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Tropical Forests

New Edition

Edited by Padmini Sudarshana,
Madhugiri Nageswara-Rao and Jaya R. Soneji

TROPICAL FORESTS - NEW EDITION

Edited by **Padmini Sudarshana, Madhugiri Nageswara-Rao** and **Jaya R. Soneji**

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Contents

Preface

Tropical forests occupy only one-tenth of the world's land area but are home to more than half of the world's flora and fauna. They comprise extremely complex labyrinth of ecological interactions. In the last few decades, their astounding richness and biodiversity are rapidly dwindling as they are deforested, fragmented, burned, logged, and converted to agricultural lands and pastures, and their forest products are being indiscriminately extracted at an alarming rate. The destruction of plants, animals, soil, and ultimately the global biodiversity, due to the clearance of these tropical forests, has not been taken into account.

There is a fear that the burgeoning human population and industrialization of developing countries, where a majority of these tropical forests are found, may lead to the clearing or modification or may be a complete disappearance of the remaining tropical forests within few decades. Of the 25 "hot spots" that are identified across the globe, 19 have human populations growing more rapidly than ever across the earth's surface. Vital biogeochemical cycles of carbon, phosphorus, nitrogen, and so on have been severely altered and have led to the change in global climate and pristine natural ecosystems. Hence, there is an urgent need to protect, restore, conserve, and improve the forest resources before they are irrevocably lost.

In this second edition of the book *Tropical Forests*, the chapters differ noticeably in the geographic focus, diverse ecosystems, time, and approach; they share the above issues and help in understanding, educating, and creating awareness on the role of "tropical forests" for the very survival of mankind, climate change, and the diversity of biota across the globe. We truly believe that the readers will appreciate the contributions each of the researchers has made and will recognize the value of each chapter. We also hope that this book will be of great use to students, scientists, ecologists, population and conservation biologists, and forest managers across the globe.

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Physicochemical Foliar Traits Predict Assemblages of Litter/Humus Detritivore Arthropods

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Additional information is available at the end of the chapter

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Abstract

Plant functional traits influence the decomposition of their own residues occurring underneath individual plant species. Arthropods associated to litter are critical components influencing decomposition. Nevertheless, few studies have established a direct relation between plant traits and belowground arthropods. To address this relation at the individual plant species scale, this study was conducted in the Guánica dry forest, Puerto Rico, by selecting five tree species and ten isolated trees/species where variations due to neighbor trees are reduced. Mature green leaves, litter, and associated arthropods were sampled from November 2004 through September 2005. Collected arthropods were counted and classified, and abundances were standardized to ind/m^2. Arthropod abundance did not differ among plant species, but richness, and species and trophic composition were different among the plant species. Predators, omnivores, and sucking herbivores showed a similar species composition among plant species, while detritivore was the only trophic groups with a different species composition among plants. These results are further supported by canonical correspondence analysis results showing that detritivore arthropod species composition covaries with the physicochemical characteristics of mature green leaves of plants. These findings support that the plant idiosyncratic characteristics affect the structure of litter/humus arthropods up to the first consumer level.

Keywords: CCA, detritivore, Guánica dry forest, NMS, plant functional traits, litter arthropods

1. Introduction

Idiosyncratic effects of plants (groups of characteristics of individual species or groups of species) are postulated to have a large impact on ecosystem processes occurring underneath the individual plant species [1, 2]. Plants affect belowground dynamics through net primary productivity and quality of resources [3]; for example, litter decomposition rates were predicted by green leaf chemistry and toughness [4], nitrogen (N) and phosphorus (P) availability in the soil was affected by plant species [5], and soil N transformation rates were higher under *Acomastylis rossii* than under *Deschampsia cespitosa*. These data suggest that the distribution of tree species, within and among stands, results in a patchy distribution of litter and therefore in variations in decomposition, nutrients, and associated decomposer organisms [3, 6].

Arthropods associated to litter are critical components that influence decomposition dynamics [7–9]. This fauna responds to variations in litter quality and quantity as a result of changes in plant species identity. For example, mesostigmatid and prostigmatid mites and other microarthropods were more abundant in aspen leaves than in pine needles [10]. Also, the abundance of bacteria, fungi, and invertebrates was higher in quaking aspen stands than in red pine or white spruce stands [11]. Wardle and Lavelle [6] found that Amazonian endogeic earthworms were abundant under *Qualea* trees and completely absent under *Dicorynia guianensis* trees. In Puerto Rico, González and Zou [12] found that the density of anecic earthworms was higher in areas that were afar from *Heliconia caribaea* trees and similarly abundant in areas close and afar from *Dacryodes excelsa* trees. Furthermore, the chemistry of litter has been shown to differentially affect decomposer organisms; for example, high polyphenol inhibited microbial growth [13], and high tannin concentrations in *Quercus ilex* were toxic for two collembolan species [14].

Although plant species have been shown to influence belowground dynamics, and litter has been shown to influence associated fauna, few studies have established a direct relation between green leaf chemistry and the belowground arthropods in order to address how plant idiosyncratic effects differently influence the litter arthropod fauna diversity. There is a lack of information on how components of arthropod diversity (i.e., abundance, richness, species, as well as trophic composition) differently respond to these idiosyncratic effects. There is also a scarcity of studies at the individual plant species scale where neighbor tree effects are reduced. To accurately describe how plant species influence belowground arthropod diversity, isolated trees provide an excellent opportunity because the effects introduced by neighbor trees are reduced. The Guánica forest is a relict of dry forest located on the southwest extreme of the island of Puerto Rico. In this forest, the vegetation growing in the coastal plateau is an open forest with dwarf trees, and vegetation is interspersed between rocks preventing the overlap of trees, therefore creating monospecific islands. These characteristics make this an ideal system to study singletree effects in complete isolation, i.e., arthropods associated to organic matter under single trees belonging to five tree species. We hypothesize that arthropod abundance, richness, as well as species composition will be different among tree species, but trophic composition will be similar because plant species vary in their chemical and morphological characteristics of the litter they produce. Therefore, we expect that plant species will have sets of different associated litter arthropods, although the trophic groups that these arthropods represent will be similar.

2. Materials and methods

2.1. Study site

The study was conducted in the Guánica dry forest (17°57′56″N, 66°52′45″W), southwestern Puerto Rico. This forest was declared a UNESCO Biosphere Reserve in 1981 because of its extension, high plant diversity, and high occurrence of endemism and habitat for endangered organisms [15]. This forest occurs on limestone [16] where the calcareous rock has low water retention ability and pH ~ 7; the excess calcium in combination with water limitation immobilizes the available phosphorus [17, 18]. The mean annual rainfall is 869 mm (range 288–1348 mm) with a major dry period that runs from December to April [16], but the monthly distribution of the rain is highly erratic [18]. For the study period, the total accumulated rainfall was 1575 mm that was distributed as 480 mm for the wet 2004 season, 120 mm for the dry 2005 season, and 975 mm for the wet 2005 season [19, 20]. The specific study site was located in the coastal vegetation association that is an open forest with dwarf trees, and the ground is exposed to rocks.

2.2. Data collection

In the coastal plateau, five representative tree species were selected. The species were *Coccoloba uvifera* and *Conocarpus erectus* only present in the coastal plateau and *Ficus citrifolia*, *Pisonia albida*, and *Tabebuia heterophylla* species present from the coast to the upper ridges in the forest. Ten trees belonging to each of the five species were selected for a total of 50 trees, which represent the sampling units.

2.3. Tree species characterization

Each tree was characterized for leaf toughness and C, N, and P contents. Leaf toughness was measured in 20 adult leaves/tree by using a punchameter Chatillon® 516 Push/Pull Gauge. Toughness is the force necessary to punch a 3 mm hole through the leaf [21, 22]. Each leaf was pierced once and in areas avoiding leaf nerves and away from the leaf border. These data give an index of toughness and the units are in newton (N). C, N, and P were measured in green leaves. For each tree/species, we collected fully expanded adult leaves that were oven dried at 65°C for 1 week. Leaves from the same tree were pooled, ground, and sieved to 1 mm (18 mesh). Total C analyses were done at the laboratory of the International Institute for Tropical Forestry (IITF), in San Juan, Puerto Rico. Total N and P content assessments were done at the Plant Ecophysiology Laboratory of the Instituto Venezolano de Investigaciones Científicas (IVIC), in Caracas, Venezuela. For C, digestion was done by using a modified version of the Huang and Schulte methodology [23], concentration of total C was determined by the dry combustion method using a CNS analyzer Leco® CNS-2000, and then total C was determined by individual IR (infrared) detectors. For N, samples were digested with sulfuric acid and selenium as catalyst at 350°C for 2 h, and then N was determined with the micro-Kjeldahl method [24]. For P, digestion was done with perchloric-sulfuric acid solution and determined by colorimetry using a modified Murphy and Riley methodology [25].

2.4. Arthropod species

Arthropod collections were performed on November 2004 and February, April, June, and September 2005. During each sampling, one 10 cm × 10 cm sample/tree/species was collected, and the sample was separated into three fractions: loose litter (upper whole leaves), old litter, and humus. Each fraction was kept separately and placed in a berlese funnel for 1 week for arthropod extraction using light [26]. This sampling design gave 5 species × 10 trees × 3 fractions × 5 samplings = 750 samples. Collected arthropods were taxonomically identified to the lowest category possible, either class, subclass, order, or suborder, classified as adult or immature, and assigned to a morphospecies and to a trophic category. The abundance of each morphospecies was recorded and standardized to a number of individuals per square meter. Morphospecies were used as surrogate for species and thus used for richness and species composition. Richness is reported as a number of morphotypes per 100 cm^2. Trophic categories were assigned based on the feeding habit of the collected individual (immature/adult), and although some groups include organisms with a variety of feeding habits, we assigned trophic categories based on the predominant feeding habit of the group, e.g., detritivore, fungivore, omnivore, predator, and sucking herbivore. Detritivores feed directly on the organic matter including microbes (e.g., Blattodea, Diplopoda, Oribatida) [27]; fungivores feed on fungi growing on the litter (i.e., Collembola); omnivores use a variety of resources in the forest either to feed or for nest construction (e.g., Hymenoptera, Isoptera); predators feed on a variety of preys (e.g., Araneae, Chilopoda), and sucking herbivores feed on plant sap by making a hole where they insert their stylet (e.g., Thysanoptera and Homoptera). Not all collected arthropods fall within these categories; as a consequence they were excluded from the analysis. When immatures from these categories live and feed on litter, they were grouped in the corresponding category. For example, dipteran larvae mainly feed on decomposing litter, and thus collected larvae were grouped in the detritivore category, but as adults these dipterans may be hematophagous or licking, and then collected adults were grouped in the corresponding category. It should be clarified that collembolans were not assigned to morphotypes since variation in the morphology can only be seen in mounted slides and by a specialist. A total of 11 trophic categories were created [28], but only detritivores, sucking herbivores, predators, fungivores, and omnivores are directly related to the dynamics of the litter/humus cover and will be considered in detail.

2.5. Data analyses

Analyses of variance (ANOVAs) were performed to establish differences in specific leaf area (SLA), toughness, C, N, and P among plant species. ANOVAs were also used to evaluate the effect of plant species on the abundance and richness of arthropods. Although the distribution of data was not normal and transformations failed to normalize the data, analyses of variance were preferred over nonparametric tests. Analyses of variance were preferred because sample size was large ($n > 30$), and they allow to evaluate interactions among factors; if nonparametric statistics were used, then each factor had to be evaluated separately, and interactions would not be considered. Abundance of arthropod morphotypes was used in a nonmetric multidimensional scaling (NMS) in combination with a multi-response permutation procedure (MRPP) to evaluate the effect of plant species on the species composition of adult arthropods. NMS is a nonparametric multivariate analysis that calculates a distance matrix using the Sorensen distance (Dist = 1–2 W/(A + B)); this distance is appropriate for the biological data because it does not take into account shared absences [29]. Based on the distance matrix, NMS generates a three-axis graph that locates sampling units in the graph area by discriminating them based on similarity so that sampling units that are close in the graph have similar species composition. It is important to clarify that given that NMS uses three axes to locate sampling units in the graph area, but only the two most explanatory axes are shown in the graph, then some statistical different sampling units may appear close in the two axes graph, but may actually be away over the third not represented axis. NMS used 50 sampling units (trees) × 143 arthropod species where matrix contents are arthropod abundance. MRPP is a nonparametric test that establishes differences among a priori factors using a distance matrix as the data set. With these data, MRPP calculates the average observed distance within predefined groups, compares this average distance to an average distance expected by chance, and tests whether the difference between observed and expected averages is due to the chance [29]. MRPP uses within group distance and calculates a measure within group homogeneity, A, that ranges between −1 and +1. When A = 1, homogeneity is highest, and all items within the group are identical; in community ecology values for A are commonly below 0.1, even when the observed distance differs significantly from the expected, meaning that a group can be heterogeneous and still be different from other groups. Heterogeneous groups have low average similarity values and can be significantly different from other groups. MRPP used 50 trees × plant species category matrix. Detritivores were further analyzed by performing a canonical correspondence analysis (CCA) that evaluated the relationship between species and environment matrices, specifically to explain structure in the arthropod detritivore community by using explanatory plant species variables [30]. The species matrix was 50 trees × 52 detritivore arthropod species where matrix contents are arthropod abundance, and the environment matrix was 50 trees × 3 variables where matrix contents were C (mg/g), N (mg/g), and P (mg/g). SLA and toughness were excluded from CCA because both correlated with other environmental variables (e.g., N). In CCA, rows and columns were standardized by centering and normalizing, scaling for ordination scores optimized detritivore species, and sampling unit scores are linear combinations of variables. The null hypothesis was no relationship between matrices where rejection of the null hypothesis indicates that both matrices covary [31], Monte Carlo tests had 100 randomizations, reported correlation coefficients are intraset correlations, and the joint biplot allows a direct spatial interpretation of the relationship between variables and sampling units [29].

3. Results

3.1. Plant species characterization

Specific leaf area was significantly different among plant species and followed the pattern *Ficus* > *Pisonia* > *Tabebuia* > *Conocarpus* > *Coccoloba* (**Table 1**). Leaf toughness was significantly different among plant species (**Table 1**) with tougher leaves in *Coccoloba* (383.7 ± 65.9 N) and

	Coccoloba	*Conocarpus*	*Ficus*	*Pisonia*	*Tabebuia*
Green leaves					
Specific leaf area (cm^2/g)	65 (±4)e	79 (±13)d	110 (±16)a	103 (±13)b	84 (±12)c
Toughness (N)	384 (±41)a	212 (±34)c	170 (±30)d	110 (±11)e	343 (±42)b
Carbon (mg/g)	502.5 (±5.7)a	481.9 (±32)b	473.0 (±10.1)b	507.1 (±9.6)a	498.8 (±4.8)a
Nitrogen (mg/g)	16.2 (±2.0)b	12.9 (±1.5)c	17.0 (±2.0)b	20.4 (±2.1)a	17.8 (±1.8)b
Phosphorus (mg/g)	0.9 (±0.3)a	1.1 (±0.6)a	1.0 (±0.1)a	1.0 (±0.2)a	0.6 (±0.1)b
C:N	31 (±4)b	38 (±3)a	28 (±4)c	25 (±3)d	28 (±3)c
C:P	589 (±200)b	550 (±262)b	493 (±36)b	541 (±164)b	796 (±149)a
N:P	19 (±8)bc	15 (±7)c	18 (±2)bc	22 (±8)b	28 (±5)a

Lowercase letters indicate significant differences among plant species for a specific trait.

Table 1. Physicochemical foliar traits of the five tree species in this study: values represent average (±sd) (n = 10 trees/species).

Tabebuia (343.1 ± 75.4 N) and tender leaves in *Pisonia* (110.3 ± 33.4 N) than in the other species. Leaf toughness followed the pattern *Coccoloba* > *Tabebuia* > *Conocarpus* > *Ficus* > *Pisonia* suggesting that there is a continuum; at one end *Coccoloba* had tough leaves, and at the other end, *Ficus* and *Pisonia* had tender leaves, while *Conocarpus* and *Tabebuia* had intermediate toughness leaves. Nutrients varied among plant species, and the degree of difference among species varied according to the specific nutrient. *Coccoloba, Tabebuia,* and *Pisonia* had significantly higher C than *Conocarpus* and *Ficus* (**Table 1**). Nitrogen was highest in *Pisonia* and followed the pattern *Pisonia* > *Tabebuia* – *Ficus* > *Coccoloba* > *Conocarpus*, and the C:N ratio inversely mirrored N concentration and followed the pattern *Conocarpus* > *Coccoloba* > *Tabebuia* – *Ficus* > *Pisonia* (**Table 1**). In addition, *Tabebuia* had lower P than *Coccoloba*, *Conocarpus*, *Pisonia*, and *Ficus*, and the C:P was highest in *Tabebuia*.

3.2. Arthropod abundance and richness

Plant species significantly affected arthropod richness (ANOVA, F = 3.39, $p < 0.001$) but not arthropod abundance (ANOVA, F = 1.65, p = 0.16). Average richness of microarthropods (the number of adult morphotypes) was significantly higher in *Ficus* and *Pisonia* than in *Tabebuia, Conocarpus*, and *Coccoloba* (**Figure 1A**). A total of 22 orders were collected, and 16 were common to all plant species; *Coccoloba* had no unique order, while Trichoptera was unique to *Conocarpus* and Chilopoda to *Ficus*, and Symphyla and Protura were shared by *Pisonia* and *Tabebuia* but absent in the other plant species (**Table 2**). Although total abundance was not significantly different among species, four orders showed significantly different abundances among plant species (**Table 2**). Acari was the most abundant order, and it was higher in *Coccoloba*, *Ficus*, and *Tabebuia* than in *Pisonia* and *Conocarpus*. Psocoptera abundance was higher in *Conocarpus* and *Ficus* than in *Pisonia*, *Coccoloba*, and *Tabebuia*. Diplopoda abundance was highest in *Pisonia*, and Pseudoscorpiones was more abundant in *Ficus* and *Coccoloba* than in *Pisonia*, *Tabebuia*, and *Conocarpus*.

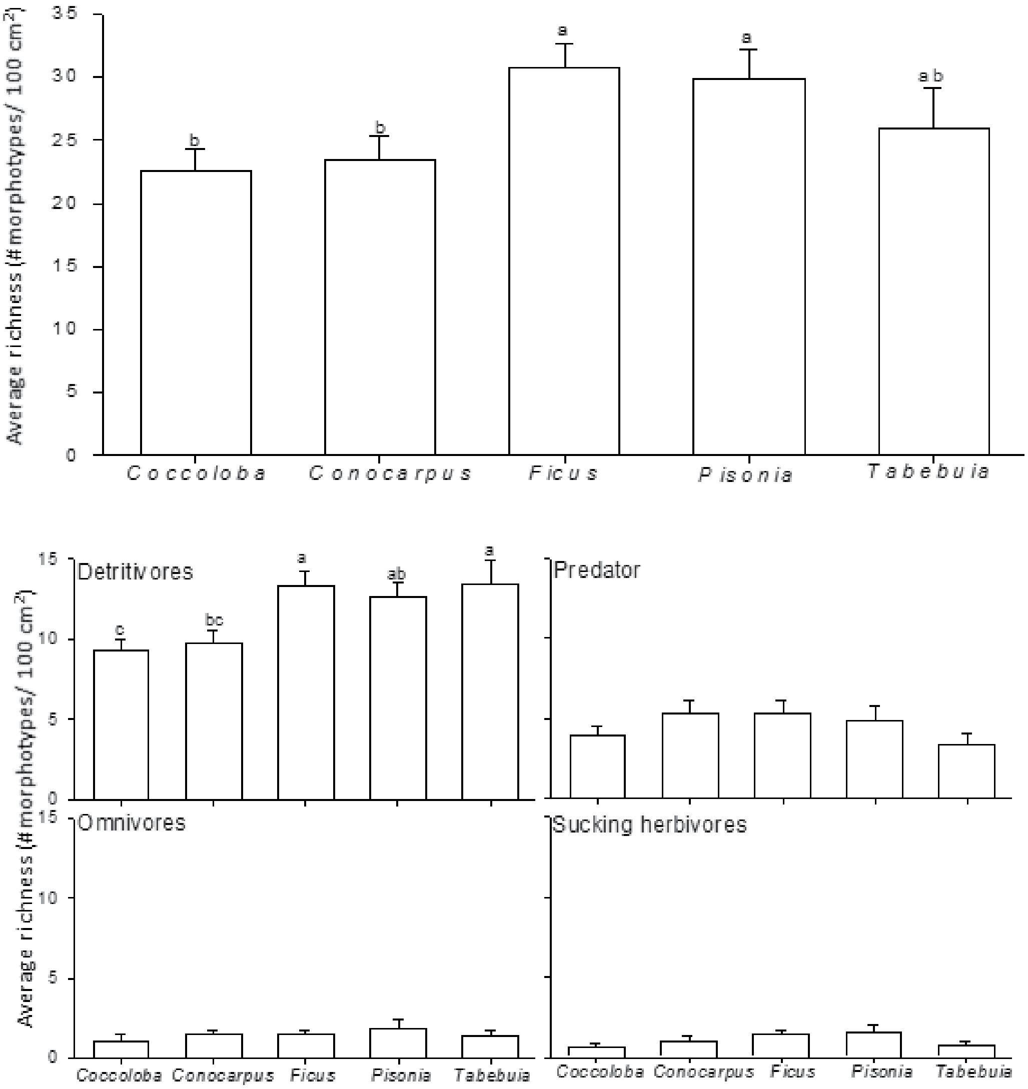

Figure 1. Average number of adult morphotypes (±s.e.) collected under the five tree species (A, upper). Average number of morphotypes (±s.e.) per trophic category collected under the five tree species (B, lower). Lowercase letters indicate significant differences among plant species.

3.3. Arthropod species composition

The species composition of all arthropods (based on adult morphotypes) was significantly different among plant species (MRPP, T = −10.878, A = 0.006, p = 0.000). Using arthropod species composition, NMS and MRPP grouped sampling units (i.e., 50 trees representing 10 trees/species × 5 study species) into three clusters: the first cluster grouped *Ficus*, *Pisonia*, and *Tabebuia*, the second one had *Conocarpus*, and the third one had *Coccoloba* (**Figure 2A**). *Coccoloba*

	Coccoloba	*Conocarpus*	*Ficus*	*Pisonia*	*Tabebuia*
Acari	837 (±1300)a	431 (±743)b	869 (±1505)a	595 (±1240)ab	959 (±2623)a
Homoptera	95 (±634)	38 (±264)	55 (±234)	103 (±658)	108 (±670)
Collembola	43 (±194)	56 (±198)	103 (±513)	115 (±524)	63 (±311)
Araneae	28 (±77)	38 (±96)	59 (±150)	53 (±204)	32 (±106)
Diptera	31 (±63)	31 (±68)	49 (±97)	56 (±146)	37 (±73)
Hymenoptera	56 (±298)	17 (±69)	31 (±98)	47 (±196)	32 (±128)
Psocoptera	11 (±46)b	42 (±132)a	45 (±111)a	33 (±87)ab	14 (±49)b
Coleoptera	41 (±218)	25 (±83)	33 (±106)	21 (±53)	15 (±56)
Pseudoscorpiones	37 (±99)a	13 (±39)c	33 (±68)a	29 (±82)ab	16 (±49)bc
Isopoda	10 (±55)	33 (±238)	21 (±80)	25 (±84)	8 (±50)
Thysanoptera	4 (±20)	12 (±49)	22 (±63)	27 (±155)	3 (±16)
Thysanura	9 (±68)	17 (±66)	15 (±64)	5 (±50)	5 (±31)
Diplopoda	1 (±12)b	2 (±14)b	1 (±12)b	15 (±71)a	3 (±16)b
Hemiptera	3 (±20)	7 (±35)	5 (±21)	3 (±16)	4 (±23)
Blattodea	1 (±12)	3 (±16)	5 (±21)	1 (±8)	1 (±12)
Opiliones	1 (±12)	2 (±18)	1 (±16)	1 (±8)	1 (±12)
Diplura	3 (±33)		1 (±8)	1 (±8)	1 (±8)
Lepidoptera	1 (±8)	2 (±18)		1 (±8)	1 (±12)
Symphyla				4 (±35)	7 (±74)
Protura				1 (±8)	1 (±12)
Trichoptera		1 (±8)			
Chilopoda			2 (±14)		
Total	67 (±194)	43 (±98)	75 (±200)	57 (±131)	66 (±212)

Lowercase letters indicate significant differences among plant species for the specific class/order.

Table 2. Mean abundance (±sd) (ind/m^2) of collected arthropods classified into taxonomic categories (class or order), under the five tree species.

had 17 unique morphotypes, and *Conocarpus* had 20 unique morphotypes, while *Pisonia* and *Ficus* shared 39 morphotypes, *Ficus* and *Tabebuia* shared 33, and *Pisonia* and *Tabebuia* shared 28 morphotypes [28].

3.4. Arthropod trophic groups

Of all the trophic groups, only the species composition of detritivore arthropods (MRPP, $T = -11.040$, $A = 0.014$, $p = 0.000$) was significantly different among plant species (**Figure 2B**). For predators (MRPP, $T = 0.593$, $A = -0.002$, $p = 0.705$), omnivores (MRPP, $T = 0.278$, $A = -0.005$, $p = 0.578$), and sucking herbivores (MRPP, $T = -0.296$, $A = 0.008$, $p = 0.345$), the species composition based on morphotypes did not change significantly among plant species. For detritivores, average abundance (ANOVA, $F = 3.36$, $p = 0.01$) and richness (ANOVA, $F = 3.27$, $p = 0.01$) were significantly different among plant species, while average abundance

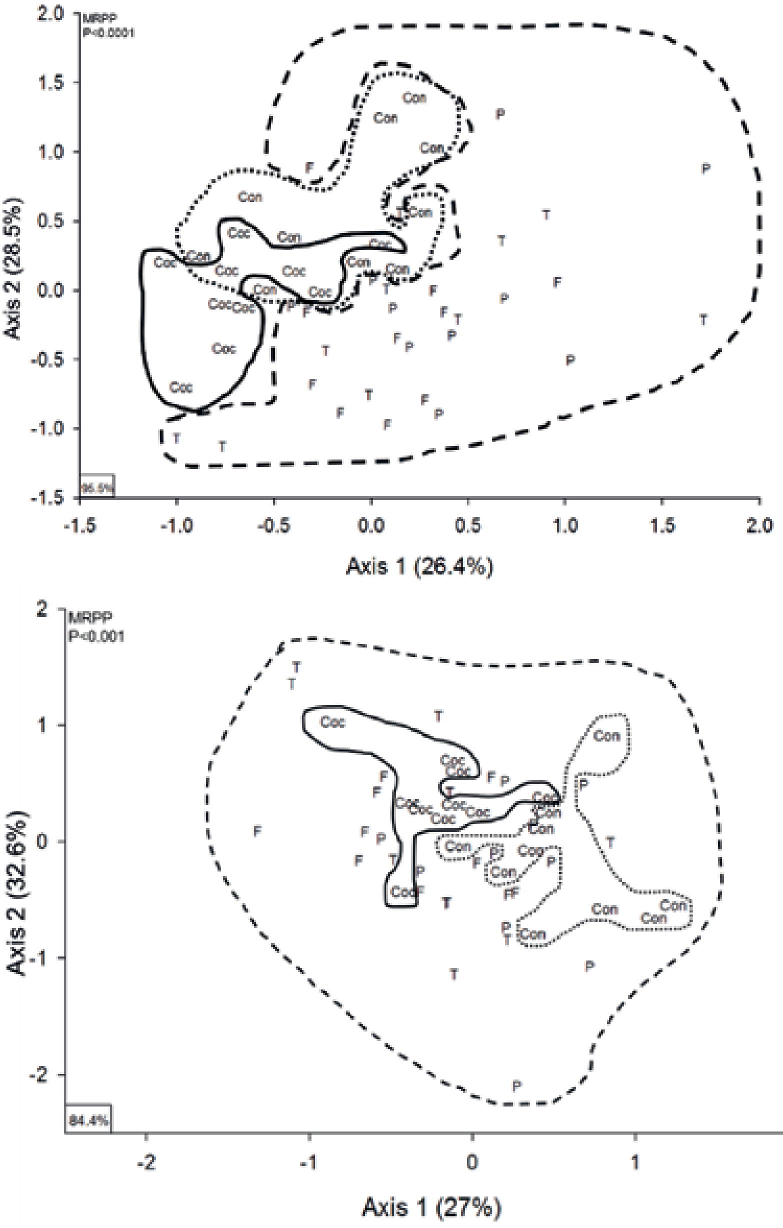

Figure 2. Nonmetric multidimensional scaling (NMDS) ordination of the 50 sampling units (5 tree species × 10 tress/species) based on arthropod species composition similarity (A, upper). NMDS ordination of the 50 sampling units based on detritivore species composition (B, lower). Coc represents *Coccoloba*, Con represents *Conocarpus*, Fic represents *Ficus*, Pis represents *Pisonia*, and Tab represents *Tabebuia*. Lines group significant different clusters: the solid line groups the *Coccoloba* cluster; the dotted line groups the *Conocarpus* cluster; and the long-dashed line groups the *Ficus* + *Pisonia* + *Tabebuia* cluster. Detritivore species composition was significantly different in *Coccoloba* when compared to *Conocarpus* (A = 0.0067, p = 0.0033), *Ficus* (A = 0.0110, p = 0.0000), *Pisonia* (A = 0.0104, p = 0.0000), and *Tabebuia* (A = 0.0121, p = 0.0000). Similarly, detritivore species composition in *Conocarpus* was significantly different when compared to *Ficus* (A = 0.0152, p = 0.0000), *Pisonia* (A = 0.0139, p = 0.0000), and *Tabebuia* (A = 0.0168, p = 0.0000). *Ficus* and *Pisonia* had similar detritivore species composition (A = −0.0004, p = 0.5606), as well as *Ficus* and *Tabebuia* (A = 0.0005, p = 0.3070) and *Pisonia* and *Tabebuia* (A = 0.0024, p = 0.0600). Since for each plant species the arthropod data set was used to perform four comparisons, only p-values smaller than 0.0125 were considered significantly different.

