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Possibility investigation of tree diversity mapping using Landsat ETM+ data in the Hyrcanian forests of Iran

Jahangir Mohammadi, Shaban Shataee *

Forestry Department, Gorgan University of Agriculture and Natural Sciences, Gorgan, Iran

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ABSTRACT

Lack of data often limits understanding and management of biodiversity in forested areas. Remote sensing imagery has considerable potential to aid in the monitoring and prediction of biodiversity across many spatial and temporal scales. In this paper, we explored the possibility of defining relationships between species diversity indices and Landsat ETM+ reflectance values for Hyrcanian forests in Golestan province of Iran. We used the COST model for atmospheric correction of the imagery. Linear regression models were implemented to predict measures of biodiversity (species richness and reciprocal of Simpson indices) using various combinations of Landsat spectral data. Species richness was modeled using the band set ETM5, ETM7, DVI, wetness and variances of ETM1, ETM2 and ETM5 (adjusted $R^2=0.59$, RMSE = 1.51). Reciprocal of Simpson index was modeled using the band set NDVI, brightness, greenness, variances of ETM2, ETM5 and ETM7 (adjusted $R^2=0.459$ RMSE = 1.15). The results demonstrated that spectral reflectance from Landsat can be used to effectively model tree species diversity. Predictive map derived from the presented methodology can help evaluate spatial aspects and monitor tree species diversity of the studied forest. The methodology also facilitates the evaluation of forest management and conservation strategies in northern Iran.

1. Introduction

Hyrcanian forests comprise a diverse vegetation cover in the north of Iran and are increasingly fragmented, degraded and converted to other forms of land use (Mohammadi et al., 2008). These impacts have resulted in a reduction of forest biological diversity, dysfunction of environmental and ecological processes that generate and maintain soil, convert solar energy into plant tissue, absorb pollutants, supply clean air and water, store essential nutrients, regulate weather and climate and provide multiple forest products (Isik et al., 1997). Accurate and practical methods of measuring and estimating the biological diversity are necessary to develop effective strategies for conservation and management of all ecosystems, such as Hyrcanian forests. For example, the spatial distribution of species over a landscape is an important indicator of diversity, through which we can prioritize the establishment of nature reserves (Carroll, 1998; Myers et al., 2000), wildlife refuges or other categories of protected areas. Consequently, tree diversity mapping is of top priority for decision makers. We can achieve effective management plans only with reliable information (Dogan & Dogan, 2006). Pilehvar et al. (2002) investigated tree diversity in Hyrcanian forests using only field data without reference to remote sensing data. They examined multi-scale Whittaker plots modified for accurate estimation of tree diversity. Statistical models based on optical remote sensing imagery have proven to be effective at predicting biodiversity across a variety of spatial and temporal scales (Waring et al., 2006). The use of satellite data such as Landsat offers the advantage of repeated multispectral observations, which is amenable to quick processing for providing spatial estimates of biodiversity. In addition, remote sensing is an important source for assessment of changes in ecosystem patterns over time. Models which predict biodiversity from spectral data are directly compatible with geographic information systems (GIS), making them ideally suited for management planning and geographic analysis. The long archive and radiometric consistency of Landsat imagery lends itself to analyzing changes in biodiversity over long periods, further facilitating progress towards sustainable development and management.

There is variety of methods to gain information on species richness or diversity through satellite data. Land cover classification (Griffiths et al., 2000; Oindo et al., 2003), productivity measurement (Bawa et al., 2002; Cayuela et al., 2006; Gillespie, 2005; Oindo & Skidmore, 2002) and heterogeneity measurement (Carlson et al., 2007; Fairbanks & McGuire, 2004; Gould, 2000; Levin et al., 2007; Palmer et al., 2002) are some of the methods. Heterogeneity in land-cover types, spectral indices and spectral variability derived from satellite imagery has been correlated with tree diversity (Gillespie et al., 2008; Gould, 2000). The underlying hypothesis in these studies is that heterogeneity in land cover and spectral variability within an area is an indicator of habitat heterogeneity, which allows more species to coexist and hence greater species richness (Carlson et al., 2007; Gillespie et al., 2008; Palmer et al., 2002). The variation in land cover

* Corresponding author.
E-mail addresses: mohamadi.jahangir@gmail.com (J. Mohammadi), shataee@yahoo.com (S. Shataee).

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types within an area has been associated with species richness (Gillespie et al., 2008; Gould, 2000).

Recent studies have indicated that remote sensing may be able to provide useful information on biodiversity (Griffiths et al., 2000; Kerr et al., 2001; Nagendra, 2001). Hernandez-Stefanoni and Ponce-Hernandez (2004) examined the spatial distribution of plant diversity indices in a tropical forest using multispectral satellite image classification and field measurements and produced a diversity map. They reported an overall accuracy of 82.3% and a kappa coefficient of 0.78 for their biodiversity map. Wenting and et al. (2004) analyzed plant diversity of a broad-leaved forest ecosystem using Landsat TM data. They demonstrated the usefulness of satellite data to predict plant diversity, and showed the species richness was highly correlated with wetness component from the Tasseled Cap transformation. Dogan and Dogan (2006) tested the predictability of several biodiversity metrics such as Shannon–Wiener, Simpson index and number of species (NS) using spatial predictor variables such as topography, geology, soil, climate, normalized difference vegetation index (NDVI), and land cover. They offered three models with adjusted $R^2=0.854$, 0.594 and 0.272 for Shannon–Wiener, Simpson, and number of species (NS) indices. Foody and Cutler (2007) examined possibility of determining species richness and composition in tropical forests of northeastern Borneo, Malaysia using Landsat TM data analyzed with neural networks. They demonstrated that TM data has good potential for mapping tree species richness and species composition. They found that field measured indices of species richness and evenness were well correlated with satellite imagery ($r=0.69$ and $r=0.45$, respectively). Foody and Cutler (2003) analyzed tree biodiversity in protected and logged Bornean tropical rain forests by satellite remote sensing. They reported the overall accuracy of 95.8% for resulted map and indicated the usefulness of satellite data as a source of information on biodiversity at the landscape scale. Gillespie et al. (2009) analyzed the estimation of tree species richness using ETM+ and Radar backscattering data in tropical forests. They demonstrated that ETM+ data has potential for estimating tree species richness. In addition, Gillespie et al. reported that mean and standard deviation of NDVI help in the prediction of tree species richness with $R^2=39\%$ and $R^2=37\%$, respectively. Other studies have indicated that remote sensing data have ability to provide useful information on biodiversity in different settings (Griffiths et al., 2000; Innes & Koch, 1998; Kerr et al., 2001; Muldavin et al, 2001; Nagendra & Gadgil, 1999). It is of utmost importance that we could provide information on forest biodiversity at the landscape scale, such that managers can readily derive practical decisions concerning the forest under intervention. Although numerous studies have utilized satellite remote sensing to analyze and predict biodiversity in the tropical rain forests, the Hyrcanian forests in the north of Iran have remained relatively unexplored. We set as our objective assessment of the capability of Landsat ETM+ data for prediction of spatial biodiversity in the Hyrcanian forests given their ecological importance and high degree of biodiversity. We approach the set objective by developing and evaluating statistical regression models relating field measured biodiversity (e.g., species richness and reciprocal Simpson index) to Landsat spectral data. We also managed to include assessment of spatial variation of tree diversity using results from statistical analyses. This approach can substantially reduce costs and time in collecting information; while it increases the accuracy of spatial estimations of tree diversity.

