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**NDVI – alpha diversity relationship
in tropical montane cloud forest of Ecuador**

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In tropical forest the biodiversity is in a constant threat, some species are listed in the IUCN as vulnerable, endangered or threatened with extinction. Thus, a fast method for biodiversity determination or monitoring can contribute to its conservation. Remote sensing has demonstrated to be a powerful tool, and together with the vegetation indexes, can determine the vegetation state of forest. Recently researches have correlated the normalized differentiated vegetation index (NDVI) with species richness, structure and biodiversity of forests obtaining successful results.

This study, conducted in a Tropical Montane Cloud Forest (TMCF) of Ecuador, aims to correlate NDVI with alpha diversity estimators to understand its relationships. NDVI of Landsat OLI 8 Level 1 images in five months was determined. We considered a scene as valid in case of cloud coverage in the areas of interest below 25%. Radiometric and atmospheric corrections, with flaash tool, and the delimitation of the study site (ROI) were developed in ENVI 5.3 program. NDVI was calculated with ENVI 5.3 program (histograms allowed the determination of mean, maximum and minimum NDVI), and with ArcGIS 10.3 (for classification index). In field, species richness, Chao1, Shannon index, Simpson index, and biomass of three plots were quantified for trees with DBH ≥ 10 cm. Then, we calculate Pearson coefficient to correlate and disentangle the effects of altitude, diversity, richness, biomass and NDVI. A positive relationship was observed between Mean NDVI and Chao1 ($p < 0.10$) and Mean NDVI – richness ($p < 0.05$). In conclusion, NDVI can be considered useful to estimate richness and biodiversity and even to detect ecotone as was the case in this research. The application of this methodology could allow biodiversity assessment and monitoring in real time and low cost, which contributes in forest conservation programs.

Keywords: Landsat, normalized differentiated vegetation index, vegetation richness, diversity, tropical montane cloud forest.

УДК 504.064.37;502.2.05

**Соотношение NDVI и альфа-разнообразия
в тропических влажных горных лесах Эквадора**

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давать отклик на внешнее воздействие. Исследование биоразнообразия методами дистанционного зондирования Земли как основы устойчивого развития экосистемы тропического леса является актуальной задачей.

В недавних работах была выявлена положительная корреляция нормализованного дифференцированного индекса растительности (NDVI) с видовым разнообразием тропических лесов. Данное исследование тропического горного туманного леса Эквадора направлено на сопоставление NDVI с оценками альфа-разнообразия для определения характера их взаимосвязи. В работе по спутниковым снимкам Landsat OLI 8 уровня обработки Level 1 был определён NDVI за пять месяцев. В полевых условиях видовое разнообразие, индекс Чоу1, индекс Шеннона, индекс Симпсона и биомасса на трёх участках были количественно определены для деревьев с диаметром ствола ≥ 10 см. Далее для выявления взаимосвязи эффектов высоты, качественных и количественных показателей разнообразия с NDVI был рассчитан коэффициент Пирсона и определена взаимосвязь между средним значением NDVI и индексом Чоу1 ($p < 0,10$), а также между средним значением NDVI и видовым богатством ($p < 0,05$). Применение этой методологии может позволить проводить оценку и мониторинг биоразнообразия в режиме реального времени и с низкими затратами, что способствует реализации программ по сохранению лесов.

Ключевые слова: Landsat, нормализованный дифференцированный индекс растительности, разнообразие растительного покрова, биоразнообразие, тропический влажный горный лес.

The Andes Mountain range is along the center of Ecuador and includes Tropical Montane Cloud Forest (TMCF). It is considered a hotspot due to their biological richness and high level of endemism. Agriculture expansion plus extensive cattle ranching and forest clearing have fragmented and isolated this ecosystem. For this reason, the tropical Andes are a world conservation priority [1–3].