	Coccoloba	*Conocarpus*	*Ficus*	*Pisonia*	*Tabebuia*
Detritivore	583 (±976)ab	341 (±575)b	567 (±970	409 (±711)b	710 (±1727)a
Sucking herbivore	99 (±633)	53 (±269)	77 (±239)	132 (±783)	111 (±676)
Predator	76 (±148)	67 (±169)	108 (±177)	91 (±227)	53 (±118)
Fungivore	52 (±206)	75 (±221)	118 (±520)	120 (±526)	87 (±318)
Omnivore	51 (±297)	15 (±68)	22 (±82)	42 (±195)	25 (±125)
Vestigial mouth	5 (±23)b	4 (±20)b	11 (±38)a	5 (±23)b	3 (±16)b
Chewing herbivore	8 (±34)a	2 (±14)b	1 (±12)b	3 (±18)b	1 (±12)b
Hematophagous	4 (±23)	5 (±28)	5 (±23)	7 (±26)	2 (±14)
Plant exudates	4 (±23)	5 (±24)	4 (±20)	7 (±34)	8 (±30)
Licking	1 (±12)	1 (±8)	3 (±16)	1 (±12)	1 (±8)
Nectarivore	0 (±0)	0 (±0)	1 (±12)	1 (±8)	0 (±0)

Lowercase letters indicate significant differences among plant species for the specific trophic category.

Table 3. Mean abundance (±s.d.) (ind/m^2) of arthropods grouped into trophic categories under the five tree species.

and richness of the remaining trophic groups did not vary significantly among plant species (**Table 3**) (**Figure 1B**). Detritivore abundance followed the pattern *Tabebuia* > *Coccoloba* and *Ficus* > *Pisonia* and *Conocarpus* (**Table 3**), while richness followed the pattern *Ficus* and *Tabebuia* > *Pisonia* > *Conocarpus* > *Coccoloba* (**Figure 1B**). The species composition of detritivore arthropods produced the same three clusters that were formed in the species composition of all arthropods. The first cluster was formed by *Ficus*, *Pisonia*, and *Tabebuia*, the second one was formed by *Conocarpus*, and the third one by *Coccoloba*.

3.5. Plant species and detritivores

Given that only detritivore species composition was different among plant species, we used a CCA to determine which plant species characteristics influenced the detritivore community. CCA results indicate that the null hypothesis of no relation was rejected; therefore, there was a significant relation between the species and the environmental variables (see data analysis for further description). The eigenvalue for axis 1 is higher than expected by chance (p = 0.01, 998

Axis	Eigenvalue	Species-environment correlation	p-value	Cumulative percentage (%) of variance	Environmental variables	Correlation with axis 1
1	0.138	0.836	0.006	5.4	N	−0.446
2	0.109	0.763		9.6	P	0.803
3	0.058	0.632		11.8	C	−0.317

p-Values for axes 2 and 3 are not reported since the randomization test for these axes may bias the p-value [43].

Table 4. CCA results showing eigenvalues and species-environment correlations based on 999 Monte Carlo test runs with randomized data. Also, correlations (as intraset correlations) of environmental variables with axis 1 are reported.

randomizations), and this axis is correlated with environmental variables (p = 0.006) (**Table 4**). Axes 1 and 2 explained a total cumulative 9.6% of the variance, and both axes had 98.7% orthogonality. This significant relation indicates that both matrices covary suggesting that the detritivore community is structured by plant CNP (**Figure 3A**). Detritivore morphotypes that were common to all plant species (**Appendix 1**, **Figure 3B**) are located near the center of the

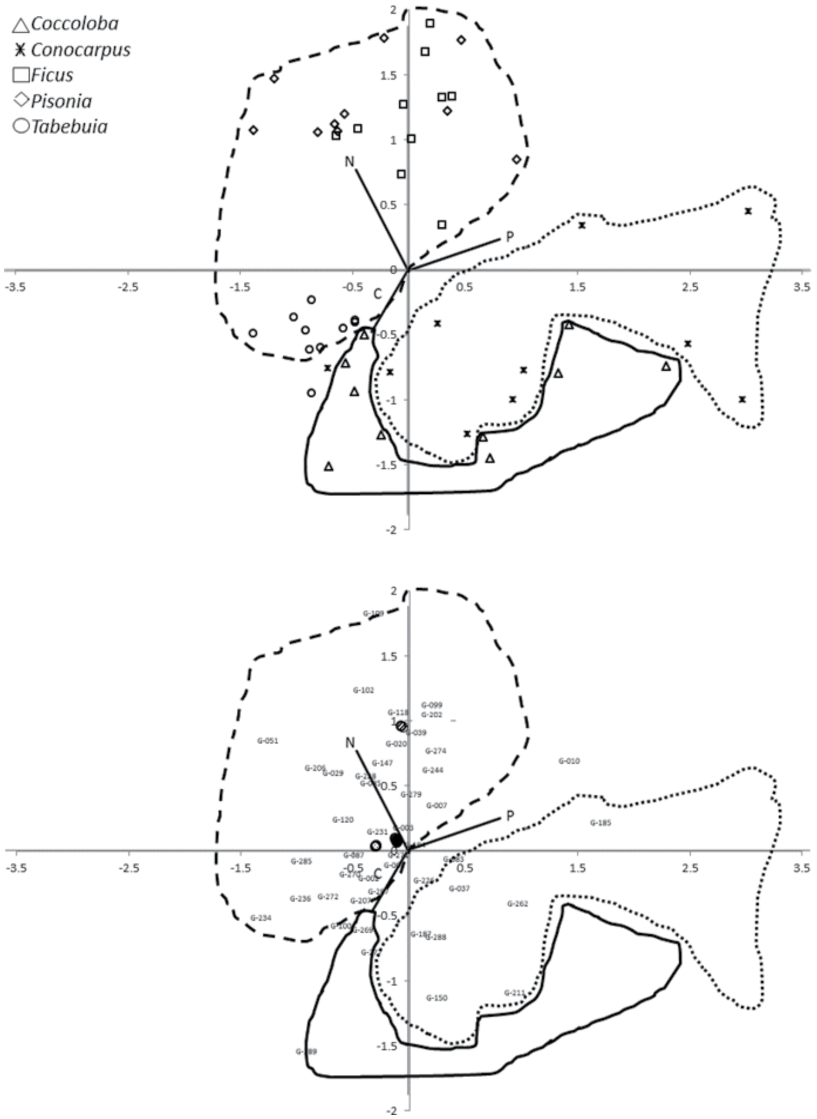

Figure 3. Ordination of the 50 sampling units using detritivore abundance as defined by canonical correspondence analysis; symbols represent tree species and lines represent significant clusters (A, upper), please see legend explanation in **Figure 1**. Ordination of the 50 sampling units using detritivore abundance as defined by CCA; symbols represent detritivore morphotypes overlaid over the CCA ordination (B, lower). (Symbols indicate morphotypes whose location overlaps: striped circle for G-119 and G-301, dotted circle for G-105 and G-188, and black circle for G-078 and G-280). The biplot overlay shows leaf N, P, and C vectors.

graph (near the intercept of X and Y) such as G-002, G-003, G-004, G-007, and G-274, while those that occurred only in high N species (e.g., *Ficus* and *Pisonia*) are located in the upper half of the graph such as G-109, G-102, G-118, G-301, and G-119. Those detritivores that occurred only under low P species (e.g., *Tabebuia*) include G-234, G-236, and G-272.

4. Discussion

We found that *Pisonia* had the highest N and *Tabebuia* had lowest P. Also, *Ficus* had higher arthropod abundance, while *Pisonia* and *Ficus* had higher arthropod richness than the other plant species. Species composition of detritivore arthropods was different among plant species, and three clusters were formed: arthropod species composition under *Ficus*, *Pisonia*, and *Tabebuia*, species composition under *Coccoloba*, and species composition under *Conocarpus*. We also found that morphotypes that grouped *Ficus*, *Pisonia*, and *Tabebuia* were located toward the high N side of the vector, while those unique to *Coccoloba* and *Conocarpus* were at the low N side of the vector. These data suggest that physicochemical foliar traits of plants directly influence litter arthropods on the lower trophic levels of the decomposer food web.

4.1. Nutrients

When compared to species growing in other dry forests, the five tree species in this study are within the range for N and for P at the lower end [32] corroborating the data of Lugo and Murphy [17]. We found that green leaf nutrients varied among species. In Guánica, for a mature stand and pooled leaves from a sample, Lugo and Murphy [17] reported 16.4 mg/g N and 0.64 mg/g P. For N, our pooled average, 16.9 (±2.7) mg/g, was similar to Lugo and Murphy, while our average for P was higher, 0.92 (±0.2) mg/g, than in Lugo and Murphy. At the species level, N was higher in *Pisonia* and lower in *Conocarpus*, while the other three species were similar to the reported value. We found P to be similarly higher in all species when compared to *Tabebuia*. In addition, Lugo and Murphy reported that N:P ratio (on a dry weight basis) was 25, while in this study, we found the pooled average of N:P to be 20.4 suggesting that the plants near the coastal cliff grow with similar soil P limitation than plants uphill. For *Pisonia*, Medina and Cuevas [18] report nutrient concentration values that are similar to those found in this study, 18.9 mg/g N and 0.95 mg/g P. For *Tabebuia* growing in the Luquillo Experimental Forest (wet forest), Sánchez et al. [33] reported N 12–16 mg/g and P 0.8–1.3 mg/g. The similarity of N and P concentration in *Tabebuia* between two contrasting sites, such as dry and wet forests, shows the plasticity of the species to adapt to different climatic regimes. The P limitation in Guánica (dry forest) is due to the high P fixing capacity of the substrate, while the P limitation in Luquillo (wet forest) is due to highly weathered soils with low P availability due to iron (Fe) fixation.

4.2. Arthropods

Total arthropod abundance was similar among plant species, but four arthropod orders were more abundant under specific plant species. Milcu et al. [34] found that decomposer species performed better under some plant species than under others because of resource quality and because of the presence of other decomposer species. These data suggest that the higher abundance of these four orders might be related to interactions with other soil fauna species and to resource quality. We also found that richness and identity of arthropods were different among plant species (38 morphotypes common to all plant species, 17 unique to *Coccoloba*, 20 to *Conocarpus*, 39 common to *Ficus* and *Pisonia*, and 33 to *Ficus* and *Tabebuia*) [28]. These data suggest that plant species identity differently influence the number and identity of arthropod species associated to the decomposing organic matter produced by each plant. De Deyn et al. [35] found that the identity of the plant species (i.e., resource quality) was the most important factor for soil nematode diversity; these findings support the idea that, similarly to nematodes, arthropod diversity is influenced by the plant species identity.

These data suggest that arthropods that depend directly on resource quality, and thus have a tight relationship with the resource, were significantly affected by the identity of plant species. In addition, it also suggests that arthropods in higher trophic levels, such as predators, are more generalist; that plant species identity effect does not cascade up; and that the exposed rocky terrain that separates the individual trees does not constitute a barrier for them to move among tree species.

4.3. Idiosyncratic effects

Aboveground plant species composition was the best predictor of arthropod assemblages [36], and arthropod species with specific requirements were associated to specific habitats [37]. Similarly, one can expect belowground arthropod assemblages to be best predicted by plant species and litter arthropod species to have specific nutrimental requirements. In our study, unique arthropod species in *Ficus* and *Pisonia* were located toward the high N vector, while unique arthropod species in *Coccoloba* and *Conocarpus* toward the low N vector. These data suggest that unique arthropod species respond to high nutritional content in high-quality plant species, while unique arthropod species respond to low nutritional content in low-quality plant species.

Litter decomposes faster in areas dominated by the plant species that produced it, the home-field advantage effect [38]. Home-field advantage has been related to the specialization of biota on litter produced by their plant through specialized enzymes, feeding on specialized fungi or animals using litter fragments in survival activities [39], and is also most pronounced in low-quality litter [40]. In decomposer food webs, lower trophic levels influence plant productivity more than higher trophic levels, and given that there is high redundancy within trophic groups, plant productivity is independent of what species are present as long as all of the trophic groups are present [41]. In addition, identity of plants affected the response of arthropods. For example, collembolans were positively affected by grasses and negatively by legumes, while earthworms were positively affected by legumes, suggesting that arthropod response varies depending on the group and nutrients [34]. Our data can be thus interpreted as arthropod species composition of lower trophic groups responds to variations in plant species characteristics, and the response depends upon the nutritional characteristics of the plant, in this case high or low N, which are correlated with the nutritional characteristics of the detritus the plant produces [4].

5. Conclusions

We expected that arthropod abundance, richness, and species as well as trophic composition would be differentially affected by the identity of the plant species. We found that the abundance of four arthropod orders was affected; also, total arthropod richness and species composition varied significantly specifically due to the response that detritivores had to physicochemical foliar traits (the only trophic group that differed among plant species). The CCA indicated that detritivore response is linked to aboveground nutritional content of plants. Wardle [3] suggests that the decomposing fauna is tightly associated to the detritus produced by plant species so that this association maximizes the decomposition and nutrient cycling. Therefore, differences in quality among plant species potentially influence litter-feeding arthropods. On the other hand, St. John et al. [42] found that mite assemblages were not affected by the identity of the grass species that mites inhabited neither in abundance, richness, or the composition. Our data support Wardle's ideas [3]. When pooled together our data suggest that litter arthropods in the lower trophic levels, such as detritivores (e.g., Acari, Psocoptera, and Diplopoda), perform better under specific plant species (therefore supporting Milcu et al.'s [34] findings) possibly because they are tied to resource quality (therefore supporting Wardle's ideas).

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Appendix 1

Average abundance (±s.d.) (ind/m^2) of detritivore arthropods identified to taxonomic categories under the five tree species.

Class	Order	Morpho.	*Coccoloba*		*Conocarpus*		*Ficus*		*Pisonia*		*Tabebuia*	
Arachnida	Acari	G-037	2880	(±1642)	1390	(±837)	850	(±645)	770	(±525)	920	(±981)
Arachnida	Acari	G-078	1380	(±577)	470	(±467)	1530	(±1405)	680	(±569)	2070	(±2720)
Arachnida	Acari	G-007	750	(±924)	150	(±212)	470	(±353)	540	(±734)	230	(±206)
Arachnida	Acari	G-003	610	(±491)	190	(±228)	830	(±1136)	290	(±318)	490	(±409)
Arachnida	Acari	G-207	530	(±1470)	170	(±254)	560	(±1465)	100	(±200)	1170	(±2099)

Class	**Order**	**Morpho.**	***Coccoloba***		***Conocarpus***		***Ficus***		***Pisonia***		***Tabebuia***	
Arachnida	Acari	G-004	470	(±462)	320	(±385)	340	(±284)	490	(±431)	1330	(±3231)
Arachnida	Acari	G-002	460	(±723)	80	(±92)	340	(±299)	210	(±328)	1200	(±1624)
Arachnida	Acari	G-105	200	(±249)	90	(±120)	340	(±259)	280	(±220)	710	(±1186)
Arachnida	Acari	G-271	150	(±440)	120	(±114)	310	(±493)	40	(±126)	210	(±321)
Arachnida	Acari	G-274	50	(±108)	10	(±32)	250	(±756)	10	(±32)	30	(±48)
Arachnida	Acari	G-188	40	(±84)	40	(±84)	90	(±160)	130	(±279)	180	(±193)
Arachnida	Acari	G-147	30	(±67)	60	(±70)	380	(±278)	270	(±374)	160	(±143)
Arachnida	Acari	G-087	20	(±42)	90	(±185)	30	(±67)	130	(±189)	20	(±42)
Arachnida	Acari	G-244	20	(±42)	150	(±372)	210	(±354)	320	(±452)	140	(±158)
Malacostraca	Isopoda	G-010	10	(±32)	290	(±882)	30	(±48)	170	(±177)	20	(±63)
Arachnida	Acari	G-120	10	(±32)	30	(±67)	90	(±145)	110	(±185)	150	(±409)
Arachnida	Acari	G-231	10	(±32)	50	(±108)	60	(±84)	100	(±94)	60	(±84)
Arachnida	Acari	G-262	140	(±443)	30	(±95)	10	(±32)	—	—	110	(±348)
Arachnida	Acari	G-226	20	(±42)	110	(±99)	60	(±170)	—	—	130	(±211)
Arachnida	Acari	G-187	10	(±32)	50	(±127)	20	(±42)	—	—	60	(±84)
Malacostraca	Isopoda	G-184	20	(±42)	10	(±32)	—	—	30	(±67)	—	—
Arachnida	Acari	G-288	20	(±63)	20	(±63)	—	—	—	—	10	(±32)
Arachnida	Acari	G-279	10	(±32)	—	—	20	(±42)	20	(±63)	30	(±67)
Arachnida	Acari	G-280	20	(±63)	—	—	30	(±95)	10	(±32)	40	(±126)
Arachnida	Acari	G-202	10	(±32)	—	—	10	(±32)	60	(±107)	10	(±32)
Arachnida	Acari	G-185	20	(±63)	—	—	10	(±32)	—	—	—	—
Hexapoda	Blattodea	G-020	10	(±32)	—	—	10	(±32)	—	—	—	—
Arachnida	Acari	G-269	10	(±32)	—	—	—	—	—	—	40	(±97)
Hexapoda	Psocoptera	G-211	10	(±32)	—	—	—	—	—	—	—	—
Arachnida	Acari	G-277	10	(±32)	—	—	—	—	—	—	—	—
Arachnida	Acari	G-287	10	(±32)	—	—	—	—	—	—	—	—
Hexapoda	Psocoptera	G-029	—	—	10	(±32)	50	(±127)	70	(±134)	40	(±84)
Malacostraca	Isopoda	G-039	—	—	10	(±32)	50	(±158)	90	(±166)	—	—
Arachnida	Acari	G-100	—	—	10	(±32)	—	—	10	(±32)	30	(±48)
Arachnida	Acari	G-083	—	—	20	(±63)	—	—	—	—	30	(±95)
Arachnida	Acari	G-150	—	—	20	(±63)	—	—	—	—	10	(±32)
Hexapoda	Psocoptera	G-289	—	—	10	(±32)	—	—	—	—	—	—
Hexapoda	Psocoptera	G-102	—	—	—	—	90	(±129)	60	(±84)	10	(±32)
Hexapoda	Psocoptera	G-118	—	—	—	—	130	(±287)	10	(±32)	—	—
Malacostraca	Isopoda	G-085	—	—	—	—	40	(±97)	—	—	20	(±63)
Hexapoda	Blattodea	G-119	—	—	—	—	10	(±32)	—	—	—	—

Class	**Order**	**Morpho.**	***Coccoloba***		***Conocarpus***		***Ficus***		***Pisonia***		***Tabebuia***	
Hexapoda	Blattodea	G-228	—	—	—	—	20	(±42)	—	—	10	(±32)
Arachnida	Acari	G-270	—	—	—	—	10	(±32)	—	—	40	(±84)
Arachnida	Acari	G-301	—	—	—	—	10	(±32)	—	—	—	—
Arachnida	Acari	G-285	—	—	—	—	—	—	10	(±32)	20	(±42)
Symphyla		G-051	—	—	—	—	—	—	60	(±158)	10	(±32)
Diplopoda		G-099	—	—	—	—	—	—	10	(±32)	—	—
Arachnida	Acari	G-109	—	—	—	—	—	—	10	(±32)	—	—
Arachnida	Acari	G-206	—	—	—	—	—	—	10	(±32)	—	—
Hexapoda	Psocoptera	G-234	—	—	—	—	—	—	—	—	10	(±32)
Hexapoda	Psocoptera	G-236	—	—	—	—	—	—	—	—	10	(±32)
Arachnida	Acari	G-272	—	—	—	—	—	—	—	—	10	(±32)

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Enhanced Phylogenetic Diversity of Anuran Communities: A Result of Species Loss in an Agricultural Environment

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Additional information is available at the end of the chapter

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Abstract

The great environmental changes induced by anthropogenic activities reshaped many ecosystem processes. Thus, the previously natural landscapes have been turned into mosaics of natural and seminatural lands embedded into human-modified landscape. To understand effects of these landscape modifications on the anuran communities, we aimed to compare pond-breeding anuran communities in a well-preserved forest with communities in agricultural landscape. We tested the values of taxonomic, phylogenetic and functional diversity, by analyzing four data matrixes containing environmental, phylogenetic, morphological and abundance information from 15 anuran species along this environmental gradient. Our analysis showed that only the phylogenetic component of the diversity was linked to the changes on the gradient and that the loss of environmental quality generates enhanced phylogenetic diversity. We showed that the anthropogenic disturbance acts negatively on anuran communities, forcing the species to adapt and behave like generalist species in order to survive at the modified places now available, where there were well-preserved forests before the humans changed it.

Keywords: anuran diversity and conservation, landscape conversion, habitat loss, Atlantic rainforest, anthropogenic disturbance

1. Introduction

The great environmental changes induced by anthropogenic activities are, in general, dated from before the industrial revolution (~1860 AD) [1]. These activities have reshaped many ecosystem processes across the globe since the human populations have become persistent in some places due the enhanced agricultural practices [2]. As a result of this growing phenomenon, the previously natural landscapes have been turned into mosaics of natural and seminatural lands embedded into human-modified landscapes [3]. Actually, these mosaic conditions of non-used land represent, almost 90% of the world's tropical forests which are inserted in reserves and parks within agricultural lands [4, 5]. Understanding the factors that affect the community assemblies has been the focus of many ecological studies [6–9]. Since the conversion of the previously undisturbed places is usually allied to unsustainable activities, which drives the ecosystem degradation throughout the loss of ecosystem services and the related cascade events [10] causing biodiversity loss across the globe and across spatial, temporal and organizational scales [11–13].

To understand these factors, some researchers have made use of a classical measure, the taxonomic unit (e.g., species) [10, 14], but it does not take into account ecological and evolutionary attributes of species. However, some modern approaches are combining functional attributes of species (individual characteristics that can be measured and that affect the fitness) with phylogenetic relationships. This approach, in addition to the taxonomic diversity, can bring different answers of a species community in relation to its habitat conditions, being these a combination of ecological and evolutionary answers [15, 16]. Environmental degradation process can be observed by studying diversity measures that are affected by disturbance conditions [17], and for this, the usage of functional, phylogenetic and taxonomic diversity is a growing tool that has been changing the focus of researchers from the use of species diversity or species composition that take no account of differences in species' life-history traits and ecological niches [17–19].

Although plenty of studies have shown strong relationships between community structure and environmental predictors and how the functional traits of species can match up with the environmental conditions [20], some adaptive processes remain unclear. This may be due the large number of traits presented by each species and/or the high species number existing in many habitats which generates an incomplete knowledge of which species traits can actually be an influence to the ecosystem processes [21]. Among all vertebrates, the amphibians are the group with highest proportion of species threatened with extinction [22], due to habitat loss, fragmentation [23], and other related environmental stressors like enhanced UV radiation incidence [24, 25] and canopy coverage loss [26]. Furthermore, the complexity on amphibian life cycle and the differences in life-history strategies between species and also their habitat associations generate a need for studies aiming to understand the true relationship between anthropogenic disturbance and the structure and organization of amphibian communities [7, 8].

In the present study, we aim to answer the following question: In relation to the anthropogenic disturbance in an agricultural-forest preserved gradient, would ponds in more preserved environment harbor higher taxonomic, functional and phylogenetic diversity patterns? So we tested the hypothesis that ponds located at most preserved and more heterogeneous environments would be taxonomically richest and would allow the coexistence of more functionally distinct species [27], expecting then a higher functional diversity and lower functional redundancy. We also expect an increase of the phylogenetic diversity (and thus a decrease in phylogenetic redundancy) at these sites, since more heterogeneous habitats can provide a wide range of microhabitat usage, diminishing the interspecific competition and allowing the coexistence of taxa with higher phylogenetic similarity [28, 29].

2. Methods

2.1. Description of the study site

The sampling areas are located at the Parque Estadual do Turvo (PET) and its adjacencies, and both belong to the Atlantic Rainforest biome. The PET is located at the Rio Grande do Sul State (27° 07′–27° 16′ S, 53° 48′–54° 04′ W; 100–400 a.s.l), at the municipality of Derrubadas, covering an area of 17,491 ha with about 90 km of perimeter of semi-deciduous forest. The study site differs from the wet evergreen forests since it is dryer and presents more open areas, sharing this same vegetational classification with the Republic of Argentina by the Moconá Provincial Park (about 1000 ha) and the Yabotí International Biosphere Reserve (236,613 ha), as well the Brazilian state of Santa Catarina by the Uruguay River [30] (**Figure 1**).

The vast majority of the surrounding areas of PET were converted into intensively agricultural landscapes dominated by crops of soybeans (~22.000 t/year), maize (7.560 t/year), wheat (6.840 t/year) and cattle (~8700 animals) pasture and where the legal buffer zones are not implemented or respected [31]. The climate is characterized as subtropical highly humid with average rainfall between 1.700 and 1.900 mm with reduction of precipitation at the winter season, and the average of temperature ranges from 20 to 23°C [32].

2.2. Data collection

The fieldwork was conducted during two anuran breeding seasons at southern Brazil, the first one from September 2013 to March 2014 and the second from September 2015 to March 2016, which comprises the spring and summer seasons at the southern hemisphere. The field

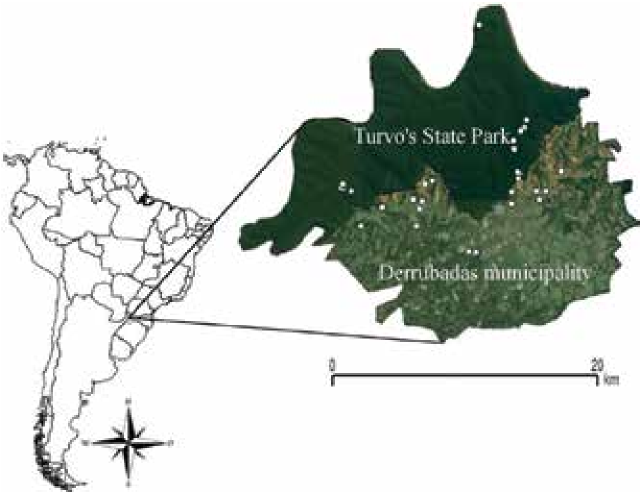

Figure 1. Map representing the sampling area on the extreme north-western of the Rio Grande do Sul State, Brazil. The white points on the map show location of the sampled ponds along the agricultural-preserved forest gradient at Parque Estadual do Turvo and surrounds. The study was performed at two consecutive breeding seasons of anurans between 2014 and 2016.

campaigns were made monthly, for approximately 10 days, when we sampled 38 ponds following an environmental gradient. The gradient ranged from the agricultural landscape where 19 ponds were located (outside of the park borders) to a preserved undisturbed forest, the inner portion of the gradient, with 19 ponds too (**Figure 1**). We collected adult anurans by using the method of "survey at breeding sites" [33], recording the number of calling males along all perimeter of ponds. Then, the maximum abundance data from each species in each pond was used to construct the composition matrix to be used at the subsequent analysis.