2. Methods

2.1. Study area

The Hyrcanian vegetation zone is a green belt stretching over the northern slopes of Alborz Mountain and covers the southern coasts of the Caspian Sea. The zone is rich and includes 80 woody species (trees and shrubs) dominated with hardwoods. The forest extends in the three provinces of Gilan, Mazandaran and Golestan. The study area is Loveh forest, a small part of the eastern Hyrcanian forest in the Golestan province comprising 7,800 hectares situated between 37° 14′ to 37°24′N latitudes and 55°33′ to 55°47′E longitudes (Fig. 1). The main tree species are *Quercus castaneafolia* (chestnut-leaved oak), *Carpinus betulus* (hornbeam), *Acer cappadocicum* (coliseum maple), *Acer velutinum* (velvet maple), *Alnus subcordata* (Caucasian alder), *Cerasus avium* (mazzard cherry), *Tilia begonifolia* (linden tree), *Parrotia persica* (Persian parotia), *Sorbus torminalis* (checker tree mountion ash), *Ulmus glabra* (elm), *Acer platanoides* (Norway maple) and *Diospyros lotus* (date pulm). The Loveh forest management plan was first managed with shelter-wood treatment method, which was later (2003) replaced with selective cutting treatment method. Silviculture treatment methods have affected the forest structure in the study area. The high biodiversity and the recent anthropogenic disturbances and silviculture practices (e.g., silviculture and harvesting treatments and regimes such as shelter-wood and selective cutting) have made the Loveh forests suitable for our study.

2.2. Field data

We applied a systematic cluster sampling method in summer 2004 to collect field data. We used 11 clusters with 90 plots (each cluster included 3×3 systematic plots) so that distance between clusters and plots were 1000 and 200 m, respectively. The plots were squares of 60×60 (0.36 ha) meters roughly corresponding to four visible and infrared ETM+ pixels (Fig. 2). The geographical center of each plot was accurately registered using a GPS device.

In each plot, we recorded species and their diameters for all trees with a diameter at breast height (D.B.H.) greater than or equal to 7.5 cm. We used richness and reciprocal of Simpson indices. Species richness represents the total number of species per plot, and Simpson index is a measure of dominance that also accounts for evenness or the relative abundance of each species on a plot. Simpson index represents the likelihood that two randomly chosen individuals will be same species. We used the reciprocal of Simpson index (1/D) (Krebs, 1998).

2.3. Satellite data and vegetation indices

We used Landsat ETM+ scene belonging to path 162, row 34 acquired on 7 August 2002. Geometric, radiometric and atmospheric correction of satellite data is often required for special applications (Lu et al., 2004). The ETM+ images had been previously ortho-rectified by Iranian National Cartography Center (NCC) with a high geometric precision. The geometric precision of images was also verified using road vector layer and field collected GPS control points. Reflectance of the objects recorded by satellite sensors is generally affected by atmospheric absorption and scattering, sensor-target-illumination geometry, and sensor calibration (Mahiny & Turner, 2007; Teillet, 1986). These normally result in distortion of actual reflectance of objects that subsequently affects the extraction of information from images. Deciding on the need to correct for atmospheric effects is often a first critical step in application of satellite data. In this study, COST method was used to convert the digital numbers to reflectance values and to accommodate for atmospheric attenuation and scattering in the visible and near-infrared bands. The COST model is an image-based absolute correction method (Mather, 2004). It uses only the cosine of sun zenith angle (cos (TZ)) as an acceptable parameter for approximating the effects of absorption by atmospheric gases and Rayleigh scattering (Mahiny & Turner, 2007; Teillet, 1986). We explored the image histogram for atmospheric haze and found the first three bands were contaminated, hence the need to the atmospheric correction. The DNs of images were converted to radiance and then to reflectance. The reflectance of the haze number was determined through the histogram evaluation and used for atmospheric correction.

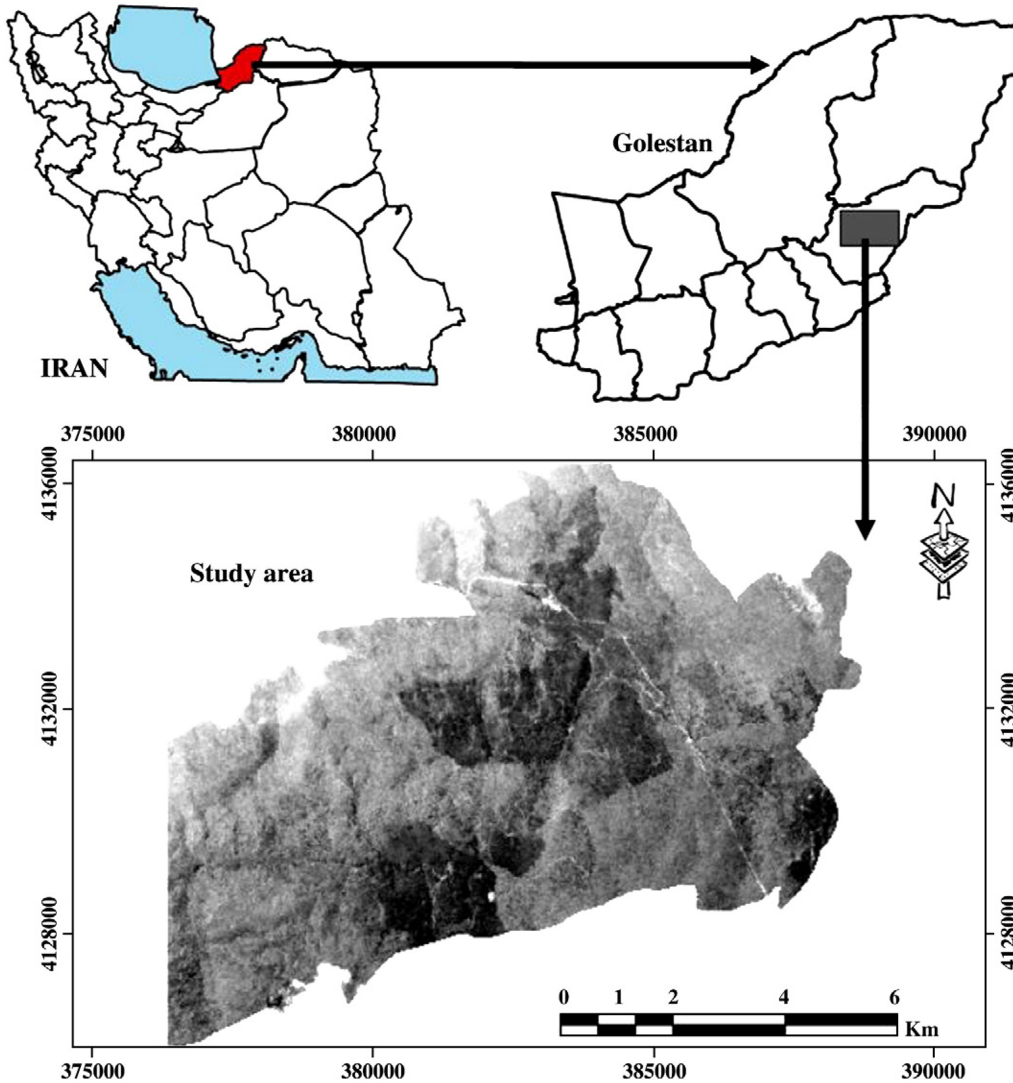

Fig. 1. Location of the study area in the Golestan Province of Iran.