The knowledge of richness species and biodiversity in these forests is necessary to develop monitoring and conservation strategies. Owing to its current state of critical conservation, the tropical forest needs a rapid method for assessment and monitoring the biodiversity. For this type of forests, with high levels of biodiversity, the traditional field methodology is often costly and time consuming [4, 5]. Remote sensing has displayed great potential to perform this labor. This is a fast and nondestructive method which allows to estimate species richness, biodiversity and characterize the structure and composition of forests [6–8].

Thanks to satellites, it is possible to acquire, process and interpret images of a distant objects. Landsat 8 satellite was launched in 2013, its images are processed by geographic information systems (GIS), and have been used to assess the state of tropical forests and quantify properties of the earth's surface at a high spatial and spectral resolution with the application of vegetation indexes [5, 9, 10]. Normalized Difference Vegetation Index (NDVI) is one of the most used vegetation index, it was introduced by Rouse et al. in 1974 and takes advantage of the fact that greener or healthier vegetation absorbs more visible light and reflects a large amount of near infrared light, while unhealthy or sparse vegetation (less green) reflects a large portion of visible light and less near infrared light [11]. Chlorophyll pigments, which are the largest

absorbers of radiation in the visible region, absorb in the red and blue regions of the visible spectrum (wavelength bands between 0.44 and 0.66 μm), but not in the green region where the reflectivity is much higher and its maximum value is observed in the near infrared range [12].

NDVI is found in many studies related with forest assessments or monitoring studies. It has been used to predict species richness [4, 13–17]. Also, it is associated with forest structure [5, 18–20]. With the contribution of the species-energy theory, NDVI has been connected with patterns of species diversity and tree species composition [4, 7, 21]. This theory states the energy as a limiting resource for species in an specific area [22]. Thus, the greater resource availability increase the primary productivity, specialization and diversity of species [5]. In addition, biodiversity and richness researches have shown a positive correlation between NDVI and diversity indexes like Shannon and Simpson [4, 23–27].

Although the number of investigations about biodiversity and its relationship with NDVI has increased, there are no studies that use this index and correlates it with species richness or biodiversity in tropical montane cloud forest (TMCF). Therefore, our aim is to demonstrate the potential of using remote sensing through NDVI to determine diversity and species richness in “El Cedral Ecological” a TMCF. The results will help to monitor the biodiversity in this type of forest and can be applied in other forests.

Materials and Methods

The study area is El Cedral Ecological with extension of 71 ha. It belongs to TCMF within Eastern Cordillera Real montane forests (NT0121). It is located in Yunguilla in the Northwestern of Pichincha province (Fig. 1),