We undertook a series of 14 measures (averages from the continuous values, chosen given their environmental and/or reproductive values) on morphological and ecological traits from eight individuals of each recorded species, to access data on functional diversity and redundancy (**Table 1**). Since the sampling method is based on the calling males, the morphometric measures were taken only from adult males. The data acquisition was performed from anurans collected during the field campaigns and also on specimens already deposited at the Universidade Federal de Santa Maria collection (ZUFSM Appendix A) between the years of 2010 and 2012 from the same area, to enlarge the database.

We also constructed a phylogenetic matrix based on the phylogenetic information of the species to access data on phylogenetic diversity and redundancy. We manually inserted six

Trait type	**Variable**	**Trait**
Snout vent length	Continuous	Total size of the body, from the tip of the nose to the cloaca
Mouth ratio	Continuous	Distance between the rear edge of the jaw joint and the tip of the snout, divided by the snout vent length
Forelimb ratio	Continuous	Greater distance from the "shoulder" to the tip of the "hand," divided by the snout vent length
Hind limb ratio	Continuous	Distance between the cloaca and the tip of the "foot," divided by the snout vent length
Perched	Binary	Place of activity/or vocalization
Ground	Binary	Place of activity/or vocalization
Water	Binary	Place of activity/or vocalization
Prolonged breeding	Binary	Time of breeding season
Explosive breeding	Binary	Time of breeding season
Reproductive Mode 1*	Binary	Reproductive mode
Reproductive Mode 2*	Binary	Reproductive mode
Reproductive Mode 11*	Binary	Reproductive mode
Reproductive Mode 24*	Binary	Reproductive mode
Reproductive Mode 30*	Binary	Reproductive mode

*Reproductive modes based on [43].

Table 1. Description of the ecomorphological traits of the anurans recorded in ponds monitored at Parque Estadual do Turvo and adjacencies between 2014 and 2016.

species (*Elachistocleis bicolor, Ololygon aromothyella, Physalaemus* aff. *gracilis, Rhinella ornata, Scinax granulatus* and *S. perereca*) not present at Pyron and Wiens' work [34]. The position of these insertions (missing species) was defined according to the position of the closest species or closest species group [35–38].

2.3. Statistical analysis

We calculated the functional and phylogenetic patterns by using Rao's quadratic entropy and the taxonomic diversity by using the Gini-Simpson's index [39, 40]. These analyses were based on [15, 16] by constructing a dataset composed by four matrices. The first one (matrix B) contains the species functional traits, the second one (matrix W) contains the abundance of species in each sampled pond, the third one (matrix E) with the environmental filter (distance from the nearest border of PET, negative values for outside and positive values for inside) and the fourth (matrix F) with the phylogenetic information (transformed then into a matrix of phylogenetic distance) of the recorded species. To perform these analyses, we used the software Phylocom [41] and SYNCSA (available at http://ecoqua.ecologia.ufrgs.br/SYNCSA.html).

As a way to explore our database and better understand the effects of richness and equability of the species distributed along the measured gradient of distance, we constructed a Whittaker diagram (or dominance diagram). After these procedures, we tested the relation of the obtained values of functional diversity and redundancy, taxonomic diversity and redundancy and phylogenetic diversity and redundancy of each pond with its distance from PET's nearest border (positive values represented the ponds inside PET's area and negative values represented ponds outside PET's boundaries). In addition, we also tested the relation of the components of the community weighted means matrix (CWM matrix containing the weighted functional traits) with the distance from the PET's nearest borders (*Vegan* Package, *lm* function, [42]).

3. Results

We found 15 anuran species from five families: Hylidae (four species), Leptodactylidae (four species), Bufonidae (two species), Phyllomedusidae, Microhylidae and Ranidae, both with one species each. We registered all the 15 species in the inner portion of gradient (the portion inside the PET) and only 10 species in the outside portion. The most conspicuous species were *Dendropsophus minutus* and *Scinax granulatus* both occurring at 31 of the 38 sampled ponds, respectively (**Table 2**). We found, based on the abundance distribution curve, that the ponds located at inner portion of the gradient have the species abundance more equally distributed (equability) than the ponds located at the outside portion (**Figure 2**).

Regarding the taxonomic, functional and phylogenetic patterns of diversity that we analysed, only the phylogenetic diversity and phylogenetic redundancy were related to the studied gradient ($r^2 = 0.14$, $p > 0.05$ and $r^2 = 0.20$, $p < 0.05$, respectively). The phylogenetic diversity (opposed to what we assumed) decreased at the inner portion of the gradient, while the phylogenetic redundancy increased (see **Figure 3A** and **B**).

Family/species	Inside	Outside	Number of ponds (total 38)
Bufonidae			
Rhinella icterica	01	04	04
Rhinella ornata	34	00	07
Hylidae			
Dendropsophus minutus	74	40	31
Hypsiboas faber	30	24	18
Ololygon aromothyella	17	00	03
Scinax fuscovarius	04	00	01
Scinax granulatus	58	23	31
Scinax perereca	24	00	10
Leptodactylidae			
Leptodactylus latrans	27	13	12
Leptodactylus mystacinus	28	19	21
Physalaemus cuvieri	45	37	25
Physalaemus aff. *gracilis*	31	04	15
Microhylidae			
Elachistocleis bicolor	12	24	15
Phyllomedusidae			
Phyllomedusa tetraploidea	18	00	08
Ranidae			
Lithobates catesbeianus[*]	50	28	23

[*] Exotic species.

Table 2. Anuran species, place of occurrence, frequency of occurrence and maximum abundance recorded in ponds monitored at Parque Estadual do Turvo and adjacencies between 2014 and 2016.

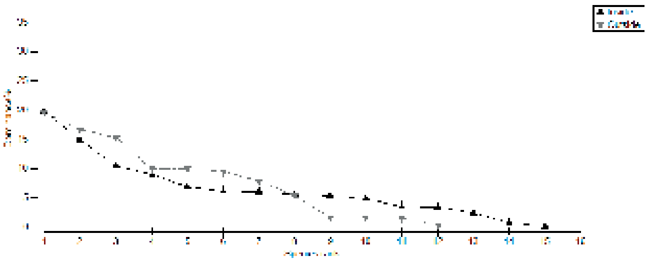

Figure 2. Whittaker diagram, showing the distribution of abundance of 15 anuran species recorded along an agricultural-preserved forest gradient at the Parque Estadual do Turvo, Rio Grande do Sul, southern Brazil. Black triangles represent the inner portion of the gradient, and the gray triangles represent the outside portion.

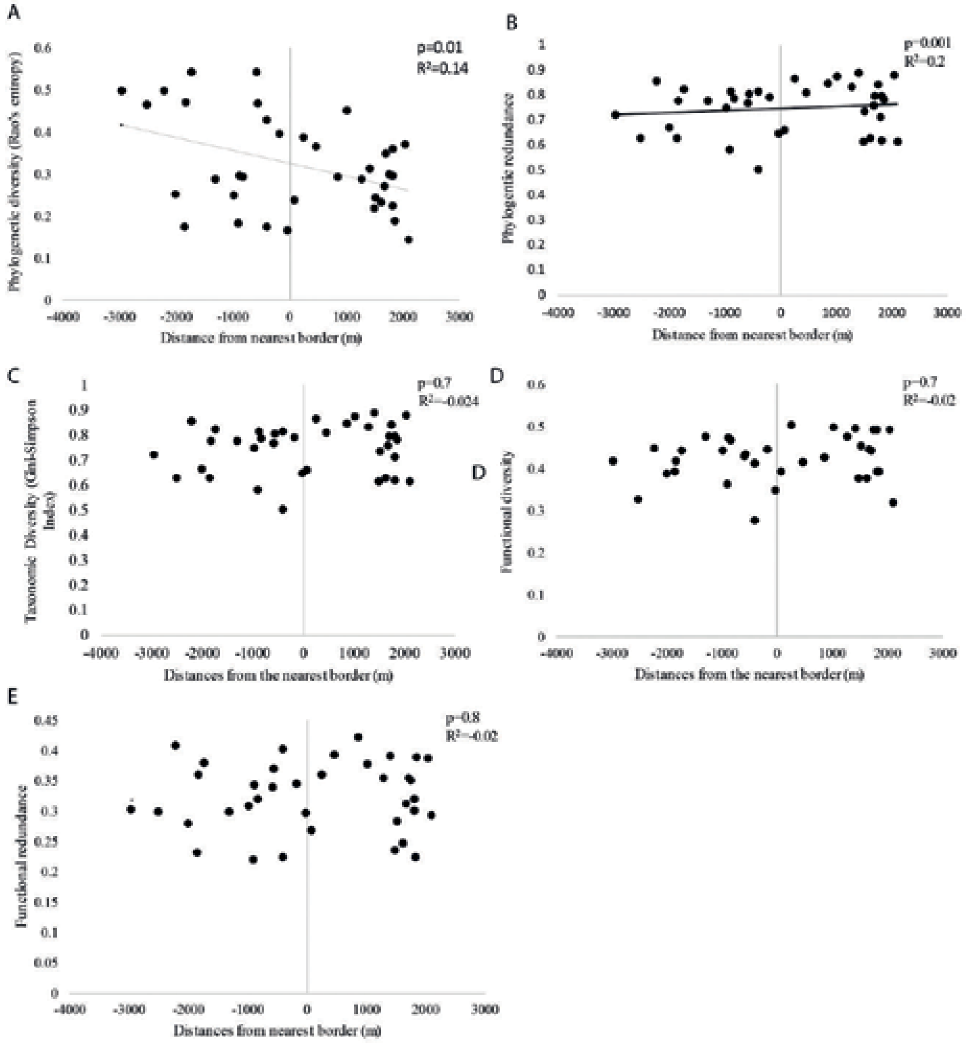

Figure 3. Regression results between anuran functional, phylogenetic ($p < 0.05$) and taxonomic diversities and redundancy along the agricultural-preserved forest gradient (environmental filter) at Parque Estadual do Turvo and adjacencies, southern Brazil between 2014 and 2016.

Despite the total functional diversity not showing statistical significance, when evaluated alone with the distance gradient, the attributes (CWM matrix) showed that the individuals from the inner portion of the gradient presented higher values of the forelimb ratios (hind limbs $r^2 = 0.13$, $p < 0.05$, forearms $r^2 = 0.11$, $p < 0.05$) and mouth size ratio ($r^2 = 0.12$, $p < 0.05$) than the individuals found at the outside portion of the gradient. The results also showed that the reproductive mode number 4 (eggs laid on small ponds constructed by the males) [43], exhibited by *Hypsiboas faber*, is more commonly found at the outside than the inner portion ($r^2 = 0.12$, $p < 0.05$; see **Figure 4A–D**).

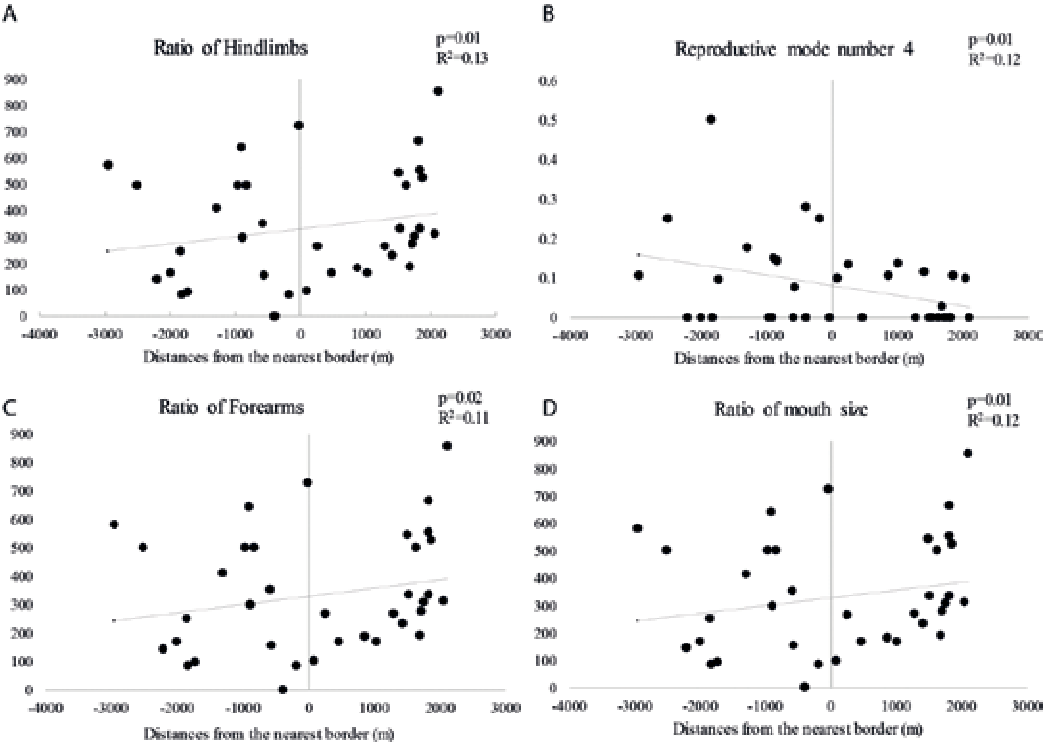

Figure 4. Regression results between the ratios of the morphological characteristics of anurans and their reproductive modes along the agricultural-preserved forest gradient (environmental filter) at Parque Estadual do Turvo and adjacencies, southern Brazil between 2014 and 2016.

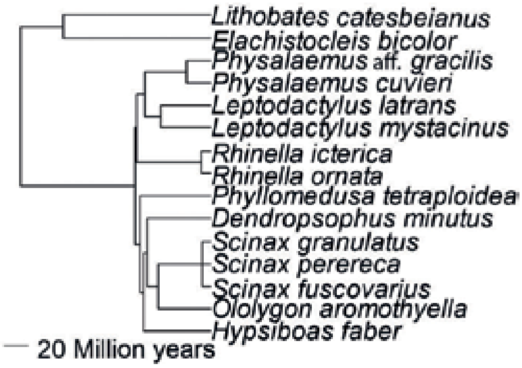

Figure 5. Phylogeny of the anurans recorded at waterbodies monitored along an environmental gradient ranging from an agricultural landscape to a well-preserved forest at the southern Brazil. Generated based in Pyron and Wiens [34], Narvaes and Rodrigues [37], Faivovich (2002), Nascimento et al. [36], de Sá et al. (2012), [38] and Vieira (2010). We defined the branch length based on the estimative of the age of the clades, given by the TimeTree (Hedges et al., 2006).

The phylogeny generated concerning the anurans showed the formation of two distinct clades (**Figure 5**). The first, the oldest clade (about 90 million years), is formed by two genera with one species each (*Lithobates catesbeianus* and *Elachistocleis bicolor*); the second clade is formed by eight genera (*Physalaemus* [two species], *Leptodactylus* [two species], *Rhinella* [two species], *Phyllomedusa* [one species], *Dendropsophus* [one species], *Scinax* [three species], *Ololygon* [one species] and *Hypsiboas* [one species]).

4. Discussion

The anuran community of the PET is characterized as a mixture of species (from several families and genera) [44] given their distribution patterns. From the 15 species found at our study, five occurred only at the inner portion of the gradient (*Ololygon aromothyella*, *Phyllomedusa tetraploidea*, *Rhinella ornata*, *S. fuscovarius* and *S. perereca*), and four of them are quite dependent of the arboreal strata or the different types of vegetation at water surface (*O. aromothyella*, *P. tetraploidea*, *S. fuscovarius* and *S. perereca*) [43, 45, 46].

The pattern observed at the Whittaker's diagram (**Figure 2**) showed the dominance of a low number of species at the inside and outside portions of the gradient. This kind of pattern is considerably recurrent; other studies already showed the decrease of richness and enhancing on dominance at places affected by anthropogenic disturbance [47–49]. In the present case, at both portions of the studied gradient, the native species *Dendropsophus minutus* and *S. granulatus* and the exotic species *Lithobates catesbeianus* presented higher abundances when compared to other species. These two native and abundant species share not just the reproductive mode but are also highly tolerant to human induced disturbances, being found close to human dwelling (or inside of them, like *S. granulatus*) and man-made water bodies. However, *L. catesbeianus* presents a high invasive potential, and as explained by Madalozzo et al. [50], its distribution is facilitated by the influence of the edge effect and the man-made water bodies along the borders of PET.

Our results show that despite the initial assumption of a higher taxonomic and functional diversity at the inner portions of the gradient, there is no significant difference between the two sampling sites. The great number of man-made water bodies available outside of PET area may explain the similarity on the taxonomic and functional diversity given the high number of generalist species that inhabit both agriculture and forest environments (e.g. *D. minutus*, *S. granulatus*, *L. catesbeianus*, and *Physalaemus* spp.) and their reproductive modes, associated to both permanent and temporary ponds. This pattern of occurrence is commonly found at studies on Atlantic rainforest *lato sensu* (with exception of the wet evergreen forest), mainly at locations that present ecotonal characteristics (given the recent anthropogenic modifications). This landscape feature may exert influence on anuran reproductive behavior and physiology, given the unpredictability of variables like temperature and evaporation at these places, enhancing the establishment of more plastic species which can respond differently and maybe more efficiently to disturbed environmental conditions [51, 52]. In this way, it is expected to find similar species (with similar functional traits) when thinking only on the pond-dwelling anurans, both, in and outside of the gradient, since they have to deal with the diversity of microhabitat of both places, diminishing the difference of this diversity patterns. However, when adding the stream (e.g. *Vitreorana uranoscopa*, *Hypsiboas curupi*, *Crossodactylus schmidti*) the marsh-dwelling anurans (e.g. *Odontophrynus americanus*, *Proceratophrys avelinoi* and *P. bigibosa*) and the extremely ephemeral pond-dwelling anurans (e.g. *Melanophryniscus*), we can expect to see greater differences.

Despite the lack of difference on taxonomic and functional diversities (and also functional redundancy), we found evidence of a decrease on the phylogenetic component of diversity toward the interior of the park. This result suggests that the environmental filter (distance) has influence on the phylogenetic structure of the assemblages and also suggests low phylogenetic competition, opposing to what can be seen outside of the park [53, 54]. However, another possibility may arise (concerning the decrease of phylogenetic diversity) with the presence of strong competitors (clades); in this case the competition would be also a biotic influence on these assemblages [55, 56]. These two non-excluding possibilities agree with the hypothesis of the niche conservatism [56, 57], so the similar ecological traits shared by the phylogenetically close species would allow them to coexist and the conservative similarity on niche usage by these species would have shaped the actual clustering or over dispersion (e.g. outside portion of the gradient).

In this way, it is expected that species occupying the same habitat (e.g. inner portion or outside portion of the gradient) will show similar morphological traits in response to the environment [58]. However, under a more competitive scenario, it would be expected that they show differences on morphology and, then, show the existence of some degree of niche specialization [59]. Despite the assumption of a similar response in morphology trait from closely related species (evolutionary), the difference found on the size of some morphological traits (e.g. hind limbs, forearms and mouth), greater from individuals from inside and smaller to individuals from outside, here, this pattern occurs following the premises of adaptive radiation, showing that when the species (or lineages) adapt themselves to explore new or different niches, the changes can be rapid [60–62]. The individuals present at the inner portion of the gradient are adapted to cope with some barriers of dispersion (e.g. fallen trees, streams) and/or make use of a larger number of habitats than the individuals present on the outside portion that are susceptible to predation, to desiccation and to pesticides (given the anthropic nature of the landscape). This is also corroborated when we see that species that construct nests that can hold water (reproductive mode 4) could be better distributed or more frequently found at places with hydrological deficit.

It is widely known that land-use intensification is one of the major threats to biodiversity in local and global perspectives. Several studies have shown that anthropogenic influence can cause a decline in several aspects of diversity in natural assemblages [22]. In this way, these modifications would not allow the species to track their optimum environment, forcing them to adapt in situ to avoid extinction [63]. These adaptations can be seen when the functional traits (functional diversity) from individuals of a highly preserved area, show similarity from individuals of a highly converted area; it is the phenotypical plasticity of these individuals that seems to be needed at these places. In the present study, we found evidence of a strong influence of the environmental conditions shaping the assemblages, given the phylogenetic clustering and the lack of difference on functional diversity.

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Appendix I. Examined anuran specimens from the Herpetological Collection of Universidade Federal de Santa Maria (ZUFSM). Missing numbers are individuals measured in field and from didactic collection

Dendropsophus minutus: ZUFSM4540, ZUFSM4558, ZUFSM4621, ZUFSM4622, ZUFSM4630 and ZUFSM4632; ***Elachistocleis bicolor:*** ZUFSM4575; ***Hypsiboas faber:*** ZUFSM *4476*, ZUFSM*4619* and ZUFSM*4661;* ***Leptodactylus fuscus:*** ZUFSM*4585*, ZUFSM*4628* and ZUFSM *4660*; ***Leptodactylus latrans:*** ZUFSM4557 and ZUFSM4604; ***Leptodactylus mystacinus:*** ZUFSM4473, ZUFSM4526 and ZUFSM4551; ***Ololygon aromothyella:*** *ZUFSM4547, ZUFSM4566, ZUFSM4596, ZUFSM4598, ZUFSM4616, ZUFSM4623, ZUFSM4633, ZUFSM4634* and *ZUFSM4635*; ***Phyllomedusa tetraploidea:*** ZUFSM*4533*, ZUFSM*4580* and ZUFSM*4581;* ***Physalaemus cuvieri:*** ZUFSM*4555,* ZUFSM*4563,* ZUFSM*4578* and ZUFSM*4579;* ***Physalaemus*** **aff.** ***gracilis:*** *ZUFSM4356, ZUFSM4358, ZUFSM4359, ZUFSM4368, ZUFSM4553, ZUFSM4572* and *ZUFSM4609;* ***Rhinella icterica:*** ZUFSM4529, ZUFSM4518, ZUFSM4516, ZUFSM4515, ZUFSM10000, ZUFSM10009, ZUFSM10010 and ZUFSM10011; ***Rhinella ornata:*** ZUFSM4477, ZUFSM4496, ZUFSM4497, ZUFSM4498, ZUFSM4499, ZUFSM4527, ZUFSM4659, ZUFSM10005, ZUFSM10006 and ZUFSM10007; ***Scinax fuscovarius:*** ZUFSM4549, ZUFSM4556, ZUFSM4576 and ZUFSM4610; ***Scinax granulatus:*** ZUFSM4550, ZUFSM4559, ZUFSM4594 and ZUFSM4607; ***Scinax perereca:*** ZUFSM2810, ZUFSM2956, ZUFSM4513, ZUFSM4597, ZUFSM4599, ZUFSM4606, ZUFSM4613, ZUFSM4617, ZUFSM4627 and ZUFSM4808.

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Chapter 3

Tropical Forests Are An Ideal Habitat for Wide Array of Wildlife Species

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Additional information is available at the end of the chapter

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Abstract

Tropical forests are one of the most diverse (1 ha may contain more than 1000 plant species) and highly productive ecosystems on the earth. They cover 15.0% of the earth's surface and harbored 80% terrestrial biodiversity. Tropical forests are home to thousands of endemic, rare, endangered, and threatened wildlife species, which play a significant role in ecosystem functions, such as pest control, pollinators, and seed dispersal. Wildlife species are bioindicators of the tropical forest ecosystems, that is, their presence or absence may provide the information about the habitat dynamics, such as vegetation structure, food resources, productivity, and anthropogenic disturbances. Despite being rich in wildlife resources, tropical forests have been extensively lost and degraded by human intervention, and their destruction is still continuous in a variety of ways. The current information on the tropical forests as an ideal habitat for a wide array of wildlife species is inadequate. It is highly essential to examine with solid grasp the suitability of the tropical forest as attractive habitat for diversity of wildlife species to understand their functional role fragile forest ecosystem and to formulate the better conservation and management strategies in future.

Keywords: tropical forest, diverse, wildlife, ecosystem, habitat, vegetation

1. General background

Tropical forests are located at tropics of Cancer 23°N and Capricorn at 23.5°S to equator (**Figure 1**) [1]. Around 60% of the tropical forest occurs in Latin America, 25% in Asia-Pacific regions, and rest 15% in Africa [2]. These forests covered <5.0% of earth's surface and comprised of 17,000 million ha, which is equal to 44.0% of the world's forest cover and exhibits a higher richness and diversity of flora and fauna species. Tropical forests are rich in vegetation

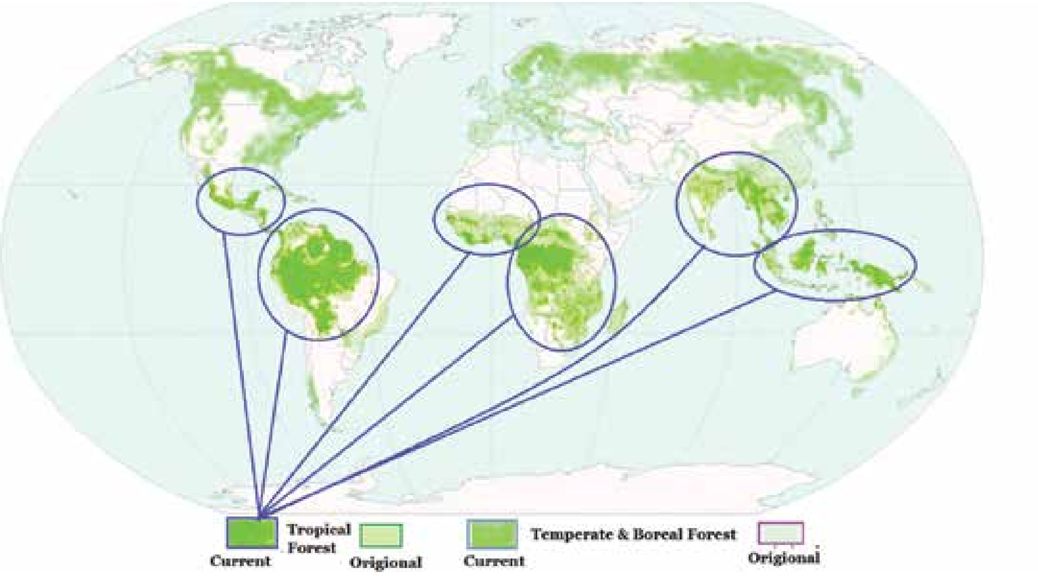

Figure 1. Location map of tropical forest around the world. Source: URL at http://rstb.royalsocietypublishing.org/content/royptb/361/1465/195/F2.large.jpg.

Figure 2. Esthetic view of tropical forest. Source: http://www.oxfordmartin.ox.ac.uk/downloads/briefings/200912-Forest Governance.pdf.

composition and structure (**Figure 2**), which has formulated heterogeneity of habitats to attract the wide array of wildlife species to inhabit and utilize the food resources in order to perform various activities and to increase the numbers of their individuals [3]. The richness and diversity of vegetation could be due to the heterogeneity of topography, site quality, rainfall pattern, and temperature [4–9].

Tropical forests are intact habitats, which are rich in vegetation diversity and food resources that have attracted higher diversity of endemic, rare, threatened, and endangered wildlife species (i.e., such as mammals, birds, reptiles, and amphibians). The wildlife species directly or indirectly depends on tropical forests to perform various activities, such as inhabit, forage, loaf, perch, and breed for their survival and existence. Determining the wildlife population community parameters in the tropical forest habitats is vital important to understand the dynamics of the tropical habitat, ecological processes, and habitat disturbance vital for the occurrence, survival, and conservation of wildlife species.

2. Types of tropical forests

Tropical forests encompass 60% tropical rainforest, while remaining 40% are comprised of seasonally dry tropical forest, mangroves, tropical freshwater swamp forest, dry forest, open eucalyptus forests, tropical coniferous forest, savannah woodlands, and montane forests [10–12]. The tropical forests have been classified as (i) tropical moist broadleaf forests, (ii) tropical dry broadleaf forest, and (iii) tropical coniferous forest. The detail of each forest type has been given below:

2.1. Tropical moist broadleaf forests

These forests are the huge area located at equatorial belts between the tropics of Cancer and Capricorn dominated with semi-evergreen and evergreen deciduous tree species. They receive >200 cm rainfall annually [13]. The tree canopy is multilayered, that is, upper story (emergent crown), medium layer, lower canopy, shrub layer, and understory. These forests are home for more than 50% of world wildlife species. The occurrence of higher number of wildlife species is due to diversity of vegetation (i.e., >1000 plant species/km^2) and multilayered vegetation structure. For example, upper story is suitable habitats for apes, monkeys, flying squirrels, and birds (i.e., flycatchers), the understory layer harbored diversity of mammals (big cats) and avian species, (i.e., babblers, bulbuls, and pittas, etc.), while undergrowth vegetation is ideal habitat for gorillas, deer, amphibians, snakes, and lizards.