Transformed bands and vegetation indices are often used to concentrate the information content from multiple bands to indices, which could be related to certain vegetation phenomena (Campbell, 2002; Jensen, 2004). After geometric rectification and atmospheric correction, relevant vegetation indices were generated. These vegetation indices included normalized difference water index (NDWI), normalized deference vegetation index (NDVI), difference vegetation index (DVI), brightness, greenness and wetness. Reflectance values and vegetation indices were extracted from the Landsat images (Jensen, 2004; Lillesand et al., 2000) using the average of a 2×2 pixel window centered on the GPS location of each field plot.

2.4. Statistical analyses

Stepwise multiple regression analyses were conducted to evaluate relationships between diversity indices as dependent and ETM+ bands and vegetation indices as independent variables. We used the Kolmogorov–Smirnov test to determine data normality. Stepwise regression analysis selects a subset of independent variables that explains most of the variability in the dependent variable. Independent variables of the final model were selected based on a combination of both their individual contribution to the model, adjusted coefficient of determination (R^2adj.) and residual mean square MS (Rawling et al., 1998).

2.5. Estimating and mapping of tree species richness and reciprocal of Simpson indices

We included 85% of plots in the modeling processes and used the remaining 15% to evaluate the accuracy of the model outputs. Linear regression models were generated for species richness and reciprocal of Simpson indices using calibration of sample data and the associated mean of Landsat ETM+ band values. The models with the highest adjusted R^2 and the lowest root mean square error (RMSE) were chosen as the best describing species richness and reciprocal of Simpson indices. We then applied the regression coefficients for species richness and reciprocal of Simpson indices to the Landsat images, and evaluated accuracy using the 15% holdout validation sample. The reliability of estimates was based on RMSE and bias as equations one and two below (Makela & Pekkarinen, 2004).

$$RMSE = \sqrt{\sum_{i=1} n(\hat{y}_i - y_i)^2 \Big/ n} \tag{1}$$

$$Bias = \sum_{i=1} n(\hat{y}_i - y_i) \Big/ n \tag{2}$$

In the equations, $\hat{y}_i$ is the estimate; y_i the observed value of y; and n the number of validation sample.

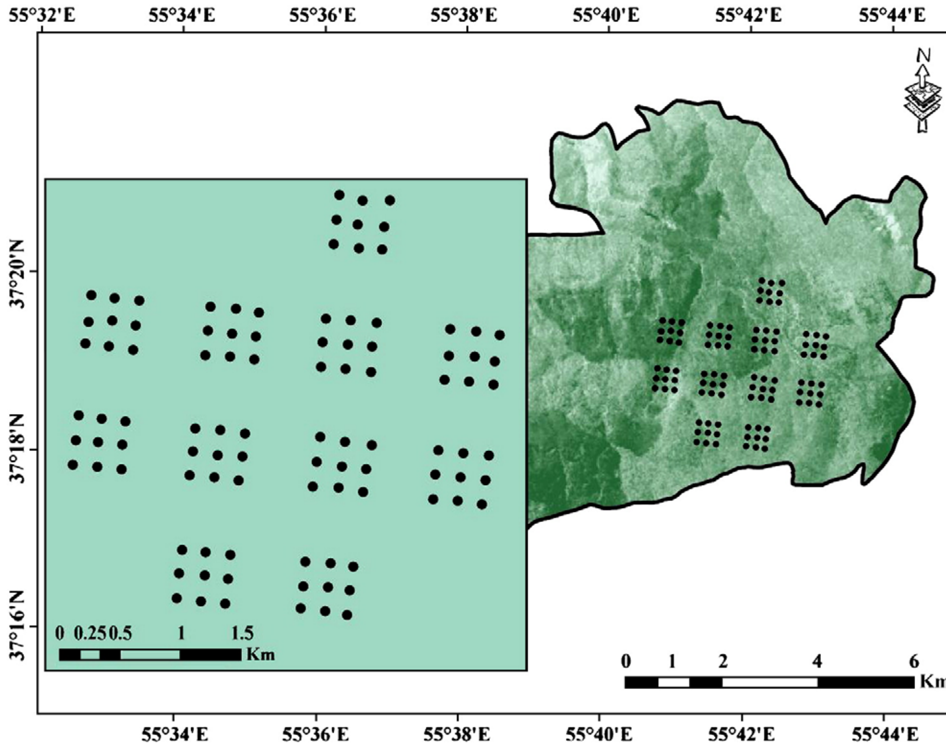

Fig. 2. A distribution map of the sample plot in the study area.

3. Results

3.1. Descriptive statistics of tree species richness and reciprocal of Simpson indices

The results of normality test showed that all variables had a normal distribution except for species richness, for which a log-transformation was used to meet the assumptions of normality. Species richness and reciprocal of Simpson index ranged from 6 to 12 and 1.48 to 4.52, respectively, indicating a wide range of tree species diversity in the study area (Table 1).

The mean species richness index was 8.14 (SD = 0.12) and the mean reciprocal of Simpson index was 2.77 (SD = 0.74). Most stands had a range of seven to nine for species richness and two to four for reciprocal of Simpson (Fig. 3a and b).

3.2. Estimating species richness and reciprocal of Simpson index using satellite data

The multiple linear regression model with ETM5, ETM7, DVI, wetness and variance of ETM1, ETM2 and ETM5 as independent variables better predicted species richness (adjusted $R^2 = 0.59$ and RMSE = 1.51) compared with other band sets and vegetation indices (Table 2).

Table 1
Descriptive statistics of model and validation samples for species richness and reciprocal of Simpson indices.

