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Regeneration Status and Role of Traditional Ecological Knowledge for Cloud Forest Ecosystem Restoration in Ecuador

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Abstract: The importance of forests for biodiversity conservation has been well recognized by the global community; as a result, conservation efforts have increased over the past two decades. In Ecuador, the lack of integrated information for defining and assessing the status of local ecosystems is a major challenge for designing conservation and restoration plans. Thus, the objectives of this study were (1) to examine the regeneration status of cloud forest remnants, some of which had experienced past human disturbance events, (2) to explore a local rural community's traditional ecological knowledge (TEK) relevant for restoration and (3) to investigate the integration between TEK and ecological science-based approaches. A survey of regeneration status was conducted in four remnants of cloud forests ($n = 16$) in Cosanga, Napo Province, in the Andes of northeastern Ecuador. The species of young trees (0.5–5 m height) were identified over 0.16 ha. In-depth interviews of individuals from local communities ($n = 48$) were conducted to identify socio-ecologically important native species. The results showed significant differences ($p < 0.001$) in species richness and the stem density of seedlings and saplings in gaps. The stem density of *Chusquea* sp., a bamboo species, explained 63% of the variation in species richness and 48% of the variation in the abundance of seedlings and saplings between plots. Informants cited 32 socio-ecologically important species, of which 26 species were cited as sources of food and habitats for wildlife. The ranking of species based on a relative importance index and a cultural value index—taking into account both the spread of knowledge among local informants and the multiplicity of uses—revealed that *Hyeromina duquei*, *Citharexylum montanum*, *Eugenia crassimarginata* and *Sapium contortum* were traditionally the most valuable species for both humans and wildlife. Informants also recommended 27 species for future planting, of which 19 species were amongst the rarest species in the regeneration survey. In conclusion, the results demonstrate a synergy between TEK and ecological science-based approaches (regeneration survey) to natural ecosystem research. Thus, traditional ecological knowledge can provide insights into ecosystem–plant–animal interaction, and to identify native species useful for both humans and wildlife for forest restoration projects to reconnect isolated cloud forest fragments.

Keywords: Cosanga; cultural value index; ethno-ecology; gap-phase regeneration; neotropical cloud forest

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1. Introduction

The importance of forests for biodiversity has been well recognized by the global community; as a result, conservation efforts have increased over the past two decades [1]. In Ecuador, deforestation and forest degradation has dated back to pre-Hispanic colonization, when human occupation of the cloud forest belt had rendered the cloud forest fallow [2]. During the colonial period, native forests were unscrupulously exploited for timber, which was later exacerbated by increasing human populations [3] and poor forest development policies that promoted reforestation programs using exotic species [4–6]. In addition, a resettlement policy promoted by governmental institutions, especially in the Amazon and the Andean Choco Regions of Ecuador, between 1960 and 1990 has resulted in extensive clearance of the natural forests [7–10]. In spite of ongoing degradation, conservation efforts, including passive forest restoration, have appeared in some rural areas of Ecuador [11–15], which are led by nonprofit environmental organizations, local communities and associations of private landowners, over the past few decades [10,15–18].

Furthermore, several governmental and private initiatives have been established to produce timber, generally based on the use of exotic species [4,9,19]. The choice of tree species for restoration using native species can influence both the rate and trajectory of restoration processes and determine the success of restoration projects [20,21]. Ideally, the species selected for restoration endeavors should tolerate the prevailing environmental conditions of the degraded site, and have diverse ecological importance and the ability to generate economic benefits for the local population [21,22]. Native species could also provide local ecological benefits, such as food as leaves, flowers and fruits for the native fauna, which can subsequently aid in pollination and the dispersion of seeds [23].

Emerging evidence shows that traditional ecological knowledge (TEK) can fill crucial gaps in our ecological understanding [24–27]. TEK is defined as a "cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" [28]. Unlike indigenous knowledge (focusing on a particular ethnic group or indigenous people), TEK focuses more on a local culture and their interactions with their biotic and abiotic environment [29,30], ranging from cursory awareness of natural histories associated with local wildlife to cultural norms for land management and resource allocation. It is a dynamic process that co-evolves with the ecosystem and the needs of local communities, thus serving as an information base for a society, facilitating communication and decision making, and as a foundation for local institutions.

The contribution of TEK to the management and conservation of natural resources has been well recognized and utilized over the past few decades [26,31,32]. However, its present or potential contribution to restoration ecology has not been well studied. As a result, the integration of traditional knowledge in restoration planning still remains undervalued in many parts of the world, including Ecuador. The general premise for the role of TEK in restoration is that natives, and even groups of settlers, often interact with a landscape for extended periods of time, bringing cost-effective knowledge, and even new information from other environments, which could be relevant for use in local restoration programs. A recent review also demonstrates that TEK can contribute to all aspects of ecological restoration, from the reconstruction of the reference ecosystem and adaptive management to species selection for restoration and monitoring and the evaluation of restoration outcomes [33].

Not all traditional practices and belief systems are ecologically sound and adaptive due to ecosystem degradation or lost knowledge, or from changing conditions, with local ethno-ecological knowledge becoming stagnant and/or irrelevant over time [34]. There is, however, supporting evidence that demonstrates the synergy between TEK and the protection of the natural environment and the possibility to integrate this knowledge within a science-based approach that could contribute to the maintenance of both nature and cultural values [27,30,31].

Thus, this study was conducted in Cosanga, Napo Province, in the Andes of north-eastern Ecuador, which is identified as a global biodiversity hotspot [35], to examine the synergy between TEK and ecological science-based approaches to the restoration of degraded cloud forests. In the study area, it is still possible to find remnants of cloud forests within public protected areas and in private ownership, with some private owners interested in conserving the forests and establishing corridors to connect the forest patches for bird watching and ecotourism purposes. The objectives of the study were (1) to examine the regeneration status of cloud forest remnants, considering previous human disturbance events, (2) to explore traditional ecological knowledge relevant for future restoration purposes and (3) to evaluate the potential integration of TEK and science-based approaches. The study specifically aimed at answering the following research questions: To what extent does past human disturbance influence the regeneration of cloud forest species? Does the population density of the disturbance indicator species explain the lack of regeneration? Is there traditional ecological knowledge in Cosanga that is relevant for conservation and restoration purposes? What are the implications of TEK for the restoration of disturbed cloud forests and the conservation of forest biodiversity?