2.2. Tropical dry broadleaf forests

Tropical dry broadleaved forest is characterized with warm temperature and seasonal rainfalls that enable flora to withstand in rainy season as well as dry season to conserve water and shedding their leaves. These forests are located at tropical and subtropical latitudes, such as southern Mexico, Africa, the Lesser Sunda Islands, Central India, Indochina, Madagascar, New Caledonia, Eastern Bolivia and Central Brazil, Caribbean, North Andes, Ecuador, and Peru. They cover about 6 million km^2 or 4% of the Earth's surface [14] and are dominated by teak, ebony, bamboo, and fig trees [15]. The soil is highly productive, and tree canopy may attain 10–30 m tall. Tropical dry broadleaved forest is suitable habitat for mammals (white-fronted capuchin monkeys, mantled howler monkeys, shrews, bats, coyotes, foxes, ringtails, raccoons, badgers, bobcats, and mountain lions), birds (crested guan, magpie jay, hawks, and bull finches), snakes, lizards, etc.

2.3. Tropical coniferous forests

These forests occur in humid climate region at Nearctic and Neotropical Ecozones from Mid-Atlantic states to Nicaragua, the Greater Antilles, Bahamas, and Bermuda [16]. They are characterized by diverse coniferous species whose needles have adjusted to deal with low precipitation (around 2.4″ or 60 mm) and moderate temperature (18 or 64°C or higher). These forests are dominated by *Pinus caribaea, P. tropicalis, P. chiapensis, P. tecunumanii, P. ayacahuite, P. maximin, Byrsonima crassifolia, Colpothrinax wrightii, Chrysobalanus icaco, Quercus cubana, Calophyllum pinetorum, Erythroxylum minutifolium, Phania cajalbanica, Vaccinium cubense, Hyperbaena columbica, Clusia rosea, Aristida* spp., *Andropogon* spp., *Quercus corrugata, Q. skinneri, Q. oleoides, Q. candicans, Q. acatenangensi, Q. brachystachys, Q. peduncularis, Q. polymorpha,* and *Q. conspersa*. The crown canopy is close and thick, the understory is rich in shrubs and small trees, while the ground is dominantly covered with ferns and grasses. These forests has harbored wide array of mammals (such as *Cervus unicolor, Muntiacus muntjak, Sus scrofa, Selenarctos thibetanus, Capricornis sumatraensis, Rafuta* spp.) and bird species (i.e., *Polyplectron chalcurum, Pericrocotus miniatus, Chloropsis venusta, Myophonus melanurus, Niltava sumatrana, Cinclidium diana, Pycnonotus leucogrammicus, P. tympanistrigus, Hypsipetes virescens, Zosterops atricapillus, Garrulax palliatus, Napothera rufipectus*, etc.).

3. Ecological importance of tropical forests

Tropical forests provide diverse ecosystem services, such as play major role in water cycle, that is, they return around 90.0% precipitation into the atmosphere in the form of water vapors, increase the life span of dams through reducing the sediments into rivers, mitigate the disasters through reducing soil erosion and land sliding, and reduce the intensity and severity of floods [17]. Tropical forests are vital important for human well-being, that is, they contribute major proportion in food security (i.e., around global crops and one-third food supply depend on wild pollinators), regulate weather condition, reduce the negative effects of climate change by acting pollution filters, and serve as storage biodiversity. It has been stated that tropical forest may harbor >50.0% of world’s terrestrial animal species [18]. Tropical forests play a crucial role in climate change, that is, the vegetation of tropical forest stored a huge amount of carbon taking from the atmosphere and stored in their various parts of the body (i.e., in leaves, stems, and roots, etc.) and serves as mega carbon storehouse or sinks (e.g., 25% store of world’s carbon). It has been known that tropical forest can store huge amount of carbon compared to those they release back into atmosphere, slow down the rate of carbon dioxide accumulation in the atmosphere, and reduce the effect of climate change. Hence, this indicated that tropical forests play a significant role to reduce the effects of climate change and reduce 12% emission of greenhouse gases into the atmosphere. Wildlife species are the essential component of the tropical forest ecosystem, that is, they play a major role, that is, pest control, pollination, and seed dispersal in tropical forest ecosystem [19]. At habitat level, the occurrence and richness of wildlife species represent a powerful tool to examine the current status of particular ecosystem. This could be that wildlife species are ecologically specialized in habitat use, diet, and highly sensitive to habitat and microclimate alteration [20–22].

Being rich in biodiversity, the tropical forests have been vanished and altered due to anthropogenic activities [23–25], habitat destruction and fragmentation, invasive species, overexploitation, and climate change [26–28].

4. Threats to tropical forests

Currently, tropical forests are facing severe potential threats due to human interventions, such as extensive habitat loss and degradation, isolation, and fragmentation due to heavy exploitation and conversions into agricultural fields and residential areas [29–31], which create a complex spatial disturbance [32–34]. More than 50% of the tropical forest areas have been lost during the past two decades through extensive deforestation for timber, fuelwood, agricultural expansion, and human-induced fire [35–37].

It has been stated that habitat loss and fragmentation of tropical forest is a major threat for wildlife species composition, relative abundance, species richness, and density, that is, it increases higher predation risk, reduced food occurrence and diversity, and genetic variability of birds, mammals, amphibians, and reptiles [38–43]. This may alter habitat thus makes it less productive and attractive thus caused the shift of wildlife species into human-dominated landscape that might be unsuitable and less productive for them [44–48]. However, the consequence of habitat loss and degradation may vary from species to species depending upon the nature and extent of habitat alteration, availability of food resources, and the rate of predation and parasitism [49, 50].

In addition, climate change is an important factor, which has effects on wildlife species phenology, geographic distribution, physiology, vegetation composition, and food resources [51, 52]. Thus, it ultimately exerts negative effects on the population community parameters of the species, i.e., some becomes endangered, vulnerable, and threatened [53–55]. This might be that the climate change may cause the rising of temperature and declining of the precipitation, which make the tropical forest dry and highly susceptible to fire and prone them into shrub lands, grassland, and savannah. The alteration in microclimate may alter the vegetation species composition, richness, and diversity [56, 57].

5. Wildlife fauna of tropical forests

5.1. Birds of tropical forests

Tropical forests are more diverse in vegetation structure and composition, which offer higher habitat complexity, that is, provide a diversity of nesting sites, greater protection from predators and harsh weather, and also plenty of food resources [58]. The vegetation climax and diversity had attracted a wide array of avian species, which are habitat and diet specialist in nature. For example, Black-naped Monarch—*Hypothymis azurea*—often prefers canopy and foraged on flying insects, Blue-headed Pitta—*Pitta baudii*—prefers to utilized the ground vegetation of evergreen broadleaved forest and prey on caterpillars of insects occurs in grasses, and Scarlet-rumped Trogon—*Harpactes duvaucelli*—is middle story bird often associated with evergreen broadleaved vegetation (**Figures 3–5**). They prefer to utilize old mature trees (large diameter and height) for foraging and nesting [59, 60]. Avian species often play a crucial role in forest ecosystem functions, that is, they pollinate the flowers and disperse the seeds from one

Figure 3. Black-naped monarch—*Hypothymis azurea.*

Figure 4. Blue-headed pitta—*Pitta baudii.*

Figure 5. Scarlet-rumped Trogon—*Harpactes duvaucelii.*

part of the forest to another [61–63] and control the pest such as rodents, insects, and squirrels, which may cause damage to the forest foliage.

Tropical forest birds are vulnerable to habitat loss, fragmentation, and changes in land use patterns [64–67]. This could be that habitat loss and fragmentation may alter the vegetation structure and composition, reduce the food resources, increase predation and brood parasitism risk, and enhance the competition for food and space [68–71]. It has been illustrated that in Southeast Asia, tropical forests are facing highest rate of habitat destruction [72–76], which exerts immense pressure on the habitat use, foraging behavior, and breeding success of avian species (**Table 1**).

Family	Scientific name	Common name	Reference
Accipitridae	*Haliastur indus*	Brahminy kite	[76]
	Spilornis rufipectus	Sulawesi serpent eagle	[76]
	Accipiter trinotatus	Spot-tailed goshawk	[76]
	Ictinaetus malayensis	Black eagle	[76]
Bucerotidae	*Penelopides exhartus*	Sulawesi dwarf hornbill	[76]
Bucerotidae	*Rhyticeros cassidix*	Knobbed hornbill	[76]
Campephagidae	*Coracina bicolor*	Pied cuckooshrike	[76]
	Coracina leucopygia	White-rumped cuckooshrike	[76]
	Coracina morio	Sulawesi cicadabird	[76]
Cardinalidae	*Cyanocompsa parellina*	Blue bunting	[77]
	Passerina cyanea	Indigo bunting	[77]
	Granatellus sallaei	Gray-throated chat	[77]
	Habia fuscicauda	Red-throated ant tanager	[77]
	Piranga roseogularis	Rose-throated ant tanager	[77]
	Piranga rubra	Summer tanager	[77]
Columbidae	*Ducula aenea*	Green imperial pigeon	[76]
	Ducula forsteni	White-bellied imperial pigeon	[76]
	Ducula luctuosa	Sliver-tipped imperial pigeon	[76]
	Macropygia amboinensis	Brown cuckoo-dove	[76]
	Treron griseicauda	Gray-checked green pigeon	[76]
	Ptilinopus melanospila	Black-naped fruit dove	[76]
	Turacoena manadensis	Sulawesi black pigeon	[76]
	Patagioenas flavirostris	Red-billed pigeon	[77]
	Columbina passerina	Common ground dove	[77]
	Columbina talpacoti	Ruddy ground dove	[77]
	Leptotila verreauxi	White-tipped dove	[77]
	Leptotila jamaicensis	Caribbean dove	[77]
Corvidae	*Corvus typicus*	Piping crow	[76]
	Psilorhinus morio	Brown jay	[77]

Family	Scientific name	Common name	Reference
	Cyanocorax yncas	Green jay	[77]
	Cyanocorax yucatanicus	Yucatan jay	[77]
Cuculidae	*Surniculus lugubris*	Drongo cuckoo	[76]
	Centropus celebensis	Bay coucal	[76]
	Piaya cayana	Squirrel cuckoo	[77]
	Dromococcyx phasianellus	Pheasant cuckoo	[77]
Dicaeidae	*Dicaeum aureolimbatum*	Yellow-sided flowerpecker	[76]
	Dicaeum celebicum	Gray-sided flowerpecker	[76]
Dicruridae	*Dicrurus hottentottus*	Hair-crested drongo	[76]
Emberizidae	*Arremonops rufivirgatus*	Olive sparrow	[77]
	Arremonops chloronotus	Green-backed sparrow	[77]
Fringillidae	*Euphonia affinis*	Scrub euphonia	[77]
	Euphonia hirundinacea	Yellow-throated euphonia	[77]
Furnariidae	*Dendrocincla anabatina*	Twany-winged woodpecker	[77]
	Dendrocincla homochroa	Ruddy woodpecker	[77]
	Sittasomus griseicapillus	Olivaceous woodpecker	[77]
	Xiphorhynchus flavigaster	Ivory-billed woodpecker	[77]
Icteridae	*Dives dives*	Melodious blackbird	[77]
	Molothrus aeneus	Bronzed cowbird	[77]
	Icterus prosthemelas	Black-cowled oriole	[77]
	Icterus cucullatus	Hooded oriole	[77]
	Icterus chrysater	Yellow-backed oriole	[77]
	Icterus mesomelas	Yellow-tailed oriole	[77]
	Icterus auratus	Orange oriole	[77]
	Icterus gularis	Altamira oriole	[77]
	Amblycercus holosericeus	Yellow-billed cacique	[77]
Mimidae	*Melanoptila glabrirostris*	Black catbird	[77]
	Dumetella carolinensis	Gray catbird	[77]
Momotidae	*Momotus momota*	Amazonian motmot	[77]
	Eumomota superciliosa	Turquoise-browed motmot	[77]
Monarchidae	*Hypothymis azurea*	Black-naped monarch	[76]
Nectariniidae	*Nectarinia aspasia*	Black sunbird	[76]
Odontophoridae	*Dactylortyx thoracicus*	Singing quail	[77]
Oriolidae	*Oriolus chinensis*	Black-naped oriole	[76]
Parulidae	*Vermivora cyanoptera*	Blue-winged warbler	[77]
	Oreothlypis peregrina	Tennessee warbler	[77]
	Setophaga americana	Northern parula	[77]

Family	Scientific name	Common name	Reference
	Setophaga magnolia	Magnolia warbler	[77]
	Setophaga caerulescens	Black-throated blue warbler	[77]
	Setophaga virens	Black-throated green warbler	[77]
	Setophaga dominica	Yellow-throated warbler	[77]
	Mniotilta varia	Black-and-white warbler	[77]
	Setophaga ruticilla	American redstart	[77]
	Seiurus aurocapilla	Ovenbird	[77]
	Geothlypis trichas	Common yellowthroat	[77]
	Setophaga citrina	Hooded warbler	[77]
Pellorneidae	*Trichastoma celebense*	Sulawesi babbler	[76]
Phasianidae	*Gallus gallus*	Red junglefowl	[76]
Picidae	*Mulleripicus fulvus*	Ashy woodpecker	[76]
	Melanerpes aurifrons	Golden-fronted woodpecker	[77]
	Picoides scalaris	Ladder-backed woodpecker	[77]
	Veniliornis fumigatus	Smoky-brown woodpecker	[77]
	Colaptes rubiginosus	Golden-olive woodpecker	[77]
	Dryocopus lineatus	Lineated woodpecker	[77]
Pittidae	*Pitta erythrogaster*	Blue-breasted pitta	[76]
Polioptilidae	*Ramphocaenus melanurus*	Long-billed gnat wren	[77]
	Polioptila caerulea	Blue-gray gnatcatcher	[77]
	Polioptila plúmbea	Tropical gnatcatcher	[77]
Psittacidae	*Tanygnathus sumatranus*	Blue-backed parrot	[76]
	Aratinga nana	Olive-throated parakeet	[77]
	Amazona albifrons	White-fronted parrot	[77]
	Trichoglossus ornatus	Ornate lorikeet	[76]
	Prioniturus platurus	Golden-mantled racquet-tailed parrot	[76]
Stenostriridae	*Culicicapa helianthea*	Citrine flycatcher	[76]
Sturnidae	*Aplonis panayensis*	Asian glossy starling	[76]
	Basilornis celebensis	Sulawesi-crested myna	[76]
	Streptocitta albicollis	White-necked myna	[76]
Thamnophilidae	*Thamnophilus doliatus*	Barred antshrike	[77]
Thraupidae	*Eucometis penicillata*	Gray-headed tanager	[77]
	Cyanerpes cyaneus	Red-legged honeycreeper	[77]
	Sporophila torqueola	White-collard seedeater	[77]
	Tiaris olivaceus	Yellow-faced grassquit	[77]
	Saltator coerulescens	Grayish saltator	[77]
	Saltator atriceps	Black-headed saltator	[77]

Family	Scientific name	Common name	Reference
Tityridae	*Pachyramphus major*	Gray-collared becard	[77]
	Pachyramphus aglaiae	Rose-throated becard	[77]
	Tityra semifasciata	Masked tityra	[77]
	Tityra inquisitor	Black-crownedt Tityra	[77]
Troglodytidae	*Pheugopedius maculipectus*	Spot-breasted wren	[77]
	Thryothorus ludovicianus	Carolina wren	[77]
	Uropsila leucogastra	White-bellied wren	[77]
Trogonidae	*Trogon melanocephalus*	Black-headed trogon	[77]
	Trogon caligatus	Gartered trogon	[77]
Turdidae	*Hylocichla mustelina*	Wood thrush	[77]
Turdidae	*Turdus grayi*	Clay-colored thrush	[77]
Tyrannidae	*Camptostoma imberbe*	Northern beardless tyrannulet	[77]
	Myiopagis viridicata	Greenish elaenia	[77]
	Elaenia flavogaster	Yellow-bellied elaenia	[77]
	Oncostoma cinereigulare	Northern bentbill	[77]
	Tolmomyias sulphurescens	Yellow-olive flatbill	[77]
	Platyrinchus cancrominus	Stub-tailed spadebill	[77]
	Contopus virens	Eastern wood pewee	[77]
	Contopus cinereus	Tropical pewee	[77]
	Empidonax minimus	Least flycatcher	[77]
	Attila spadiceus	Bright-rumped attila	[77]
	Myiarchus yucatanensis	Yucatan flycatcher	[77]
	Myiarchus tuberculifer	Dusky-capped flycatcher	[77]
	Myiarchus tyrannulus	Brown-crested flycatcher	[77]
	Pitangus sulphuratus	Great kiskadee	[77]
	Megarynchus pitangua	Boat-billed flycatcher	[77]
	Myiozetetes similis	Social flycatcher	[77]
	Tyrannus melancholicus	Tropical kingbird	[77]
	Tyrannus couchii	Couch's kingbird	[77]
Vireonidae	*Vireo griseus*	White-eyed vireo	[77]
	Vireo pallens	Mangrove vireo	[77]
	Vireo flavifrons	Yellow-throated vireo	[77]
	Hylophilus decurtatus	Lesser greenlet	[77]
	Cyclarhis gujanensis	Rufous-browed pepper shrike	[77]
Zosteropidae	*Zosterops celebense*	Pale-bellied white-eye	[76]

Table 1. List of bird species occurring in tropical forests.

5.2. Mammals of tropical forests

Mammals are crucial element of tropical forest ecosystems [78, 79]. They exhibit a wide range of niches, exploit diverse tropical forest resources, and play a crucial role in vegetation composition and ecosystem functions, i.e., they forage on the grasses, control weed, pollinate flowers especially bats, and disperse seed from one area to another area after consuming in the form of pallets [63, 80–83].

Mammals are considered the third most threatened and endangered animals, for example, Mantled Hawler Monkey—*Alouatta palliata*—and Amazonian Tapir—*Tapirus terrestris*—(**Figures 6** and **7**) due to habitat loss and destruction, illegal hunting, and trapping [84–86]. It has been stated that >30% mammal species are threatened and their population is still declining day by day through a variety of ways [87] (**Table 2**).

Figure 6. Mantled Hawler monkey—*Alouatta palliata.*

Source: URL at http://www.earthtimes.org/newsimage/211215tapir

Figure 7. Amazonian tapir—*Tapirus terrestris.*

Family	**Scientific name**	**Common name**	**Reference**
Atelidae	*Alouatta palliata*	Mantled howler monkey	[87]
Bovidae	*Cephalophus harveyi*	Harvey's duiker	[88]
	Cephalophus spadix	Abbott's duiker	[88]
	Neotragus moschatus	Suni	[88]
	Syncerus caffer	African buffalo	[88]
Bradypodidae	*Bradypus variegatus*	Brown-throated slot	[87]
Canidae	*Lycalopex culpaeus*	Andean fox	[87]
Cebidae	*Cebus aequatorialis*	Ecuadorian capuchin	[87]
Cercopithecidae	*Cercocebus sanjei*	Sanje mangabey	[88]
	Papio cynocephalus	Yellow baboon	[88]
	Procolobus gordonorum	Udzungwa red colobus	[88]
	Colobus angolensis	Angolan colobus	[88]
Cuniculidae	*Cuniculus paca*	Lowland paca	[87]
Dasyproctidae	*Dasyprocta punctata*	Central American agouti	[87]
Didelphidae	*Didelphis marsupialis*	Common opossum	[87]
Elephantidae	*Loxodonta africana*	African elephant	[88]
Erinacaeidae	*Echinosorex gymnura*	Moon rat	[89]
Felidae	*Herpailurus yagouaroundi*	Eyra cat	[87]
	Leopardus pardalis	Ocelot cat	[87]
	Puma concolor	Cougar	[87]
	Panthera pardus	Leopard	[88]
Herpestidae	*Herpestes brachyurus*	Short-tailed mongoose	[89]
Herpestidae	*Bdeogale crassicauda*	Bushy-tailed mongoose	[88]
	Mungos mungo	Banded mongoose	[88]
Hystricidae	*Hystrix africaeaustralis*	Cape porcupine	[88]
Macroscelidida	*Rhynchocyon cirnei*	Checkered elephant shrew	[88]
	Rhynchocyon udzungwensis	Gray-faced elephant shrew	[88]
	Petrodromus tetradactylus	Four-toed elephant shrew	[88]
Megalonychidae	*Choloepus hoffmanni*	Hoffmann's two-toed slot	[87]
Muridae	*Leopoldamys sabanus*	Long-tailed giant rat	[89]
	Maxomys baeodon	Small spiny rat	[89]
	Maxomys ochraceiventer	Chestnut-bellied spiny rat	[89]
	Maxomys rajah	Rajah spiny rat	[89]
	Maxomys surifer	Red spiny rat	[89]
	Maxomys whiteheadi	Whitehead's spiny rat	[89]
	Niviventer cremoriventer	Dark-tailed tree rat	[89]

Family	Scientific name	Common name	Reference
	Rattus exulans	Polynesian rat	[89]
	Rattus rattus	Black rat	[89]
	Rattus tiomanicus	Malayan field rat	[89]
	Sundamys muelleri	Muller's giant sunda rat	[89]
Mustelidae	*Eira barbara*	Tayra	[87]
	Lontra longicaudis	Neotropical otter	[87]
	Mellivora capensis	Honey badger	[88]
Myrmecophagidae	*Tamandua mexicana*	Northern tamandua	[87]
Nandiniidae	*Nandinia binotata*	African palm civet	[88]
Nesomyidae	*Cricetomys gambianus*	Giant pouched rat	[88]
Procaviidae	*Dendrohyrax arboreus*	Tree hyrax	[88]
	Nasua narica	White–nosed coati	[87]
	Potos flavus	Kinkajou	[87]
Sciuridae	*Sciurus granatensis*	Red–tailed squirrel	[87]
	Simosciurus stramineus	Guayaquil squirrel	[87]
	Glyphotes simus	Sculptor squirrel	[89]
	Sundasciurus brookei	Brooke's squirrel	[89]
	Sundasciurus hippurus	Horse-tailed squirrel	[89]
	Lariscus hosei	Four–striped ground squirrel	[89]
	Sundasciurus lowii	Low's squirrel	[89]
	Sundasciurus tenuis	Slender squirrel	[89]
	Paraxeus vexillarius	Tanganyika mountain squirrel	[88]
Suidae	*Potamochoerus larvatus*	Bush pig	[88]
Tayassuidae	*Pecari tajacu*	Collard peccary	[87]
Tupaiidae	*Tupaia gracilis*	Slender tree shrew	[89]
	Tupaia minor	Pygmy tree shrew	[89]
	Tupaia tana	Large tree shrew	[89]
Viverridae	*Civettictis civetta*	African civet	[88]

Table 2. List of mammal species occurring in tropical forests.

5.3. Amphibians of tropical forests

Amphibians are most abundant vertebrate in tropical forests, that is, they vary in color, behavior, habitat selection, size, and population density. Tropical amphibians are widely distributed and habitat specialist animals, that is, they often prefer the riparian areas of tropical forests (**Figure 8**). Amphibians depend on multiple environmental gradients and are closely

Source: http://www.nhptv.org/wild/images/silverlongfingeredfrog.jpg

Figure 8. Silver long-fingered frog—*Cardioglossa leucomystax*.

associated with habitat types, such as riparian, forest, streams, and path or road edge. Amphibian community structure was influenced by habitat heterogeneity, stream turbidity, river size, water depth, occurrence of aquatic vegetation, and density of understorey vegetation [90]. They are closely associated with habitat structure, food resources, and microclimate variables, that is, temperature and precipitation.

The loss of amphibians seriously disturbed ecological function of tropical food chain and food web. This could be that they are important component in tropical food web, that is, have occupied diverse niches from planktivore to carnivore and often serves as major sources of food for wildlife species in tropical forest. From the ecological point of view, they are best indicators of habitat fragments, ecosystem stress, and aquatic pollution, etc. In addition, amphibians have been used in ecological, embryological, physiological, and genetic research purposes.

One-third populations of amphibian species had been listed as threatened and endangered due to human intervention [91, 92]. Habitat characteristics [93], habitat fragments due to forest logging [94–98], habitat loss and degradation [99–101], environment variables [102], invasive predator species [103], diseases [104], and leaf litter [105] are major driven factors which effect on amphibian assemblages and population parameters. However, the effect of these driven factors may vary depending on the nature of the habitat disturbance, change in microclimate, and alteration in food resource. This could be that the leaf litter, canopy cover, tree size, stream size, availability of river, and refuge areas are highly essential for their survival and reproduction (**Table 3**) [106, 107].

5.4. Reptiles of tropical forests

Tropical forest is diverse and complex ecosystem which harbors most abundant and diverse reptile species [112]. Reptiles are primary consumers, that is, they prey on many animal species, such as birds, mammals, and amphibians (**Figure 9**). They provide ecological services into tropical forest ecosystem, such as control the population of pest (i.e., insects, rodents,

Family	**Scientific name**	**Common name**	**Reference**
Arthropleptidae	*Cardioglossa leucomystax*	Silver long-fingered frog	[108]
	Leptopelis hyloides	African tree frog	[108]
	Leptopelis occidentalis	Tai forest tree frog	[108]
	Leptopelis macrotis	Big-eyed forest tree frog	[108]
Astylosternidae	*Astylosternus occidentalis*	Western night frog	[108]
Bufonidae	*Rhinella marina*	Cane toad	[109]
	Incilius nebulifer	Coastal-plain toad	[109]
	Ansonia muelleri	Muller's toad	[111]
	Chaunus marinus	Cane toad	[110]
	Ollotis marmorea	Marbled toad	[110]
Ceratobatrachidae	*Platymantis corrugatus*	Rough-backed forest frog	[111]
Craugastoridae	*Craugastor decoratus*	Adorned robber frog	[109]
	Craugastor mexicanus	Mexican robber frog	[110]
	Craugastor hobartsmithi	Pygmy robber frog	[110]
Dicroglossidae	*Limnonectes magnus*	Mindanao-fanged frog	[111]
Eleutherodactylidae	*Eleutherodactylus longipes*	Long-footed chirping frog	[109]
	Eleutherodactylus verrucipes	Big-eared chirping frog	[109]
	Eleutherodactylus modestus	Blunt-toed chirping frog	[110]
	Eleutherodactylus nitidus	Spiny peeping frog	[110]
Hylidae	*Ecnomiohyla miotympanum*	Small-eared tree frog	[109]
	Smilisca baudinii	Baudin's tree frog	[109]
	Trachycephalus typhonius	Warty tree frog	[109]
	Exerodonta smaragdina	Emerald tree frog	[110]
	Pachymedusa dacnicolor	Mexican leaf frog	[110]
	Smilisca baudinii	Mexican tree frog	[110]
	Smilisca fodiens	Lowland burrowing tree frog	[110]
	Tlalocohyla smithii	Dwarf Mexican tree frog	[110]
	Trachycephalus venulosus	Veined tree frog	[110]
	Triprion spatulatus	Shovel-nosed tree frog	[110]
Hyperoliidae	*Hyperolius concolor*	Hallowell's sedge frog	[108]
	Hyperolius guttulatus	Dotted reed frog	[108]
	Hyperolius picturatus	Tanzania reed frog	[108]
	Hyperolius sylvaticus	Bobiri reed frog	[108]
	Hyperolius zonatus	Nimba reed frog	[108]
	Hyperolius fusciventris	Lime reed frog	[108]
	Hyperolius chlorosteus	Sierra Leone reed frog	[108]

Family	Scientific name	Common name	Reference
	Afrixalus dorsalis	Brown banana frog	[108]
	Afrixalus nigeriensis	Nigeria banana frog	[108]
	Afrixalus vibekae	Nimba banana frog	[108]
	Kassina lamottei	Rainforest running frog	[108]
	Acanthixalus sonjae	Ivory Coast wart frog	[108]
Leptodactylidae	*Leptodactylus melanonotus*	Black-backed frog	[110]
Megophryidae	*Megophrys stejnegeri*	Mindanao-horned frog	[111]
Microhylidae	*Gastrophryne usta*	Two-spaded narrow-mouthed toad	[110]
	Kalophrynus pleurostigma	Narrow-mouthed frog	[111]
Phrynobatrachidae	*Phrynobatrachus gutturosus*	Chabanaud's river frog	[108]
	Phrynobatrachus fraterculus	Macenta river frog	[108]
	Phrynobatrachus guineensis	Guinea river frog	[108]
	Phrynobatrachus phyllophilus	Tai river frog	[108]
	Phrynobatrachus liberiensis	Liberia river frog	[108]
	Phrynobatrachus alleni	Allen's river frog	[108]
	Phrynobatrachus plicatus	Coast river frog	[108]
	Phrynobatrachus taiensis	Rugegewald river frog	[108]
	Phrynobatrachus annulatus	Ringed river frog	[108]
Ranidae	*Lithobates berlandieri*	Rio Grande leopard frog	[109]
	Lithobates johni	Moore's frog	[109]
	Lithobates spectabilis	Showy leopard frog	[109]
	Staurois natator	Rock frog	[111]
	Rana grandocula	Big-eyed frog	[111]
	Lithobates forreri	Forr'ers grass frog	[110]
Rhacophoridae	*Polypedates leucomystax*	Four-lined tree frog	[111]
	Philautus acutirostris	Pointed-snouted tree frog	[111]
	Chiromantis rufescens	African foam-nested tree frog	[108]

Table 3. List of amphibian species occurring in tropical forests.

squirrels, tree shrews, small birds, etc. [113, 114], which are destructive to the vegetation. Likewise, they are also source of food for other animals, such as birds, mammals, amphibians, and even reptiles [115].

