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Using selected biophysical parameters and remote sensing in tree species diversity and size monitoring in natural woodlands under non-rainfall limitation conditions

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Abstract

This study assessed the feasibility of using selected biophysical parameters (Slope, altitude, aspect, soil pH, phosphorous, nitrogen and carbon) and remote sensing to monitor tree species diversity and size in an example of natural woodlands in a non-rainfall limitation region. The assessment was done across three different land use systems namely communal, old resettlement and newly resettled areas. Tree species diversity was quantified using the Shannon weaver index while tree species height and diameter at breast height were assessed using the modified Shannon Weaver index. The relationship between species diversity and selected biophysical factors was assessed using regression analysis. The relationship between remotely sensed data and species diversity was assessed by regression analysis of the standard deviation of Normalised Difference vegetation Index (NDVI) and Shannon weaver index. Results indicate that all individual biophysical parameters have a contributory influence on species diversity. However, the relationship was shown to be weak with a correlation coefficiency of between -0.04 and 0.05 for all selected individual parameters. A significant correlation was only detected between tree species diversity and aspect. The standard deviation of NDVI was positively related to species diversity. The study concludes that, there is potential in the feasibility of using the selected biophysical parameters and remote sensing in tree species diversity monitoring in natural woodlands under non-rainfall limitation conditions. Future work is required to verify the detected trends in behaviour of tree species in relation to biophysical parameters and NDVI.

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Introduction

Biodiversity is a key issue of nature conservation, and tree species diversity is one of its most important components (Ito, 1997). It matters to people and is an indispensable part of a sustainable world (EASAC, 2005). In Zimbabwe, woodlands extend over a great number of ecosystems, harbouring a rich diversity of species and genes. Thus, within biodiversity conservation, top priority should be given to woodlands. The diversity of tree species is fundamental to total woodland biodiversity, because trees provide resources and habitats for almost all other vegetative and non vegetative species (Cannon *et al.*, 1998; Pandeya *et al.*, 2007). To study tree species diversity in woodlands is key to conserving biodiversity of woodlands ecosystems. In addition, studying tree species diversity and size helps in the understanding of relationships between ecological elements of woodlands and improved principles of woodland management (Marini *et al.,* 2007).

Monitoring of biological diversity and/or its elements can be of great value as it enables understanding of current biodiversity status and carving of appropriate management tools. It is important therefore to establish fast and effective ways to monitor this biodiversity. Thus, remote sensing and proxy indicators can be a useful in this regard, which allows the monitoring of biodiversity over large area within a short space of time. It is therefore important to assess the feasibility of using remote sensing and environmental parameters in predicting species diversity. A number of different methods quantifying species diversity have been developed (Ludwig and Reynolds, 1988; Patil and Taillie, 1982; Merganic and Smelko, 2004). Ecologists define species diversity on the basis of two factors: (l) the number of species in the community usually called species richness and (2) the relative abundance of species, or species evenness.

Some theoretical studies have established a direct positive relationship between species evenness and species richness. However, recent empirical studies have shown the relationship not to be always positive (Stirling and Wilsey, 2001; Triin Reitalu *et al.*, 2009). Species evenness and richness also differ in their responses to local habitat factors (Ma, 2005; Wilsey and Stirling, 2007), suggesting that the two diversity components may vary independently and be influenced by different ecological processes (Fattahi and Ildoromi, 2011). Some studies have shown that species evenness show a stronger association than species richness (Mattingly *et al.*, 2007). It is in this context that this study will use species evenness as the biodiversity index to assess the feasibility of using selected environmental parameters and remote sensing to determine species diversity.