2. Materials and Methods

2.1. Study Site

The present study was conducted in Cosanga, Napo Province, in the Andes of northeastern Ecuador, which lies between 0°30′39″–0°33′4″ N latitude and 77°50′39″–77°55′40″ W longitude [16]. The Cosanga parish, established officially in 1961, is located between the boundaries of two nature reserves, Sumaco and Antisana, and close to the Sumaco Biosphere Reserve buffer zone with a total area of 401.2 km^2 (Figure 1). Its vegetation type is characterized as tropical mountain cloud forest (accounting for 10% of the land cover), highland mountain forest and Páramo vegetation (dense alpine vegetation growing on a thick mat of sponge-like, highly absorbent mosses and grasses). The annual rainfall averages between 2500 and 3500 mm per year and the mean monthly temperatures range from 15 to 17 °C, and the general climate is best described as cool and rainy. The forest soil is predominantly Cambisol, with spatial heterogeneity in waterlogged conditions.

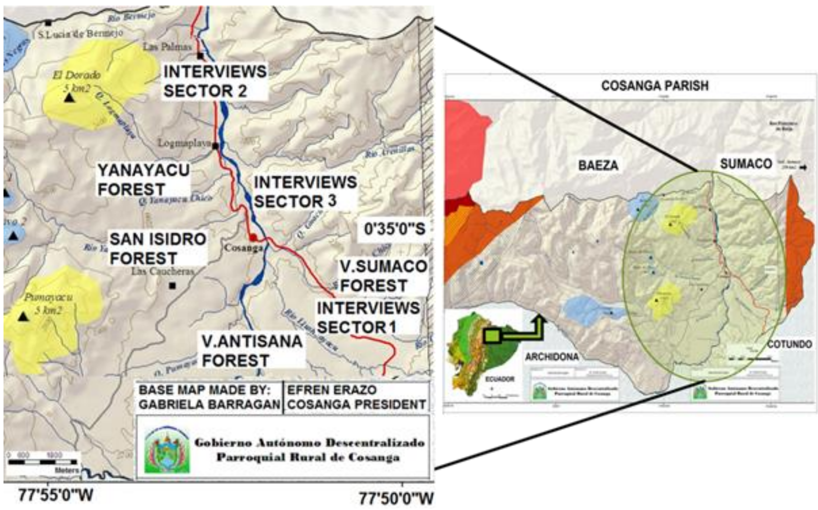

Figure 1. Map of the study area, located in the northeast of Ecuador; the numbers 1 to 3 represent the study sub areas. Map based on a parish management plan from 2012.

For the regeneration survey, four remnants of cloud forests, namely, Vinillos Antisana, Vinillos Sumaco, San Isidro and Yanayacu, were selected based on the local knowledge of the area of the conservation guides and discussions with experts and owners of the forest remnants. The Vinillos Antisana forest remnant is located in the reserve's lower northeast corner, in which we worked in an area of around 40 ha, of which around 50% lies on steep slopes. The remnant forests at Vinillos Sumaco, San Isidro and Yanayacu are privately owned, and inside each of those private forestlands, we worked in areas of around 40 ha. These forests are dedicated to promoting the conservation of the native forest in Cosanga by their respective owners, including Yanayacu Biological Station, San Isidro, Sierra Azul, San Jorge and Chontayacu [16,18,36]. These forest remnants are important for local wildlife conservation and for generating ecotourism, research and education opportunities for the local communities. During the fieldwork, signals of disturbance, such as timber extraction and the dominance of *Chusquea* sp. (a diverse genus of bamboos), which is a typical indicator of past anthropogenic disturbances, were observed.

2.2. Regeneration Survey

In each cloud forest remnant, four sub-blocks of five ha were delineated, and within each sub-block, six transect lines, 150 m long and 30 m wide, were laid. Along each transect line, an observation of all gaps was made to randomly select the four biggest gaps. In the center of each selected gap, a plot of 10 m $\times$ 10 m was established, and all woody species from 0.5 to 5 m in height were identified and counted. Most of the species were identified in situ during the inventory, and those that were difficult to identify in the field were collected and taken to the National Herbarium of Ecuador for identification by taxonomy experts. Voucher specimens were deposited at the same herbarium. The number of individuals of the disturbance indicator species, *Chusquea* sp., was also counted in each gap during the inventory.

2.3. Survey of Traditional Ecological Knowledge

Based on information relating to the tree species present in the cloud forest remnants, we prepared a semi-structured ethno-ecological survey, which was conducted in 2014, in order to find out the trees species that are important for the local population and wildlife. Information was gathered through two semi-structured, in-depth interviews of 48 informants, who were randomly selected from a list from the Cosanga Cattle Producers Association, which has 102 members. To obtain representative samples, the informants were randomly selected from 14 study sites close to the cloud forest remnants where the young tree regeneration survey was conducted. During the interview, the following data were gathered: demographic data of the informants, land use history, knowledge of native tree species with a consideration of human and wildlife uses, species recommended for planting and future farmland use plans. The interview about species and their uses was conducted in two steps. First, open questions were posed to every informant in order to determine their level of knowledge of different local tree species and their uses (e.g., medicine, food, timber, wildlife habitat). In the subsequent interview, a list of 28 species, together with photos, selected based on a survey of remaining cloud forests and group discussions with conservation experts, was presented to the informants, and the informants were asked whether they knew the species and to mention their importance for human and wildlife uses.

2.4. Data Analyses

Species richness and the abundance of individuals in the regeneration phase were computed for each forest block within each remnant of cloud forests according to growth habits (tree versus treelets). A two-way analysis of variance was performed to examine significant differences in species richness and abundance among forest remnants and growth habits, considering the density of the disturbance indicator species as a covariate. Means that exhibited significant differences were further compared using Tukey's test. To further explore the relationship between the population density of the disturbance indicator species and species richness and abundance, linear regression analysis was performed using the R program [37].