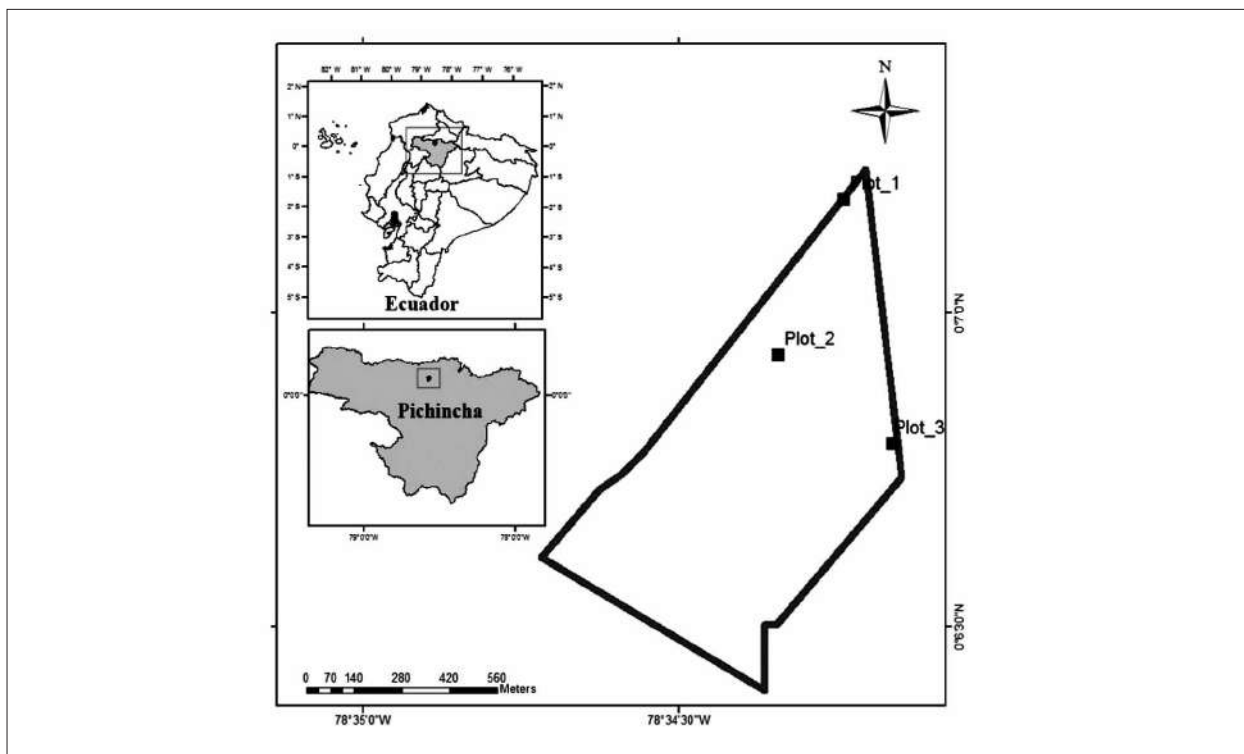


Fig. 1. Distribution map of the plots in the study area

in Ecuador country (latitude 0.114055° and longitude -78.570176°). The topography is rugged with sloping ravines and few flat areas. The annual precipitation ranges are between 1394 to 2414 mm. The vegetation cover is continuous with a canopy between 20 and 25 meters high. The site experiences two rainy seasons: March – April and October – November. According with the methodology of the National Forest Assessment of Ecuador [28], three plots of $60\text{ m} \times 60\text{ m}$ were established (plot 1: 2521 meters above sea level (m.a.s.l.), plot 2: 2409 m.a.s.l., and plot 3: 2220 m.a.s.l.).

In each plot of $60\text{ m} \times 60\text{ m}$, all individuals with a Diameter at Breast Height (DBH) $\geq 10\text{ cm}$ were sampled. The DBH $\geq 10\text{ cm}$ was measured at 1.3 meters [29]. The species identification was carried out based on botanical samples collected previously [30], virtual herbarium specimens, specialized literature of similar vegetation to the study area. Later, scientific names and distributions of the species were verified with the Catalog of Vascular Plants of Ecuador [31], and the database from Tropicos website [32]. Finally, a database with taxonomic information (S1) associated to each specimen was created and transformed to compatibles files with statistical packages PAST 2.17c [33], and JMP v 8.0 [34] where alpha species diversity estimators (richness S , Chao1, Shannon and Simpson indexes) were quantified.

For richness (S) calculation, the total number of species in each plot was registered [35]. Also, the richness estimator Chao1, based on the rare species number, was determined with the following formula [36]:

$$\text{Chao1} = S + \frac{a^2}{2b}$$

In the formula S is the species number in a sample, a is the number of singletons and b is the number of doubletons [37]. In addition, Shannon index (H) [38, 39] was calculated with the following formula:

$$H = -\sum_{i=1}^S p_i \cdot \ln p_i,$$

where S is the species number, p_i the total sample proportion corresponding to the specie i in a plot, and \ln is natural logarithm. We considered low diversity $H = 0 - 0.35$, medium diversity $H = 0.36 - 0.7$, and high diversity $H = 0.71 - 1$.

Also, Simpson index ($D1$) was determined by the following formula:

$$D1 = 1 - \sum_{i=1}^S p_i^2.$$

The variables represent the same as in Shannon index. The interval of $D1$ is between 0 and 1, $D1 = 0$ means one species.

