Connecting Indigenous and Scientific Ecological Knowledge in the Madidi National Park, Bolivia †

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Abstract: Across the Amazon basin, indigenous communities harbor a deep understanding of their surrounding ecosystems. However, the extent to which humans depend on ecosystem services across different ethnic groups and spatial scales remains poorly understood. The purpose of this study is to understand the role of ecological processes in determining the human use of plants on the context of the Tacana people in Madidi National Park (Bolivia). Two different hypothesis are tested: (1) the availability of the species shapes their final use and (2) plant biodiversity influences how the forest is used. The data were compiled in a total of 44 plots (0.1 ha), measuring all woody plants with dbh ≥ 2.5 cm, within five different regions (both submontane and lowland tierra-firme forests). Results showed that (1) the species apparency plays a significant role in the selection of plants for its use, (2) the maximal use of a forest depends on intermediate levels of plant diversity. This study highlights the human capacity to adapt to specific environmental conditions, based on the availability or biodiversity of the plant resources. Therefore, the integration of indigenous perception in conservation strategies is crucial as the ecology of the Amazonia is shaped by the long-lasting effects of its ancient and modern inhabitants.

Keywords: Ethnobotany; Traditional knowledge; Plant diversity; Amazonia; tierra firme forests; Ecosystem services; Sustainability; Livelihoods

1. Introduction

The ecology of the Amazon reflects the interaction between the natural environment and the influence of human long-settled populations [1]. Indigenous communities living in these environments have developed numerous strategies to use the natural resources. Understanding the ecological factors that shape the use of plant resources is essential for the management and conservation of this unique and threatened ecosystem [2].

Ethnobotany aims to understand how humans use plant resources in their natural environments [3]. In this study, we explore how different ecological theories are related to the traditional knowledge of the Tacana people in the Madidi National Park. More specifically, two different hypothesis are tested: (1) the availability of the species might influence the final use by the Tacana people and (2) the plant biodiversity have an effect in the degree of forests' usefulness.

1.1. Species Availability Influences Plant Use

The Ecological Apparency Hypothesis (EAH) explores the relationship between the importance of the use and the availability of local resources [4], revealing that the plant species that are most used are those most frequently encountered. Although it has been generally proved that resource availability may influence human choice, results do not reach an agreement. The EAH has been demonstrated both in tropical rainforests [2,4–12] and in semi-arid regions [10,13,14]. However, some studies have found opposite results to those expected by the EAH [4,15,16]. Additionally, the relationship between species availability and its utilization varies according to the use category. Whereas fuel [2,10], timber [17], construction [6,18,19] and technology show a positive relationship with plant availability, there is typically no general pattern for the medicinal category [6,19], with studies showing both positive [9,20] and negative relationships with plant availability [21].

Here, the overall objective was to test the support to the EAH based on the cultural and ecological importance of tropical tree species in the Madidi National Park. Thus, we asked the following questions: (1.1) how the usefulness of the species relates to its ecological importance?; and (1.2) which use categories support the EAH?

1.2. Biodiversity Shapes Forest Use

The presence of different species in a given forest allows humans to maximize the number of plants they can draw for their livelihoods [22]. Therefore, biodiversity might be the major identifiable ecological variable that explains useful plant diversity [3]: the higher the species diversity of a region, the greater is the potential of perceived usefulness. However, studies combining ethnobotanical research with biodiversity are scarce and their results are heterogeneous. Some studies have evidenced the existence of positive correlations between biodiversity and useful species [3,23], whereas others found negative significant correlations [22,24], meaning that the overall use value of transects decreases with increasing plant diversity, which might be indicating that anthropogenic pressure might endanger biodiversity. Then, we ask, how the use of a forest is related with species diversity?

2. Materials and Methods

2.1. Floristic Inventory

The study sites were the Amazonian forests of the Madidi National Park, Bolivia (Figure 1). The study area was placed in both tierra firme lowlands and submontane regions, with a range of elevations from 260 to 1070 m. The inventory was carried out in closed canopy of an old growth mature forest [25].

The field inventory was carried out between 2001-2002, based on temporary plots following a defined protocol [26]. A total of 41 plots of 0.1 ha (50x20 m) were established at five different sites in a north-south gradient. The plots were at least 500 m apart to assure floristic independence.

All trees, palms, lianas and hemiepiphytes with diameter at breast height (DBH) ≥ 2.5 cm were measured and inventoried. All stems were identified in the field, when possible, or collected for further determination. Vouchers MJM 3876-7051 [25] were kept in the LPB (La Paz Herbario Nacional de Bolivia).
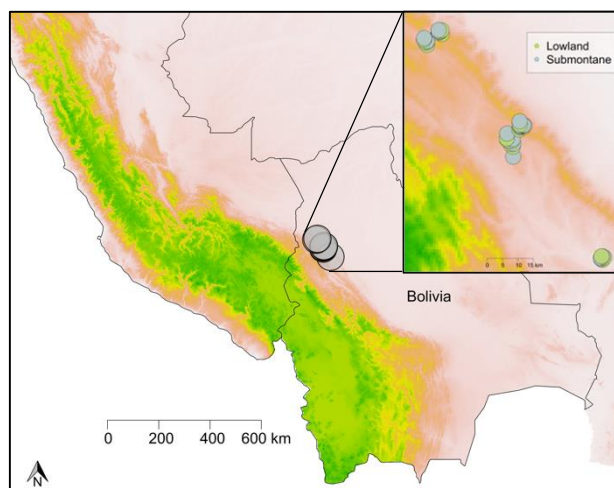
Figure 1. Location of the study area and the 41 plots placed in both lowland and submontane forest in Madidi National Park, Bolivian Amazonia.