However, we have noted that diversity changes in space and time as it is influenced by abiotic and biotic factors, and disturbances (Frelich *et al.*, 1998; Nagaraja *et al.*, 2005; Ucler *et al.*, 2007). Elements that affect plant growth and resource availability, such as climate, are regarded as primary influencing factors (Terradas *et al.*, 2004), while other environmental parameters, such as elevation, are considered indirect factors because they themselves have no direct impact on plant growth, but are correlated with the primary factors (Pausas *et al.*, 2003; Bhattarai *et al.*, 2004). Quite often, the relationship between diversity and elevation is investigated (Grytnes and Vetaas, 2002; Bhattarai and Vetaas, 2003; Bachman *et al.*, 2004), while the effects of other topographic features are rarely examined (Johnson, 1986; Palmer *et al.*, 2000). Furthermore, most of the published works analyse environmental factors only with regard to species richness, representing just one component of species diversity (Merganic *et al.,* 2004). This research aims to assess the feasibility of using the indirect factors such as aspect, slope, soil pH, nitrogen, carbon and Phosphorus to predict tree species diversity, expressed by the Shannon-Weaver index, and size in natural woodlands in a non-rainfall limitation area in Mashonaland West, Zimbabwe. This study also aims to clarify the relationship between tree species diversity and remotely sensed vegetation index. These relationships, if found to be significant, could be used for estimating the actual species diversity from usual forest stand parameters. This could aid to the simplification of models applied for the management of natural resources.

Materials and methods

The study area

The study was carried out in a non-rainfall limitation zone comprising three areas with settlement history. One of the areas was settled for more than 50 years, another was settled for more than 30 years while the other one was settled for about 15 years. These areas are located in Bindura and Shamva districts 31°E 17°S of Mashonaland Central province (Figure1).

Specifically, the data was collected from Kanyera Village, Chomutomora village and Hereford farm. The three areas are in Natural Region 2A receiving an average of 14 – 16 rainy pentads per season and an annual rainfall total between 600 and 800 mm (Chapungu and Yekeye, 2013).

Site selection Criteria

Villages studied were selected based on the following criteria:

• Non-rainfall limitation regions, which are more suitable for biomass accumulation in woodlands.

• More representative with all the three land tenure systems near to each other. This made it more convenient to travel from one study area to the other.

• Representativeness in proportion of woodlands and other land uses such as grasslands and cropping fields.

• Representativeness of the respective farming system.

• Variations in their population density which could affect their use of tree species.

Thus, consequently Kanyera village was selected as a representative of communal areas, Chomutomora as a representative of old resettlement systems and Hereford representing newly resettled areas.

Ground sampling design

A nested non-aligned block sampling design (Chapungu and Yekeye, 2013) was used in which sample locations were randomly nested as shown in Figure 2. This design was used because it permits multi-scale assessment of variables in which small and large variations over large areas will be captured (Urban 2002). A grid of 750m*750m was drawn within the village boundary. The grid was further subdivided into 25 sub-cells (grids of 150m*150m) from which three of them were randomly selected. The three selected cells of 150m were further divided into 25 micro cells (grids of 30m*30m) where three locations were randomly selected. The centre of the three selected 30m*30m grids occupying more than 10% of the woodland boundaries were used for ground sampling in the field.

Using this design a total of 134 sampling points were derived from the woodlands of the whole study area. Of these 32 points were sampled in Kanyera, 45 points in Chomutomora and 57 points in Hereford. Though initially 88 points were derived from Hereford because of the larger area of woodlands, some of the land was considered to be sacred by the villagers hence they were not sampled. The locations of the sampling points and the proportion of the woodlands within each village are shown in Table 1 and Figure 3 respectively.

Field Sampling and Measurements

The selected sampling points were identified, in the field using a hand held Global Positioning System (GPS) receiver at less than 0.5-meter error. 30 *30m quadrats were then developed from the identified points. Quadrat size was determined using the species area method (Cain, 1938). The identified location was used as the centre the quadrat.

Quantification of tree species diversity

Rooted frequency (Chapungu and Yekeye, 2013) was used to measure tree species abundance, implying that trees rooted within the quadrats were counted. Height was used to separate trees from shrubs using the FAO classification (FAO, 2005). In this study trees were classified at a height of 3 metres and shrubs less than 3 metres. Tree species were identified with the help of a botanist from the National Herbarium centre. To avoid double counting of species the quadrat of 30m*30m was subdivided into four-sub quadrats of 15m*15m where an individual count of species was done. For the species identified their abundance were recorded on the data collection sheet. Tree height was measured using a clinometer, and diameter at breast height was measured using a diameter tape.

To assess tree species diversity, the Shannon-Weaver Index, which usually combines aspects of richness and evenness (H), was used. This method was used because it is a successful tool for the evaluation and quantification of plant and animal diversity, and an easy and practical measure of area diversity (Dale *et al.*, 1994).