Reptiles are facing severe threats due to human activities, that is, habitat loss, and indiscriminate trapping and hunting for their skin and food thus become threatened and endangered [116–118]. The population decline of various reptile species in tropical forest may cause ecological imbalance that effected on the ecological functions (**Table 4**) [119, 120].

Figure 9. Reticulated python—*Python reticulatus.*

Family	Scientific name	Common name	Reference
Agamidae	*Gonocephalus semperi*	Mindoro forest dragon	[111]
	Ptyctolaemus gularis	Green fan-throated lizard	[121]
	Gerrhonotus liocephalus	Alligator lizard	[110]
Boidae	*Boa constrictor*	Red-tailed boa snake	[110]
Colubridae	*Boiga dendrophila*	Golden-ringed cat snake	[111]
	Psammodynastes pulverulentus	Common mock viper	[111]
	Oligodon maculatus	Barred short-headed snake	[111]
	Calamaria gervaisii	Philippine dwarf/Gervais' worm Snake	[111]
	Lycodon dumerili	Dumeril's wolf snake	[111]
	Lycodon aulicus	Indian wolf snake	[121]
	Lycodon jara	Twin-spotted wolf snake	[121]
	Lycodon zawi	Zaw's wolf snake	[121]
	Oligodon dorsalis	Gray's kukri snake	[121]
	Oligodon taeniolata	Streaked kukri snake	[121]
	Psammodynastes pulverulentus	Common mock viper	[121]
	Ptyas korros	Indo–Chinese rat snake	[121]
	Ptyas mucosa	Oriental rat snake	[121]
	Rhabdophis subminiatus	Red-necked Keelback snake	[121]

Family	Scientific name	Common name	Reference
	Dipsas gaigeae	Gaige's thirst snail-eater snake	[110]
	Drymarchon corais	Indigo snake	[110]
	Drymobius margaritiferus	Speckled racer snake	[110]
	Imantodes gemmistratus	Central American tree snake	[110]
	Lampropeltis triangulum	Milk snake	[110]
	Leptophis diplotropis	Pacific Coast parrot snake	[110]
	Masticophis mentovarius	Neotropical whip snake	[110]
	Oxybelis aeneus	Mexican vine snake	[110]
	Senticolis triaspis	Green rat snake	[110]
	Sibon nebulata	Clouded snake	[110]
	Tantilla calamarina	Pacific Coast centipede snake	[110]
	Trimorphodon biscutatus	Western Lyre snake	[110]
Dactyloidae	*Anolis nebulosus*	Clouded anole	[110, 122]
Dipsadidae	*Hypsiglena torquata*	Night snake	[110]
	Leptodeira maculata	South-western cat-eyed snake	[110]
	Manolepis putnami	Ridge-head snake	[110]
	Pseudoleptodeira latifasciata	False cat-eyed snake	[110]
	Leptodeira uribei	Uribe's false cat-eyed snake	[110]
Elapidae	*Naja kaouthia*	Monocled cobra	[121]
	Naja naja	Indian cobra	[121]
	Ophiophagus hannah	King cobra	[121]
	Micrurus distans	West Mexican coral snake	[110]
Eublepharidae	*Coleonyx elegans*	Yucatan-banded gecko	[122]
Gekkonidae	*Gekko mindorensis*	Mindoro narrow-disked gecko	[111]
	Hemidactylus bowringii	Oriental leaf-towed gecko	[121]
	Hemidactylus brookii	Brooke's house gecko	[121]
	Hemidactylus flaviviridis	Yellow-bellied house gecko	[121]
	Hemidactylus frenatus	Pacific gecko	[121]
	Hemidactylus garnotii	Indo-Pacific gecko	[121]
	Hemidactylus platyurus	Flat-tailed house gecko	[121]
	Coleonyx elegans	Yucatan-banded gecko	[110]
	Phyllodactylus lanei	Lane's leaf-toed gecko	[110]
	Hemidactylus frenatus	Pacific gecko	[122]
Geoemydidae	*Rhinoclemmys pulcherrima*	Painted wood turtle	[110]
	Rhinoclemmys rubida	Mexican-spotted wood turtle	[110]
Helodermatidae	*Heloderma horridum*	Mexican-beaded lizard	[110, 122]
Iguanidae	*Ctenosaura pectinata*	Mexican spiny-tailed iguana	[110]

Family	Scientific name	Common name	Reference
	Iguana iguana	Green iguana	[110, 122]
	Phrynosoma asio	Giant-horned lizard	[110]
	Sceloporus horridus	Horrible spiny lizard	[110]
	Ctenosaura pectinata	Mexican spiny-tailed iguana	[122]
Leptotyphiopidae	*Leptotyphlops humilis*	Western thread/Blind snake	[110]
Microhylidae	*Hypopachus variolosus*	Mexican narrow-mouthed toad	[110]
Pareidae	*Pareas monticola*	Common slug snake	[121]
Phrynosomatidae	*Sceloporus melanorhinus*	Black-nosed lizard	[110]
	Sceloporus utiformis	Spiny lizard	[110]
	Urosaurus bicarinatus	Tropical tree lizard	[110, 122]
	Phrynosoma asio	Giant-horned lizard	[122]
	Sceloporus uniformis celaenorrhinus	Yellow–backed Spiny Lizard	[122]
	Phyllodactylus lanei	Lane's leaf-toed gecko	[122]
Plethodontidae	*Chiropterotriton chondrostega*	Gristle-headed splayfoot salamander	[109]
Pythonidae	*Python reticulatus*	Reticulated python	[111, 121]
	Python molurus	Indian/Black-tailed python	[121]
	Loxocemus bicolor	Mexican burrowing python	[110]
Scincidae	*Sphenomorphus variegatus*	Variegated skink	[111]
	Sphenomorphus beyeri	Beyer's sphenomorphus	[111]
	Lipinia pulchella	Yellow-striped slender tree skink	[111]
	Eutropis multicarinata borealis	Philippine mabuya	[111]
	Eutropis englei	Six–striped mabouya	[111]
	Lygosoma bowringii	Bowring's supple skink	[121]
	Lygosoma lineolatum	Striped writhing skink	[121]
	Lygosoma punctata	Dotted writhing skink	[121]
	Sphenomorphus maculatus	Spotted forest skink	[121]
	Takydromus khasiensis	Java grass lizard	[121]
	Plestiodon parvulus	Southern pygmy skink	[110]
	Scincella assatus	Red forest skink	[110]
	Marisora brachypoda	Middle American short-limbed skink	[122]
Teiidae	*Ameiva undulata*	Rainbow amevia lizard	[110]
	Aspidoscelis lineattissimus	Many-lined whiptail	[110]
	Aspidoscelis communis lineattissima	Giant whiptail lizard	[110, 122]
Typhlopidae	*Ramphotyphlops braminus*	Brahminy blind snake	[121]
	Typhlops diardii	Diard's blind snake	[121]
	Typhlops jerdoni	Jerdon's worm snake	[121]
Varanidae	*Varanus bengalensis*	Clouded monitor lizard	[121]

Family	Scientific name	Common name	Reference
	Varanus flavescens	Yellow monitor lizard	[121]
	Varanus salvator	Asian water monitor lizard	[121]
Viperidae	*Tropidolaemus wagleri subannulatus*	Bornean-keeled pit viper	[111]
	Crotalus basiliscus	Basilisk rattle snake	[110]

Table 4. List of reptile species occurs in tropical forest.

6. Conclusion

In conclusion, this review has attempted to highlight that the tropical forests are ideal habitat for a variety of wildlife species, especially birds, mammals, reptiles, and amphibians. This might be due to the occurrence of heterogeneity of vegetation structure and composition, richness and diversity of food resources, safe breeding and nesting sites, and shelter from predators and harsh weather. These forests should be kept intact, preserved, and managed scientifically on a sustainable basis to reduce the human interference and for future generation.

7. Recommendation for future research and conservation

Furthermore, in future, a detailed research on the wildlife ecology should be carried out by investigating the effects of independent environmental variables with respect to the habitat selection and association, vegetation structure and composition, home range and distribution, population parameters, occurrence of food resources and distribution, influence of human interventions on wildlife population, habitat disturbance, etc. This will help to identify the threats facing different wildlife species and their habitats, indicate the current status of wildlife population within the landscape, and determine the productivity of the particular area.

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Chapter 4

Methods to Evaluate Land-Atmosphere Exchanges in Amazonia Based on Satellite Imagery and Ground Measurements

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Additional information is available at the end of the chapter

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Abstract

During the last three decades, intensive campaigns and experiments have been conducted for acquiring micrometeorological data in the Amazonian ecosystems, which has increased our understanding of the variation, especially seasonally, of the total energy available for the atmospheric heating process by the surface, evapotranspiration and carbon exchanges. However, the measurements obtained by such experiments generally cover small areas and are not representative of the spatial variability of these processes. This chapter aims to discuss several algorithms developed to estimate surface energy and carbon fluxes combining satellite data and micrometeorological observations, highlighting the potentialities and limitations of such models for applications in the Amazon region. We show that the use of these models presents an important role in understanding the spatial and temporal patterns of biophysical surface parameters in a region where most of the information is local. Data generated may be used as inputs in earth system surface models allowing the evaluation of the impact, both in regional as well as global scales, caused by land-use and land-cover changes.

Keywords: surface energy budget, CO_2 fluxes, eddy covariance, remote sensing, Amazon region

1. Introduction

Amazon rainforests directly influences the terrestrial climate system due to the emission or absorption of carbon dioxide (CO_2) and evapotranspiration (ET), that is, through the processes of transpiration of plants and evaporation of water contained in leaves, stems, litter and soil [1, 2]. In addition to providing water vapor to the environment, influencing the general circulation in the tropics and contributing to regional precipitation, the Amazon rainforests are important in the atmospheric carbon cycle [3, 4]. Consequently, deforestation in the Amazon can lead to changes in surface net radiation (R_n), resulting in higher or lower availability of energy for the evapotranspiration processes and in the amount of CO_2 absorbed or released by the atmosphere [5–7].

The relevance of physical phenomena related to energy exchanges between the surface and atmosphere under climate change leads to the need for improving studies on both temporal as well as spatial scales [8, 9]. During the last three decades, intensive campaigns and experiments have been developed for acquiring micrometeorological data in the Amazonian ecosystems, which has increased our understanding of the variations, especially seasonally, of the total energy available for the atmospheric heating process by the surface, ET and atmospheric CO_2 exchanges [10, 11]. However, measurements obtained by such experiments are usually local and representative of small areas, and therefore not representative of the spatial variability of these processes [12, 13].

In this context, new methodologies have been developed to obtain the components related to energy and CO_2 exchanges between the surface and atmosphere, such as the use of remote sensing (RS). Usually, the use of orbital sensors to estimate energy and CO_2 fluxes are performed using models that consider information obtained directly from the satellite images as inputs, such as reflectance and land surface temperature (LST) [14, 15]. Regarding the estimation of surface energy fluxes, several algorithms have been developed, such as the Simplified Surface Energy Balance Index (S-SEBI) [16] and Evapotranspiration Assessment from Space (EVASPA) [17]. To estimate CO_2 fluxes, we can highlight Parametric Production Efficiency Model (C-Fix) [18] and Temperature and Greenness Rectangle Model (TGR) [19]. These models were applied in different terrestrial biomes; however, it is worth mentioning that in the Amazon region such approach for the determination of energy and CO_2 fluxes using RS data is still incipient [20–25].

Based on the considerations above, this chapter aims to present and discuss several models developed to estimate surface energy and CO_2 fluxes by combining satellite data and micrometeorological observations, highlighting the potentialities and limitations of such models for applications in the Amazon region.

2. Biosphere-atmosphere interactions studies in the Amazon region using in-situ measurements

Since the 1980s, a series of micrometeorological experiments have been conducted in the Amazon region aiming to better understand the interactions between the rainforests and the atmosphere (i.e. Amazonian Research Micrometeorological Experiment (ARME, 1983–1985) [26], Amazonian Boundary-Layer Experiment (ABLE, 1985–1987) [27], Anglo-Brazilian Amazonian Climate Observational Study (ABRACOS, 1991–1995) [28], and Green Ocean Amazon Experiment (GO-AMAZON, 2014–2015) [29]). Currently, the main source of surface measurements in the region is the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) [30]. LBA has sites on different land-use locations in the states of Rondonia (RO), Amazonas (AM), Para (PA) and Tocantins (TO). LBA data have been used to analyze the current state of the Amazonian ecosystem, as well as to serve as input and validation parameters for climate prediction numerical models [31].

Typical variables collected at these surface experiments are incoming solar radiation ($K\downarrow$), outgoing solar radiation ($K\uparrow$), albedo (α_s) [32, 33], incoming ($L\downarrow$) thermal infrared (TIR) radiation, emitted TIR ($L\uparrow$), net radiation (R_n) [34, 35], soil heat flux (G), sensible heat flux (H), latent heat flux (λE) [10, 36], and the net ecosystem exchange (NEE) [5, 37]. It is important to mention that most of the observational studies in the Amazon region have been performed over primary forest and pasture areas. In this context, one way to extend such analyses to the diverse ecosystems of the Amazon is the combined use of surface measurements (i.e. plot-level and flux towers biometric studies) and RS data [38, 39].

3. Modeling energy and CO_2 fluxes combining remote sensing and ground data

The frequency at which satellite data are obtained and processed, combined with the possibility of regional and global studies, provides an excellent cost-benefit ratio. In recent years, there has been a gradual advance in the technical characteristics of the sensors onboard orbital platforms, which present increasingly improved spatial, temporal, radiometric, and spectral resolutions. Within this context, the scientific community has used orbital data to estimate surface biophysical and hydrological parameters using different algorithms. Focusing on the estimation of energy and CO_2 fluxes using RS and ground observations, this topic presents the main models available in the literature that can be applied in the Amazon region.

3.1. Models to estimate energy fluxes

First studies to estimate energy fluxes using RS date back to the 1970s [40], driven by the limited spatial density of surface measurements, which prevented more robust large-scale studies [41]. Currently, studies are focused not only in the estimation but also on describing the land-vegetation-atmosphere energy exchange processes in order to better understand, for example, the feedback mechanisms between the surface and the boundary layer. This issue is gaining importance due to potential climate change [42].

Energy fluxes models differ according to the input data, assumptions and accuracy of the results [43, 44]. However, a common aspect among the algorithms is the orbital input data, once all algorithms require information regarding the visible, near infrared and thermal infrared spectral regions. The primary estimates from such models are related to R_n, G, H, λE and, consequently, ET. ET is considered a key variable in such models, and, likewise, the most complex variable when referring to the accurate estimate. **Figure 1** [25] exemplifies ET estimates in the Amazon region obtained through MODIS images. Briefly, according to Ruhoff et al. [45], such algorithms are based on (1) empirical and statistical methods, (2) residual energy balance methods, and (3) other physical methods (i.e. Penmann-Monteith equation [46]).

3.1.1. Surface energy balance algorithms for land (SEBAL)

SEBAL [47] is a model based on empirical relationships and physical parametrizations. It was developed to estimate the energy available at surface using daily orbital data and minimal field measurements. Input variables are related to air temperature and wind speed during the satellite passing. SEBAL has been improved since its conception, for example, with the addition of new parametrizations such as those for α_s [48], and G [49].

The algorithm consists of several steps, with R_n being the first component of the energy balance to be obtained. Following R_n, it is possible to estimate G (as a function of R_n, normalized difference

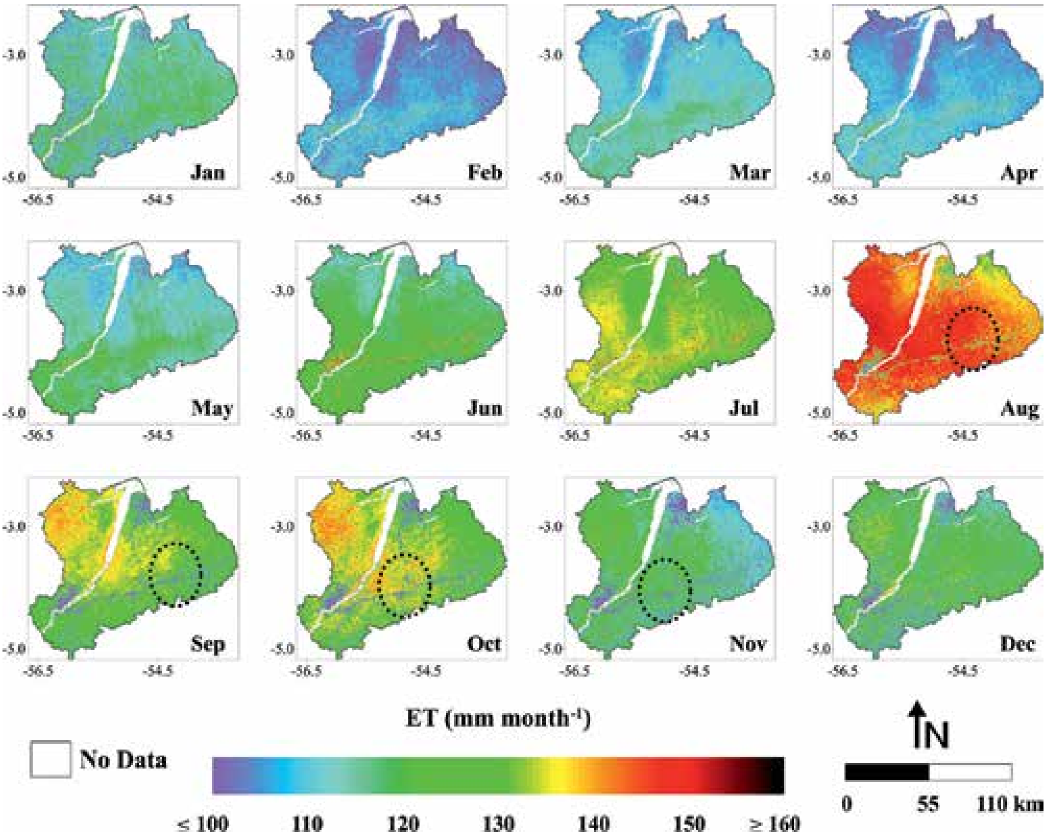

Figure 1. Obtained from the study of De Oliveira et al. [25]. Monthly averages of evapotranspiration (ET) (mm month^{-1}), between the years 2001 and 2006, in the eastern flank of the Amazon region, using MODIS images. The black dashed circles show the spatial pattern of deforestation in the Amazon, known as the fish bone.

vegetation index (NDVI), α_s, and land surface temperature (LST)), and H, which requires the determination of pixels representing extreme conditions of temperature and humidity in the study area, referred to as hot and cold pixels. The determination of hot and cold pixels is an issue, where the lack of user-experience can introduce errors, such as defining fire pixels as hot pixels and cloud pixels as cold pixels [50]. Recent studies proposed statistical approaches to automatically select hot and cold pixels [51]. One of the last steps of SEBAL is the estimation of daily actual ET (ET_{r24h}):

$$ET_{r_{24h}} = 86400 \frac{\Lambda R_{n24h}}{\lambda} \tag{1}$$

where Λ is the evaporative fraction, R_{n24h} is the average daily radiation budget, and λ corresponds to the latent heat of water vaporization ($\lambda = 2.45 \times 10^6$ J Kg^{-1}).

SEBAL has been applied and validated in different regions [14, 52–54]. This model is sensitive to land-use, allowing for evaluations in agricultural areas, deserts, prairies, and forests [55, 56]. Regarding the accuracy of the estimates, studies indicate relative errors ranging between ~5 and 17% [14, 57–59]. The error variation was mostly related to the spatial resolution of the satellite images used. Also, it should be highlighted that the main sources of uncertainties in SEBAL are related to the determination of H and the low sensitivity of the model to soil moisture and water stress [47].

Studies using SEBAL have been conducted in the Amazon region, such as in De Oliveira and Moraes [21], De Oliveira et al. [22], Liberato et al. [60], Santos et al. [61], and Ferreira et al. [62]. These studies were performed in the southwestern and eastern parts of the Amazon using LBA data from the following sites: Fazenda Nossa Senhora Aparecida (FNSA) (RO), Reserva Biologica do Jaru (RBJ) (RO), Floresta Nacional de Caxiuana (CAX) (PA), and Floresta Nacional do Tapajos (FNT) (PA). Orbital input data were acquired from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors onboard Terra and Aqua satellites and the Thematic Mapper (TM) sensor onboard LANDSAT-5. Results found for Rn were satisfactory, presenting relative errors of ~1–16%. For ET, the errors were higher, in the order of ~25%. It should be noted that such studies were conducted over relatively small/medium areas (~7500.000 hectares) and some of them covered only pixels where the flux towers were located due to the difficulty in acquiring cloud free images.

A possible way to operationalize SEBAL for larger scale studies in the Amazon region is using data from 8 or 16 days composites or monthly images from MODIS sensor [63], in which cloud cover effects are attenuated. Although considering that the algorithm was developed for daily images, difficulties emerge related to the surface input data, which need to be acquired during the satellite crossing. In this regard, we highlight the study conducted by De Oliveira et al. [22], in which an approach was developed to estimate R_n and its components under all-sky conditions for the Amazon region through SEBAL model utilizing only RS and reanalysis data. Comparison between estimates obtained by the proposed method and observations from LBA towers showed errors between ~13–16% and ~11–16% for instantaneous and daily R_n, respectively. According the authors, the approach was an alternative to minimize the problem related to strong cloudiness over the region and allowed for consistently mapping the spatial distribution of net radiation components in Amazonia. In this regard, we highlight that further studies should focus in the determination of ET, the most important component of the Amazon hydrological balance.

3.1.2. Simplified surface energy balance index (S-SEBI)

S-SEBI [16] is a semi-empirical model developed soon after SEBAL, such that both models are very similar. The main differences between both models are related to the estimation of thermal infrared radiation emitted from the surface, H and λE [64], which will be discussed further. S-SEBI needs spectral radiance orbital data obtained during clear sky conditions from visible, near infrared and thermal infrared spectral regions to define the initial variables of the model, which are the reflectance, LST and vegetation indices. From these initial variables and the inclusion of air temperature data, it is possible to estimate all the energy balance terms [65, 66].

R_n is estimated from the residual term of solar radiation and thermal infrared exchanges, and G is estimated from the empirical relationship between the characteristics of the surface and the vegetation [67]. It is important to highlight that G is one of the components of the energy balance equation most difficult to be accurately estimated using RS data. Therefore, regardless of the parametrization or the model applied, the equation to obtain G must be adjusted locally in order to achieve better results [68]. It is important to mention here that in forested areas such variable is not relevant to the energy balance; however, over bare soil or areas with sparse vegetation G is an important component of the energy balance.

H and λE are estimated from the evaporative fraction ($\ni$) [16], consisting on the main difference between SEBAL and S-SEBI models [43]. In S-SEBI, sensible and latent heat fluxes are obtained at the same time directly from the $\wedge$, while in SEBAL such variables are estimated separately. Thus, it is not necessary to select pixels representing the null conditions of the fluxes when using S-SEBI. According to Roerink et al. [16], there is a correlation between reflectance and LST in areas presenting constant atmospheric forcings. Therefore, it is assumed that the $\wedge$ varies linearly with LST for a given albedo. By using regressions, it is possible to identify the superior (drier, higher H) and inferior (wetter, higher λE) limits of LST. From the instantaneous values of H and λE, daily ET can be estimated for the entire image.

Studies based on S-SEBI generally use TM/LANDSAT-5 data and are focused on evaluating agricultural areas in Europe and Asia [69–71]. In Brazil, S-SEBI was applied in the semi-arid [72] and in the southwestern regions [73]. Errors found in these studies ranged from ~10 to 30%. It is worth mentioning that S-SEBI usually presents higher errors than those obtained from SEBAL, which, according to Sobrino et al. [67], is related to the more robust estimation of H in the algorithm proposed by Bastiaanssen et al. [57]. However, there are advantages when using S-SEBI, such as the need of only one surface variable input (air temperature). In this case, the choice of the algorithm depends on both the availability of surface data and the intended application. In relation to Amazonia, a region with a lack of surface observations, S-SEBI may be a suitable proposition. Nevertheless, such as pointed out for SEBAL, the ideal application of S-SEBI in the region should focus on the use of MODIS composites.

3.1.3. Surface energy balance system (SEBS)

SEBS [74] is a single-source model developed to estimate the atmospheric turbulent fluxes using RS data. In single-source models, which also include SEBAL (Section 3.1.1) and S-SEBI (Section 3.1.2), the general assumption made is that the radiometric surface temperature measured by a radiometer (orbital sensor) is equivalent to aerodynamic surface temperature [75]. As discussed in the previous sections, these models are based on the difference between dry and wet limits to estimate ET on a pixel-by-pixel basis. Such limits usually follow these characteristics: (1) maximum (minimum) LST, and (2) low or no (high or maximum) ET [41].

To generate such estimates, SEBS requires three types of input datasets. The first dataset consists on α_s, LST, vegetal cover fraction, and leaf area index (LAI) which usually obtained from RS images combined with specific information of the study area [76, 77]. Additional data includes vapor pressure deficit, air temperature and humidity, as well as wind speed, obtained from surface-level stations or reanalysis data. The third dataset is related to the incoming solar and thermal infrared radiation fluxes, which can be obtained directly from the surface-level measurements or reanalysis data.

Estimates of R_n and G follow the same assumptions as SEBAL and S-SEBI, while the estimates of H and λE present differences. In SEBS, for the dry limit, λE is assumed as zero (λE_{dry}), due to the soil moisture limitation, meaning that H reaches its maximum value (H_{dry}). Considering the wet limit, ET occurs in the potential rate (λE_{wet}), and H reaches its maximum value (H_{wet}). After the calculation of H_{dry}, H_{wet} and H, based on Monin-Obukhov Similarity Theory [78], the relative evaporation and reference evaporation fractions (Λ_r and Λ_{ref}, respectively) are obtained from Eqs. (2) and (3).

$$\Lambda_r = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}} \tag{2}$$

$$\Lambda_{ref} = \frac{\Lambda_r \lambda E_{wet}}{R_n - G} \tag{3}$$

By inverting Eq. (3), it is possible to determinate λE for all pixels of the image. It is worth mentioning that during the parametrization of the turbulent processes in the layer immediately above the vegetation is necessary to define the surface roughness length [79]. Most of the algorithms consider a fixed value for the surface roughness length, while SEBS proposed a new formulation to define such variable, which, according to Li et al. [43], is one important advantage of using SEBS, since H is estimated more accurately.

Several studies have shown the potential of SEBS in daily, monthly and annually estimates of ET on local and regional scales [80–83]. Among the studies presented above, we highlight the work developed by Jia et al. [80] to estimate ET in the delta of the Yellow river in China. The authors used MODIS composites of reflectance, LST, and LAI to obtain ET values for 14 different land-use types, achieving mean square errors of ~0.9–1.3 mm. Overall, studies show that the errors between SEBS estimates and in situ measurements range between ~8 and 15% [84, 85]. Summarizing, SEBS presents advantages when compared to other algorithms, such as the surface roughness length estimate and the possibility of using MODIS composites; however, it requires a large number of surface parameters, which in regions like the Amazon can be an important issue.

3.1.4. Evapotranspiration assessment from space (EVASPA)

EVASPA [17] is a model developed to estimate ET using RS data considering spatial and temporal scales relevant for hydrological studies. Important characteristics of this algorithm include: (1) possibility of integrating data from multi-sensors, (2) estimation of the uncertainties, and (3) production of ET maps for days when there are no RS images available. EVASPA is based on S-SEBI [16] (Section 3.1.2) and the triangle method [85], which are very similar in general. The study of Gillies et al. [86] provides a review of the principles of the triangle method to estimate ET.

EVASPA model is focused on generate ET estimates on the kilometric scale using MODIS sensor data from both Terra and Aqua satellites. However, the algorithm enables the generation of estimates using higher spatial resolution sensors, such as TM/LANDSAT 5 and ASTER/Terra. In this regard, we highlight that this is a relatively recent model where equations for higher spatial resolution sensors are still not implemented. EVASPA estimates are generated using MODIS daily and eight- or 16-day data regarding α_s, LST, emissivity, LAI, and vegetation indices. The surface-level input data required consist in incoming solar and thermal infrared radiation. Numerical terrain information is also necessary and is usually obtained from the global digital elevation model GTOPO30 (http://edcdaac.usgs.gov/gtopo30/gtopo30.asp).