The above ground biomass (AGB) of each individual of each plot was estimated based on the

allometric equation for humid montane forests [40]. In this equation, D represents the diameter (cm) and $Dens$ is the wood density (g/cm^3). In order to get density values, a bibliographic review for each species was carried out and an average value was assigned [41]. The AGB formula is:

$$AGB = \exp[3.44153 + (-1.80919 \cdot \ln D) + (1.23665 \cdot (\ln D)^2) + (-0.12606 \cdot (\ln D)^3) + 1.7438 \cdot \ln(Dens)]$$

Five Landsat OLI 8 Level 1 images were downloaded from the United States Geological Surveys (USGS), for March, August, September, October and December. Thus, an annual variation in the vegetation index could be determined. A valid Landsat image had as a requirement the percentage of cloud coverage less than 25 in the area of interest. Landsat image processing was developed in ENVI 5.3 program. Here, the area of interest (ROI) was specified in the multispectral file (MTL). Radiometric calibration and atmospheric correction, with FLAASH Atmospheric Correction Model of the program, were performed. From these images, the NDVI was calculated with the formula:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where NIR is near infrared region (wavelength bands between 0.75–1.3 μm) and RED is red region (wavelength bands between 0.62–0.75 μm) of visible spectrum [12]. The relations between the coefficients in the formula generates values in the range of -1 and +1 (Table 1), where the intervals represent different types of land cover [42–44].

Finally, the quick statistics (mean, maximum, minimum and StdDev) from histograms were extracted for each NDVI image, and the corresponding NDVI values for pixels of the three plots were extracted from each image.

Then, Mean NDVI of all pixels falling in each plot (60 m \times 60 m) at different elevation gradient and in each month was determined. These results were correlated with elevation, diversity indexes (Shannon Wiener, Simpson), richness (S and Chao1), and biomass for each plot in STATISTICA program. Finally, for the most significant correlations, simple linear regressions were developed in RStudio software [45]. The strength of relationship was assessed by using coefficient of determination (r^2) and p value.

Results

A total of 657 individuals with a DBH ≥ 10 cm were registered in 3 plots (1.08 ha). In plot 1, the total individuals were 239 and 40 species were found. Plot 2 obtained a total of 247 individuals and 45 species. Finally, the total individuals in plot 3 was 171 with 43 species. Thus, the density of individuals in plot 3 was the lowest. When considering the altitudinal gradient, it was found that plot 2, located a 2409 m.a.s.l., possess the greatest species richness ($S = 45$, Chao1 = 51), followed by plot 3 (2220 m.a.s.l.) with 43 species (Chao1 = 49.6) and plot 1 (2521 m.a.s.l.) with 40 species (Chao1 = 44.5). These data could define plot 2 as an ecotone between this 300-meter gradient, if we consider that diversity (Shannon and Simpson indexes) decreases with altitude (Table 2).

Table 1

Intervals of NDVI scale

NDVI values	Type of land cover
< 0	No vegetation, water, clouds
0–0.09	Bare ground (degraded land, settlements, soil without vegetation cover)
0.1–0.29	Sparse Vegetation (scattered shrub, irrigated crops)
0.3–0.49	Medium Vegetation (forest plantations, bushes, slow-growing plantations)
> 0.5	Dense Vegetation (forest, dense growth plants)

Table 2

Richness and Diversity indexes for 3 plots in “El Cedral”

Richness and Diversity indexes	Plot 1	Plot 2	Plot 3
	(2521 m.a.s.l.)	(2409 m.a.s.l.)	(2220 m.a.s.l.)
Shannon Wiener	3.15	3.105	3.38
Simpson	0.93	0.91	0.95
Chao 1	44.5	51	49.6
Richness (S)	40	45	43