This index was calculated using the formula:

$H = - Sum\ (P_1 In\ (P_1))$ (equation 1)

Where the summation is over all species and P_1 is the relative abundance of species in the quadrat. This index measures the average degree of uncertainty in predicting to what species chosen at random from a collection of *S* species and *N* individuals will belong (Lugwig 1988). Species evenness (E) was also calculated using the formula:

$E = H/In\ (S)$ (equation 2)

Where *H* is the Shannon Weaver index and *S* is species richness observed within the quadrat. This index assumes that when all species in the sample are equally abundant evenness should be at maximum and decreases towards zero as the relative abundance of species diverge away from evenness (Lugwig, 1988). Variations in tree size i.e. height and diameter at breast height were calculated using the Modified Shannon index using the following formula:

$MH = -Sum\ ((P_1 In\ (P_1))$ (equation 3)

Where P_i is the relative size of tree species observed in the quadrat divided by the maximum size of tree observed in all the quadrats. Significant difference in variations in tree species diversity (H), evenness (E), height and diameter at breast height within the three small-scale farming areas was tested using Analysis of Variance (ANOVA) for data which was normal (Shannon index and Modified Shannon index for tree height and diameter at breast height), and Kruskal Wallis test for data that was not normal (species evenness). These indices were also correlated to environmental factors.

Measuring Environmental factors

The environmental factors that were hypothesised to have effect on species spatial diversity include altitude, slope, aspect, soil pH, Phosphorous, nitrogen and carbon. These were measured to facilitate comparison with species diversity

Soil Sampling and collection

(equation 1)

A Global Positioning Systems (GPS) receiver was used to navigate to the sampling points where a radial arm (figure 4) was constructed within the 30 m2quadrat. The radial arm consisted of sampling plots in which quadrats designed to cover 1m2 each were located. In each quadrat an auger was used to take some soil samples.

The radial arm was designed to facilitate the capture of all variations within the 30 m² plots through considering four points: one from the centre, one from the north, one from the south west and the other from the south east. Angle between arms was 120° and its length was 12.2 metres. To construct the radial arm, a campus was used to establish the azimuth of the arms. The soil was mixed to a composite soil sample and packed into a plastic bag.

(equation 2)

Slope and altitude

The slope of the area within the quadrat was measured using a clinometer and recorded on the data sheet. Altitude of the area was read from the GPS receiver readings and recorded. To minimise error in altitude recordings, three readings were made and the mean of the three readings was then used for analysis.

Analysis of soil samples

Composite soil samples obtained from the fields were air dried for more than five days and coded. The samples were taken for laboratory analysis for total carbon, available phosphorus, pH, nitrogen and texture as indicators for fertility at the Department of Soil Science at the University of Zimbabwe.

Satellite image processing

Landsat TM image acquired on 12 June 2012 was used to extract information on land cover. Digital Numbers (DN) which range from 0-255 were first converted to reflectance values, which were then used to calculate NDVI .The procedure involved first the conversion of DN values to radiance using the formula

$$L_\lambda = Lmin_\lambda + \left(\frac{Lmax_\lambda - Lmin_\lambda}{QCALMAX}\right) QCAL \quad \text{Equation 1}$$

Where *QCAL* is the calibrated and quantized scaled radiance in units of digital numbers, $Lmin_\lambda$ is the spectral radiance at *QCAL* = 0, $Lmax_\lambda$ is the spectral radiance at *QCAL* = *QCALMAX,* and *QCALMAX* is the range of the rescaled radiance in digital numbers. Radiance was then calibrated to reflectance using the formula:

$$\rho_p = \frac{\pi L_\lambda d^2}{E_{sun}(\lambda)\cos\theta_s} \quad \text{Equation 2}$$

Where L_λ is the spectral radiance, *d* is the Earth-Sun distance in astronomical units, $E_{sun}(\lambda)$ is the mean solar exo-atmospheric irradiance, and $\cos\theta_s$ is the solar zenith angle in degrees. Normalised Vegetation Index was then calculated from reflectance values using the formula:

NDVI =(NIR-R)/ (NIR+R) (equation 3)

Where *NIR* and *R* are respective spectral reflectance values in the near infra-red (0.76-0.90 µm) and the red (0.63-0.69 µm) spectral wavelengths of Landsat TM. NDVI was used because it is an established index for estimating vegetation quantity (Walsh, 2001). Although it is sensitive to soil and atmospheric effects NDVI also provides an effective measure of photosynthetically active biomass (Tucker, 1986; Turner, 1989). In this study the standard deviation of NDVI data obtained from Landsat TM image was correlated to diversity indices (Shannon's index and evenness) of tree species using Spearman's rank correlation coefficient, as the data was not normally distributed. The standard deviation was used as a measure of variance.