The model has several equations for each parameter necessary to estimate ET, such as R_n [65], G [87], and Λ [88]. Therefore, different estimates of ET are provided depending on the input data, enabling the evaluation of the uncertainties in the estimates of ET. Still, the model contains algorithms to interpolate ET estimates in days without orbital data or cloud cover [89]. Consequently, the model is an interesting option for applications in the Amazon, where it is difficult to obtain cloud free data in the region. Finally, it is worth mentioning the possibility of comparing EVASPA estimates with MODIS global ET product (MOD16) [90], which will be discussed in sequence. EVASPA generates as outputs graphics of accumulated monthly and annual ET, difference maps, and dispersion diagrams.

Initially, EVASPA validation was performed using in situ data acquired from a site located in southern France between 2009 and 2011 [17]. Mean square error corresponded to 0.78 mm, while R^2 was 0.76. It is noteworthy that both the characteristics of the model (i.e. reduced surface data required and the possibility of estimates for days without RS images available) and initial validation results are promising, therefore EVASPA presents a considerable potential for application in the Amazon region.

3.2. Models to estimate CO_2 fluxes

The eddy covariance system is the most common way to evaluate the carbon balance over terrestrial ecosystems [91]. However, estimates obtained from such system represent only fluxes at the tower scale, which ranges from hundreds of meters to a few kilometers. Therefore, many studies have been conducted aiming to understand the processes involving the carbon gained from ecosystems through photosynthesis and the carbon loss through respiration using RS data and modeling [53].

Most of the models are based on a radiation use efficiency (RUE) approach, although there are other empirical approaches. The concept of RUE was proposed by Monteith [92] and later became the basis for the use of RS to quantify the vegetation productivity. The algorithms are based on the relationship between RUE, absorbed photosynthetically active radiation (APAR), fraction of absorbed photosynthetically active radiation (fAPAR), and additional environmental variables that may limit photosynthesis [93]. Major difficulties in estimating RUE at large areas include dependency of environmental variables and the vegetation characteristics, as well as issues to estimating APAR (i.e. dependency of atmosphere dynamics) [94]. The primary outputs of these models are related to gross primary productivity (GPP), net primary productivity (NPP), ecosystem respiration (R_{eco}), and net ecosystem carbon exchange (NEE). **Figure 2** [25] illustrates GPP estimates in the Amazon region using MODIS images.

3.2.1. *Carnegie-Ames-Stanford approach (CASA)*

CASA [95] is a model based on the processes of carbon assimilation and respiration to estimate NPP using satellite observations. The model incorporates assumptions of most biogeochemical algorithms, that is, CO_2 fluxes are controlled by ecosystem properties and driven by climate variability. The CASA formulation is based on the concept of vegetation greenness [96, 97]. Vegetation greenness level can be estimated from vegetation indices derived from RS, e.g. NDVI, given the good correlation between these indices with different biophysical parameters of the vegetation (i.e. fAPAR, LAI) [98].

CASA estimates NPP from RUE [92]. Thus, plant biomass production is estimated as a product of incoming solar radiation (K↓), fAPAR, and a term of radiation use efficiency (ε) ($\varepsilon = 0.389$ g C m^{-2} MJ^{-1}), which is multiplied by scale factors (f) of air temperature (T_{air}) and soil moisture (w), according to Eq. (4):

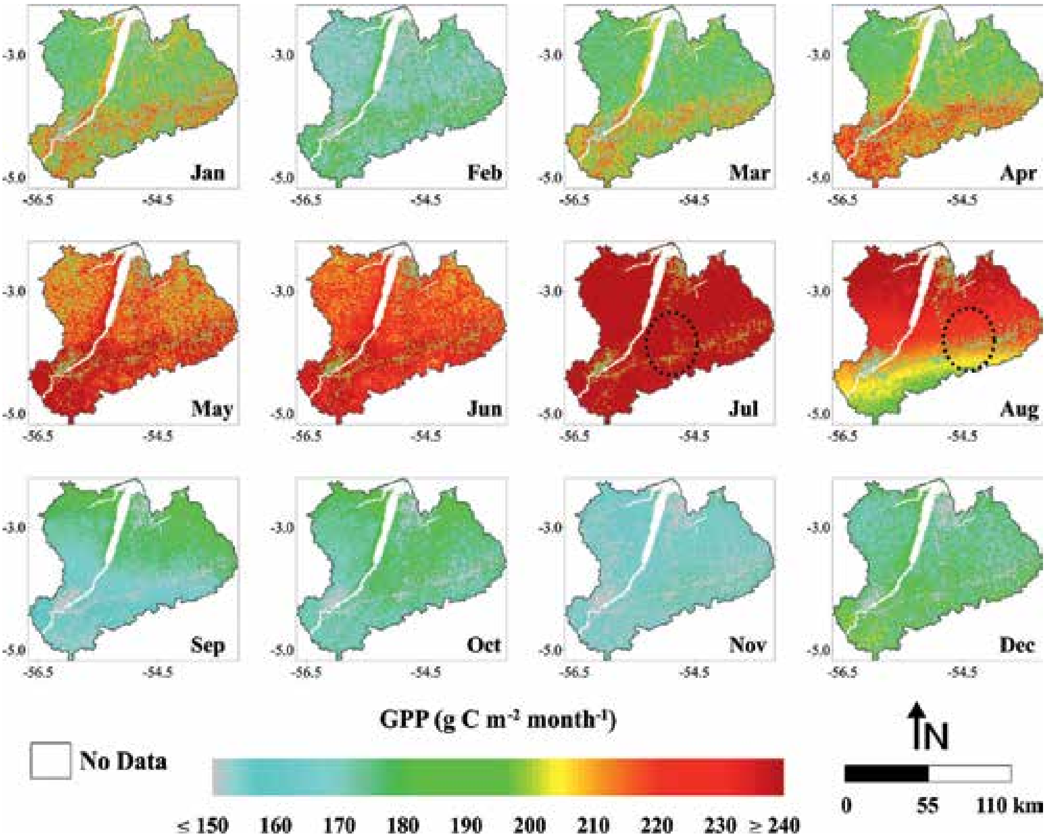

Figure 2. Obtained from the study of De Oliveira et al. [25]. Monthly averages of gross primary production (GPP) (g C m^{-2} $month^{-1}$), between the years 2001 and 2006, in the eastern flank of the Amazon region, using MODIS images. The black dashed circles show the spatial pattern of deforestation in the Amazon, known as the fish bone.

$$NPP = K\downarrow fAPAR\varepsilon f(T_{air})f(w) \tag{4}$$

As noted, air temperature and soil moisture are used to reduce the RUE from the maximum value. CASA requires surface measurements related to solar radiation, air temperature and precipitation as input data. The estimates generated from the model are usually well correlated with NPP obtained from the regional scale field observations; however, when compared to specific ecosystems (i.e. agricultural crops, forests and pastures) the correlations are low [99]. According to Yu et al. [100], this occurs because maximum RUE from CASA ($\varepsilon = 0.389$ g C m^{-2} MJ^{-1}) is not comparable to the RUE from diverse biomes.

3.2.2. Parametric production efficiency model (C-Fix)

C-Fix [18] is a model based on Monteith [92] and developed to quantify carbon fluxes on local, regional and global scales [101, 102]. Similar to CASA (Section 3.2.1), the key-element of C-Fix is that the biophysical state of the vegetation cover can be inferred from RS data. Therefore, C-Fix is basically derived from three steps: (1) mapping the vigor of the vegetation using NDVI estimated from orbital sensors, (2) estimation of fAPAR based on the relationship proposed by Myneni and Williams [103], and (3) inclusion of air temperature and incoming solar radiation measurements.

C-Fix provides the estimation of GPP, NPP, and net ecosystem productivity (NEP) according to the following equations:

$$GPP = f(T_{air})f\left(CO_{2,fert}\right)\varepsilon fAPARcK\downarrow \tag{5}$$

$$NPP = GPP(1 - R_a) \tag{6}$$

$$NEP = NPP - R_h \tag{7}$$

In Eqs. (5)–(7), $f(T_{air})$ is a normalized factor of air temperature, $f(CO_{2,fert})$ is a normalized factor of CO_2 fertilization, ε is the term of radiation use efficiency ($\varepsilon = 1.10$ g C m^{-2} MJ^{-1}), c is the climatic efficiency ($c = 0.48$) [104], R_a is the autotropic respiration, and R_h is the heterotrophic respiration. Variables R_a and R_h are obtained from the algorithms proposed by Veroustraete et al. [105]. Maximum RUE in C-Fix is constant ($\varepsilon = 1.10$ g C m^{-2} MJ^{-1}), reduced by the normalizing factors of air temperature and fertilization by CO_2 dependency. Meteorological input data for the model are incoming solar radiation and air temperature.

Regarding C-Fix validation, studies indicate a reasonable correlation between fluxes estimated from the model and eddy covariance measurements (R^2~0.75) [18]. Recent upgrades in C-Fix, such as the insertion of hydric limitation functions have provided an improvement in the model performance when compared to field measurements [106]. However, there is a lack of studies to precisely evaluate the main sources of uncertainties in the model.

Studies conducted in Europe, using orbital data derived from AVHRR/NOAA and VEGETATION/SPOT 4 [18, 107], show that the model provided a solid basis for estimating the temporal and spatial distribution of the main components of the carbon budget in forest ecosystems on a regional scale. Such results, combined with the performance assessment and the requirement of few in situ information, show the potential of applying C-Fix in Amazonia.

3.2.3. Vegetation photosynthesis model (VPM)

VPM [108] was developed to estimate GPP in forest areas using vegetation indices obtained from optical sensors. During the last three decades, NDVI time series have been used in modeling GPP and NPP [109]; however, NDVI presents limitations, such as the sensitivity to atmospheric aerosols [110]. The inclusion of spectral bands located in the blue and short wave infrared regions in sensors such as the VEGETATION/SPOT 4 and MODIS/Terra and Aqua enabled the estimation of different vegetation indices that reduced some of the limitations and uncertainties imposed when merely using NDVI. In view of that, estimates generated from VPM consider EVI [111] and the land surface water index (LSWI) [112].

VPM is also based on an RUE approach, however it presents a key difference which is assuming that forest canopy is composed of photosynthetically active vegetation (PAV) (i.e. chloroplasts) and non-photosynthetically vegetation (NPV) (i.e. senescent leaves and branches) [97]. GPP estimated using VPM is obtained from the following equation:

$$\mathrm{GPP} = \varepsilon \mathrm{fAPAR}_{\mathrm{PAV}}\,\mathrm{IPAR} \tag{8}$$

In Eq. (8), $\mathrm{fAPAR}_{\mathrm{PAV}}$ is the fraction of photosynthetically active radiation absorbed by PAV, and IPAR represents the incoming photosynthetically active radiation. $\mathrm{fAPAR}_{\mathrm{PAV}}$ is estimated as a linear function of EVI [108]. The contribution of fAPAR in $\mathrm{fAPAR}_{\mathrm{PAV}}$ and $\mathrm{fAPAR}_{\mathrm{NPV}}$ is important, since the presence of NPV significantly affects fAPAR at the canopy scale. For example, in forests with LAI < 3.0, NPV increased fAPAR by ~10–40% [113]. Also, it is important to point out that only $\mathrm{fAPAR}_{\mathrm{PAV}}$ is used in photosynthesis. Therefore, it is evident that this partition is a critical issue when modeling GPP or NPP in forests, considering $\mathrm{fAPAR}_{\mathrm{PAV}}$ may substantially increase the estimates. However, most of the CO_2 fluxes algorithms do not incorporate this assumption.

Another highlight of VPM is that the term ε is not constant, as opposed to CASA and C-Fix, varying according to the vegetation. ε parametrization in distinct forest formations is given by NEE and IPAR measurements obtained from flux towers located in specific sites. Research was conducted to define this variable in the boreal forest ($\varepsilon = 2.21$ g C m^{-2} MJ^{-1}) [108], and also in tropical rainforest ($\varepsilon = 2.48$ g C m^{-2} MJ^{-1}) [114]. Functions of air temperature, phenology, and water content of leaves (estimated from LSWI) are used to reduce the scale of ε. Required surface information of VPM are air temperature, NEE and IPAR.

Regarding the validation of VPM, Liu et al. [115] obtained R^2~0.88 when comparing the model outputs with surface measurements, while Jiang et al. [116] found relative errors of ~59%. According to Xiao et al. [108], the main sources of errors of VPM are related to the low sensitivity to PAR and air temperature, as well as the non-correction of the bidirectional effects on vegetation indices. VPM was applied to different forest ecosystems across the globe, among them, the Amazon rainforest [114]. The study conducted by Xiao et al. [114] used

VEGETATION/SPOT 4 and MODIS/Terra and Aqua (daily and 8-day composites) data to generate estimates of GPP over the FNT/K67 site in the state of Para, Brazil. The model estimates showed high NPP in the end of the dry season, which was consistent with the high ET and GPP measured by the micrometeorological tower.

VPM presents a high potential for the seasonal estimation of productivity in tropical forests. However, most of the studies using the model generated estimates only for the tower pixel and adjacent areas (i.e. 3x3 pixels) [114, 115]. Despite the possibility to retrieve GPP locally with a reasonable accuracy [108], the operationalization of VPM for regional analyzes requires modifications to the model, mainly related to the estimation of e for distinct forest formations and/or large areas.

3.2.4. Temperature and greenness rectangle model (TGR)

TGR [19] was developed to estimate the productivity of terrestrial ecosystems using MODIS/Terra and Aqua data. The model is based on studies conducted by Rahman et al. [117], in which a strong linear correlation between EVI and GPP in different forest formations was shown, and Sims et al. [118], which showed that LST can be used to infer the influence of water stress on GPP. Thus, TGR uses as inputs EVI and LST derived from MODIS and in situ IPAR measurements to estimate GPP on 16-day intervals. Three major aspects of TGR should be highlighted: (1) the algorithm strictly follows the RUE concept, (2) it has a low dependency of surface measurements, and (3) the overlapping of information in correlated explanatory variables is avoided.

Based on the proposition of Monteith [92], GPP in TGR model is estimated according to Eq. (9):

$$\mathrm{GPP} = \varepsilon * f(\mathrm{EVI}, \mathrm{L}, \mathrm{ST})\mathrm{IPAR} \tag{9}$$

The term ε^* refers to the amount of carbon fixed per unit of IPAR. It should be noted that this assumption is different from the traditional definition of RUE, which is the amount of carbon fixed per unit of APAR. In TGR, as well as in most of the vegetation productivity models, the term of radiation use efficiency is multiplied by a scale factor, aiming to reduce estimates under unfavorable conditions (i.e. high or low temperature and high vapor pressure deficit). For this purpose, EVI [119] and LST [108] are used. According to Yang et al. [19], it is inappropriate to simply multiply the effect of these two variables, considering that both are physically interdependent. Therefore, to define the f value from EVI and LST the algorithm proposes a methodology based on the least square method [19]. Studies indicate that IPAR may range from ~40 to 50% of the incoming solar radiation [120]. Thus, Yang et al. [19] suggest the use of in situ measurements of this variable in order to reduce the uncertainties.

In TGR, as for VPM (Section 3.2.3), the term RUE is not constant, allowing the calibration for different vegetation formulations. The study of Yang et al. [19] described values of this term for eight types of vegetation, including pasture, savanna, and mixed forest. This study also validated the model considering measurements obtained from 13 different experimental sites in the United States. Results showed that estimates from TGR agreed with tower flux measurements for almost all types of vegetation, with R^2~0.67–0.91. TGR allows to capture the GPP patterns over large areas, which is necessary for applications in the Amazon region.

In this context, we highlight that the use of IPAR data obtained directly from MODIS [121] would eliminate the need of in situ measurements, enhancing the potential of TGR for applications in Amazonia. According to Yang et al. [19], future studies will focus on validating TGR estimates over tropical forest areas.

3.3. Remote sensing global products

RS is the main tool for observing the state and processes of terrestrial surface and atmosphere [122]. LANDSAT, SPOT, NOAA, Terra and Aqua platforms have provided time series of data in different spatial and temporal resolutions, which are applied in a wide range of studies [123]. One application is related to global climate change, where RS data have been used as inputs in climate models to simulate climate dynamics and future projections [124]. Accordingly, it is notable an effort of the scientific community in generating RS derived standardized global products, specially related to the biophysical domain.

Currently, some of the most important global products based on satellite observations are derived from MODIS/Terra and Aqua sensors. MODIS was developed by the Goddard Space Flight Center (GSFC/NASA) and presents an imaging system composed by 36 spectral bands, from the visible to the thermal infrared regions. MODIS temporal resolution is daily for latitudes above 30° and 2 days for latitudes below 30° [125]. Surface products derived from MODIS are related to α_s [126], LST [127], vegetation indices [128], land-use [129] and other variables. More specifically, regarding energy and carbon fluxes, we highlight the ET (MOD16) [90], GPP and NPP (MOD17) [130] products.

3.3.1. MOD16

The MOD16 [90] product was developed to estimate global surface ET from MODIS/Terra and Aqua data and meteorological information obtained from the Global Modeling and Assimilation Office (GMAO). The algorithm is based on Penmann-Monteith equation [46]:

$$\mathrm{ET} = \frac{\Delta(\mathrm{R_n} - \mathrm{G}) + \varrho_\mathrm{a}\,\mathrm{c_p}(\mathrm{e_s} - \mathrm{e_a})/\mathrm{r_a}}{\Delta + \gamma(1 + {}^{r_s}\!/_{r_a})} \tag{10}$$

In Eq. (10), Δ is the gradient of saturated vapor pressure to air temperature, $\mathrm{R_n}$ is the net radiation, G is the soil heat flux, ϱ_a is the air density, c_ϱ is the specific heat of air at constant pressure, $\mathrm{e_s}$ and $\mathrm{e_a}$ are the saturated vapor pressure and actual vapor pressure, respectively, γ is the psychometric constant (0.066 kPa°C^{-1}), and $\mathrm{r_s}$ and $\mathrm{r_a}$ are the surface and aerodynamic resistance, respectively. MODIS input data in the algorithm include α_s, LAI, and land-use. Regarding the meteorological variables, solar radiation, air temperature, and water vapor pressure reanalysis data are used. Summarizing, MOD16 data are provided with spatial resolution of 500 m and 1 km and cover an area of ~109 millions of km^2. MOD16 provides potential and actual ET fluxes at 8 days, monthly and annual intervals.

MOD16 was initially validated using measurements from 46 different tower fluxes across the United States, obtaining R^2~0.65 [90]. It is possible to point out main two sources of uncertainties related to MOD16: (1) GMAO reanalysis data, mostly due to the low spatial resolution (~100 km) when compared to MOD16 (500 m and 1 km), and (2) LAI and land-use products, which may present reasonable inaccuracies depending on the biome, which, consequently, will result in the incorrect determination of parameters to calculate plants transpiration [90]. Most studies using MOD16 are focused on Asia and Middle East, aiming to evaluate watersheds [131, 132] and different land-uses, especially in agricultural areas [133]. Validation performed on such studies agree with results found by Mu et al. [90].

Recent studies validated MOD16 in the Cerrado and Amazon biomes [45, 25]. Over Cerrado, the algorithm presented relative high correlation coefficients, ranging between ~0.78 and 0.81 [45]. Results obtained for the Amazon were less satisfactory. Validation performed using tower fluxes data located over forest and pasture areas showed R^2 values between ~0.32 and 0.76 [25]. It should be noted that simplifications in MOD16 algorithm regarding some parameters such as canopy conductance are defined as constant for a given biome (even in a heterogeneous one, such as the Amazon). This may be one of the reasons for low correlations between the estimated and observed data in the region. This is actually one of the main challenges of global algorithms, which need to be complex to accurately represent the physical processes on the surface, and simultaneously simple enough to be implemented globally [45]. Despite this, MOD16 was able to represent the spatial variability of ET in the Amazon. This is an important result and one interesting way to better evaluate the results of this model for the Amazon would be through the comparison between MOD16 outputs with more local estimates based on the models described in Sections 3.1.1–3.1.4.

3.3.2. MOD17

The MOD17 product [130] provides continuous estimates of GPP and NPP over the vegetated surface of the planet. As well as models described in Sections 3.2.1–3.2.4, the MOD17 algorithm is based on the RUE approach [92]. According to this approach, the productivity of vegetation under reasonable water and soil fertility conditions is linearly correlated with the amount of APAR. MOD17 is based on three basic relationships (Eqs. (11)–(13)) to estimate GPP and net photosynthesis (PS_{Net}), on eight-day and monthly intervals, and annual NPP.

$$\mathrm{GPP} = \varepsilon\left(\mathrm{T}_{\mathrm{air,min}}\right)\mathrm{f(VPD)APAR} \tag{11}$$

$$\mathrm{PS}_{\mathrm{Net}} = \mathrm{GPP} - \mathrm{R}_{\mathrm{lr}} \tag{12}$$

$$\mathrm{NPP} = \sum\left(\mathrm{PS}_{\mathrm{Net}}\right) - \mathrm{R}_{\mathrm{g}} - \mathrm{R}_{\mathrm{m}} \tag{13}$$

In the equations presented above, $f(T_{air,min})$ and f(VPD) are scale factors associated, respectively, to minimum air temperature and vapor pressure deficit, R_{lr} is the maintenance respiration of leaves and thin roots, R_g is the growing respiration, and R_m represents the maintenance respiration of living cells in the woody tissue. It is worth mentioning that the algorithm defines distinct values for ε, depending on the vegetation. ε values are distinct for forest, savanna, pasture, and agricultural areas. $T_{air,min}$ and VPD values, as well as respiration values, are based on a lookup table composed of specific physiological parameters for each terrestrial biome [134]. MOD17 product is estimated from MODIS standard products (i.e. fAPAR and LAI) and reanalysis data (i.e. air temperature and solar radiation) from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). MOD17 outputs (GPP, PS_{Net} (eight-day and monthly), and NPP (annual)), as well as MOD16 outputs, are provided with 500 m and 1 km spatial resolution.

Validation studies comparing MOD17 estimates with flux tower measurements found relative errors between ~24 and 70%, and correlation coefficients ranging between ~0.26 and 0.88 [135–137]. Generally, GPP and NPP derived from MOD17 follow the expected seasonal patterns according to the land-use and climate; however, values tend to be overestimated over low productivity sites (i.e. croplands), and underestimated over high productivity sites (i.e. forests). The main sources of errors in MOD17 are associated with the MODIS fAPAR product and reanalysis data [138].

MOD17 product has been validated over different regions [137, 139, 140]. Regarding the Amazon, an important area in the global carbon cycle, we highlight the study recently developed by De Oliveira et al. [25] in Para state, eastern Brazilian Amazonia. The mean relative error found for MOD17 GPP was about 13% of the field measurements (LBA flux towers). An underestimation was observed for primary and secondary forests (-4.1 and -3.6 g C m^{-2}, respectively) and an overestimation for pasture (2.2 g C m^{-2}). According to the authors, the MOD17 product was able to provide reliable information about the spatial and temporal variability of GPP in the eastern flank of Amazonia.

4. Concluding remarks

Micrometeorological studies in Amazonian ecosystems have limited spatial and temporal coverage, and therefore RS becomes a tool to enhance the comprehension of surface processes in the region. Models to estimate energy and carbon balance components from orbital data differ according to the input data, parametrizations and accuracy of the results. The algorithms to estimate energy fluxes use as inputs images from visible and infrared (near and thermal) spectral regions and are based on empirical and physical methods. In situ measurements are typically related to air temperature and wind speed, and most uncertainties are concentrated in the estimation of H and ET (when obtained as a residual term of the energy budget). On the other hand, CO_2 fluxes models need data from the visible and near infrared spectral regions and are based on the RUE concept. Main challenges of such models consist in the estimation of RUE for different ecosystems, as well as to obtain surface solar radiation data with a reasonable spatial resolution.

Regarding the use of such models in the Amazon region, some difficulties emerge: (1) obtaining cloud free orbital data, and (2) availability of field observations. Therefore, the choice of the algorithm must consider the possibility of using daily composites, and minimal need of in situ data. Other issues, such as the complexity and operability of the models may be considered. It is then possible to point out algorithms that present greater potential of application in the region and/or where efforts for implementation should focus. Regarding energy balance, two models stand out: SEBAL [47], due to the reduced need for field measurements and because the model was previously validated in the region and showed good results, and EVASPA [17], due to the operability and possibility of generating estimates during days when there are no orbital data available. In relation to the carbon models, it is suggested the use of

VPM [108], once the model was applied to distinct forest ecosystems (including the Amazon) showing good results, and TGR [19], due to the fact that the model is based on MODIS composites and has a low dependence of field data.

Regarding the use of global RS products in the Amazon, it is important to emphasize that such products usually enable the analysis of spatial patterns of surface parameters; however, they present inaccuracies when referring to the magnitude of the estimates. A noteworthy aspect is that studies conducted in tropical regions, among them the Amazon, have proposed methodologies based on integrating satellite images and reanalysis climate data in hydrological and ecosystem models based on local measurements [2, 22, 23, 45, 141, 142]. Although there are difficulties, for example those related to representing the ecophysiological processes from leaf to canopy scale, such approaches constitute promising opportunities for future research.

The use of models based on satellite images presents an important role in understanding the spatial and temporal patterns of biophysical surface parameters in a region where most of the information is local. Data generated from such algorithms may be used as inputs in earth system surface models allowing, among others, to evaluate the impact, both in regional and global scales, caused by land-use and land-cover changes.

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People's Perceptions of Ecosystem Services Provided by Tropical Dry Forests: A Comparative Case Study in Southern Ecuador

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Abstract

This research explores the perspective of social actors about the ecosystem services (ES) provided by tropical dry forests (TDF) in two protected areas in southern Ecuador that differ in their management schemes. Identifying the ES and understanding the preferences of local communities is seen as a means for improving decision making, especially in the protected areas. Therefore, our goal was to apply social assessment tools in order to have an in depth appreciation of the factors influencing the perception of social actors in a comparative case study. Since the research was conducted in two areas with similar ecosystem, but with different management, it illustrates the potential role that management policies have at shaping the perception of social actors regarding TDF's ecosystem services. The results suggest that people perceive and prioritize ecosystem services differently according to the area and that such perception and prioritization is influenced not only by the management processes but also by the role that social actors play in the protected area.

Keywords: protected areas management, social assessment, stakeholder perception, sustainability, tropical dry forests

1. Introduction

Conservation studies have recently focused on highlighting the benefits of ecosystem services (ES) to human wellbeing as an incentive for people to protect nature. As a result, ES have been incorporated in the discourse of sustainable resource management and policy making, emerging as the new form of nature commodification to encourage societies to work on conservation.

ES have been defined as the benefits derived from ecosystem functions. The Millennium Ecosystem Assessment (2005) classifies them into four categories: (a) provision services, including the production of raw materials, water and fuels used directly by humans; (b) regulation services, related to processes that influence climate and hydrological cycles; (c) cultural services, referring to educational, scientific, and esthetic benefits; and, (d) supporting services which support other ecosystem services like soil composition, nutrient cycling and primary production [1]. Previous research on ES has been approached mainly from three different perspectives. An ecologic perspective mainly focused on biophysical analyses of the capability of ecosystems to deliver services [2], on the economic valuation of these services [3], and on social methods intended to gauge the values, attitudes and meanings that underline the demand for ES. While economic and ecologic methods have been largely applied in the identification and valuation of ES, a group of researchers pointed out that the social assessment methods have not been fully endorsed. According to Sagie et al. [4] the potential advantage of using such an approach resides in that it helps to understand the importance that local populations place on ES. Moreover, in developing countries, this approach is encouraged as it helps to provide information of ES when scientific knowledge is missing or is difficult to collect [4]. Furthermore, it provides policymakers with information regarding preferences and perspectives of social actors making it easier to tailor specific conservation strategies to suit the realities of local communities [5].

Tropical dry forests (TDF) are ideal ecosystems for studying the importance of ES to local communities as they offer a wide array of services, yet they have been scarcely studied. Some researchers have mentioned that the capacity of TDF to adapt to drought conditions makes them an important genetic reservoir for future restoration projects [6, 7]. For other researchers, TDF occupied the fourth place as carbon sinks [5], while other researchers claimed that these forests offer recreation and tourism services and hold a species richness to provide fodder, timber and non-timber products, climate regulation, and habitat for species [8]. Additionally, these ecosystems support the livelihoods of millions of families worldwide [9, 10]. Despite the importance of these ecosystems, TDF are highly endangered. According to Espinosa et al. [11], there exists a lack of knowledge about the utility of these ecosystems that have led to undervalue these forests.