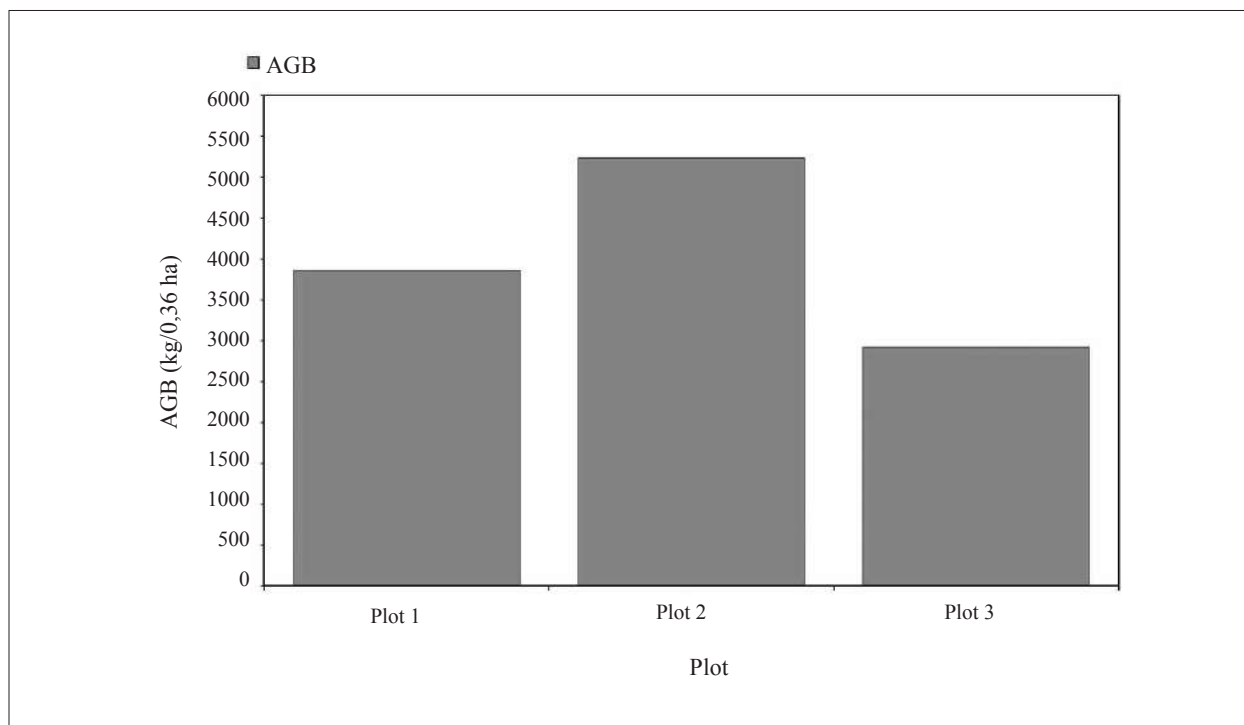


Fig. 2. Aboveground biomass (AGB) in kg/0.36 ha for three plots in “El Cedral”

The calculated biomass was 3858.41 kg/0.36 ha (Mean 16.14, Sd 7.77) in plot 1, 5230.48 kg/0.36 ha (Mean 21.17, Sd 10.74) in plot 2 and 2926.58 kg/0.36ha (Mean 17.11, Sd 8.48) in plot 3. Like in richness species, plot 2 showed the greatest value of biomass (Fig. 2).

Mean NDVI differences, for each plot, between rainy season (March, August, September, and October) and dry season (December) are clear (Fig. 3, see color insert IV). All NDVI for each plot in rainy season is more than 0.5 (Dense vegetation), while mean NDVI in December is located in the interval 0.3–0.49 (Medium vegetation). Accordingly, NDVI value decreases between rainy and dry season.

In the monthly NDVI data (Table 3) the same result of the NDVI graphs can be observed. In the rainy season, the months of March, August, September and October shows a mean NDVI of 0.82, 0.92, 0.86 and 0.79 respectively, that corresponds to dense vegetation. On the other hand, on December (dry season month) the media NDVI for the tree plots is 0.47 (medium vegetation).

In the relationships NDVI-richness and NDVI-biodiversity at different altitudes and seasons, it was found that in rainy season the NDVI correlates with Chao1 index with a positive Pearson coefficient (March: $r = 0.992$, August: $r = 0.983$, September: $r = 0.963$, October: $r = 0.7$) with a significance between 0.07 and 0.1.