2.2. Ethnobotanical Data Collection

Before initiating in situ data collection, an oral consent was obtained at both the community and the participant. Seven male experienced informants (>40 years old) from the Tacana communities of Macahua, Tumupasa, and San Buenaventura participated in this study. Semi-structured ethnobotanical interviews about the traditional uses of all the inventoried plant individuals were performed in the plots. The questions were: "do you know this stem (vernacular name)?", "Can you tell me the possible uses for it?" [21,27]. The use-reports from interviews were classified into 10 use categories (construction, cultural, environmental, fuel, food, medicine, marketed, tools, toxic and wild animal food) and their respective subcategories following the Economic Botany Data Collection Standard [28], with recently proposed modifications to adapt it to tropical regions [27]. Ethic statement - Approval for this study was granted by the Committee for Ethical Research of the Universidad Autónoma de Madrid (#48-922; PI Manuel J. Macía).

2.3. Data Analysis

2.3.1. Species Availability Influences Plant Use

Regarding the ecological importance, the Importance Value Index (IVI) was used as an indicator of the species apparency because it includes its relative dominance, frequency and abundance of each species [21]. To identify which are the most important species to the Tacana ethnic group, the Use Value Index (UV) for each species was calculated using the following formula [29]:

$$UV = \Sigma Ui / N, \tag{1}$$

being Ui the number of uses mentioned by each informant i, N is the total number of informants interviewed in the locality. Similarly, the UV per use-category (UVc) was calculated, dividing the informants who cited each given use by the total number of informants [30]. Then, UV and IVI were log-log transformed. The variables were analyzed by means of Spearman rank correlation coefficient for non-parametric data on a log basis.

2.3.2. Biodiversity Shapes Forest Use

In order to explore the relationship between the cultural importance of a forest and its diversity, Fisher's alpha index was used as a proxy of biodiversity, because relates the total number of woody plants species and the total number of individuals for each plot [31]. To asses forest cultural importance, the Use Value Index of a plot (UVp) was calculated as the summed Use Value Index (UV)

of all individual plants (n) divided by the total number of plant individuals (N) found in the plot [22,32,33]:

$$UVp = \Sigma(UVs * n) / N, \tag{2}$$

The relation between Fisher's alpha index and its UVp value for the different plots was analyzed using generalized linear modelling (GLM) with a Gaussian error distribution (Table 2). We selected the UVp as the response variable and Fisher's alpha (linear and quadratic terms), the forest types (Lowland and Submontane forest), and the interaction between the covariant and the factor, as the explanatory variables. Models were compared using the Akaike Information Criterion (AIC) [34]. In order to avoid heterogeneity of the different forest shaping the humpbacked curves, the analysis was carried out for both lowlands and submontane forests.

All the analyses were conducted in the R 3.0.3 software [35].

Table 2. Ranking alternative GLMs by AIC-based model selection procedure.

Alternative models (UVp as a function of biodiversity)	AIC
UVp~ Fisher α	20.47
UVp~ Fisher α * Forest Type	18.46
UVp~ Fisher α + Forest Type	17.35
UVp~ Fisher α * Forest Type + Fisher α^2 * Forest Type	17.94
UVp~ Fisher α * Forest Type + Fisher α^2	15.96
UVp~ Fisher Alpha + Fisher Alpha ^{2} + Forest Type	**14.36**

3. Results

3.1. Species Availability Influences Plant Use

A total of 11,955 individuals, 795 species and 99 families were found in 41 0.1-ha plots of the Amazonian forests of the Madidi National Park (Bolivia). A total of 436 (54.84%) species were reported as useful by the Tacana ethnic group. More than half of the species were used for construction and fuel, while the remaining were used mostly for food, tools, medicines and cultural activities. The UV and all the UVc were significantly correlated with the IVI (Table 1) and the scatter plot showed this positive correlation between the UV and the IVI (Figure 2). When analysing per categories, UVc showed a strong linear relation with its IVI for construction and fuel uses (Table 1). On the other hand, the Cultural and Medicinal categories had a small Spearman´s coefficient, indicating a weaker relation with the IVI.

Table 1. r_s Spearman correlation values between IVI and UV, all significant p<0.001; S, number of species in each category.