Data related to TEK were analyzed using descriptive statistics and quantitative indices. For each species, use reports (UR), defined as the sum of the number of informants (i) who mentioned the use of the species, s, in the use category, u, were computed as follows [38]

$$UR_s = \sum_{u=1}^{NC} \sum_{i=1}^{N} UR_{ui.}$$

First, the UR of all the informants (from i = 1 to N) within each use category for that species (s) were summed; then, all the UR of each use category (from u = 1 to NC) were summed to obtain the total number of use reports of the species. The socio-ecological importance of each tree species was compared using three quantitative indices: the relative frequency of citation (RFC), the relative importance index (RI) and the cultural value index (CV), which are robust quantitative methods used in ethno-botanical studies [38–40]. The relative frequency of citation of a species (RFCs) was obtained by dividing the number of informants who mention the use of the species, also known as the frequency of citation (FCs), by the number of informants participating in the survey (N), as expressed below:

$$RFC_s = \frac{FC_s}{N}$$

Theoretically, RFCs values vary between 0, when nobody mentioned any use of the species, and 1, when all informants would mention the use of the species.

The relative importance of a species (RIs) was computed by combining both the frequency of citation and the number of use categories (NU) using the following formula:

$$RI_s = \frac{RFC_{s(max)} + RNU_{s(max)}}{2}$$

RFCs (max) is the relative frequency of citation over the maximum, obtained by dividing FCs by the maximum value for all the species of the survey; i.e., RFCs (max) = FCs/max (FC). RNUs (max) is the relative number of use categories over the maximum, and is obtained by dividing the number of uses of the species by the maximum value for all the species of the survey; i.e., RNUs (max) = NUs/max (NU). The RI index theoretically varies between 0, when nobody mentions any use of the plant, and 1, when the plant was the most frequently mentioned as useful and in the maximum number of use categories.

The cultural value index of a species (CVs) is computed by combining the number of different uses reported for the species (NUs), the relative frequency of citation of the species (FCs) and the sum of all the UR for the species (URui) relative to the sum of all the UR for the species (NC) and the total number of informants, N. The equation can be expressed as follows:

$$CV_s = \left[\frac{NU_s}{NC}\right] \times \left[\frac{FC_s}{N}\right] \times \left[\sum_{u=1}^{NC}\sum_{i=1}^{N} UR_{ui}/N\right]$$

CVs reaches its theoretical maximum value if all informants would mention the use of the species (FCs = N) in all the use categories considered in the survey (NUs = NC); thus, the first two factors would be equal to 1, while the third factor would vary from 0 to NC.

3. Results

3.1. Regeneration Status

A total of 154 species were recorded in gaps of remnant cloud forests, of which 76 species were trees and 82 species were treelets, 13 were unidentified and one was identified at the genus level. The total stem density/ha was 18 375, of which trees accounted for 44% and treelets for 56%. *Piper kelleyi* Tepe was the most abundant treelet species (1675 stems/ha), while *Erythrina edulis* Triana ex.Michli was the most abundant tree species (1300 stems/ha) representing the regeneration community in gaps. We recorded the 10 rarest species (6 stems/ha) in the tree and treelet communities. A complete list of species together with stem density/ha is presented in the Appendix A.

At the plot level, significant differences in species richness and stem density were detected among cloud forest remnants and between growth habits (Table 1). There was also an interaction effect of forest remnants and growth habits on species richness, while the covariate (the density of the disturbance indicator species) had significant effects on both species richness and stem density. The species richness of treelets was higher than that of trees in Vinillos Antisana and Yanayacu compared to San Isidro, Vinillos Sumaco and Yanayacu (Table 2). Stem density, i.e., the averaged overall levels of growth form, was higher in Vinillos Antisana than in San Isidro and Yanayacu, while the stem density of treelets was higher than that of trees (Table 2).

Table 1. Summary of GLM univariate analysis for testing significant differences in species richness (SR), abundance (AB) and number of indicator species (NIS) among forest remnants and between growth habits.

Variable	Source of Variation	d.f. *	F-Value	*p*-Value
SR	No. of indicator sp.	1	337.96	<0.001
	Forest remnant (FR)	3	3.97	0.010
	Growth habit (GH)	1	48.73	<0.001
	FR × GH	3	3.59	0.016
	Error	119		
AB	No. of indicator sp.	1	88.16	<0.001
	Forest remnant (FR)	3	4.22	0.007
	Growth habit (GH)	1	21.32	<0.001
	FR × GH	3	0.09	0.964
	Error	119		
NIS	Forest remnant (FR)	3	7.19	<0.001
	Error	124		

* d.f. = degrees of freedom.

Table 2. Plot-wise species richness, abundance and population density of indicator species in each cloud forest remnant (mean ± SE). Where SI, VA, VS and YA stands for San Isidro, Vinillos Antisana, Vinillos Sumaco and Yanayacu, respectively.

Variables	Growth Habit	Forest Remnant SI	VA	VS	YA
Species richness	Tree	8 ± 1	13 ± 1	11 ± 1	8 ± 1
	Treelet	11 ± 1	15 ± 1	10 ± 1	11 ± 1
Abundance	Tree	13 ± 2	31 ± 4	20 ± 3	17 ± 2
	Treelet	23 ± 3	36 ± 2	25 ± 4	20 ± 2
No. of indicator species		22 ± 1	15 ± 1	19 ± 1	21 ± 1

The density of the disturbance indicator species was lower in Vinillos Antisana than in San Isidro, Vinillos Sumaco and Yanayacu (Table 2). The regression analysis revealed a negative relationship between the stem density of the disturbance indicator species and species richness (Figure 2A) and the abundance (Figure 2B) of seedlings and saplings. The stem density of the disturbance indicator species explained 63% of the variation in species richness between plots (gaps), while it explained 48% of the variation in the abundance of seedlings and saplings.

3.2. Traditional Knowledge of Species Uses

Informants' uses of tree species were grouped into seven emic categories, with a total number of 2 321 use reports (Table 3). The proportion of use reports for poles for the fencing of pasture lands and timber for construction, furniture making and handcraft accounted for 27% and 26% of the total use reports, respectively. The reported use of species for wildlife was largely as a source of food for birds (18%), while wildlife habitat in the form of perching and nesting grounds and uses for medicinal purposes had the lowest reports.

A total of 32 species were reported by the informants to be socio-ecologically important (Table 4), with the number of uses of a species ranging from one to a maximum of five. The total use report values were 105–188 for 11 species, 61–93 for seven species and less than 50 for 14 species. Species with more than 25 for citation frequency for both human and wildlife uses included *Hyeromina duquei*, *Citharexylum montanum*, *Eugenia crassimarginata*, *Ocotea insularis*, *Saurauia prainiana*, *Sapium contortum*, *E. edulis*, *Ficus maxima* and *Ceroxylon* *echinulatum*. In addition, seven species, *Tibouchina mollis*, *Vismia tomentosa*, *Nectandra acutifolia*, *Delostoma integrifolium*, *Alnus acuminate*, *Weinmannia macrophylla* and *Alchornea latifolia*, were frequently cited as important for various human uses. Among the species useful for wildlife, *C. echinulatum* was cited as important for both food and habitat (perching and nesting grounds) for various birds and small mammals.