	Species richness		Reciprocal of Simpson	
	Model	Validation	Model	Validation
N	75	15	75	15
Mean	8.14	8.5	2.77	3.15
SD	0.12	0.16	0.74	1.06
Range	6	5	4.2	4.13
Minimum	6	6	1.47	1.49
Maximum	12	11	5.67	5.62

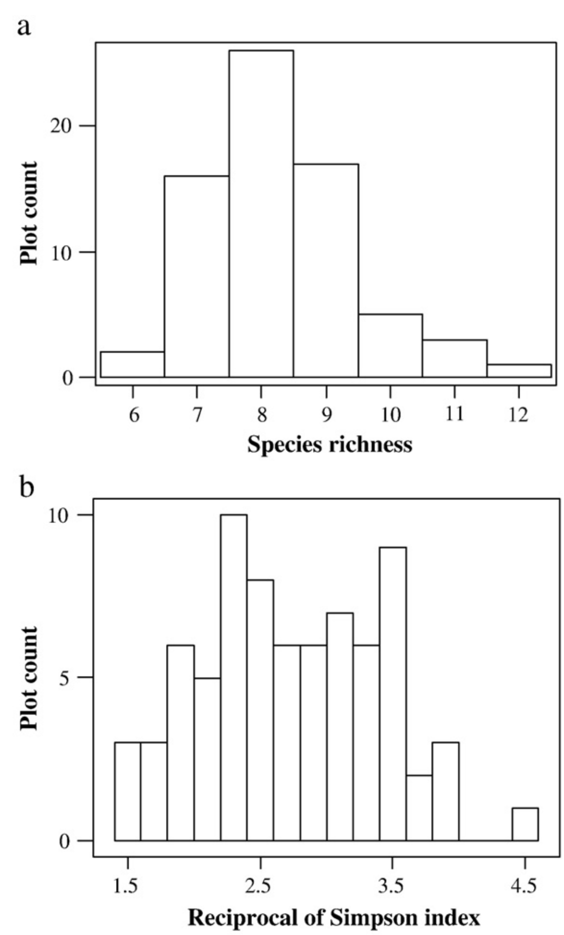

Fig. 3. Distribution of tree diversity indices in the study area depicted by (a) species richness histogram for field plots and (b) reciprocal of Simpson histogram for field plots.

Table 2
Results of multiple regression analysis for estimating tree species richness and reciprocal of Simpson using ETM+ bands (original and artificial).

Dependent variable	Independent variables	Coefficient	Constant	R^2 (adj)	RMSE	Bias
Log_{10} species richness	ETM5	−0.0379				
	ETM7	0.253				
	DVI	0.0452				
	Wetness	0.125	−29.9	0.59	1.51	0.12
	Variance ETM1	4.28				
	Variance ETM2	−3.79				
	Variance ETM5	1.34				
Reciprocal of Simpson index	NDVI	−0.172				
	Brightness	−0.246				
	Greenness	0.272	−4.64	0.459	1.15	0.39
	Variance ETM2	−4.07				
	Variance ETM5	0.409				
	Variance ETM7	1.18				

The regression model is significant at 95% level ($p = 0.05$).

Also, The multiple linear regression model with NDVI, brightness, greenness and variance of ETM2, ETM5 and ETM7 (Table 2) as independent variables better predicted the reciprocal of Simpson index (adjusted $R^2 = 0.459$ and RMSE = 1.15) compared with other band sets and vegetation indices.

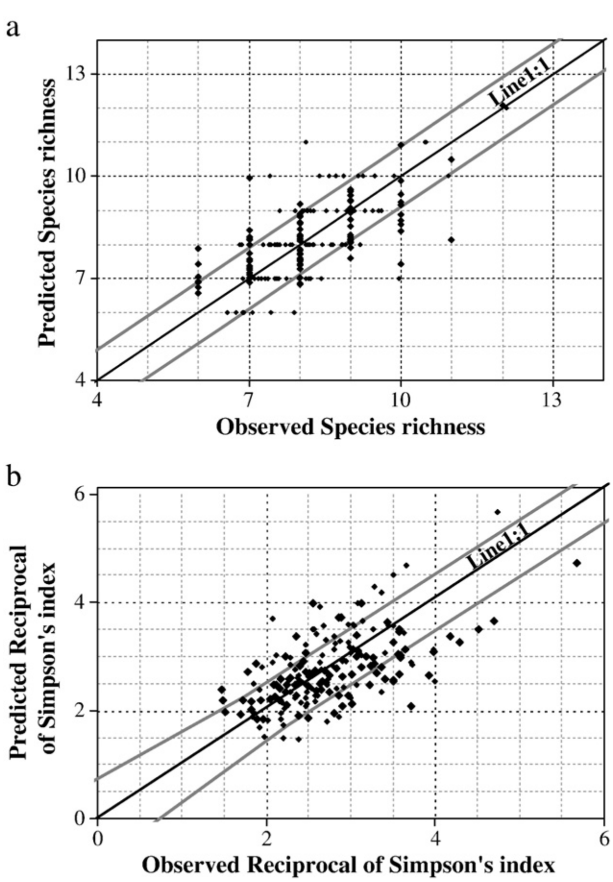

Fig. 4. a and b. Scatter plot of observed versus predicted species richness and reciprocal of Simpson index and 0.99% confidence limits.

Table 3
Correlation coefficients observed between species richness and reciprocal of Simpson indices and Landsat ETM bands and its derivatives.

	Species richness		Reciprocal of Simpson index	
	R	p-value	R	p-value
ETM5	0.2	0.08	−0.05	0.64
ETM7	0.29[a]	0.01	−0.01	0.9
NDVI	−0.15	0.2	−0.06	0.57
Greenness	0.155	0.19	0.29[b]	0.01
Brightness	0.265[a]	0.02	0.33[b]	0.004
Wetness	−0.19	0.1	−0.325[b]	0.004
DVI	0.31[b]	0.008	0.28[a]	0.01
Variance ETM1	0.27[a]	0.02	0.036	0.75
Variance ETM2	0.04	0.7	−0.023	0.84
Variance ETM5	0.55[b]	0.000	0.4[b]	0.000
Variance ETM7	0.19	0.1	0.38[b]	0.001

[a] Statistically significant at $p = 0.05$.
[b] Statistically significant at $p = 0.01$.

Scatter plots of predicted species richness and reciprocal of Simpson index versus observed values are given in Fig. 4a and b.

3.3. The relationship between spectral values and species diversity indices

Results of correlation in Table 3 show that the highest correlation r-value of ETM5, ETM7, DVI, and variances of ETM1 and ETM5 with species richness are 0.2 ($p<0.08$), 0.29 ($p<0.01$), 0.31 ($p<0.008$), 0.27 ($p<0.02$) and 0.55 ($p<0.0001$). Likewise, brightness, greenness, variances of ETM5 and ETM7 resulted in the highest correlations for reciprocal of Simpson index r-value of 0.33 ($p<0.004$), 0.29 ($p<0.01$), 0.4 ($p<0.001$) and 0.38 ($p<0.001$) (Table 3).

Tree species richness and reciprocal of Simpson were best estimated for stands with 7 to 9 in species richness and 2 to 4 in reciprocal of Simpson indices (Fig. 5).

3.4. Mapping tree species richness and reciprocal of Simpson indices

The models presented in Table 2 were used to generate species richness and reciprocal of Simpson indices (Figs. 6 and 7). In Fig. 6, darker green tones represent the higher tree species richness and the lighter tons represent lower species richness (Fig. 6).

For reciprocal of Simpson index, two maps were created which are shown in Fig. 7. In this figure, darker green tones represent the higher tree diversity and the lighter regions represent lower tree diversity where humans have destructed forest the most (Fig. 7).