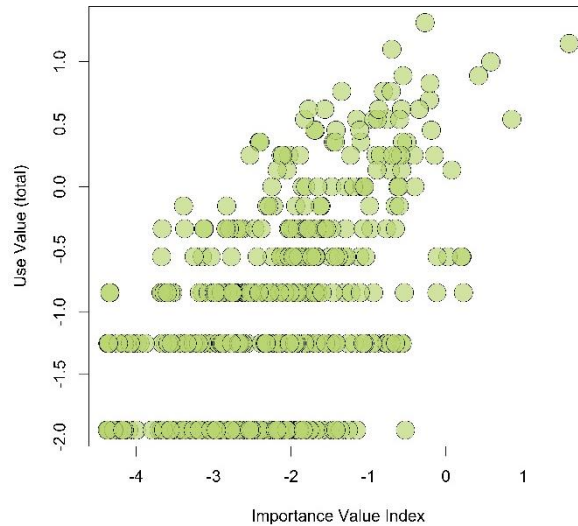| Category	S	r_s
Total	436	0.60
Construction	240	0.48
Fuel	194	0.44
Tools	130	0.30
Food	138	0.28
Medicinal	118	0.27
Cultural	85	0.25

Figure 2. Scatter plot of the use value (UV) against Importance Value Index (IVI). Each point represents the combination of UV and IVI of each species (n = 795).
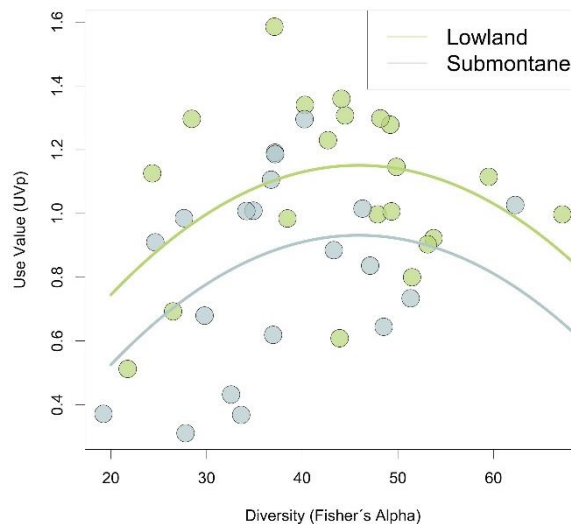
3.2. Biodiversity Shapes Forest Use

Figure 3. Prediction of the best-fit model for the relationship between UVp and Fisher´s alpha diversity. Each point represents the combination between Fisher´s alpha and UVp of each of the plots.

In ethnobotany, the use as a function of the species richness has only been assessed under linear correlations. Here, we alternatively studied this relationship under a nonlinear response model. With increasing diversity, a greater UVp is found, until reaching a certain plateau. Then, the pattern reverses and when increasing Fisher´s alpha, the UVp drops (Figure 3).

4. Discussion

4.1. Species Availability Influences Plant Use

This study shows that the availability of a resource plays a significant role in the human choice of plant species, but the strength of the relationship between environmental and local use varies depending on the category of use, following the general pattern on studies in humid forests [8]. This result can be explained in light of the Optimal Foraging Theory (OFT), that has been frequently applied to humans in order to explain its resource use patterns [2,7]: Tacana people may behave as

"generalist" when the resources are chosen for categories of use as construction and fuel. This selection is mainly driven by the apparency and availability of the species rather than its quality. When regarding wood requirements, plants are more easily substitutable in terms of their physical qualities (e.g., mechanical resistance or durability) and are likely to be shared by many species [2,21]. In addition, more available means more reliable because it is most likely to be accessed when demanded [36]. On the other hand, Tacana people behave as "specialist" when the resources are destined for Cultural or Medicinal categories, meaning that other factors than apparency influence the selection of these species. The quality of the resource might outweigh availability, becoming a limiting factor for the human choice. Plants need to accomplish certain intrinsic requirements to be destined to this specific use, holding specific chemical characteristics, responsible for their edibility, taste or medicinal properties [21]. These properties might be much harder to substitute, forcing the use of this specific plant despite its apparency. Therefore, the dynamic balance between availability and quality when selecting species mirrors in humans the ability of performing as generalists or specialists.

3.2. Biodiversity Shapes Forest Use

The present study reports that the maximal use of a forest is dependent on intermediate levels of plant diversity. The usefulness of a forest increases with diversity, until reaching an optimum here high plant variation of structures, chemical compositions and lifespan [37], enables usefulness to be maximized. At this peak, there is an optimal equilibrium between the quantity and the quality of the resource: a great number of useful species together with species with a greater use. The presence of different species enable humans to maximize the number of plants from which they can draw for their livelihoods [14]. Then, usefulness decreases as diversity increases due to the decline of species with high use, as a consequence of the development of rare species. Rare species are often less reliable in terms of use due to its reduced likelihood to be accessed when demanded [36].

5. Conclusions

This study highlights the human capacity to adapt to specific environmental conditions, based on the availability or biodiversity of the plant resources. The reliance of local people on rainforest has often been cited as one reason for conservation of these forests. We suggest future research to explore the indigenous reality in depth in order to develop consistent conservation strategies that reinforce the ethnic identity and reduce environmental damage.

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