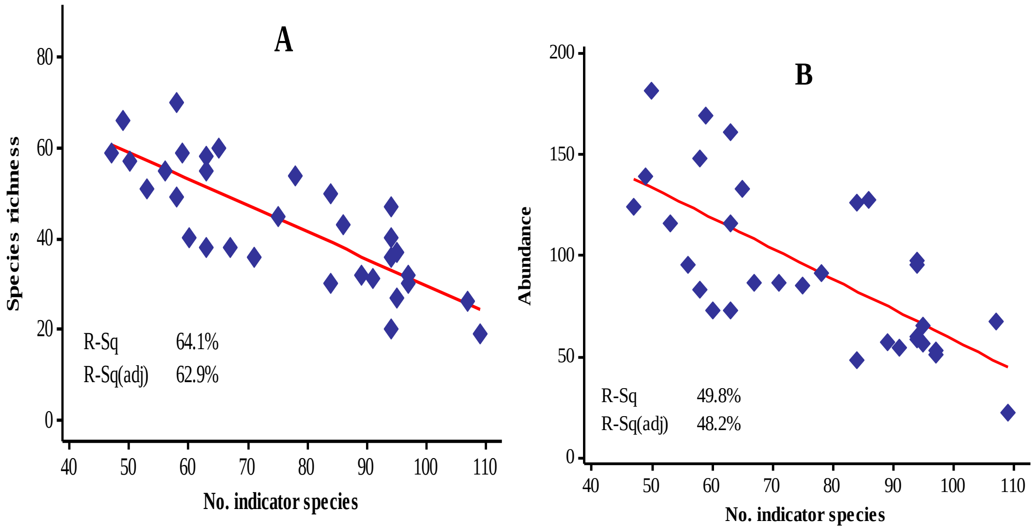

Figure 2. Relationship between stem density of disturbance indicator species and species richness (**A**) and abundance (**B**) of seedlings and saplings recorded in gaps of remnant cloud forests. Both species richness (p = 0.01) and abundance (p = 0.032) were significantly correlated with the number of indicator species.

Table 3. Number of use reports (UR) and percentage of total use categories.

Categories	Number of UR	Percentage
Poles for fencing	625	27
Timber and furniture	593	26
Food for wildlife	415	18
Fruit and ornamentals	395	17
Firewood	202	9
Medicines and herbs	62	3
Wildlife habitat	29	1
Total	2321	

The rankings of native tree species useful for both human and wildlife, using different indices, exhibited minor inconsistencies (Table 5). The relative importance index (RI) and cultural value index (CV), which took into account the multiplicity of uses consistently ranked, revealed *H. duquei*, *C. montanum*, *E. crassimarginata* and *S. contortum* as the most socio-ecologically important species. Conversely, the relative frequency of citation (RFC), which considered the spread of knowledge of useful species among informants, consistently ranked two species only, *H. duquei* and *E. crassimarginata*, as the most important species. All indices, however, consistently ranked the five least socio-ecologically important species, known by their local common names as Pandola, Musmus, Ispingo, Morus and Jungleus.

3.3. Species Recommended for Future Planting

The informants recommended 27 species for future planting in Cosanga for both production and conservation purposes (Figure 3). The most highly recommended species was *H. duquei* (83%), followed by *A. acuminata* (58%), *O. insularis* (42%), *C. montana* (29%) and *C. montanum* (29%). Among the recommended species, eight species did not show any regeneration in gaps (e.g., *A. acuminate*, *D. integrifolium* and *Pouteria* sp.) while 11 species had less than 10 individuals in the regeneration phase (e.g., *S. contortum*, *F. maxima*, *Croton* sp., *V. tomentosa* and *T. lepidota*). As a whole, there was a good concordance between the recommended species and poor regeneration in the gaps of remnant cloud forests; i.e., there were 19 species with poor regeneration status.

Table 4. Frequency of citation (FC) of a species by use category (together with number of uses (NU) as well as overall FC and use report (UR). TF = timber and furniture, PF = poles for fencing, MH = medicines and herbs, FO = fruits and ornamentals, FW = firewood, WF = food for wildlife, WH = habitat for wildlife.

Species	TF	PF	MH	FO	FW	WF	WH	FC (human)	FC (wildlife)	NU	UR
Hyeromina duquei	47	47	0	47	0	47	0	47	47	4	188
Citharexylum montanum	38	38	0	38	38	33	0	38	33	5	185
Eugenia crassimarginata	42	42	0	42	0	38	0	42	38	4	164
Vismia tomentosa	43	43	0	0	43	9	0	43	9	4	138
Delostoma integrifolium	33	33	0	33	33	0	3	33	3	5	135
Alnus acuminata	33	33	0	33	33	0	1	33	1	5	133
Sapium contortum	33	33	0	0	33	34	0	33	34	4	133
Ocotea insularis	44	44	0	0	0	36	0	44	36	3	124
Ficus maxima	29	29	29	0	0	27	0	29	27	4	114
Ceroxylon echinulatum	20	20	0	20	0	25	25	20	25	5	110
Erythrina edulis	0	31	0	31	0	43	0	31	43	3	105
Tibouchina mollis	0	44	0	44	0	5	0	44	5	3	93
Alchornea latifolia	27	27	0	27	0	8	0	27	8	4	89
Nectandra acutifolia	36	36	0	0	0	4	0	36	4	3	76
Saurauia prainiana	0	0	0	35	0	39	0	35	39	2	74
Guarea kunthiana	16	16	0	16	0	15	0	16	15	4	63
Weinmannia macrophylla	30	30	0	0	0	1	0	30	1	3	61
Inga aff. acuminata	16	16	0	16	0	13	0	16	13	4	61
Trichilia septentrionalis	13	13	0	13	0	6	0	13	6	4	45
Clusia lineata	14	14	0	0	14	2	0	14	2	4	44
Cedrela montana	43	0	0	0	0	0	0	43	0	1	43
Oreopanax palamophyllus	14	14	14	0	0	1	0	14	1	4	43
Hedyosmum luteynii	0	0	19	0	0	12	0	19	12	2	31
Turpinia aff. occidentalis	10	10	0	0	0	11	0	10	11	3	31
Critoniopsis occidentalis	5	5	0	0	5	3	0	5	3	4	18
Solanum cf. *hypermegethes*	3	3	0	0	3	1	0	3	1	4	10
Miconia glandulistyla	0	3	0	0	0	1	0	3	1	2	4
Jungleus (unidentified sp.)	1	0	0	0	0	1	0	1	1	2	2
Nectandra sp	1	0	0	0	0	0	0	1	0	1	1
Morus insignes	1	0	0	0	0	0	0	1	0	1	1
Musmus (unidentified sp.)	0	1	0	0	0	0	0	1	0	1	1
Pandola (unidentified sp.)	1	0	0	0	0	0	0	1	0	1	1