Results and discussions

Tree species diversity, size and selected environmental parameters

Tree species diversity and size, which were significantly different within the three villages, were tested to see if they are significantly related to environmental factors. Table 1 shows the results. A relationship exists between each environmental factor and species diversity. However, the relationship is not significant ($p>0.05$) and it is weak for all environmental parameters considered except aspect and altitude. Thus, we cannot predict species diversity and size using the selected (slope, phosphorous, pH, Carbon and Nitrogen) individual parameters. However, the fact that a relationship exists shows that these parameters may have a contributory effect to species diversity. This is because individual tree species respond differently to environmental conditions. Tree species of different size and age growing on the same site respond differently to changes in moisture conditions. Slow growing tree species have higher growth rates during the wetter periods compared to fast growing species that show an apparent reduction in growth rates over the same rainy period (Chenje *et al*, 1998). Thus since the diversity indices are combining different species, environmental factors' influence may not be largely recognised.

Table 1. Area covered by woodlands in Hereford, Chomutomora and Kanyera.

Village	Total area in hectares.	Woodland area.	% Cover of woodland.	Number of sampling points.
Kanyera	731	231	31.6	32
Chomutomora	789	382	48.4	45
Hereford	1358	471	34.6	57

Results show an inverse relationship between altitude and species diversity. Thus, species evenness decreases as height above sea level increases. The same applies to species richness. A study by Grytnes and Vetaas, (2002) in the Himalayas has shown that the number of species in 100-m altitudinal bands increases steeply with altitude until 1,500 m above sea level. Between 1,500 and 2,500 m, little change in the number of species is observed, but above this altitude, a decrease in species richness is evident. However, results of this study have shown that at 1100m altitude the number of tree species will begin to decline. The important point noted is that altitude has an influence on species diversity. The degree of influence depends on other factors such as the types of tree species under study and the climatic conditions of the study area.

Table 2. The relationship between selected parameters and species diversity and size.

		Altitude	Slope	Aspect	Phosphorus	pH	Carbon	Nitrogen
Species evenness	correlation coefficient	-0.1	0.03	0.05	-0.23	-0.17	0.02	-0.02
	(sig 2 tailed)	0.489	0.813	0.694	0.093	0.219	0.873	0.883
Diameter at Breast Height	correlation coefficient	0.14	0.24	-0.09	0.23	0.19	0.27	0.27
	(sig 2 tailed)	0.325	0.948	0.073	0.521	0.092	0.169	0.053

This study has shown that, although altitude influences species diversity, we cannot confidently predict species diversity ($p=0.489$, $\alpha=0.05$) based on altitude. Thus, we cannot use altitude to predict species evenness or richness in woodland under non-rainfall limitation zone.