With richness (S) the relationship with NDVI was also positive, however the level of significance was lower than the previous mentioned. This could be mainly due to the small number of plots sampled. A strong and significant correlation was found between mean NDVI and elevation in October (Fig. 4, $r = -0.99$, $p < 0.06$). In remain months, a negative correlation was also obtained, but the significance was lower, due to the number of plots.

Discussion

The alpha diversity indexes yielded high diversity results for TMCF. Similar results have been seen in Ecuador, such as those found in the study carried out in Andean Montane Evergreen Forest at an altitude of 2705 m.a.s.l. Here, diversity was high with a maximum index of Shannon species of 0.90 and Simpson of 0.87. In general, in this type of tropical forest at altitudes between 2000 and 3000 m.a.s.l., similar diversity values are observed, as is the case of Peruvian Andean Montane Cloud Forest where diversity indexes reached higher values. Simpson index was located between 0.8 and 0.19 and Shannon index between 2.7 and 3.6 [46]. Likewise, in Myanmar Tropical Forest the maximum Shannon Diversity Index was 3.20 and Simpson Diversity Index 0.96. This study pointed precipitation as crucial factor in the development of plant diversity [47].

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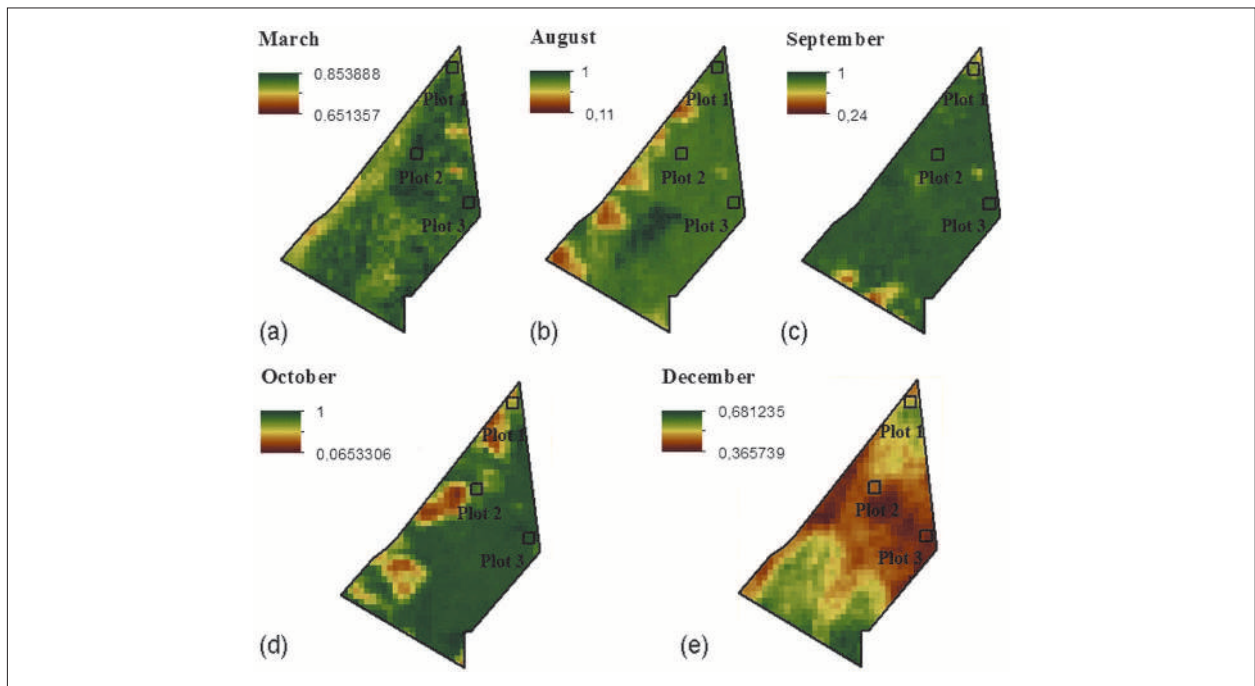