Table 5. Ranking of species useful for humans and wildlife in Cosanga using relative frequency of citation (RFC), relative importance index (RI) and cultural value index (CV). Species are arranged in decreasing order of CV and species ranking based on each index.

	Indices			Rank		
Species	**RFC**	**RI**	**CV**	**RFC**	**RI**	**CV**
Hyeromina duquei	0.979	0.900	2.191	1	1	1
Citharexylum montanum	0.740	0.878	2.036	6	2	2
Eugenia crassimarginata	0.833	0.826	1.627	2	3	3
Sapium contortum	0.698	0.756	1.105	7	4	4
Ocotea insularis	0.833	0.726	0.923	2	6	5
Vismia tomentosa	0.542	0.677	0.890	9	11	6

Table 5. *Cont.*

	Indices			Rank		
Species	**RFC**	**RI**	**CV**	**RFC**	**RI**	**CV**
Ficus maxima	0.583	0.698	0.792	8	7	7
Ceroxylon echinulatum	0.469	0.739	0.767	11	5	8
Delostoma integrifolium	0.375	0.691	0.753	14	9	9
Erythrina edulis	0.771	0.694	0.723	4	8	10
Alnus acuminata	0.354	0.681	0.701	16	10	11
Tibouchina lepidota	0.510	0.561	0.424	10	15	12
Alchornea pearcei	0.365	0.586	0.386	15	13	13
Saurauia aff. tomentosa	0.771	0.594	0.340	4	12	14
Nectandra acutifolia	0.417	0.513	0.283	13	17	15
Guarea kunthiana	0.323	0.565	0.242	17	14	16
Inga aff. acuminata	0.302	0.554	0.219	20	16	17
Weinmannia macrophylla	0.323	0.465	0.176	17	21	18
Trichilia septentrionalis	0.198	0.501	0.106	22	18	19
Clusia lineata	0.167	0.485	0.087	23	19	20
Oreopanax palamophyllus	0.156	0.480	0.080	24	20	21
Turpinia aff. occidentalis	0.219	0.412	0.061	21	24	22
Hedyosmum luteynii	0.323	0.365	0.060	17	25	23
Cedrela montana	0.448	0.329	0.057	12	26	24
Critoniopsis occidentalis	0.083	0.443	0.018	25	22	25
Solanum cf. *hypermegethes*	0.042	0.421	0.005	26	23	26
Miconia glandulistyla	0.042	0.221	0.001	26	27	27
Jungleus (unidentified sp.)	0.021	0.211	0.000	28	28	28
Morus insignes	0.010	0.105	0.000	29	29	28
Nectandra sp.	0.010	0.105	0.000	29	29	28
Musmus (unidentified sp.)	0.010	0.105	0.000	29	29	28
Pandola (unidentified sp.)	0.010	0.105	0.000	29	29	28

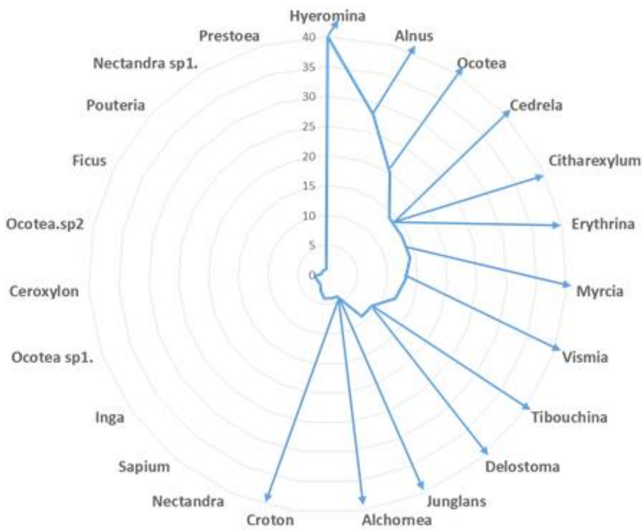

Figure 3. Species recommended for future planting in Cosanga for productive and conservation purposes by informants. Values represent the number of informants that recommended a species (note: only genus name is used for the species for the sake of figure clarity).

4. Discussion

Integrated ethno-ecological knowledge on the interaction between wildlife and their dependence and integration within local ecosystems provides an important information base for the generation of locally adaptive conservation and restoration strategies. This is particularly the case in tropical regions and outside protected areas [41,42], where native ecosystems have experienced rapid degradation [43–46]. As such, our study provides useful insights into the potential for integrating TEK and ecological science-based approaches.

In the primary forest remnants regeneration survey, we recorded 154 species, excluding species that were not identified at the species level because of their scarcity or lack of reproductive structures. The floristic composition recorded in this study is much higher than that recorded in the gap-building phases of the tropical montane cloud forests of northeastern Mexico [47]. The most dominant families in the primary forest gap-regeneration phase include Melastomataceae, Piperaceae, Fabaceae and Euphorbiaceae, which are also common in secondary forest remnants [48], suggesting that light-demanding species are dominant in the gaps.

The mean species richness and stem density per plot varied among the remnants of cloud forests. This variation could be partly explained by the abundance of bamboo species (*Chusquea* sp.). The frequent occurrence of bamboo restricts the recruitment and establishment of woody flora due to its strong competitive ability to consume resources and growing space [49]. Bamboos are known for their rapid and early colonization of disturbed sites [50]. Their dominance is associated with their ability to generally use the stored resources in the below-ground rhizomes for the production of fresh culms and leaves, which again start producing photosynthates to be stored for next year's biological production and clump maintenance [51]. Among the four studied primary forest remnants, Vinillos Antisana, which is located inside the Antisana Reserve, presented the highest number of species and the lowest records for *Chusquea*. Within the primary forest natural gaps, we found species associated with secondary forests; however, we also found species typically represented in primary forests, i.e., several timber species from the Lauraceae, Meliaceae, Myrtaces and Euphorbiaceae families characteristic of mature forests.

