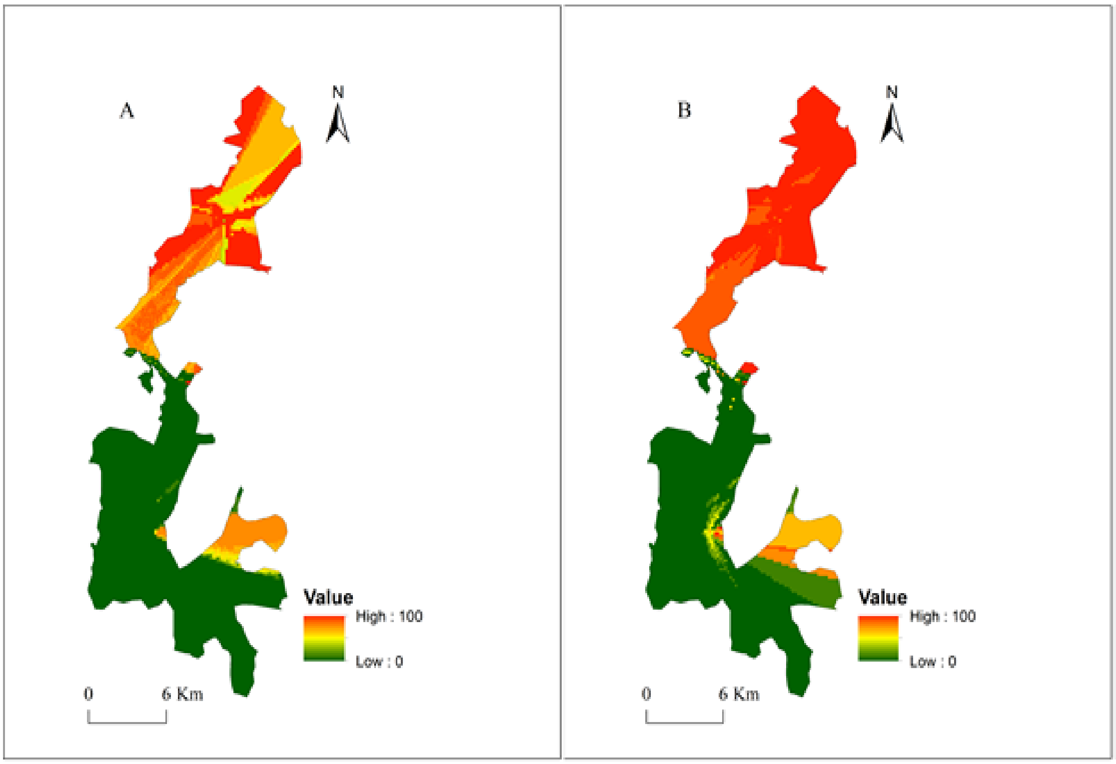

Figure 5. *Probability for high (A) and low (B) species diversity*

Fragmentation impacts on species abundance under dynamic soil health conditions

Individual species responded differently to changes in patch area. Species abundance of some tree species declined with an increase in patch area, while others decreased. For instance, the abundance of *Syzygium cordatum Hochst.ex C.Krauss, Allanblackia uluguruensis Engl*, and *Maesa lanceolata Forssk* increased in disturbed areas compared to intact areas. These species prefer abundant light associated with forest fragmentation (Cunningham, 2001). Other species such as *Mytenus undata Thunb*, *Zenkerella capparidacea (Taub*.) *J.Leon*, and *Oxyanthus specious DC* were more abundant in intact habitats than fragmented areas. This suggested that such species are prone to forest disturbance and therefore need to be prioritized for conservation.

More tree species were scattered with a low similarity along study plots with frequent occurrence of tree stumps where field assessments were conducted. A negative correlation was established on the abundance of species like *Oxyanthus specious* which decreased with an increase in patch area while *Mytenus undata Thunb*, *Zenkerella capparidacea (Taub.) J.Leon* and *Oxyanthus specious DC* significantly decreased. A decrease in patch area provides an indication that a habitat undergoing fragmentation (McGarigal and Cushman, 2002; Wu et al., 2002; McGarigal, 2006). It opens up other avenues for increasing edge effects caused by human settlements and tree logging which in turn interferes with the habitat configuration of species through increased

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exposure to soil erosion and drying up of soil moisture and erosion of nutrients (Gould, 2000; Burgess et al., 2007b). The findings are consistent with the study by Echeverría et al., (2007) which established fragmentation effects on vegetation species in southern Chile. Fragmentation also escalates the degree of patchiness of a habitat which has an effect on an ecosystem's configuration and biophysical processes (Lovett et al., 2006; Maeda et al., 2010).

Furthermore, species abundance varied significantly, which could be attributed to changes in soil in both intact and fragmented areas. The threat posed to soil is an aspect that suggests progressive fragmentation could intensify the susceptibility of important ecosystem soil elements to attrition. The level of soil nitrogen in fragmented areas was less compared to that in less fragmented areas. Typically, a fragmenting habitat is characterized by low nitrogen content (Billings and Gaydess, 2008). Changing land use play a role as they influence soil health properties (Davidson et al., 2004; Amazonas et al., 2011). Frequent disturbances opens up intact habitats to soil erosion, loss of organic matter and other necessary elements useful for vegetation growth (Guggenberger et al., 1994; Foley et al., 2005).