We conducted a cross-tabulation of species richness and reciprocal of Simpson indices and then re-classified the result into nine classes of species richness and reciprocal of Simpson indices (Fig. 8). Fig. 8 shows the areas specified by differing species richness and reciprocal of Simpson indices that is directly useful to forest managers for sustainable management of the area and for identification of locations within stands that treatments and other management plans are necessary. The figure also shows the areas with high species diversity and the destructed areas, helpful in prioritization of candidate locations for conservation.

In addition to RMSE and Bias estimations, we calculated residuals for validity assessment of the regression models. We carried out RMSE and bias estimations using 15% of the data that had been set aside for validity assessment. The results of these evaluations are given in Table 2 that shows the high accuracy of the regression models in predicting the dependent variables given the independent variables.

The species richness modeling showed a nearly nil residual (Fig. 9b) and a normal distribution ($p>0.05$) (Fig. 9a) with no skewness of values (Fig. 9c). In addition, an overview of the diagram

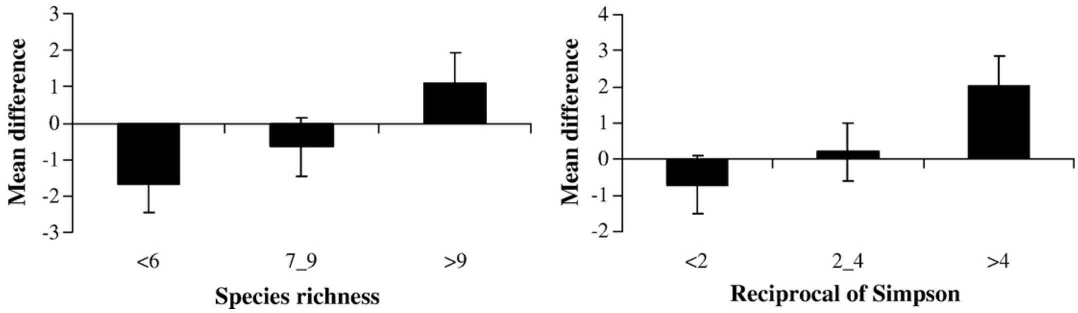

Fig. 5. Distribution of prediction differences using ETM+ data for species richness and reciprocal of Simpson estimation based on the validation samples. The vertical bars show the mean difference computed as predicted subtracted from actual values for three classes. The error bars represent the standard errors.

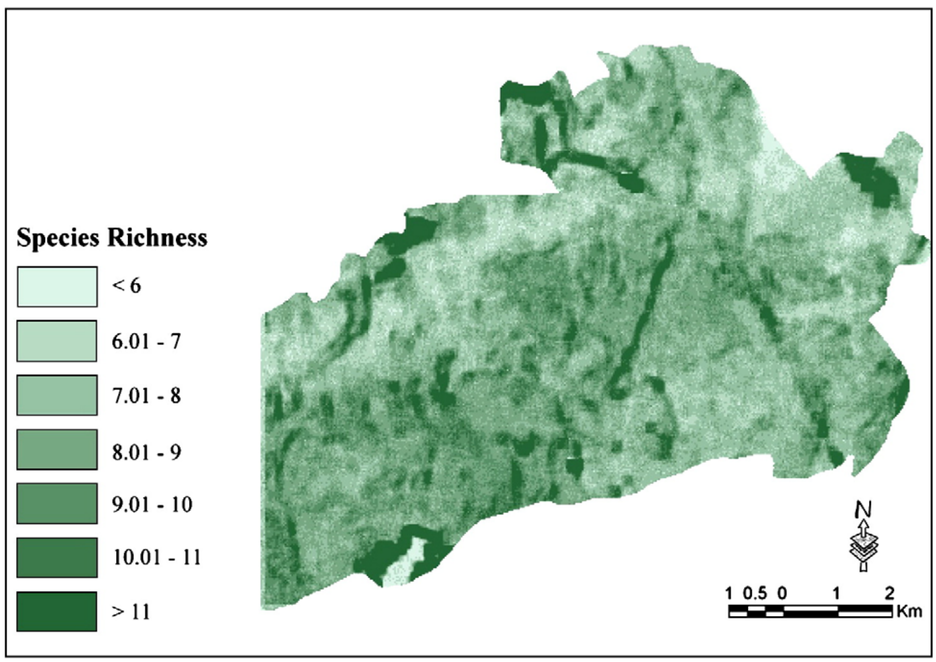

Fig. 6. Tree species richness map of study area generated from ETM+ data.

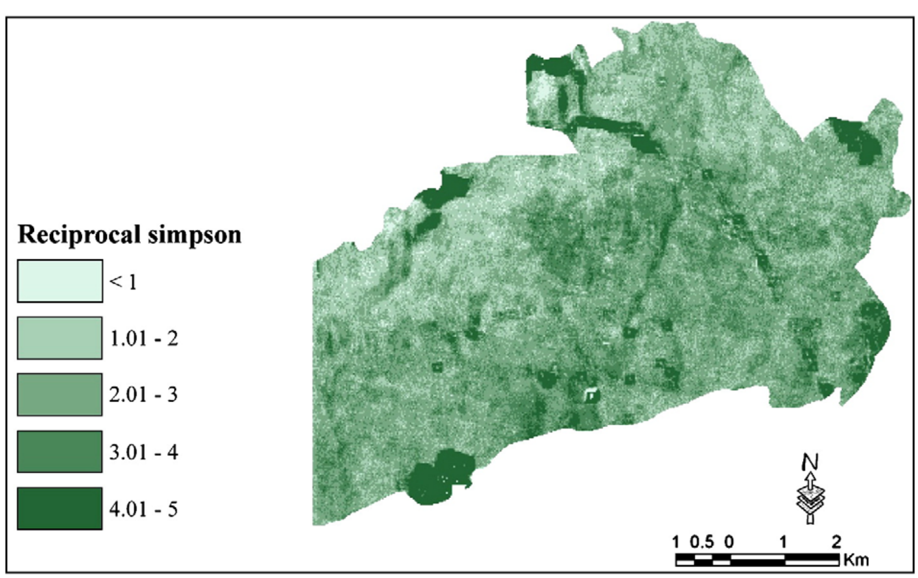

Fig. 7. Species diversity map using Reciprocal of Simpson index generated from ETM+ data.