In our study, we found a high abundance of *Piper bullosum* C. DC. However, we recently found out that a new species, which looks very similar, had been identified [52] as *P. kelleyi*. We were able to identify 78 individuals of *P. bullosum* and 268 as *P. kelleyi*. This species is important for sustaining high population levels of insects and butterflies and important for the maintenance of several species of birds.

The high spatial variability of species regeneration in gaps might be attributed to topographic and soil conditions. The study area is characterized by an undulating topography from lowland to steep slopes. Previous studies in Ecuador have shown that stem density and tree species diversity decrease with increasing altitudes from the tropical lowland to montane forests [53,54]. We observed that regeneration appears to be more abundant in the gentle slopes and lower on steep slopes, which is consistent with previous studies in Neotropical seasonally deciduous forest species [55,56]. Soil conditions also vary among forest remnants, where Cambisols, stagnic Cambisols and Andosol are dominant in Vinillos Antisana, Cambisols in Vinillos Sumaco and in San Isidro, and Histic Gleysol, Andosol and Cambisols in Yanayacu, with varying soil water saturation [57]. Long periods of high precipitation in the study areas facilitate the formation of swampy areas, which, in turn, hinders regeneration due to anaerobic conditions that restricts root activities. As a whole, habitat heterogeneity plays a key role in gap-phase regeneration in primary and in disturbed cloud forests, which is consistent with previous studies of the lowlands, highlands and transitional areas of cloud forest around 2000 m elevation in Ecuador [53,58–60].

Results from surveys of traditional ecological knowledge are consistent with the general premise that TEK can provide valuable information about the relationship between local people and their natural environments. This is particularly relevant to restoration and conservation projects with information gained in less time and at a lower cost than fieldwork. The informants identified 32 species that are culturally important, of which 25 species are reported to be useful as food for wildlife and three species as valuable perching and nesting grounds. Among the tree species suggested by Cosanga farmers are several species from the Lauraceae family, which are also well represented in the old growth forest remnants. All the species from this family are used, especially for construction and furniture, and produce a variety of small 'avocado' like fruits highly prized by mammals, such as the spectacled bear, and birds, such as wild turkeys and quetzals.

Given the rising interest in the conservation of biodiversity in the area, such information is vital for the selection of native species for planting in conservation zones, including corridors that connect forest remnants. The choice of such species can favor those that act as bird perches to further facilitate seed dispersal at a landscape scale [61,62]. It should be worth mentioning that the study area is one of the winning sites for bird species observed during the international Christmas bird count for the period 2011–2014 [36].

Interestingly, informants' recommendation of species for future planting complements the findings of the regeneration survey. Informants recommended 27 species, of which 19 species are very rare in the gaps of remnant forests, whereas some species, such as *E. edulis*, are the most abundant. Matching the most appropriate species to the prevailing environment and the listing numbers and proportions of species to be planted are important for ecological restoration procedures [63]. In this context, TEK provides valuable insights into the selection of species.

5. Conclusions

Given the complexity of environmental problems, with particular issues involved in tackling ongoing forest degradation, there is a growing concern at local, national and international levels to conserve and restore degraded forest ecosystems. However, there is a lack of local site-specific information in the rural areas of many tropical areas, such as the Cosanga Parish in Ecuador. This study aimed to generate information valuable for the conservation and restoration of degraded forest ecosystems. Based on the findings, the following conclusions can be drawn:

(1) Regeneration in old growth forest gaps, which had experienced previous anthropogenic disturbances, is limited by the rampant colonization of gaps by bamboo species and micro-habitat conditions created by topographic and soil conditions;
(2) TEK can contribute to ecological restoration through species selection for restoration planting;
(3) There is synergy between TEK and ecological science-based approaches (e.g., regeneration surveys). Thus, natural ecosystem studies and traditional ecological knowledge can provide relevant information about ecosystem–plant–animal interactions, and identify native tree species useful for both humans and wildlife. This information, in turn, can serve as an important entry point in the design, application and monitoring of site-specific restoration interventions, with the establishment of future ecological corridors oriented to connecting isolated primary and secondary forest remnants.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

A complete list of species recorded in the gaps of Cosanga cloud forests, together with the number of individuals of each species.

Family	Scientific Name	Tree	Treelet	Grand Total
Actinidiaceae	Actinidiaceae sp.1		49	49
Actinidiaceae	*Saurauia prainiana Buscal.*		83	83
Actinidiaceae	*Saurauia* sp.1		1	1
Actinidiaceae	*Sauraurea ademodonta Sleumer*		4	4
Actinidiaceae	*Saurauia aff. tomentosa (Kunth) Spreng.*		18	18
Actinidiaceae	*Saurauia* sp.		3	3
Annonaceae	*Xylopia* sp.	2		2
Annonaceae	*Aquifoliaceae*	1		1
Annonaceae	*Ilex laurina Kunth*	1		1
Araliaceae	*Araliaceae* sp.1	5		5
Araliaceae	*Oreopanax palamophyllus Harms*	27		27
Araliaceae	*Schefflera dielsii Harms*	45		45
Araliaceae	*Schefflera* sp.2	7		7
Arecaceae	*Arecaceae sp.*		1	1
Arecaceae	*Arecaceae* sp.1		10	10
Arecaceae	*Arecaceae* sp.2		1	1
Arecaceae	*Ceroxylon echinulatum Galeano*	7		7
Arecaceae	*Chamaedorea pinnatifrons*	6		6
Arecaceae	*Geonoma orbignyana Mart.*		109	109
Arecaceae	*Geonoma* sp.		3	3
Arecaceae	*Prestoea acuminata (Willd.) H.E. Moore*		3	3
Asteraceae	*Astracea* sp.1		1	1
Asteraceae	*Critoniopsis elbertiana (Cuatrec.) H. Rob.*	2		2
Asteraceae	*Critoniopsis occidentalis (Cuatrec.) H. Rob.*	20		20
Boraginaceae	*Cordia colombiana Killip*	3		3
Boraginaceae	*Cordia ucayaliensis (I.M. Johnst.) I.M.*	3		3
Brunelliaceae	*Brunellia tomentosa Bonpl.*	1		1
Caprifoliaceae	*Viburnum* sp.		4	4
Caricaceae	*Carica* sp.		1	1
Caricaceae	*Celastraceae*		3	3
Chloranthaceae	*Hedyosmum luteynii Todzia*	3		3
Chloranthaceae	*Hedyosmum* sp.	2		2
Clusiaceae	*Chrysochlamys membranacea Planch. & Triana*	5		5
Clusiaceae	*Clusia lineata (Benth.) Planch. & Triana*	10		10
Clusiaceae	*Clusia loranthacea Planch. & Triana*	1		1
Cunoniaceae	*Weinmannia macrophylla Kunth*	2		2
Cunoniaceae	*Weinmannia pinnata L.*	5		5
Cyatheaceae	*Cyathea caracasana (Klotzsch) Domin*	39		39
Euphorbiaceae	*Alchornea grandiflora Müll. Arg.*	7		7
Euphorbiaceae	*Alchornea latifolia Sw.*	39		39
Euphorbiaceae	*Croton* sp.	4		4
Euphorbiaceae	*Euphorbiaceae* sp.		1	1
Euphorbiaceae	*Sapium contortum Huber*	3		3
Euphorbiaceae	*Sapium marmieri Huber*	2		2
Euphorbiaceae	*Tetrorchidium macrophyllum Müll. Arg.*	5		5
Fabaceae	*Dussia tessmannii Harms*	3		3
Fabaceae	*Erythrina edulis Triana ex.Michli*	208		208