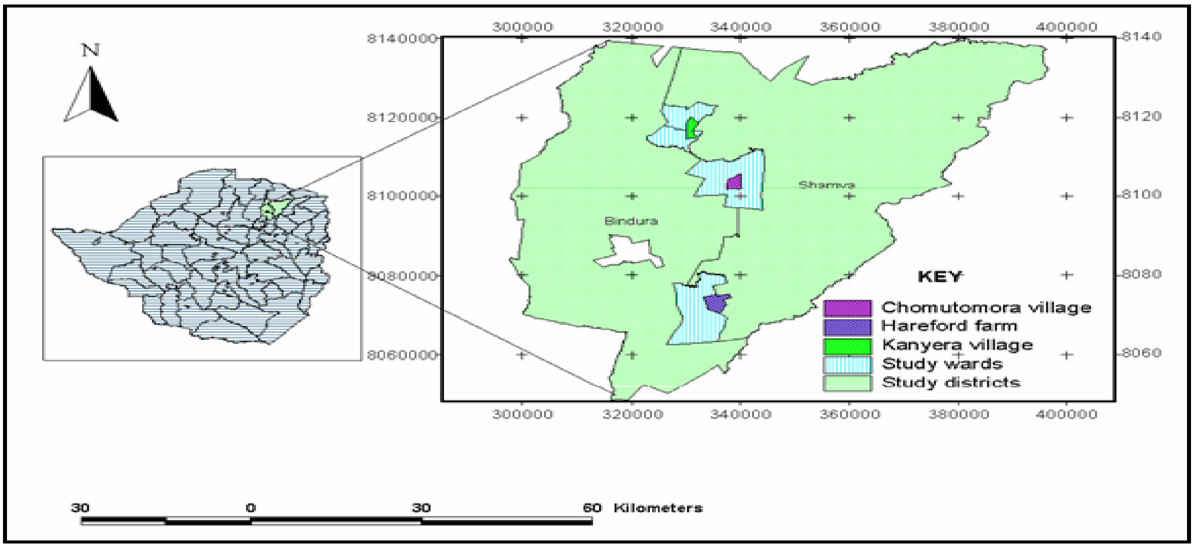

Fig. 1. The geographical location of the study sites.

The diameter of tree species at breast height is related (r=0.14) to altitude. However the relationship is weak. There is no significant (p=0.325, α=0.05) relationship between the two. Thus we cannot predict tree size based on altitude. Although the relationship is not significant, it has been observed that, trees at lower altitudes were smaller in size than those at higher altitudes. This may be due to exploitation of natural woodland by surrounding communities Slope has been shown to affect tree species diversity and size in this study. Our results concur with those of previous studies (Armesto and Martı´nez, 1978; Fuentes *et al.*, 1984) in that tree species composition and size are affected by slope. Although previous studies have shown that the relationship between species composition and slope is significant, this study did not find a significant (p=0.694, α=0.05) relationship. The relationship, whilst it exist, it is weak ((r=0.03) for species evenness and r=0.24 for diameter at breast height).

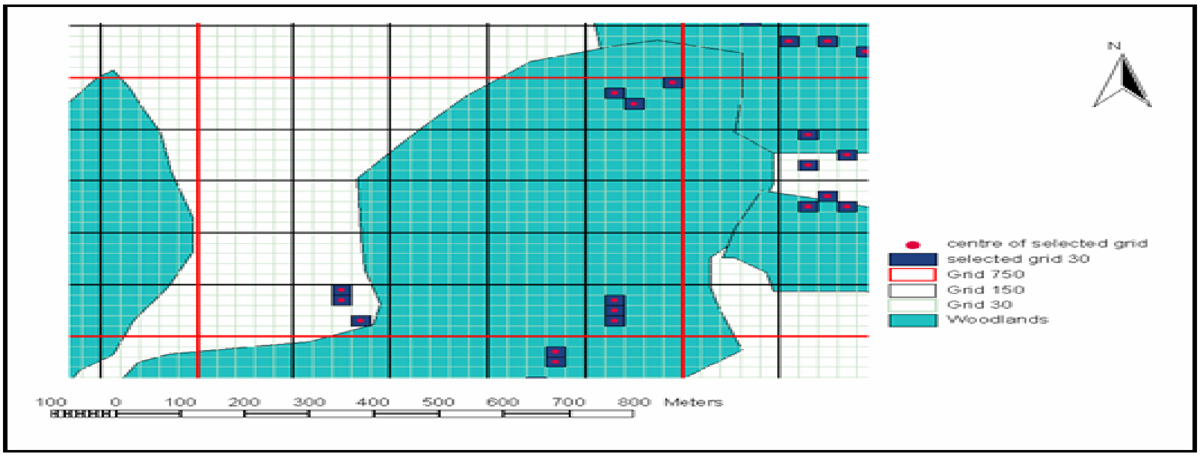

Fig. 2. Non-aligned block sampling design using grids of 750m, 150m and 30m. Adapted from Chapungu and Yekeye, 2013).