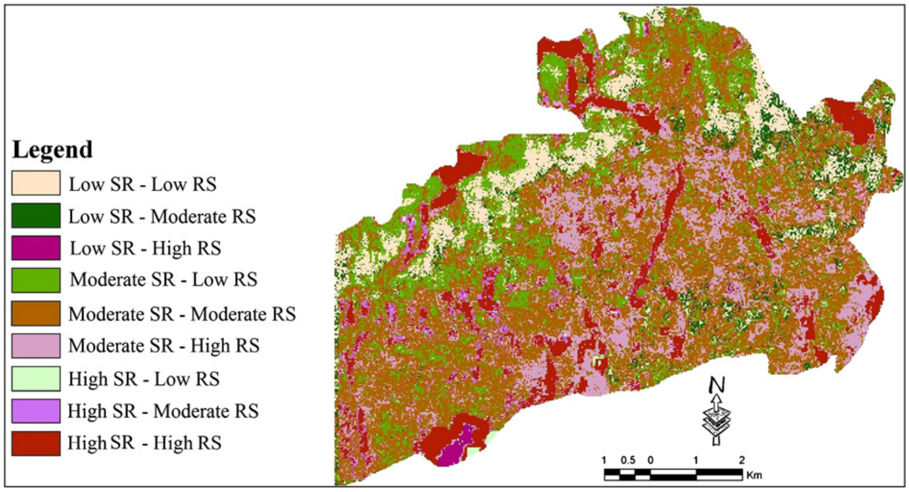

Fig. 8. The map created from cross-tabulation of SR (species richness) and RS (reciprocal of Simpson) indices.

of residuals versus order of the data shows that values are scattered uniformly above and below the zero line with a stable variance (Fig. 9d). The results of residual analysis, R^2 and RMSE showed that the regression models have been fitted acceptably.

The reciprocal of Simpson modeling showed a nearly nil residual (Fig. 10b) and a normal distribution ($p>0.05$) (Fig. 10a) with no skewness of the values (Fig. 10c). In addition, looking at the diagram of the residuals versus order of the data shows that values are scattered uniformly above and below the zero line with a stable variance (Fig. 10d). From the figures of modeling accuracy, we conclude that the regression models have fitted the data well.

4. Discussion

The significant relationship at the 99% probability level, normality of the residuals, an adjusted $R^2$0.59, and a RMSE of 1.51 all testify to the relative applicability of the method to estimate tree species richness using ETM+ in the study area. The band set consisting of ETM5, ETM7, DVI, wetness and variance ETM1, ETM2 and ETM5 explained more variance in tree species richness than other band sets and vegetation indices. R^2 values obtained in this study were higher than those reported by Gillespie et al. ($R^2=0.392$, 2009) and Dogan and Dogan ($R^2=0.272$, 2006).

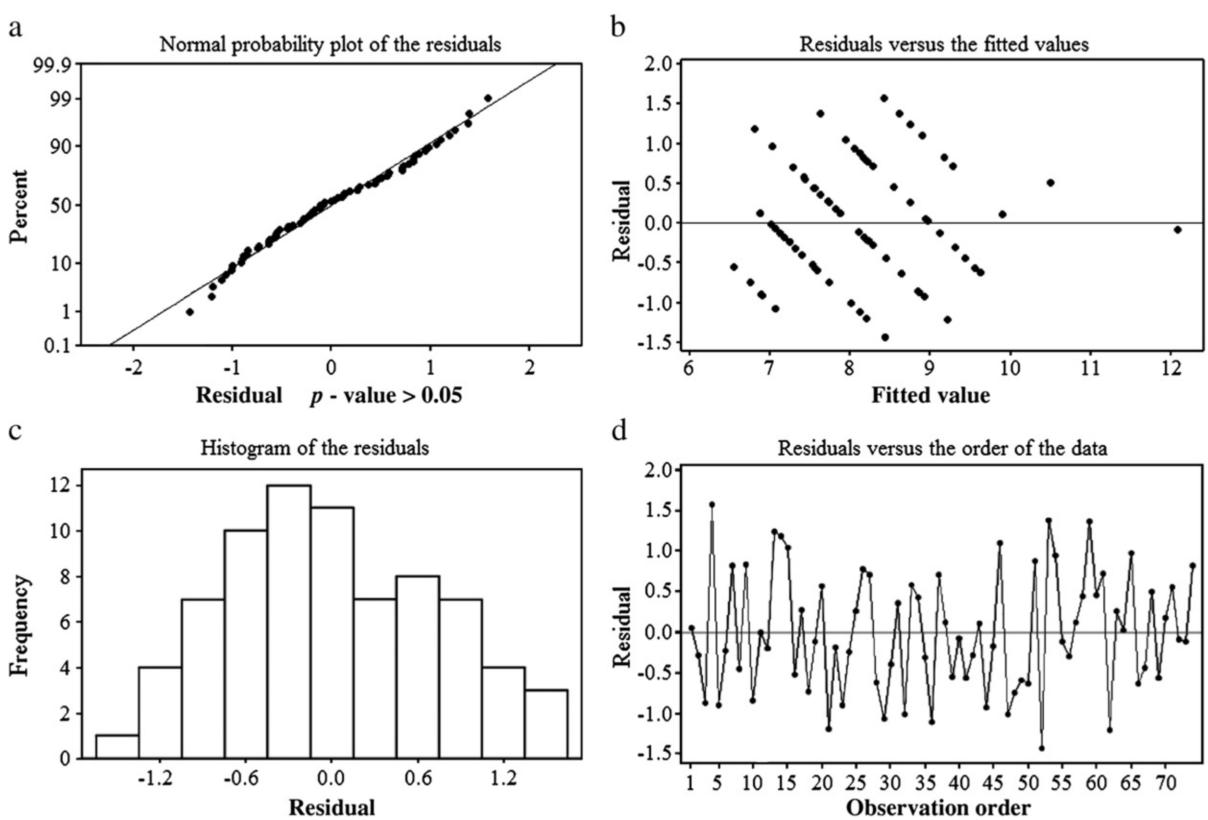

Fig. 9. Four types of residual diagrams to estimate fitness of linear regression for modeling the species richness using ETM+ data. a) Normal probability plot of residuals diagram, b) Residual versus the fitted values, c) Histogram of residuals and d) Residual versus order of data.