Fig. 3. "El Cedral" Normalized Differential Vegetation Index map for: (a) March 2019, (b) August 2019, (c) September 2019, (d) October 2019, (e) December 2019

Table 3

Minimum, maximum, and mean NDVI ± standard deviation of NDVI by months

Plot	Min NDVI	Max NDVI	Mean NDVI	StdDev
March				
Plot 1	0.80	0.83	0.81	0.01
Plot 2	0.82	0.84	0.83	0.01
Plot 3	0.82	0.83	0.83	0.00
NDVI Mean (month)	0.81	0.83	0.82	0.01
August				
Plot 1	0.86	0.93	0.89	0.02
Plot 2	0.90	0.96	0.93	0.02
Plot 3	0.90	0.95	0.93	0.02
NDVI Mean (month)	0.89	0.95	0.92	0.02
September				
Plot 1	0.69	0.85	0.79	0.05
Plot 2	0.88	0.91	0.89	0.01
Plot 3	0.87	0.93	0.90	0.02
NDVI Mean (month)	0.81	0.90	0.86	0.03
October				
Plot 1	0.45	0.85	0.70	0.13
Plot 2	0.70	0.84	0.79	0.25
Plot 3	0.82	0.93	0.89	0.03
NDVI Mean (month)	0.66	0.87	0.79	0.14
December				
Plot 1	0.51	0.58	0.54	0.03
Plot 2	0.44	0.47	0.46	0.01
Plot 3	0.41	0.43	0.42	0.01
NDVI Mean (month)	0.45	0.49	0.47	0.01

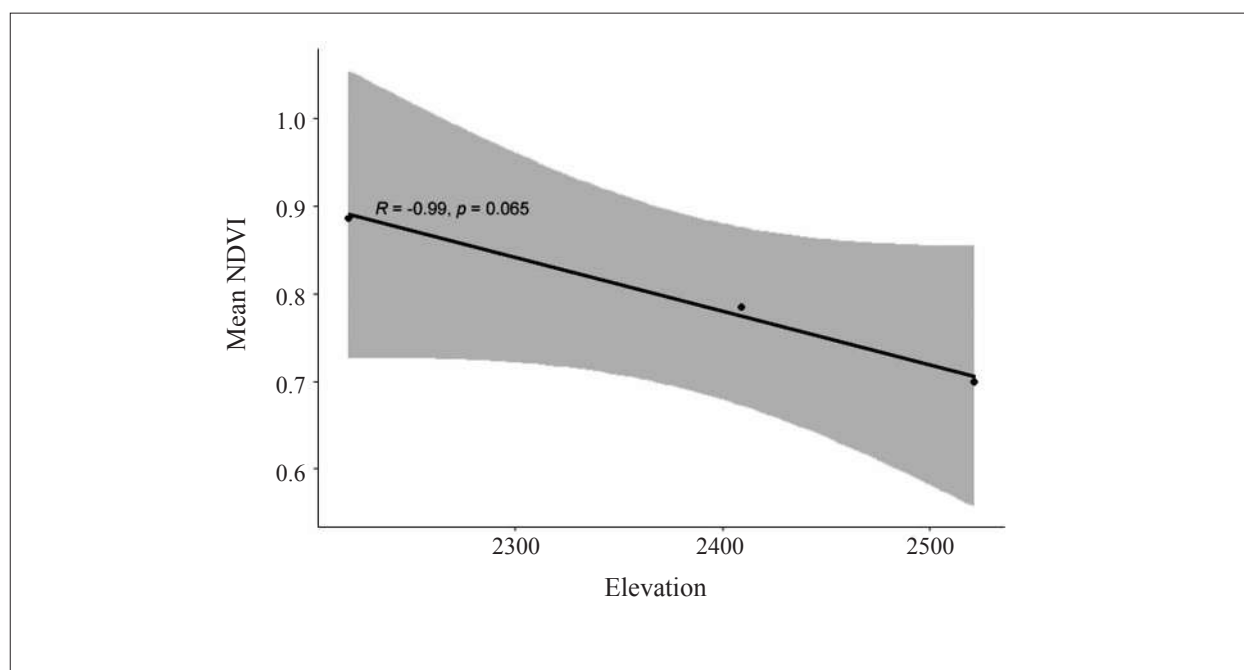


Fig. 4. Relationship between mean NDVI (October) and elevation (m.a.s.l.)