Impacts of fragmentation on species diversity

Applying remote sensing variables such as the fragmentation index map, DEM and edaphic factors were useful in species diversity prediction. In this study, species diversity was better predicted using customized variables with an AUC of 0.86 when the model was tested using partial ROC value of 1.27. High species diversity was associated with less fragmented land use type, high terrain and good soil conditions not exposed to harsh environmental conditions and heat. This was reflected in jackknife analysis that showed variables with the highest effect on the model. The soil variables and DEM influenced the model by 72%. The GARP model result produced an AUC of 0.89. GARP model has the advantage of predicting entire species diversity distribution as opposed to Maxent which only predicts the distribution of input occurrence data (Townsend Peterson et al., 2007). It has also been successfully used in other studies targeting regional or local scale predictions (Woodward and Beerling, 1997).

High species diversity was evident in intact non-fragmented areas. Areas characterized by zero values were not well placed to support high species diversity due to the wide extent of fragmentation. Low species diversity was prevalent in fragmented areas associated with low values of nitrogen, carbon, potassium and phosphorus in the Uluguru North. This is attributed to increased anthropogenic activities in the area (Shirima et al., 2011). This further confirms a similar study finding which associated high species diversity with intact areas attributed to less human disturbances (Rashid et al., 2013). Other related studies established less species in sites exposed to predation (Olson et al., 2014).

Based on the GARP algorithm, generally, Uluguru forest block has a high potential for high species diversity. It is possible to restore the entire region into a high species diversity site despite the increasing rate of external perturbations from anthropogenic activities. Ecologists support the argument that disturbed ecosystems with a high diversity response have a better chance of restoration after disturbance, as opposed to ecosystems with low diversity (Folke et al., 2004). If the habitat is conserved, most likely endemic and vulnerable species will be protected from more exposure to harsh environmental conditions (Armenteras et al., 2003; Burgess et al., 2007b; Buermann et

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al., 2008; Burgess et al., 2013) and other ecological risks (Folke et al., 2004). This could significantly contribute to low endemism and extinction rates (Şekercioğlu et al., 2004).

Conservation Implications

Anthropogenic activity affects species occurrences and survival rates (Tilman and Lehman, 2001; Pineda and Halffter, 2004; MacDougall et al., 2013). The site portrays a strong probability of high species diversity with a great ecological resilience capacity. Conservation organizations and decision makers need to encourage good conservation practices that will counteract loss of vegetation in the area. One of the challenges facing management of fragile ecosystems is development of socio-ecological resilience that can in principle contain dynamic landscapes (Daily, 2000; Fischer et al., 2004; Folke et al., 2004; Foley et al., 2005). The need for example, to support development of appropriate scenarios with the capacity to support sustainable livelihoods while conserving the habitat need to be strengthened. The other factor which may account for species losses is poor institutional frameworks. A previous finding indicated that institutions, which are lacking in Uluguru region, play a critical role in fostering community response to sustainable use of natural resources. Based on field observations, most communities are not motivated into sustainable forest conservation activities. Therefore, pursuing sustainable forest management while integrating local institutional frameworks can be a sound and a better step in strengthening governance frameworks in biodiversity conservation (Lopa et al., 2012).

Based on findings of this study, habitat fragmentation can be considered to be a major threat to conservation in the region. Findings showed that in areas of high terrain, the intensity of fragmentation was relatively high. This could be associated with rich biodiversity resources in high terrain areas in the Ulugurus (Swetnam et al., 2011). Though the abundance of species varied with changes in habitat status, it emerged that most dominant species were affected. It will be appropriate if decision makers and conservation biologists could support conservation efforts in the region as it still remains susceptible to increased endemism and extinction. This is due to the increasing population leading to clearing of the Uluguru slopes in search of greener pastures (Burgess et al., 2007b). Furthermore, expansion of the urban set-ups at Morogoro town and surrounding smaller towns facilitate easy accessibility to markets in Morogoro region which drive forest loss in Uluguru.

Generally, the Eastern Arc mountains have a very conducive and reliable climate (Mumbi et al., 2008). This is useful in establishment of agricultural systems and therefore attractive to subsistence farmers in Tanzania (Burgess et al., 2007a). Intensification of agricultural systems and settlements presents a key threat to species abundance and survival in the Ulugurus (Burgess et al., 2007b). Although population density is projected to intensify in the coming decades, the worst case scenario is expected (Fjeldså, 1999; Hall et al., 2009; Swetnam et al., 2011). Most likely species existence might become irreplaceable in the long-term if the trend persists (Rondinini et al., 2006).

Conclusions

The present study has yielded valuable insights regarding the ecological importance of forest fragmentation on the abundance and diversity of fundamental species in Tanzania. Overall, fragmentation presents a great challenge to species abundance and

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diversity in the Uluguru forest block. We make important observations from the study: 1) Fragmentation is having an impact on species abundance under changing soil conditions, and 2) The use of Genetic Algorithm for Rule-Set Prediction (GARP model) and remote sensing variables are useful in discerning impacts of fragmentation on species diversity in the Uluguru forest block. Our study results suggest the need to accord priority to habitat restoration and conservation efforts in the long term plans for the fragmenting habitat.

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