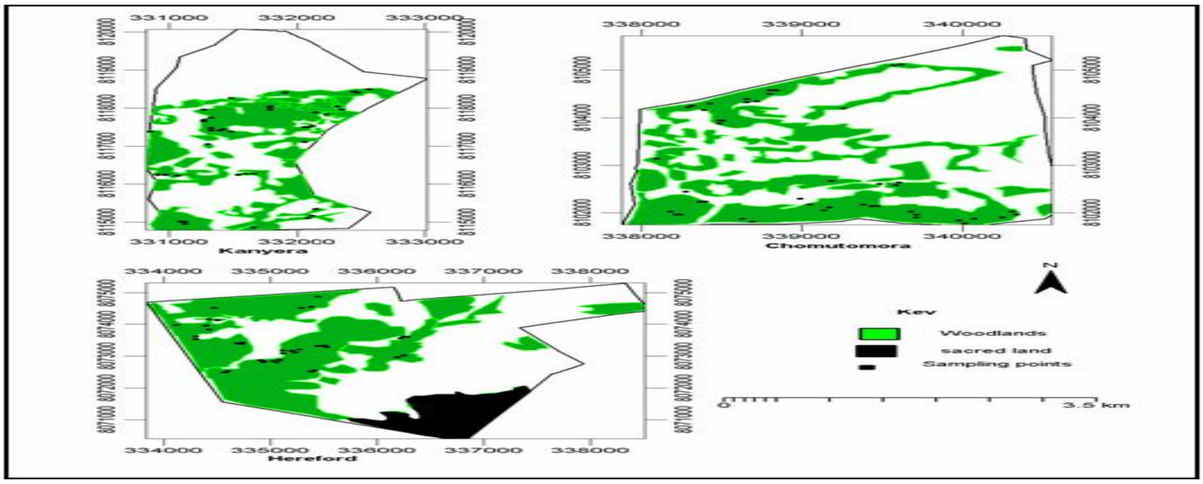

Fig. 3. Areas covered by woodlands within each study unit: Adapted from Chapungu and Yekeye (2013).

Johnson (1986) also found strong influence of altitude, slope and aspect on species composition of the forests. Our analysis revealed that from these three and other parameters considered aspect influences tree species diversity at most. However, our data do not allow us to state at which aspect the lowest or highest diversity can be expected. From the topographic characteristics, the effect of altitude on species diversity is examined in the scientific literature (Grytnes and Vetaas, 2002; Pausas *et al.*, 2003; Bhattarai *et al.*, 2004). In most cases, hump-shaped curves with maximum species diversity at mid-elevations are reported (Bhattarai and Vetaas, 2003; Bachman *et al.*, 2004). A similar pattern was observed in our analysis, although the correlation was not significant (Table 1). Such loose relationships between species diversity and altitude were reported in other studies (Merganic *et al*, 2004).

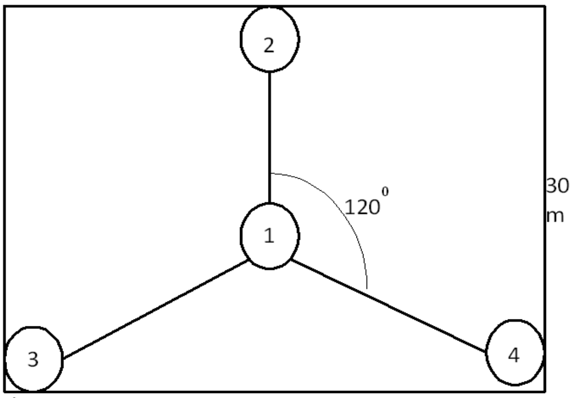

Fig. 4. The radial arm.

Relationship between remotely sensed vegetation indices and species diversity

Variations in the NDVI values were computed at different scales in the three villages as shown in Figures 5,6 and 7.

These variations were tested to find if they were significantly related to tree species diversity. The Spearman's Rank revealed that there was a significant ($p<0.05$) relationship between variations in tree species evenness and the variations in the standard deviation of NDVI. The correlations coefficients at different scales are shown in Figure 8. It is shown that the correlation coefficient of species diversity and the variance in the standard deviation of NDVI increase with an increase in scale from 90m to 210m. After 210m the relationship begins to decline. The relationship between variations in tree species diversity and the standard deviation of NDVI can be explained in terms of the differences in scale suggesting that this relationship is scale dependent (Strahler, 1986; Woodcock, 2001). At a smaller scale (90m) the relationship is low and the optimum scale at which we can relate tree species evenness and the standard deviation of NDVI is at 210m.The reason for this phenomenon may be because at (90m) the variance in NDVI values is influenced by the dominant species and the non-dominant species tend to be averaged out. As the scale increases some non-dominant species begin to be realized in this case at woodland level. As we also increase the scale to forest level we can then get the maximum variance of tree species evenness.