Family	Scientific Name	Tree	Treelet	Grand Total
Fabaceae	*Inga* sp.	2		2
Fabaceae	*Inga aff. acuminata Benth*	9		9
Fabaceae	*Senna obliqua G. Don*	1		1
Hypericaceae	*Vismia lateriflora Pers.*	8		8
Icacinaceae	*Citronella incarum (J.F. Macbr.) R.A. Howard*		2	2
Indet.	Ind. sp.1	1		1
Indet.	Ind. sp.1.1	1		1
Indet.	Ind. sp.1.3	2		2
Indet.	Ind. sp.1.8	1		1
Indet.	Ind. sp.2.1	1		1
Indet.	Ind. sp.2	1		1
Indet.	Ind. sp.2.1		14	14
Indet.	Ind. sp.2.4		8	8
Indet.	Ind. sp.2.5		9	9
Indet.	Ind. sp.2.6		2	2
Indet.	Ind. sp.5	1		1
Indet.	Ind. sp.8	1		1
Indet.	Ind. sp.2.7		2	2
Lauraceae	*Aniba riparia (Nees) Mez*	7		7
Lauraceae	*Licaria* sp.	2		2
Lauraceae	*Nectandra acutifolia (Ruiz & Pav.) Mez*	7		7
Lauraceae	*Nectandra membranacea (Sw.) Griseb.*	15		15
Lauraceae	*Nectandra* sp.	4		4
Lauraceae	*Ocotea aff. cernua (Meisn.) Mez*	3		3
Lauraceae	*Ocotea insularis (Meisn.) Mez*	7		7
Lauraceae	*Ocotea javitensis (Kunth) Pittier*	4		4
Lauraceae	*Ocotea oblonga (Meisn.) Mez*	5		5
Lauraceae	*Ocotea* sp.	55		55
Lauraceae	*Ocotea* sp.1	20		20
Lauraceae	*Ocotea stuebelii*	9		9
Lauraceae	*Persea areolatocostae (C.K. Allen) Vander Werff*	9		9
Lauraceae	*Persea subcordata (Ruiz & Pav.) Nees*	10		10
Lauraceae	*Pleurothyrium* sp.	1		1
Lauraceae	*Pleurothyrium trianae (Mez) Rohwer*	10		10
Lecythidaceae	*Gustavia hexapetala (Aubl.) Sm.*	2		2
Malpighiaceae	*Bunchosia argentea (Jacq.) DC.*	8		8
Melastomataceae	*Axinaea sodiroi Wurdack*		8	8
Melastomataceae	*Axinaea* sp.		1	1
Melastomataceae	*Conostegia aff. centronioides Markgr.*		51	51
Melastomataceae	*Melastomat.* sp.	69		69
Melastomataceae	*Melastomat.* sp.1		11	11
Melastomataceae	*Melastomat.* sp.2	1		1
Melastomataceae	*Melastomat.* sp.3	23		23
Melastomataceae	*Melastomat.* sp.4	1		1
Melastomataceae	*Melastomat.* sp.5	8		8
Melastomataceae	*Meriania drakei (Cogn.) Wurdack*		20	20
Melastomataceae	*Meriania hexamera Sprague.*	2		2
Melastomataceae	*Meriania* sp.		45	45
Melastomataceae	*Meriania tomentosa (Cogn.) Wurdack*		1	1
Melastomataceae	*Miconia aequatorialis Wurdack*		3	3
Melastomataceae	*Miconia aggregata Gleason*		9	9
Melastomataceae	*Miconia barbeyana Cogn.*		3	3
Melastomataceae	*Miconia brevitheca Gleason*		7	7
Melastomataceae	*Miconia clathrantha Triana ex Cogn.*	27		27
Melastomataceae	*Miconia floribunda (Bonpl.) DC.*		25	25
Melastomataceae	*Miconia glandulistyla (Bonpl.) DC.*	48		48