In Ecuador, the best remnants of TDF are located in the South between the provinces of Loja and El Oro [12]. These forests provide a wide array of ES with climate regulation, water provision, risks prevention against flooding and landslides among the most acknowledged services [13]. In the last decade, new ES have been attributed to these forests including nature conservation and tourism [14]. Together, these services have boosted the efforts for protecting TDF by governmental and non-governmental organizations in Ecuador [15]. However, in spite of the efforts to protect these ecosystems, TDF in southern Ecuador are still threatened by unsustainable agricultural activities [16, 17], and illegal practices such as hunting. Because most of the threat drivers come from anthropogenic activities, the analysis of perceptions about the use of natural resources is crucial to identify people's ES demand [18] in order to identify more effective conservation strategies that involve people's needs.

By employing social research methods, namely questionnaires and semi-structured interviews, in this study we looked at exploring the perceptions that local communities have regarding the use of ES. The study was undertaken in southern Ecuador communities living within or nearby two protected areas holding TDF. These protected areas were selected because they differ in their management processes. In pursuing our objective, we will draw from a comparative case study design, with the aim of identifying and characterizing the ES that are more relevant for local people and to associate the functions and services to particular stakeholder interests and their preferences.

2. Study areas

The study area involves two protected areas holding TDF located in southern Ecuador. The Ceiba Reserve (Ceiba) is a private protected forest situated at south-west Ecuador in the province of Zapotillo, bordering with Peru (4°19′58″ S, 80°24′34″ W) (**Figure 1**). This reserve belongs to an NGO Naturaleza y Cultura Internacional (NCI), who bought the land from local landowners as a mechanism to protect two of the last remnants of dry forest expanding to Peru [17]. It holds 9405.10 ha of relative homogenous dry forest ranging from 200 to 600 masl. In this region two climate seasons occur, the rainy season which extends from January to March, and the dry season that extends for the rest of the year [19]. Moreover, this reserve belongs to the hotspot "Tumbesian Region" [20, 21]. Ceiba sustains 370 families dedicated to goat grazing, corn growing, and apiculture, who work together with NCI to keep sustainable agricultural practices and to protect the local biodiversity [22].

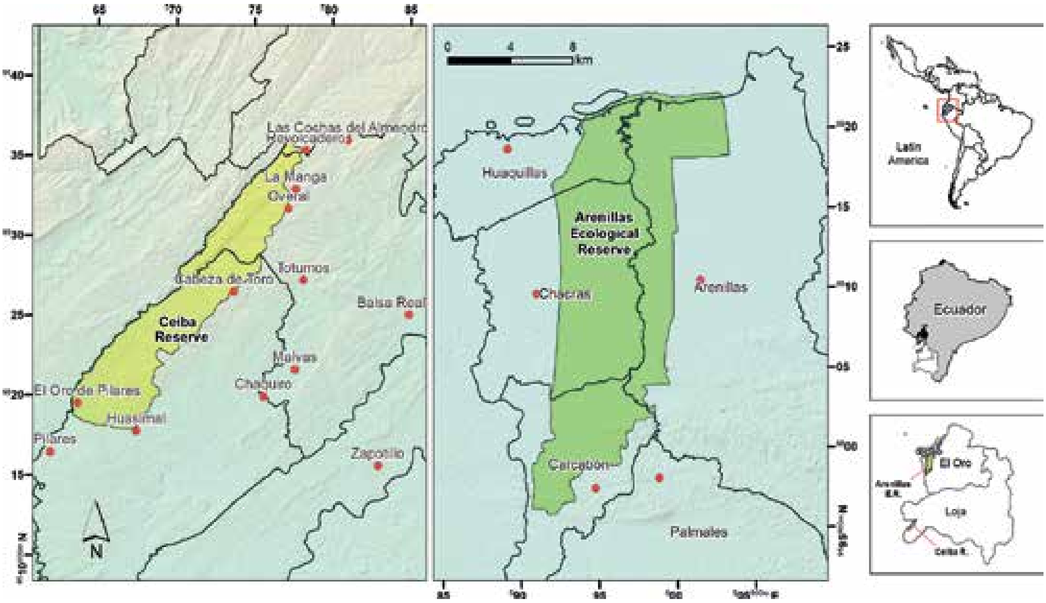

Figure 1. Geographic location of the study area. Red dots represent the places were data was collected.

According to the NCI website [23], Ceiba is managed with the help of local communities who are allowed to maintain sustainable agricultural practices within its territory after obtaining a permission granted by the owners of the area. Moreover, NCI claims to have helped local residents to obtain legal status and rights over the land they have been historically settled in.

The other protected area under study is the Arenillas Ecological Reserve (Arenillas). This protected area was established by the Central Government and is located at south–west between the provinces of Arenillas and Huaquillas (3° 32′ 20.4″ S, 80° 8′ 45.6″ W) in the littoral region [14] (**Figure 1**). It holds 13,170 ha of TDF ranging from 0 to 300 m of altitude that also belongs to the hotspot "Tumbesian Region." The reserve is characterized by its high endemism and presence of species with restricted distribution, especially 55 species of birds considered unique to the dry forests of Ecuador and Peru. Arenillas is under the highest protection category in the country namely Ecological Reserve [13].

Arenillas was always under the custody of the Ecuadorian government since its location between Peru and Ecuador has been strategic for the national security. In 2001, this area was declared as an "Ecological reserve" in the Ecuadorian National System of Protected Areas. This management category has the primary goal of conserving genetic material, ecological diversity as well as scenic beauties. No other activity is permitted within the reserve. According to Briceño et al. [14], the historical management of this reserve has prevented local communities from visiting the area, limiting their knowledge regarding the reserve and the resources it offers.

3. Methods and data analysis

As mentioned earlier, we aimed to identify the ES that are more relevant for local people living near Ceiba and Arenillas, as well as to determine if the perception of such services is related to the type of user and the management of each protected area. In doing so, we selected a comparative case study design. This type of design is recommended when looking for similarities and differences between two cases [22], namely protected areas. In the issue of ES, the majority of studies have focused on quantitative studies regarding economic payments for ES [24, 25], neglecting the importance of mixing qualitative and quantitative data gathering instruments to collect data about people's perception of ES and the relevance of such perception in the management of any protected area. With these conclusions as a backdrop, we draw data from semi-structured interviews and questionnaires as detailed below:

Semi-structured interviews: A total of 32 social actors were identified, 13 in Arenillas, and 19 in Ceiba. The actors were selected according to their interaction with the protected areas either in the use, conservation or management. The social actors interviewed were grouped into the following categories: (i) Public and private managers, (ii) Municipality members, (iii) Local representatives, (iv) Agrarian cooperatives and Associations, and (v) Local Representatives.

Additional influential social actors were identified in each area and were incorporated in the study. For example, in Arenillas, school teachers were included in the study as they regularly visit the reserve with students and have knowledge about the reserve and its ecosystem. In Ceiba, this group was left out of the analysis as the teachers did not interact with the reserve.

The interviews were valuable to identify the ES perceived by key social actors and to understand the reasons for these actors to prioritize some ES. The interview guide was validated through a pilot test conducted with people from the areas sharing similar demographic characteristics. The interview lasted approximately 40 min. All interviews were tape-recorded under informant's consent and later transcribed. The coding process used the categories provided by the Millennium Ecosystem Assessment for ES and further developed by Groot et al. [26]. The subcodes that emerged from the data followed the steps suggested by Saldaña [27]. By following this process, we were able to highlight the ES that were more valuable and visible to participants constructing thus an ES panel for each study area. The panels constructed were presented to each actor who was asked later to identify the five most important ES according to their perception as well as to assign a value to each of the prioritize services from one to five. Being five the most important and one the least important service.

For the analysis and interpretation of the ES, prioritized by participants in both Ceiba and Arenillas, an average per actor was calculated from the assessment of each prioritized ES. The results of each ES were then normalized between zero and one in order to facilitate their representation and comparison [28]. For comparison purposes, the values were presented as a percentage to improve the visualization of the results (Eq. (1)).

$$x' = \frac{x - x_{min}}{x_{\max - }x_{min}} \tag{1}$$

where x′ = normalized value, x = value to be normalized, x_max = maximum value to normalize, x_min = minimum value of group value.

Questionnaires: By using the data of the latest Ecuadorian population census [29], with a standard error of 5% and 95% of confidence intervals, a sample of 240 people was established. Nonetheless, in Arenillas 24 people rejected to participate having a final population sample of 96 people, whereas, in Ceiba 20 people indicated that they did not feel like answering the questions leaving a final population sample of 100 people. In both areas, refusals were based on the grounds of scarce knowledge and acquaintance with the protected areas under study. The final sample included a total of 196 questionnaires that were randomly applied to people living in the surrounding areas of Arenillas and living within and nearby Ceiba. The survey aimed at complementing the information gathered in the interviews. Respondents were approached at their households or at public places such as recreational parks and church gathering. In Arenillas, respondents were mainly men (58%) between 18 and 30 years old (31%), and with a secondary school education (37%). In the Ceiba reserve, respondents were mainly women (57%), over 60 years old (23%), whose primary occupations were housewives (48%) and agriculturalists (37%). The questionnaire was valuable to add data from the general public regarding ES identification and prioritization. The questionnaire was validated through a pilot test conducted with people from the Arenillas reserve sharing similar demographic characteristics. Data obtained from both interviews and questionnaires were analyzed together to identify similarities and differences between survey and interview participants from both areas. The data were analyzed through descriptive statistics.

4. Results

4.1. Ecosystem services identified and prioritized in each study area

In the first round of questions, both interview and survey participants were asked to state the benefits that they or other community members obtain from the protected areas studied. A total of 13 ES were identified by interview and questionnaire participants in Arenillas, whereas in Ceiba, a total of 12 ES were identified (**Table 1**).

For comparison purposes, we divided the table according to the protected area studied, namely Ceiba and Arenillas. The results were categorized according to the ES classification proposed by the Millennium Ecosystem Assessment. Study participants mostly identified provisioning and cultural services. Regulation services were also mentioned but to a lesser extent while supporting services were hardly mentioned by the participants from both areas.

Moreover, the results indicate that participants from both areas prioritize similar ES. However, the order in which they prioritized the services differed slightly in each area. The most prioritized ES in Ceiba were provisioning services, particularly agriculture and goat and deer husbandry. Based on these responses, we assert that participants valued the TDF mainly in terms of the services provided by agro-ecosystems. Accordingly, the most valued services included food production, irrigation water, climate regulation, and habitat provision for deer and goats. Contrasting these results, Arenillas residents prioritized mostly cultural services, which are embraced as an opportunity for recreation as well as tourism (**Figure 2**).

Additionally, interview data suggest that the participants from Ceiba and Arenillas appreciated ES differently. In Ceiba, participants prioritized TDF's ES as a collective benefit for agricultural purposes, whereas residents from Arenillas prioritized TDF as individual benefits such as fuel wood or poaching. Although hardly mentioned, Arenillas' residents more often cited regulation services and showed a better understanding of the indirect services provided by TDF.

4.2. Provisioning services

In Ceiba, the provision of food was ranked highest in the prioritization of ES (96%), being the production of crops such as onions, corn and rice of vital importance to the economy of the families along with the husbandry of goats and deer. According to Benítez and Medina [30], agriculture and husbandry are critical for local people of Ceiba, as 70% of the territory of the province of Zapotillo where Ceiba is located is dedicated to goat grazing. It is not a surprise then that for people living within or nearby Ceiba, food provision and fodder for husbandry were the most prioritized services. In Arenillas, food provision was also prioritized but to a lesser extent than in Ceiba (54%). According to the development plan (2002–2012) [31], the main economic activities in the region are agriculture (49.6%), followed by service activities

Ecosystem Services (ES)	**Specific (ES)**	**CEIBA RESERVE**		**ARENILLAS ECOLOGICAL RESERVE**	
		Indicator	**%**	***Indicator***	**%**
Provision services	Food	Agriculture (Onion, rice and corn)	96	Lemon growing	54
		Husbandry (Goats and deer)		Deer and squirrel poaching	
		Apiculture (Melipona)			
		Food hunting / gathering			
	Raw material	Fodder (*Prosopis juliflora*)	52	Fuel wood (Guayacán, hualtaco) for brick manufacturing.	43
		Timber (Hualtaco/ Guayacán)			
		Construction (Barbasco, hualtaco)			
		Firewood(Algarrobo)			
Regulation services	Water regulation	Water provision	19	Water provision	5
		Water infiltration			
	Life cycle maintenance	Habitat provision	14	Habitat provisioning	34
	Climate regulation	Carbon sequestration	16	Air quality	40
		Air quality		Protective barrier, shade	21
		Climate regulation			
	Erosion prevention	Desertification protection	9	Desertification protection	31
	Pest control	Pest control	1	unidentified	
	Pollination	Pollination	5	unidentified	
Cultural services	Opportunity for Recreation and tourism	Nature tourism, trees blooming	8	Nature tourism, trees blooming	64
		Gastronomy tourism (*Chivo al hueco*, Goat cheese, milk, and custard)			
		Community tourism principles			
	Aesthetical information	Landscape, Guayacan blooming season, waterfall (Coronel)	9	Landscape, photography	5
	Research	Scientific knowledge developing	6	Scientific knowledge developing	11
				environmental education	
	Inspiration for culture		11	unidentified	
		Traditional knowledge			
	Spiritual experience	unidentified		Spiritual experience	1
	Existence value	unidentified		Existence value	3

Table 1. Social perception of the main ecosystem services.

(23.9%) and commerce (10.7%). The diversification of the economic activity in this area and the presence of urban population suggest lower levels of appreciation towards the provisioning services in comparison with the rural population of Ceiba.

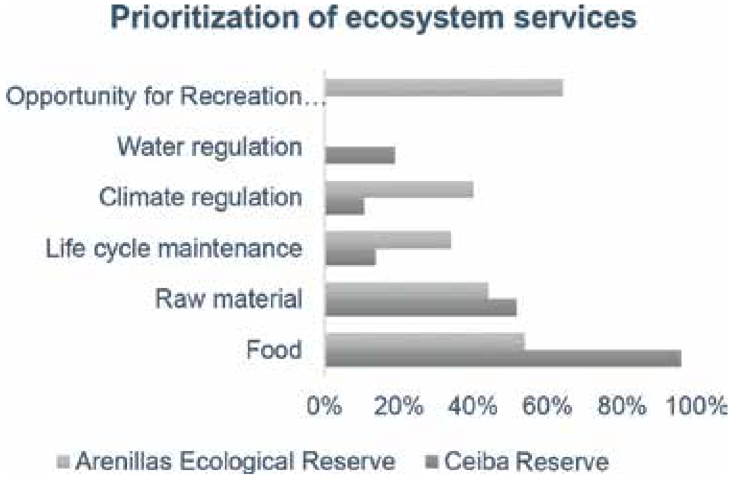

Figure 2. Prioritization of ecosystem services (n=196).

There are also notable differences in the use of provisioning services in both areas. Both Ceiba and Arenillas residents use timber from Guayacan trees due to its suitability for construction. While Ceiba residents use the wood for fodder, fences construction and firewood (52%), Arenillas' residents mentioned its use for brick manufacturing and sometimes the construction of fences (43%). These differences may be explained by their views on extracting natural resources. Ceiba residents seemed very much aware of the benefits that TDF provide and expressed their use of timber in sustainable narratives. As some of the interviewees expressed:

"Nowadays this area has changed since we ourselves look after it, instead of logging, we have planted. We have been even working 8 years for the palo santo project. We collect the fruits in winter time and send them later to Loja for extracting the oil" Cabeza de Toro settler.

Overall, individuals from Ceiba acknowledged that the NGO had a positive impact on their lives, indicating that their behavior and attitudes towards the forest have changed, as expressed in the following quotation:

"We thank NCI for giving us the vision and the path to look after the forest. There used to be logging including Peruvians invading to cut down Guayacan [Tabebuia chrysantha]. We are organized as a group now and keep going forward, one can see the change" Ceiba settler.

In Ceiba, the NGO owners had created a Community Organization called "*2 de Febrero*" with the aim of including inhabitants from neighboring areas in the management of the protected area. "*This management is based on community needs,*" claimed an NCI member. The current management had encouraged production, enabling the establishment of small enterprises of goat dairy products such as cheese, milk and liquid toffee [*natilla*], as expressed by this community member "*We have been trained to venture in different activities such as beekeeping and farm animal management.*"

The management has also reorganized a pre-existing patrol group which is accountable for enforcing the zoning established for goat grazing. Members of this group graze their own goats but also look after grazing areas, an activity that makes NGO members proud. "*Ceiba has the luxury of having 70 volunteers that make constant circuits around the area. We have only one ranger hired by the institution.*"

Community members share this pride, who acknowledge that the NGO has improved their agricultural practices, which in turn has increased their income and has decreased the negative impact on biodiversity, as expressed by this community member "*At first we thought they* [NGO] *came to kick us out, and that we were not going to be able to graze our animals, but it was the opposite.*"

In Arenillas, people seemed hesitant to express openly their use of timber, as they acknowledged the strict protection the Reserve was under. The provisioning services, indicated in Arenillas, involved poaching and fuel wood, both critical for local communities. According to Briceño et al. [14], local people used to hunt animals, particularly deer and squirrel, for subsistence. However, since this protected area is owned by the Central Government, these activities are considered 'illegal'. The conservation status held by this Reserve, however, did not prevent local people from hunting and collecting fuel wood which is used for brick manufacturing, one of the main economic activities in the area as one of the informants offered:

"*People generally sneak into the reserve and cut Guayacan, Palo Santo [Bursera graveolens] and Ceibo [Ceibo trichistandra] trees. These are usually used to build fences… Some people pile the trees until they have 50 logs and then they sell them to brick manufactures. We also hear about people getting into the reserve to hunt deer to eat it.*"

4.3. Regulation services

The regulation services prioritized in Ceiba were water regulation (19%), climate regulation (16%) and habitat provision (14%), being agriculture and husbandry the main source of maintenance for the communities living near or surrounding the reserve, it's no surprise that the regulation services mentioned were associated with inputs to production (fulfilling water requirements for agriculture, and presence of shrubs for husbandry). One of the residents expressed the regulation services in the following terms:

"The main benefit of the forest is mainly for animals, the refuge, the shrubs for goats, especially in winter when the mountain lush with vegetation, it attracts winter, because before this was a dry terrain" Resident of La Manga.

Favorable climate conditions are also essential for the growth of crops and maintenance of agroecosystems. The influence of the NCI on the perception of the local community is evident in the narratives expressed by the study participants.

"…The forest provides a natural climate that benefits the provision of oxygen and fodder for animals. Without the forest, the sun would burn us. Where the forests are there is rain…"

As Daniel et al. [32] explains while regulation services are more complex to be perceived, they have been brought to public attention by discussions of climate change and recent natural disasters. According to Peñaranda [15], Ceiba owners promoted regulation services to gain the acceptance of community members to adhere to conservation strategies. One of the personnel of NCI expressed.

"we worked a lot in training people about the benefits of Dry forests. People now know that if they chop trees, it will not rain. Now they understand the magnitude of the damage they commit when they act against nature."

In Arenillas, the regulation services such as air quality and habitat provisioning were related to the pristine services a protected area provides as a habitat for provision for fauna and flora, air quality and climate regulation. This intangible and indirect use of the Arenillas coupled with the limited access to the reserve helped shape this perception among residents. The following quotation reflects the grounds on which people prioritize these services:

"When I pass with my vehicle, I open the window and breathe the air of the reserve [Arenillas]. I fill my lungs with oxygen and my organs with pure air. This should be charged, give added value to what trees produce" Resident Arenillas.

Desertification barrier was more mentioned in the responses provided by Arenillas settlers. Being near the frontier of Peru and its arid coastal ecosystem, residents valued the reserve for being a barrier that diminishes the further expansion of desert. As expressed by one of the settlers.

"The Reserve creates the environmental conditions so that it rains in Arenillas. The reserve supplies water and supplies it to two populations with 90 thousand inhabitants. In addition, the Arenillas Ecological Reserve cleans the air and is slowing down the desert that comes from the north of Peru."

4.4. Cultural services

As we mentioned earlier, in the Arenillas reserve it is not possible to use fodder, fuel wood, or practice any productive activity such as agriculture, only tourism and research activities are allowed. This conservation status may explain participant's prioritization of tourism in Arenillas. One of the informants offered:

"People from outside [from other regions] visit the Arenillas reserve in order to feel the tranquility that they experience there, especially during the flowering of Guayacán" Resident Arenillas.

In 2015, the Regional Division of the Ministry of Environment started promoting tourism and recreational activities in the area in response to the so-called annual flowering of the *T. chrysantha* (Guayacán) which was being promoted as a national tourist attraction [15]. This event awakened the interest of social actors regarding cultural ES as following quoted by a Municipal employee: *"We are starting to promote tourism, but we need to strengthen it. For example, the flowering of the Guayacan is something spectacular that we must pay attention to and make it known at a cantonal and provincial level."*

Notwithstanding Ceiba holds a similar ecosystem with a vast territory of Guayacan forests, participants from this area did not share the view of Arenillas residents about promoting tourism activities. Some of the reasons for this difference are explained a technical staff member of NCI: *"our objective as NCI is not to promote tourism."* Ceiba participants also expressed that this event was promoted in nearby communities but not in the Private Reserve la Ceiba. Additionally, participants around Ceiba claimed that they do not count with the equipment or the capacity to attract tourists to the area. Despite their lack of enthusiasm towards tourism activities, respondents from the Ceiba reserve expressed their appreciation towards the flowering of Guayacan as a landscape esthetic value. Moreover, participants from Ceiba perceived TDF as spaces of cultural heritage and places of local traditions, customs and legends.

4.5. Identification of ES by type of social actor

The results of the prioritization by type of social actor can be viewed in **Table 2**.

4.5.1. Public and private managers of the protected areas

In Arenillas, public managers placed a greater importance on cultural services particularly on the facilities that TDF offer to conduct education and research (75%). The second most mentioned ES by these participants was the capacity of TDF to provide shade (41%) followed by medicinal uses (40%). Special importance was highlighted to the Algarrobo tree (*Prosopis pallida*) to heal stomach diseases. This group of participants, however, did not attribute any value to the regulation service of water provision nor the cultural services related to landscape, existence value, or spiritual experience.

On the contrary, for the private managers of Ceiba the most important services provided by TDF involve their capacity to reduce desertification (100%), to provide habitat for plants and animals (85%), and to provide water (39%). This group gave the lowest scores to the pollination service, the value of the landscape, and the development of scientific knowledge.

4.5.2. Municipality members

In the Arenillas reserve, municipality members showed a better understanding of the ES provided by TDF indicating nine types of services including medicinal services and a source of Fuelwood. They described ES as a concept applied principally to agro-ecosystems whereby the main benefits are obtained from raw material (49%), and medicinal resources (60%). Water regulation (50%) was also viewed as an important ES. Contrasting the general prioritized results, this group did not assign any value to some cultural services such as existence and spiritual values.

In Ceiba, municipality members were the most enthusiastic group at implementing tourism activities in the area. They ascribed a substantial level of importance to the Guayacan flowering event (100%) and to developing nature tourism (62%). The ability of TDF to regulate water cycles was also mentioned (39%). This group of social actors seemed to be less aware of the regulation services provided by TDF such as habitat provision and desertification.

4.5.3. Local representatives

Local representatives in Arenillas assigned a greater value to spiritual experiences related to the reserve (100%), followed by air quality regulation (44%) and the ability of TDF to

CEIBA RESERVE	**E**	**n=120**	5%		8%		15%	0%	0%	60%	0%			0%		10%
	D	**n=4**	18%		22%		85%	11%	100%	0%	0%			0%		30%
	C	**n=5**	27%		16%		0%	36%	0%	0%	0%			67%		0%
	B	**n=6**	32%		39%		0%	45%	0%	20%	0%			17%		30%
	A	**n=4**	18%		14%		0%	7%	0%	20%	100%			17%		30%
	ES Indicator		Agriculture (Onion, rice and corn)		Fodder (*Prosopis juliflora*)		Habitat provision	Carbon sequestration	Desertification protection		Landscape, Guayacan blooming season, waterfall (Coronel)			Scientific knowledge developing		Cultural Heritage
	Mapped ecosystem service		(P)Food		(P)Raw material		(R)Life cycle maintenance	(R)Climate regulation	(R)Erosion prevention	(R)Pollination	(C)Aesthetical information			(C)Research		(C) Inspiration for culture
ARENILLAS ECOLOGICAL RESERVE	**f**	**n=96**	3%	0%		0%	17%	0%	0%	0%	10%	75%	0%		0%	100%
	e	**n=3**	26%	18%		40%	29%	0%	41%	4%	10%	0%	75%		0%	0%
	d	**n=2**	3%	13%		0%	13%	16%	18%	28%	8%	0%	0%		0%	0%
	c	**n=2**	3%	22%		0%	21%	19%	0%	12%	8%	0%	0%		0%	0%
	b	**n=4**	17%	24%		0%	0%	44%	6%	32%	29%	0%	25%		100%	0%
	a	**n=5**	49%	22%		60%	21%	22%	35%	24%	35%	25%	0%		0%	0%
	ES Indicator		Fuel wood (Guayacán, hualtaco) for brick manufacturing.	Lemon growing	Deer and squirrel poaching	Algarrobo use for stomachic diseases,	Habitat provisioning	Pure air, oxygen	Protective barrier, shade	Desertification protection	Nature tourism, trees blooming	Landscape, photography	Scientific knowledge developing	environmental education		
	Mapped ecosystem service		(Provision)Raw materials	(Provision)Food		(Provision) Medicinal resources	(Regulation) Life cycle maintenance	(R)Air quality regulation	(Regulation) Climate regulation	(Regulation) Erosion prevention	(Cultural) Opportunity for Recreation and tourism	(Cultural) Aesthetical information	(Cultural)Research		(Cultural) Spiritual experience	(Cultural) Existence value

a—municipality, **b**—local representatives, **c**—cooperatives, **d**—local teachers, **e**—ministry of the environment, **f**—survey.
A—municipality, **B**—local representatives, **C**—association, **D**—Naturaleza y Cultura Internacional (NCI), **E**—survey,

Table 2. Perception of environmental services by social actors in the Arenillas Ecological Reserve and Ceiba Reserve.

prevent desertification processes (32%). On the contrary, Ceiba local representatives rated highly the capacity of the TDF to sequester carbon (45%). They referred to this service in the following terms "provide oxygen" and "pure air." Within this group, agriculturalists more frequently mentioned provision services such as fodder (39%) and agriculture (32%).

4.5.4. Agrarian cooperatives and associations

The participants pertaining to this group were dedicated to agricultural activities in both areas. It was therefore not a surprise that they both assigned higher values to provisioning and regulation services related to their activities. Food production was the most mentioned ES by both groups, in Arenillas (22%), and in Ceiba (27%). Water provision was also mentioned by both groups, in Arenillas (25%) and to a lesser degree in Ceiba (6%). The main difference between participants in this group is rooted in that social actors in Ceiba perceived research development as an important ES (67%), while stakeholders in Arenillas did not attribute value to any cultural service.

4.5.5. Local residents

Among local residents, we were able to identify substantive differences. In Arenillas, surrounding communities were more keen on the cultural services provided by TDF and mostly prioritized the existence value (100%), followed by landscape photography (75%). As we mentioned earlier, this appreciation is linked with the more urbanized population residing near Arenillas, who prefer to use the reserve for tourism purposes. Contrasting these results, populations surrounding Ceiba attributed a higher value to regulation services such as pollination (60%) and habitat provision (15%).

Additionally, survey results suggested that local residents not only differ in their perception of the ES provided by TDF, but also in their knowledge about the managers of the reserve. While in Arenillas, the majority of respondents declared not knowing who currently manages the reserve (68%) in Ceiba the majority of respondents knew it (65%). These results are explained by historical processes related to local communities' involvement with the management of the area. According to Briceño et al. [14], in Arenillas, the historical isolation of local communities from the reserve has influenced on resident's familiarity with the area and on the type of ES prioritized. In this respect, Boyd and Boyd [33], indicated that only when ES are incorporated into the production of goods and services they are valued by different social actors. Consequently, since residents of Arenillas are not allowed to use provisioning services should not be a surprise that this group of social actors prioritized cultural services.

On the contrary, in Ceiba some local social groups are involved in the management of the area and prioritized more regulation services such as pollination. Again, these results should be expected since they are working closely with the reserve managers as offered by a community member: "*thanks to NCI we have a new vision of what is the best way to manage the forest… we have trained on working with bees… we shifted from trees to bee boxes.*"

5. Discussion

The findings of this research revealed that local residents living nearby or within Ceiba and Arenillas perceive and appreciate a wide range of ES provided by TDFs in southern Ecuador. The social actors in both areas mentioned provisioning services and cultural services, and to a lesser degree regulation services but hardly mentioned any supporting services. Supporting services were difficult to identify by social actors' especially those who are not familiar with ecological and biophysical processes. This finding supports conclusions from other studies suggesting that supporting services are harder to identify by the people [4].