Similar values of AGB for cloud forest in Ecuador were found in the Río Guajalito Reserve, where other allometric equation was applied [48]. In such study, the estimated tree biomass for primary forest was 15160 kg/ha and we determined for the three plots the AGB amounts of 10717.8, 14529.11 and 8129.38 kg/ha.

A positive and strong relationship between NDVI and Chao1 was expected because it is known that between species richness and primary productivity there is a positive relationship [22], which in other forest studies has been estimated with NDVI as reflectance indicator [49]. In addition, these findings are consistent with the research results where the species richness was identified using remote sensing and NDVI [4, 13, 14, 16, 27, 50, 51]. This suggests that NDVI calculated from Landsat 8 images could be used to estimate species richness in TMCF when plot data are available.

Regarding the relationship between mean NDVI and elevation, its negative correlation means that when the elevation diminishes the NDVI increases. This can be explained with the fact that the number of individuals, also decreased with the altitude. Thus, in plot 3 the number of individuals was the lowest. According to [52], in the majority of altitudes the relationship between NDVI and elevation is positive. Nevertheless, in the range of altitude between 2200 to 2500 m.a.s.l. a negative relationship has been observed like in this research. A high NDVI showed in the lower elevation is because of a higher productivity owing to high temperature and sufficient water availability [53]. In addition, it is important to mention that plot 2 was catalogued as an ecotone because it can explain the NDVI decrease between plot 1 and plot 2.

Since species diversity is related to richness and abundance [54], a strong correlation between Shannon and Simpson indexes with NDVI was expected [20]. Nevertheless, the relationship was moderate and positive, like in other studies [5, 13, 55] where Shannon index and Simpson index were applied [4, 24, 26, 56]. Our correlations were not significant, hence, we recommended to sample more plots to discover the real relationship between these parameters. The plot size of 60 m × 60 m was established due to the fact that the pixel dimension of Landsat image is 30 m × 30 m and the small number of plots (3) was because of the difficulty in establishing extensive plots (60 × 60) homogeneous in terms of slope percentage. TMCF in the study area has a strong steep and very strong steep slope and the larger the plot, the less homoge-

neous it is [57]. Besides the TMCF usually are difficult to access [58]. Based on bibliography reviewed about positive and significant relationships between NDVI and diversity indices with a greater number of plots [4–6, 9, 15, 16, 19, 20, 24, 27, 52], the relationships in this study were also expected to be significant considering the difficulties mentioned.

Conclusion

Remote sensing, with the use of satellite images, has been playing an increasingly important role in forest conservation. Together with vegetation indexes have estimated richness, diversity and biomass over time. Within its advantages are high spatial-temporal resolution and easy global availability. On the other hand, its applicability is still limited by technical issues such as cloudiness in the images and the need for calibrations and corrections. Nevertheless, when overcome these limitations through appropriate techniques and the inclusion of environmental factors, diversity predictions can be more accurate.

By using field data and satellite imagery, our study has important implications in understanding the relationships between NDVI and alpha species diversity. We found a strong positive and significant relationship between species richness and NDVI. This relationship was analyzed in the two seasons of tropical forest and it was observed that in the rainy season the NDVI is higher, which is attributed to precipitation that offer better water availability and temperature to increase the photosynthetic rate and therefore productivity. The differences in seasonal NDVI are crucial to understand as it can be predicted how forests will respond to future climate changes. Finally, NDVI can be considered a useful method to estimate richness and biodiversity (using a greater number of plots) and even to detect ecotone as was the case in this research.

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