Family	Scientific Name	Tree	Treelet	Grand Total
Melastomataceae	*Miconia napoana Wurdack*	4		4
Melastomataceae	*Miconia nutans Donn. Sm.*		17	17
Melastomataceae	*Miconia rivalis Wurdack*		1	1
Melastomataceae	*Miconia* sp.	34		34
Melastomataceae	*Miconia* sp.1	28		28
Melastomataceae	*Miconia* sp.2	20		20
Melastomataceae	*Miconia theaezans (Bonpl.) Cogn.*	11		11
Melastomataceae	*Ossaea micrantha (Sw.) Macfad. ex Cong.*		48	48
Melastomataceae	*Tibouchina mollis (Bonpl.) Cogn.*		7	7
Meliaceae	*Meliaceae* sp.	3		3
Meliaceae	*Ruagea glabra Triana & Planch.*	14		14
Meliaceae	*Trichilia septentrionalis C. DC.*	25		25
Meliaceae	*Trichilia* sp.1	11		11
Monimiaceae	*Molinedia* sp.		1	1
Monimiaceae	*Mollinedia ovata Ruiz & Pav.*		13	13
Moraceae	*Ficus castellviana Dugand*	1		1
Moraceae	*Ficus cuatrecasana Dugand*	1		1
Moraceae	*Ficus maxima Mill.*	5		5
Moraceae	*Ficus* sp.	9		9
Moraceae	*Ficus tonduzii Standl.*	2		2
Moraceae	*Morus insignis Bureau*	14		14
Myricaceae	*Myrica* sp.		1	1
Myrsinaceae	*Cybianthus pastensis (Mez) G. Agostini*		3	3
Myrsinaceae	*Geissanthus aff. Pichinchae Mez*		6	6
Myrsinaceae	*Myrcia* sp.		12	12
Myrsinaceae	*Myrsine coriacea (Sw.) R. Br. ex Roem. & Schult.*		1	1
Myrtaceae	*Eugenia crassimarginata M.L. Kawas. & B. Holst*		5	5
Myrtaceae	*Myrcia* cf. *obumbrans (O. Berg) McVaugh*	31		31
Myrtaceae	*Myrtaceae* sp.		6	6
Phyllanthaceae	*Hieronyma asperifolia Pax & K. Hoffm.*	1		1
Phyllanthaceae	*Hieronyma* cf. *Macrocarpa Müll. Arg.*	68		68
Phyllanthaceae	*Hieronyma oblonga (Tul.) Müll. Arg.*	1		1
Phyllanthaceae	*Hieronyma* sp.1	20		20
Phyllanthaceae	*Phyllanthus sponiifolius Müll. Arg.*		19	19
Piperaceae	*Piper aff. arboreum Aubl.*		4	4
Piperaceae	*Piper bullosum C. DC.*		87	87
Piperaceae	*Piper crassinervium Kunth.*		6	6
Piperaceae	*Piper kelleyi Tepe*		268	268
Piperaceae	*Piper obliqua Ruiz & Pav.*		1	1
Piperaceae	*Piper perareolatum C. DC.*		9	9
Piperaceae	*Piper pittieri C. DC.*		21	21
Piperaceae	*Piper* sp.		40	40
Piperaceae	*Piper* sp.1		5	5
Piperaceae	*Piper* sp.3		1	1
Piperaceae	*Piper* sp.2		1	1
Rosaceae	*Prunus herthae Diels*		4	4
Rosaceae	*Prunus muris Cuatrec.*		1	1
Rubiaceae	*Chinchona aff. pubensis Vahl.*	13		13
Rubiaceae	*Duroia* sp.		2	2
Rubiaceae	*Faramea glandulosa Poepp.*		97	97
Rubiaceae	*Gonzalagunia* sp.		3	3
Rubiaceae	*Notopleura macrophylla (Ruiz & Pav.) C.M.*		7	7
Rubiaceae	*Palicourea amethystina (Ruiz & Pav.) DC.*		8	8
Rubiaceae	*Palicourea demissa Standl.*		26	26
Rubiaceae	*Palicourea prodiga Standl. ex C.M. Taylor*		12	12
Rubiaceae	*Picramnia magnifolia J.F. Macbr.*		1	1
Rubiaceae	*Rubiaceae* sp.1		34	34

Family	Scientific Name	Tree	Treelet	Grand Total
Rubiaceae	*Rubiaceae* sp.2		5	5
Rubiaceae	*Rubiaceae* sp.3		1	1
Rubiaceae	*Rubiaceae* sp.4		9	9
Rubiaceae	*Rubiaceae* sp.5		20	20
Rubiaceae	*Rubiaceae* sp.6		4	4
Rubiaceae	*Rubiaceae* sp.7		2	2
Rubiaceae	*Rubiaceae* sp.8		4	4
Sabiaceae	*Meliosma* sp.		3	3
Salicaceae	*Casearia aff. nigricans Sleumer*		10	10
Salicaceae	*Casearia mariquitensis (Kunth).*		2	2
Salicaceae	*Casearia quinduensis Tul.*		6	6
Salicaceae	*Casearia sylvestris S.W*		2	2
Salicaceae	*Salicaceae* sp.		5	5
Sapindaceae	*Allophyllus* sp.		4	4
Simaroubaceae	*Picramnia magnifolia J.F. Macbr.*		3	3
Siparunaceae	*Siparuna lepidota (Kunth) A. DC.*		17	17
Siparunaceae	*Siparuna macrotepala Perkins*		3	3
Siparunaceae	*Siparuna pyricarpa (Ruiz & Pav.) Perkins*		5	5
Solanaceae	*Cestrum aff. schlechtendahlii*		79	79
Solanaceae	*Cestrum megalophyllum*		1	1
Solanaceae	*Cestrum peruvianum Roem.*		7	7
Solanaceae	*Cestrum racemosum Ruiz & Pav.*		1	1
Solanaceae	*Cestrum* sp.		3	3
Solanaceae	*Iochroma calycinum Benth.*		8	8
Solanaceae	*Iochroma* sp.1		8	8
Solanaceae	*Sessea* sp.	1		1
Solanaceae	*solanaceae* sp.2		27	27
Solanaceae	*Solanaceae* sp.3		22	22
Solanaceae	*Solanaceae* sp.4		6	6
Solanaceae	*Solanaceae* sp5	2		2
Solanaceae	*Solanaceae* sp6		4	4
Solanaceae	*Solanum abitaguense S. Knapp*		6	6
Solanaceae	*Solanum anisophyllum Van Heurck & Müll.*		13	13
Solanaceae	*Solanum* cf. *hypermegethes Werderm.*		3	3
Solanaceae	*Solanum dolosum C.V. Morton ex S. Knapp*		44	44
Solanaceae	*Solanum ovalifolium Dunal*		9	9
Solanaceae	*Solanum* sp1.		24	24
Staphyleaceae	*Turpinia occidentalis (Sw.) G. Don*	43		43
Symplocaceae	*Symplocos fuliginosa B. Ståhl*		1	1
Urticaceae	*Cecropia ficifolia Warb. ex Snethl.*	5		5
Urticaceae	*Cecropia angustifolia Trécul*	67		67
Urticaceae	*Cecropia* sp.	9		9
Urticaceae	*Urera baccifera (L.) Gaudich. ex Wedd.*		2	2
Verbenaceae	*Citharexylum montanum Moldenke*		22	22
Verbenaceae	*Citharexylum* sp.		9	9

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