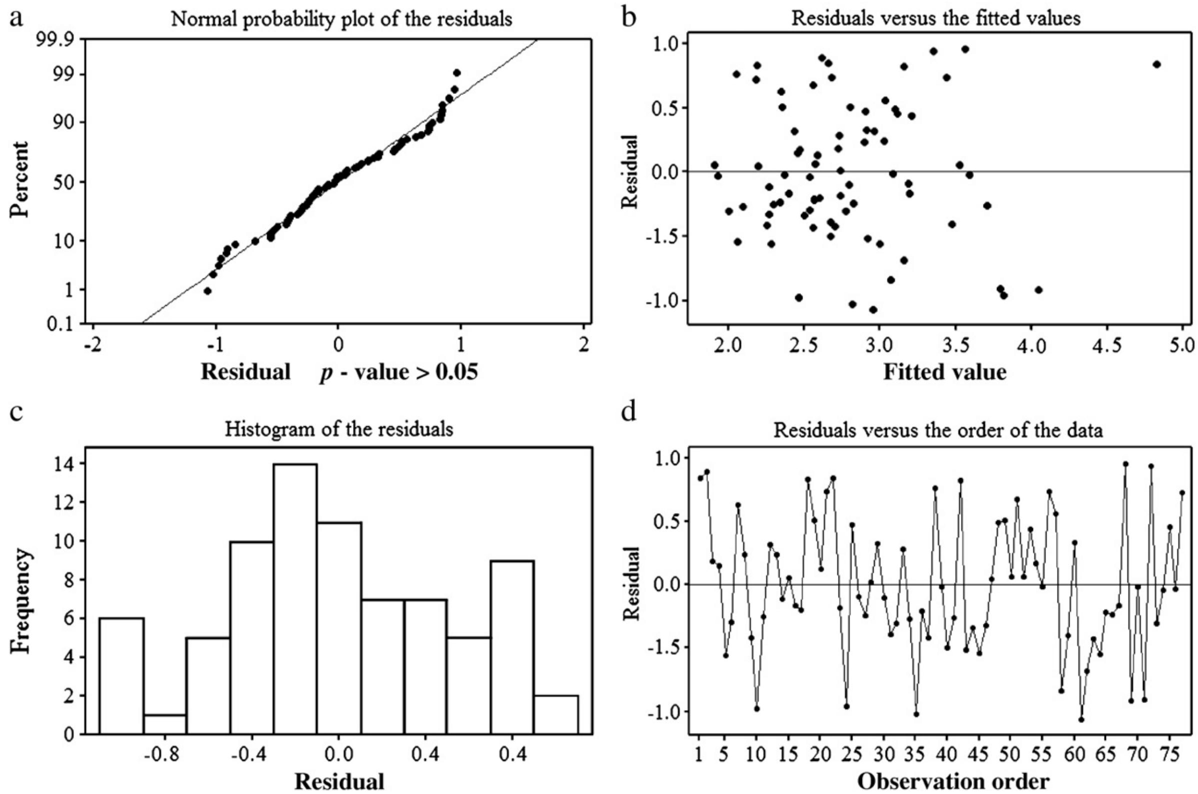

Fig. 10. Four types of residual diagrams to estimate fitness of linear regression for modeling the reciprocal of Simpson using ETM+ data. a) Normal probability plot of residuals diagram, b) Residual versus the fitted values, c) Histogram of residuals and d) Residual versus order of data.

The significant relationship at the 99% probability level, normality of the residuals, an adjusted $R^2$0.495, and a RMSE of 1.15 all testify to the relative applicability of the method to estimate reciprocal of Simpson index using ETM+ data in the study area. The band set consisting of NDVI, brightness, greenness, and variance ETM2, ETM5 and ETM7 explained more variance in reciprocal of Simpson index than other band sets and vegetation indices.

These results are similar to those obtained in other studies (Foody & Cutler, 2007; Hernandez-Stefanoni & Dupuy, 2007; Hernandez-Stefanoni & Ponce-Hernandez, 2004; Wenting et al., 2004) where researchers demonstrated that satellite data can identify broad patterns of tree species diversity.

The result of study showed that the variation in the brightness is positively correlated with species diversity within a landscape. It is clear that with application of shelter-wood system and with increase in age of the trees, the canopy closure and density increases so that there are fewer gaps in the canopy. In addition, in the study area, after applying the silviculture treatments, stands are transformed into mono-storied and even age forest with low variation in canopy height, which leads to an increase in brightness values. Therefore, the variation in brightness values is positively correlated with species diversity within the study area.

Consistent with previous studies (Bawa et al., 2002; Hernandez-Stefanoni & Dupuy, 2007; Oindo & Skidmore, 2002), reflectance values in the infrared bands increased with species diversity indices that indicates high responses in the near-infrared wavelengths caused by light scattering of Mesophyll leaf structure.

Also, consistent with previous studies (Wenting et al., 2004), wetness component of Tasseled cap was highly correlated with tree species richness. The variances in spectral values of bands show different status of canopy closure and can measure forest structure characteristics such as canopy roughness (Hudak & Wessman, 1998). At the earlier stages of stand establishment, the species richness in Canopy is high and with increase in age with dominating of some species, the canopy richness will decrease (Swaine & Hall, 1983, Whitmore, 1990). The variances of spectral bands can provide a textural assessment of canopy and heterogeneity that may also be associated with tree species diversity. Therefore, variances of spectral bands have been shown to be positively associated with species diversity.

Generally, results of this study showed that the ETM+ data could be useful for estimating tree species richness and therefore can be employed to assess and monitor status of tree diversity in the northeastern forests of Iran. The results of this study would also be useful for evaluating management and conservation plans and strategies. The results of this study also showed that ETM+ data are related to tree species richness and reciprocal of Simpson indices, a knowledge that could be used by resource managers to gain insights into biodiversity distribution over large areas.

Furthermore, the information on biodiversity is helpful in updating existing species diversity maps. The results provided by this study would be useful for identifying the differences in species diversity in the same forest stands. Using multi-temporal analysis of datasets provides information on species diversity after natural events and human intervention like pest infestation, fires, natural disasters, human utilizations and management activities. Periodically, updated information through satellite remote sensing technology could provide valuable information about changes in species diversity and help forest managers to design and apply suitable management plans.

5. Conclusion

In this study, we tested and assessed the capability of ETM+ data in modeling and mapping of diversity indices. We found statistically significant relationships between species diversity values calculated through richness and reciprocal of Simpson indices and ETM+ data. These relationships enabled us to map species diversity indices at unobserved locations. According to the results, both tree species richness and reciprocal of Simpson indices reveal richness and evenness aspects of species diversity. Our study showed that the generated models are applicable to the study area with potential of application to regional assessment and development of local conservation strategies in poorly surveyed Hyrcanian forests. Generally, applying the obtained results in larger areas requires transferring the model coefficients to adjacent scenes and testing the results. Future work to expand the application through remote sensing data for species diversity estimates in other forested area entails consideration of sensor specifications. Using satellite images with a higher spatial resolution like IKONOS and Quick bird and use of DGPS for determination of accurate location of plot centers might improve estimation of species diversity. Based on the results of this study, we conclude that ETM+ data are a source of information on biodiversity at the landscape scale for the study area, which in turn is useful in informing conservation science and management.

References

Bawa, K., Rose, J., Ganeshaiah, K. N., Barve, N., Kiran, M. C., & Umashaanker, R. (2002). Assessing biodiversity from space: an example from the Western Ghats. India. *Conservation Ecology*, *6*(2), 7.

Campbell, J. B. (2002). *Introduction to remote sensing.* New York: The Guilford Press.

Carlson, K. M., Asner, G. P., Hughes, R. F., Ostertag, R., & Martin, R. E. (2007). Hyper spectral remote sensing of canopy biodiversity in Hawaiian lowland rainforests. *Ecosystems*, *10*, 536−549.

Carroll, S. S. (1998). Modeling abiotic indicators when obtaining spatial predictions of species richness. *Environment Ecology Statistics*, *5*, 257−276.

Cayuela, L., Benayas, J. M., Justel, A., & Salas-Rey, J. (2006). Modeling tree diversity in a highly fragmented tropical mountain landscape. *Global Ecology and Biogeography*, *15*, 602−613.

Dogan, H. M., & Dogan, M. (2006). A new approach to diversity indices — Modeling and mapping plant biodiversity of Nallihan (A3-Ankara/Turkey) forest ecosystem in frame of geographic information systems. *Biodiversity and Conservation*, *15*, 855−878.