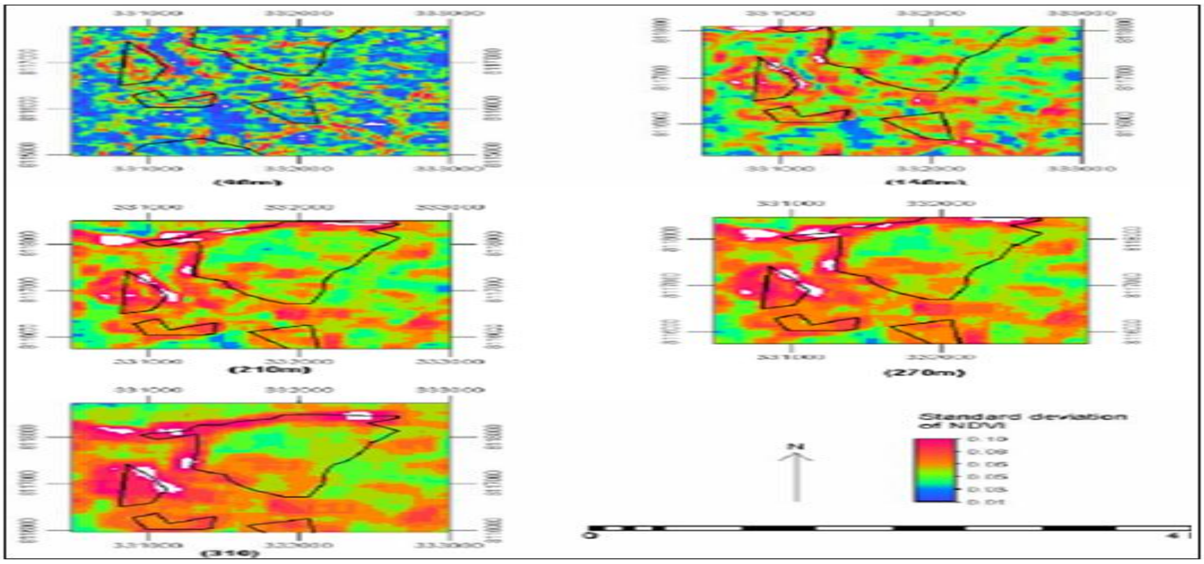

Fig. 5. Spatial variation of the standard deviation of NDVI in Kanyera village overlaid with woodland boundaries (black lines). Blank spaces indicate negative values.

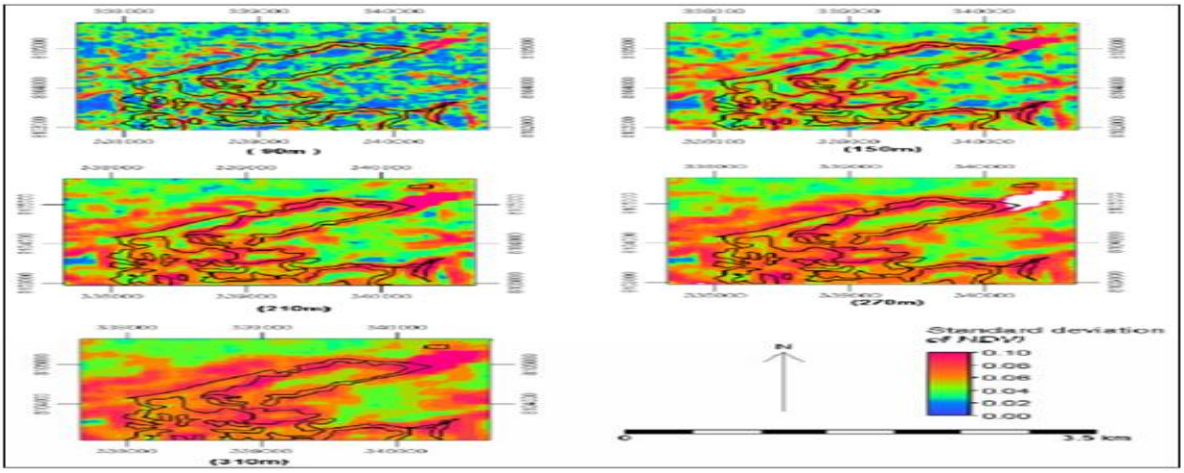

Fig. 6. Spatial variation of the standard deviation of NDVI in Chomutomora area overlaid with woodland boundaries (black lines). Blank spaces indicate negative values.