Fairbanks, D. H. K., & McGuire, K. C. (2004). Patterns of floristic richness in vegetation communities of California: Regional scale analysis with multi-temporal NDVI. *Global Ecology and Biogeography*, *13*, 221−235.

Foody, G. M., & Cutler, M. E. J. (2003). Tree biodiversity in protected and logged Bornean tropical rain forests and its measurement by satellite remote sensing. *Journal of Biogeography*, *30*(7), 1053−1066.

Foody, G. M., & Cutler, M. E. J. (2007). Mapping the species richness and composition of tropical forests from remotely sensed data with neural networks. *Ecological Modeling*, *19*(5), 37−42.

Gillespie, T. W. (2005). Predicting woody-plant species richness in tropical dry forests: A case study from South Florida, USA. *Ecological Applications*, *15*(1), 27−37.

Gillespie, T. W., Foody, G., Rocchina, D., Giorgi, A. P., & Saatchi, S. (2008). Measuring and modeling biodiversity from space. *Progress in Physical Geography*, *32*(2), 203−221.

Gillespie, T. W., Saatchi, S., Pau, S., Bohlman, S., Giorgi, A. P., & Lewis, S. (2009). Towards quantifying tropical tree species richness in tropical forests. *International Journal of Remote Sensing*, *30*(6), 1629−1634.

Gould, W. (2000). Remote sensing of vegetation, plant species richness, and regional biodiversity hot spots. *Ecological Applications*, *10*, 1861−1870.

Griffiths, G. H., Lee, J., & Eversham, B. C. (2000). Landscape pattern and species richness: Regional scale analysis from remote sensing. *International Journal of Remote Sensing*, *21*, 2685−2704.

Hernandez-Stefanoni, J. L., & Dupuy, J. M. (2007). Mapping species density of trees, shrubs and vines in a tropical forest, using field measurements, satellite multi spectral imagery and spatial interpolation. *Biodiversity and Conservation*, *16*(13), 3817−3833.

Hernandez-Stefanoni, J. L., & Ponce-Hernandez, R. (2004). Mapping the spatial distribution of plant diversity indices in a tropical forest using multi-spectral satellite image classification and field measurements. *Biodiversity and Conservation*, *13*, 2599−2621.

Hudak, A., & Wessman, C. (1998). Textural analysis of historical aerial photography to characterize woody plant encroachment in South Africa savanna. *Remote Sensing of Environment*, *66*, 317−330.

Innes, J. L., & Koch, B. (1998). Forest biodiversity and its assessment by remote sensing. *Global Ecology and Biogeography*, *7*(6), 397−419.

Isik, K., Yaltikik, F., & Akesen, A. (1997). The interrelationship of forests, biological diversity and the maintenance of natural resources. *Unasylva FAO*, *48*, 190−191.

Jensen, J. R. (2004). *Introductory digital image processing: A remote sensing perspective.* New Jersey: Prentice-Hall.

Kerr, J. T., Southowood, T. R. E., & Chilar, J. (2001). Remotely sensing habitat diversity predicts butterfly species richness and community similarity in Canada. *Proceeding of the national academy of sciences of the United States of America*, *98*, 11365−11370.

Krebs, C. J. (1998). *Ecological methodology*, 2nd. edition Manlo Park: Addison- Wesley 620pp.

Levin, N., Shimida, A., Levanoni, O., Tamari, H., & Kark, S. (2007). Predicting mountain plant richness and rarity from space using satellite-derived vegetation indices. *Diversity and Distribution*, *13*, 1−12.

Lillesand, T., Keifer, R. W., & Chipman, J. W. (2000). *Remote sensing and image interpretation.* New York: John Wiley and Sons.

Lu, D., Mausel, P., Broondizio, E., & Moran, E. (2004). Relationships between forests stand parameters and Landsat TM spectral responses in the Brazilian Amazon Basin. *Forest Ecology and Management*, *198*, 149−167.

Mahiny, A. S., & Turner, B. J. (2007). A comparison of four common atmospheric correction methods. *Photogrammetric Engineering and Remote Sensing*, *73*(4), 361−368.

Makela, H., & Pekkarinen, A. (2004). Estimation of forest stands volumes by Landsat TM imagery and stand-level field-inventory data. *Forest Ecology and Management*, *196*, 245−255.

Mather, P. M. (2004). *Computer processing of remotely sensed images: An introduction.* England: John Wiley and Sons.

Mohammadi, J., Shataee, Sh., Habashi, H., & Amiri, M. (2008). The effect of shelter wood logging on the diversity of tree species in the Loveh's Forest, Gorgan. *Iranian Journal of Forest and Popular Research*, *16*(2), 241−250.

Muldavin, E. H., Neville, P., & Harpper, G. (2001). Indices of grassland biodiversity in the Chihuahuan desert ecoregion derived from remote sensing. *Conservation Biology*, *15*, 844−855.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Fonseca, G., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *43*(24), 853−858.

Nagendra, H. (2001). Using remote sensing to assess biodiversity. *International Journal of Remote Sensing*, *22*, 2377−2400.

Nagendra, H., & Gadgil, M. (1999). Satellite imagery as a tool for monitoring species diversity: An assessment. *Journal of Applied Ecology*, *36*, 388−397.

Oindo, B. O., & Skidmore, A. K. (2002). Interannual variability of NDVI and species richness in Kenya. *Biological Conservation*, *86*(3), 379−391.

Oindo, B. O., Skidmore, A. K., & De Salvo, P. (2003). Mapping habitat and biological diversity in the Maasai Mara ecosystem. *International Journal of Remote Sensing*, *24*, 1053−1069.

Palmer, M. W., Earls, P., Hoagland, B. W., White, P. S., & Wohlgemuth, T. (2002). Quantitative tools for perfecting species lists. *Environmetrics*, *13*, 121−137.

Pilehvar, B., Makhdoom, M. F., Namiranian, M., & Jalili, A. (2002). Measuring woody plant diversity “Vaz” forest by using Whittaker multi-scale plots modified for Northern forest of Iran. *Pajouhesh-va-sazandegi in Natural Resources*, *53*, 41−45.

Rawling, J. O., Sastry, G. P., & Dickey, D. A. (1998). Applied regression analysis. New York: Springer Press 650pp.

Swaine, M. D., & Hall, J. B. (1983). Early succession in tropical forests. *Journal of Ecology*, *71*, 601−627.

Teillet, P. M. (1986). Image correction for radiometric effects in remote sensing. *International Journal of Remote Sensing*, *7*, 1637−1651.

Waring, R. H., Coops, N., Fan, C. W., & Nightingale, J. M. (2006). MODIS enhanced vegetation index predicts tree species richness across forested ecoregions in the contiguous U.S.A. *Remote Sensing of Environment*, *103*, 218−226.

Wenting, X., Bingfang, W., Yichen, T., & Yuan, Z. (2004). Mapping plant diversity of broad-leaved forest ecosystem using Landsat TM data. *Geosciences and Remote Sensing Symposium*, *20–24*(7), 4598−4600.

Whitmore, T. C. (1990). *An introduction to tropical rain forests* (pp. 1915−1921). Oxford, UK: Clarendon Press.