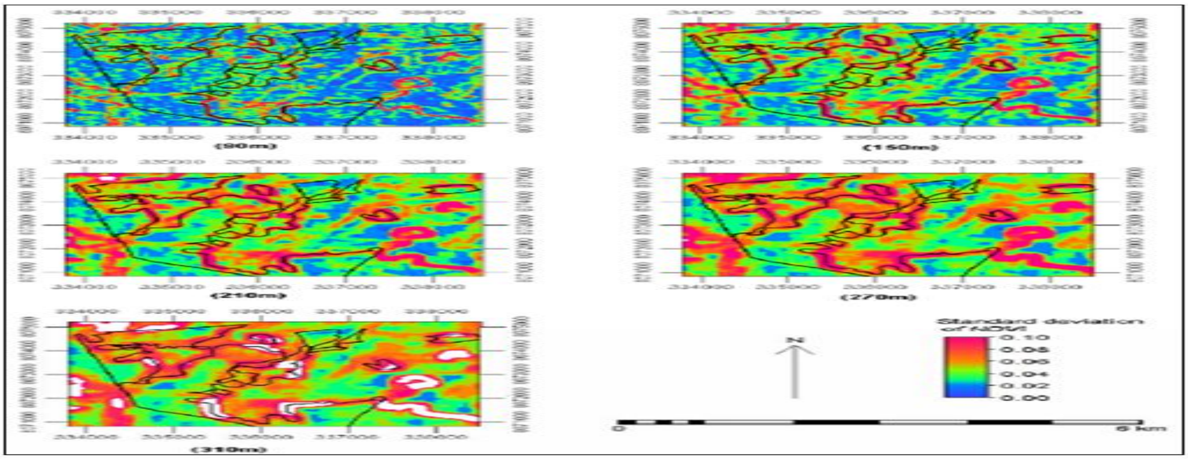

Fig. 7. Spatial variation of the standard deviation of NDVI in Hereford area overlaid with woodland boundaries (black lines). Blank spaces indicate negative values.

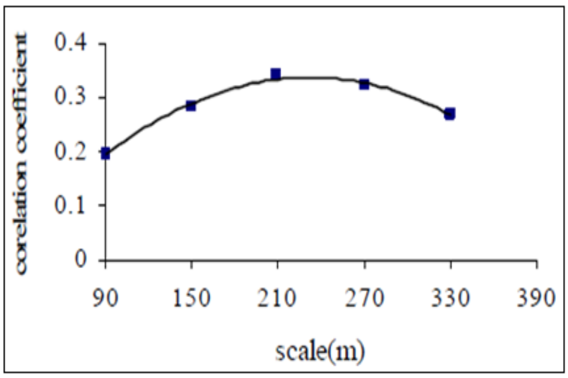

Fig. 8. Relationship between tree species diversity and standard deviation of NDVI at different scale.

Conclusions

This study highlighted the relationships between selected biophysical parameters (Slope, altitude, aspect, soil pH, phosphorous, nitrogen and carbon) and tree species diversity in woodland under non rainfall limitation area and revealed how these factors affected the diversity. It has also shown the relationship between remotely sensed data and species diversity. We conclude that there is a loose relationship between the selected biophysical parameters (except aspect and altitude) and tree species diversity. However, these parameters are likely to have a contributory effect to diversity since a relationship exists though not significant. We also conclude that the standard deviation of NDVI is significantly related to tree species diversity. Therefore, although further studies are required to verify the trends and relationships, there is great potential in using the selected biophysical parameters and remote sensing to assess tree species diversity and size. Based on these results, we suggest that the assessment of tree species diversity should be done more often using proxy indicators that make the process more efficient and effective. We recommend the need to undertake systematic and long-term biodiversity research programmes that are critical for effective and enlightened decision-making and policy formulation.

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