Our results suggest that there are two underlying forces that influence how people perceive their ecosystem: (1) the management strategies undertaken in each protected area, and, (2) the involvement of the different social actors with the reserves. Regarding the management strategies, we argue that the perceptions of ES provided by TDF are influenced by the models applied in the management of the protected areas. While in both areas the access to resources such as timber or pastures is restricted and regulated, in Ceiba sustainable activities, including agriculture, are allowed inside its territory if the owners permit it, whereas in Arenillas any production activity is banned by the Ministry of Environment.

The exclusionary model applied in Arenillas follows the trend applied in protected areas whereby these areas are set aside for recreation and restricted from other uses [34]. This conservation approach, as Pimbert et al. [35] pointed it out, seeks to exclude local communities from all forms of participation. Because conservation initiatives, namely protected areas, have mainly focused on protecting the regulation services and promoting the cultural services, it is not surprising that in Arenillas the ES that were most highly rated were cultural services. On the contrary, in terms of conservation, the inclusive management approach developed in Ceiba has positively influenced in that people perceive and value provisioning services as well as being aware of the impacts they have on the ecosystem.

While these results are promising for the conservation purposes, it is worthy to note that we have not analyzed how this inclusive management is influencing on the access to natural resources and on the people's livelihoods.

Regarding the second force, some authors have argued that the perception of ES and its further conservation depends on the beneficiaries of such services [9, 14, 36]. For instance, Benez et al. [37], and Verón et al. [38] indicated that ES are appreciated according to cultural values wherein the same service, namely water provision, could be perceived as human consumption or as hydroelectric power. Likewise, Reid et al. [39] suggested that ES are valued according to the level of urbanization and modernity wherein food supply is perceived differently in urban or non-urban areas. For example, mammals' abundance in the Arctic is highly valued as a food source whereas in urban environments meat suppliers may be less critical to the well-being of metropolitan populations given the wide array of protein substitutes and therefore are less valued.

Against the conclusions of these studies, we argue that the perception and prioritization of ES is also influenced by the extent to which a person or community is involved with the protected area. Prior studies [40–42], mentioned that regulation services are commonly perceived by populations whose members are not directly involved in agricultural activity. The results of our study indicate that municipality members, governmental officials and protected area managers, including community members contributing with the protected area, perceived more commonly regulation and support services whereas agriculturalists perceive more provisioning services. This suggests that the occupation and personal involvement with the management of the area inform the services that are perceived and prioritize. Moreover, while we agree that regulation services are hard to identify [43, 44], we argue that this is true for populations whose livelihoods depend on provisioning services. Indeed, the results of our study suggest that social actors perceiving and prioritizing regulation services were municipality members, protected area managers, and teachers. Finally, in Arenillas, people living nearby the reserve recognized the potential of developing tourism activities that would, in turn, generate an additional source of income for the communities. In Ceiba, cultural services were cited by municipality members and members of associations, but the cultural services were related to the intrinsic value of the TDF and the recognition of this ecosystem as an important area to transmit knowledge to different sectors. It was not associated with any economic benefit.

6. Conclusions and future challenges

This study is a first step to build on the knowledge of TDF in an Ecuadorian context. It highlights the necessity to incorporate people's voices in the management of protected areas to achieve better conservation results. The integration of local people in policy making leads to a better compliance with conservation objectives [45–48], the results of our study also confirm these findings. This is especially important in developing countries where the stakeholders have not been fully integrated in the management process and where policymakers tend to prefer a top-down organization system. We argue that while this approach to conservation might be useful to conserve the natural environment, it doesn't necessarily guarantee the acquiescence of local communities with conservation policies on the long run, as the case of Arenillas showed us. We suggest that local governments should double their efforts in promoting a truly inclusive decision-making process.

The findings of this research also revealed that social assessment methods are useful in the initial phase of studying ecosystem services as it permits managers to have an in-depth knowledge of the values, needs, preferences, and strains of the different stakeholders involved in a protected area. However, it fails to reveal some important supporting and regulation ecosystem functions and services that are invisible to local communities. Further studies should be carried out from an economic and ecologic point of view to obtain more rigorous assessments.

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Chapter 6

South China Tropical Forest Changes in Response to Economic Development and Protection Policies

Shudong Wang and Taixia Wu

Additional information is available at the end of the chapter

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Abstract

The destruction of tropical forests continues to attract attention from the international community. China's National Forest Administration has adopted protective measures for tropical forests, and efforts have been developed to balance forest protection and economic development in Hainan Island, China. However, the response of natural tropical forest to local economic development and the effectiveness of forest management and protection policies remain unclear because of complexity of tropical evergreen ecosystems. After comprehensive analysis of spectral characteristics, spatial distribution, patch shape, and other characteristics of main forests, we developed an information extraction method based on the decision tree method, combining digital elevation model (DEM) and forest planning maps, and established flowcharts and processes for sophisticated object-based information extraction. The accuracy of our method was 92%, and the method proved to be applicable and effective in the classification of complex surface features in a tropical evergreen ecosystem. Forces resulting in the change of these forests were explored by analyzing the relationships between economic development, protection policies, as well as environmental factors.

Keywords: tropical forest, economic forest, forest management, Hainan Island, remote sensing, GIS, development and protection policies

1. Introduction

Deforestation, especially of natural tropical forests, has attracted international attention as these tropical forests have very high levels of biodiversity [1–4]. Tropical forests mainly occur in developing countries. However, large areas of natural forests have disappeared as a result of continuous human population growth and their economic development. Some protective measures have been adopted, but it is still difficult to prevent the loss of natural tropical forests due to conflicts between economic development and forest protection.

In China, the total area of tropical forest is currently increasing because of national reforestation policies, but the proportion of natural tropical forest to economic forest has changed in recent years [5]. As a result, changes have occurred affecting the maintenance of biodiversity, ecological functioning, and stability of forest ecosystem [6–8]. The Hainan Island of China has a large area of tropical forest, which serves as a natural treasure of biodiversity [2]. In recent years, the island has seen rapid economic development. Natural tropical forest is being constantly replaced by economic forest because of increasing demand for rubber, timber, and other forest products since 1988. To develop the economy in a sustainable and ecologically sensitive manner, the local government has proposed various ecological protection measures since 1998. In fact, the tropical forest in Hainan Island has greatly changed because of economic development and protection policies after 1998. Tropical forests are known to be impacted by population growth, economic development, national policies, and natural factors (such as terrain, climate, etc.) [5]. However, the key factors causing the changes of tropical forest remain unclear.

Because the proportion of natural tropical forest to economic forest has changed, two key challenges arise: (1) understanding how and why natural tropical forests are changing, and which factors have led to the changes; (2) understanding the fate and implications of the succession of different forest types. Thus, monitoring the dynamics of those changes occurring in natural tropical forest and economic forest becomes necessary, together with the identification of the main factors leading to those changes over broad spatial and temporal scales.

Brandt et al. recognized that mapping forest distribution and succession are an essential component of forest biodiversity assessment [2]. Remote sensing provides an efficient technique for the monitoring and managing of tropical forests [9]. In addition, a combination of remote sensing and GIS techniques could help scientists discover the intrinsic forces driving the dynamics of forests.

However, some challenges remain in using remote sensing image classification. For example, for vegetation classification, there is a problem with mixed pixels resulting from same objects exhibiting different reflectance at varying wavelengths [10]. Also, it is difficult to improve the precision of the process of extraction without the support of a prior knowledge, such as the spatial distribution of various forests or patch shapes.

In addition, the use of pixel-based methods is tiring and labor-intensive work, and misclassification of pixels is likely to occur because of errors during spectrum analysis [11]. For example, some natural forests lying within shaded areas of mountains tend to be regarded as other land use types. An object-oriented method could segment remote sensing images into different patch sizes based on integrated features of the spectrum, texture, shape of patch, and so forth [12]. In addition, the decision tree method could gradually extract individual land use types, using remote sensing extraction models and relevant auxiliary data, such as the distribution of various forest types.

In fact, much auxiliary information could be used. For example, when compared with rubber and pulp plantations, the remotely sensed spectra of natural forest exhibit more differences from December to the following January than it does during other seasons [13]. In addition, remotely sensed images of natural forest, and rubber and pulp plantations each have obvious characteristics related to their distribution, patch shape, and texture. For example, pulp and rubber plantations usually occur in areas where the slope is less than 25°, and rubber plantations often lie at comparatively lower elevations.

To overcome the abovementioned challenges, we used an object-oriented, decision tree method to deal with the complex change processes of natural forest, and rubber and pulp plantations for the first time. The overlay technique of GIS was also used to map natural forest, and rubber and pulp plantations during 1988–2008, and to analyze the main factors driving forest change and the relationships between the three forest types. Our objectives were to:

1. Map the spatial extent of natural forest, and rubber and pulp plantations, and to analyze temporal and spatial succession occurring during 1988 and 2008.
2. Assess the relationships between the spatial patterns of multiple forests; identify the main factors driving changes.

2. Materials and methods

2.1. Study area

The study area covers 14,000 km^2 in the central part of Hainan Island (**Figure 1**). The study area has a warm and humid tropical monsoon climate with annual average temperatures ranging from 22 to 26°C. Mountainous areas surround Five Finger Mountain and Yinggeling in Hainan Island. The island's natural tropical forest mainly includes tropical monsoon forest, tropical rain forest, evergreen broad-leaved forest, and coniferous forest. Economic forest mainly includes rubber plantations and orchards, which usually occur in the flatlands at the

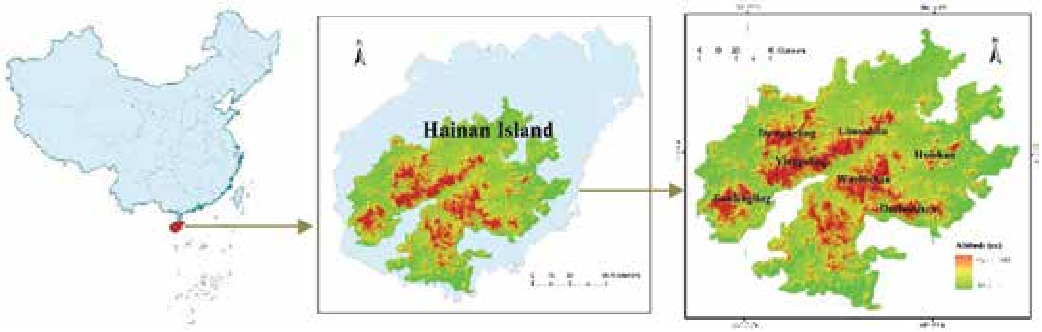


Figure 1. The location of the study area (the central Hainan Island in China).

foot of the mountains. Some national and provincial reserves have been established since the 1970s to protect the biodiversity of these tropical forests.

The natural vegetation of Hainan Island is tropical monsoon forest, tropical rain forest, evergreen broad-leaved forest, mangroves, coniferous forests, shrubs, and grassland types. The main species of artificial vegetation are casuarina equisetifolia, eucalyptus, rubber, lemongrass, pepper, mango, and banana. The crops mainly include rice, sugarcane, sweet potato, cassava, and vegetables.

2.2. Data sources

Landsat TM images (path/row 124/47) cover the study area. We used six images captured from December to the following February in 1988, 1998, and 2008; these images were obtained from the University of Maryland website (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp) and satellite ground stations in China. The images were georeferenced with a precision better than 0.4 pixels. Finally, the digital data of these images were calibrated to surface reflectance values using the Fast Line-of-Sight Atmospheric correction of Spectral Hypercubes (FLAASH) Module in ENVI v.4.6. Other sources of information included a digital elevation model (DEM), and social, economic, and field survey data. DEM data were obtained from Aster satellite data (https://wist.echo.nasa.gov/~wist/api/imswelcome/). Slope and elevation data were derived from the DEM using the ARCGIS9.3 software. Some basic data (transportation corridors, population, national and provincial reserves, meteorological, social and economic data) were obtained from the Hainan Provincial Academy of Environmental Sciences. Field surveys were also conducted to collect information on the distribution of forests.

2.3. Methods

2.3.1. Extraction of multiple forest information datasets

We compared the spectral differences of Landsat TM images captured in 1988, 1998, and 2008 of multiple forests in different seasons within a year, and selected images taken between December and the following January (e.g., December 1988 to January 1989) (**Figure 2**). Then we established flowcharts and processes for use with a sophisticated object-oriented decision tree method. First, these images were divided into multiscale segmentations based on the texture, spectrum, patch shape, and distribution of land use types using the Cognition 7.5 software. There are also other parameters need to be set, such as scale, shape, and compactness, which are obtained from the ground comparative research. Second, a set of indices extracting remote sensing information were calculated (**Figure 3**), including MNDWI = (Green – MIR)/(Green + SWIR) [14], the Universal Pattern Decomposition Method (VIUPD), RVI = NIR/Red and the Grass and Shrub Differing Index GSI = (MIR–NIR)/(MIR + NIR). The wave bands of Green, Red, MIR, SWIR, and NIR were used in these models, since they contribute to identify different objects. It is concluded that the MNDVI, VIUPD, RVI, and GSI performed well in the information extraction of complex features. MNDWI is a modified normalized difference

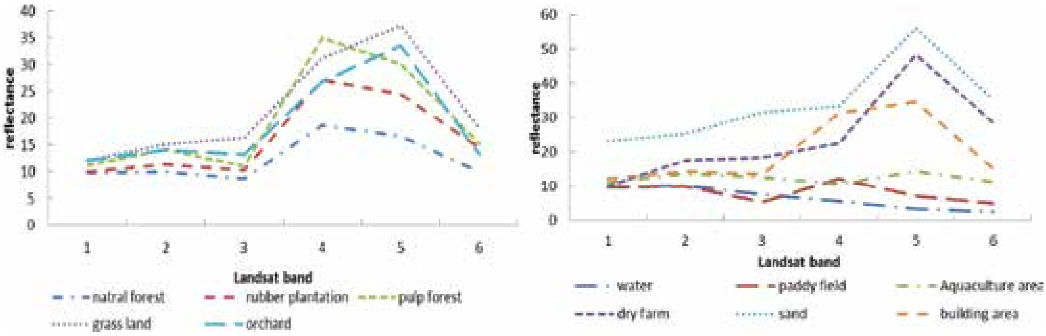


Figure 2. Examples of how phenology was used to discriminate the different forest classes. Representative pixels from three forest and other land use classes look similar under visual inspection on Landsat images from December to the following February.

water index, which is a simple graphical indicator that can be used to analyze whether the target being observed is water or not. The vegetation index RVI is very sensitive to vegetation canopy chlorophyll content [15]. VIUPD is a vegetation index and sensitively reflects the amount of vegetation and the degree of vegetation vigor. GSI is grass and shrub differing index and can be used to identify bushes and grass from other kinds of trees [5, 15]. Then, the object-oriented forests information was extracted based on decision tree. The extraction results are shown in **Figures 4–7**. Multisource data (including slope from the DEM, pulp plantation planning maps, and other auxiliary data) were used to extract different land use types. According to the stage order, we first separated water-related ground objects (water bodies, paddy fields, and aquaculture areas) from images using the MNDWI model and

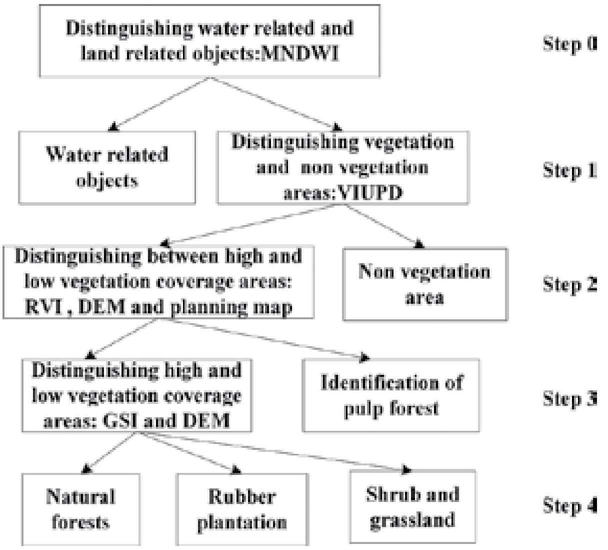


Figure 3. The steps to extract object-oriented information of forests based on decision tree.

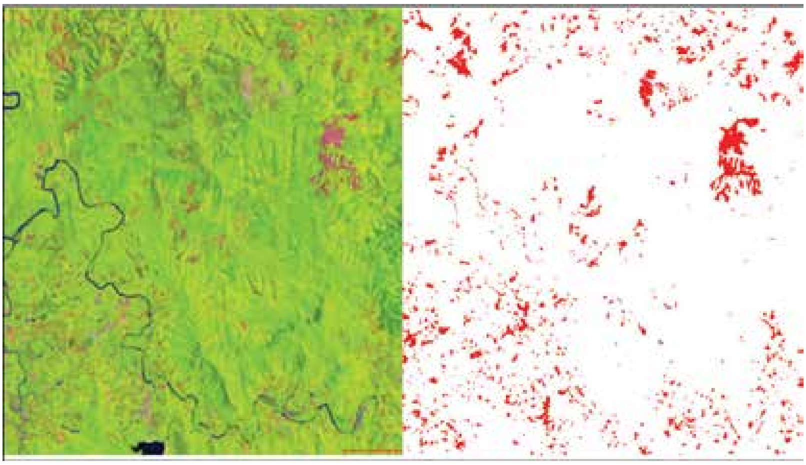


Figure 4. Extraction of orchard information based on GSI and R5-R6 method.

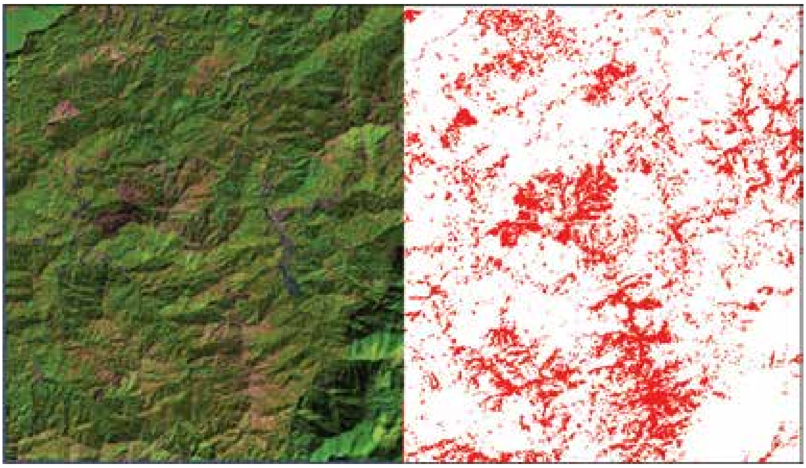


Figure 5. Shrub information extraction based on GSI method.

then identified areas without vegetation coverage, such as urbanized areas, using the VIUPD method. Next, the RVI model, slope from DEM, and economic forest planning map were used to extract and delineate pulp plantation areas from other land use types. Finally, we separated natural forest and rubber plantation areas from grassland and orchards using the Grass and Shrub Differing Index (GSI) model and slope data from DEM. To correct some mistakes, we did some field investigation. For example, we initially were not sure whether some patches were rubber plantation or not in Landsat TM image, but we found through field investigation that these patches indeed were rubber plantation if they were near river and residential area, so we might correct these mistakes through water system distribution map.

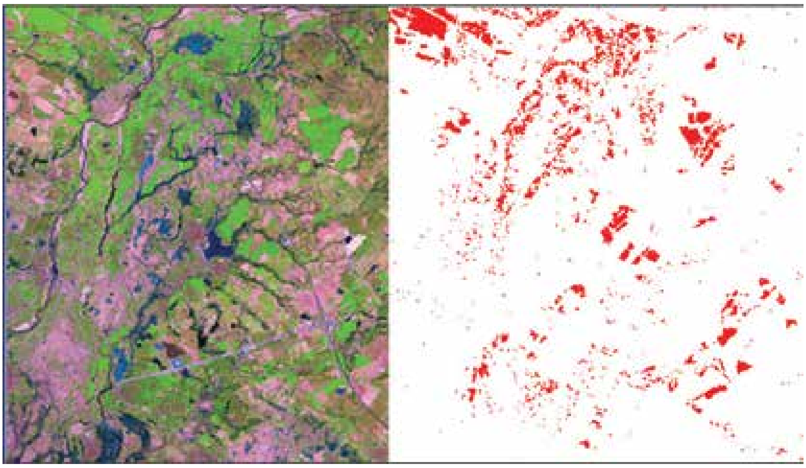


Figure 6. Extraction of pulp plantations information based on RVI method.

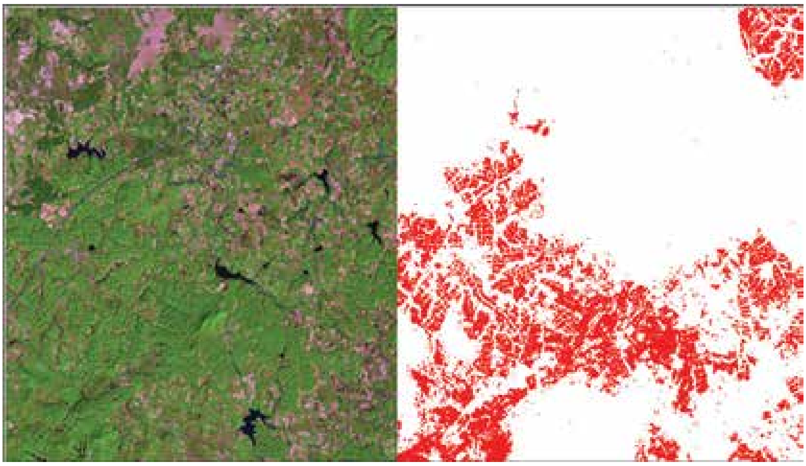


Figure 7. Rubber information extraction based on RVI and texture information method.

2.3.2. *Change detection and key driving factor identification*

Three forest types and other land use types in the study area were extracted: natural forest, rubber plantation, pulp plantation, and other land use types (e.g., paddy fields, dry lands, orchards, sand, and urbanized areas). Map overlays of forest type for 1988, 1998, and 2008 were created using the GIS software to quantify the dynamic transformation between different forest types. Economic activities and protection measures were considered, and a comparative analysis method was used to compare natural rubber demand and price changes, the area of natural forests and the area of economic forests before and after the implementation of protection measures.

To reveal the intrinsic driving factors from 1988 to 2008, in addition to considering economic and policy factors, the following factors were also considered: nature protection areas, farms, transportation corridors, and the elevation and slope of each site. The data of nature protection areas were derived from the map of national nature protection area; the data of farms and transportation were extracted from Landsat TM images; the data of elevation and slope were extracted from DEM. The study area was divided into grid cells, and the information for each grid cell was extracted by the spatial analysis model of the GIS software. By using random permutation tests [16] to choose grid cells in each year, the association of different forest types with the abovementioned factors was examined. We used the average Euclidean distance between the multiple forest patches and these driving factors to capture differences in conservation value and human activity. For multiple forest conversions, the following method was used to identify the key factors: the patch of the different forest area serves as the basic unit; then, adjacent patches with the same change trends were classified into a uniform block. The average value of a factor in each block with the same trend was used to serve as a sample, and the value of the factor served as a collective value. The ratio of the area covered by a particular land use type in 2008 was compared with the corresponding blocks of the two previous periods (1988 and 1998) to detect changes using the overlay. Then, we took the altitude, slope, and the minimum distance from the farmland and road to the area where transformation occurred as variable and took the transformation of forest types as dependent variable. General regression analyses between them were conducted by collectively analyzing the blocks with the same trends.

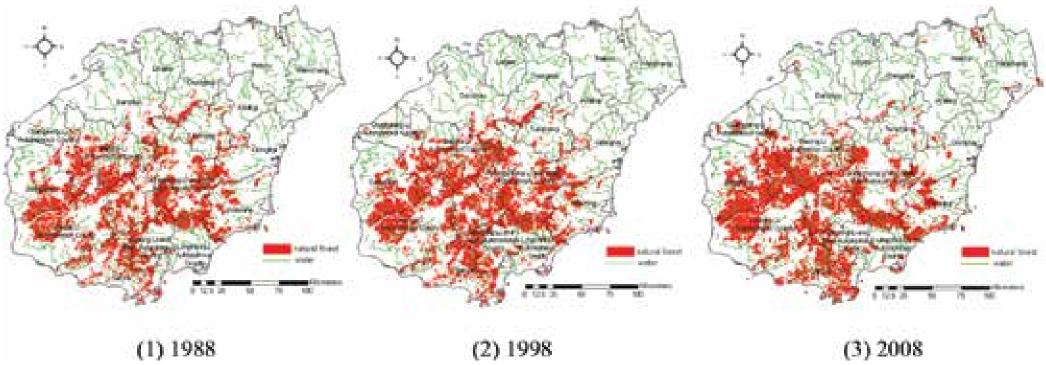
3. Results and Discussion

3.1. Detection of changes in natural forest, and rubber and pulp plantations

3.1.1. Spatial distribution of natural forest, and rubber and pulp plantations

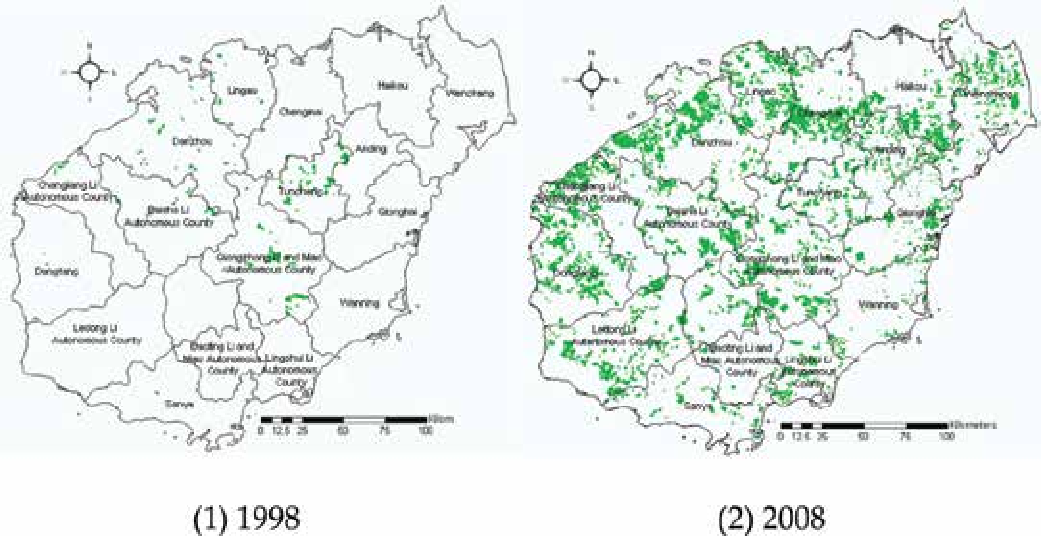
Combining DEM with remote sensing monitoring results in 1988, 1998, and 2008 (**Figure 8(1)–(3)**), the natural forests are mainly distributed in Wuzhishan mountain, Jianfengling mountain, Bawangling mountain, Diaoluoshan mountain, Limushan mountain of central Hainan Island areas above 600 m above sea level, while the central mountain valleys are invaded by other ecosystem types. There is relatively little natural forest distribution between 100 and 600 m above sea level, and below 100 m above sea level are mostly sparse grasslands.

As can be seen from **Figure 9(1)** and **(2)**, the planting scale of pulp plantation was relatively small in 1998, mainly scattered distribution in Qiongzhong Li and Miao Autonomous County, Tunchang County, Baisha Li Autonomous County, Danzhou city, and Lingao County. From **Figure 9(2)**, the pulp plantation planting area of 2008 has significantly increased compared with 1998. The spatial distribution of 2008 is relatively wide and evenness. The eastern of the northwest, Changjiang Li Autonomous County, Danzhou city, Lingao County offshore area and northern Chengmai County, Anding County formed strip-shaped shelterbelts, accounting for 29% of the total area of pulp plantations (194,000 hectares). These shelterbelts are responsible for windbreak, sand retention, and storm surge prevention. There is a sparse distribution of in the northern, southern, and southeastern coastal areas of Haikou. From the terrain view, there is wide distribution of pulp plantations between the coastal plains to the platform below 25 degrees slope. Part of the pulp forest distribution in the mountains above 25 degrees occupied the central mountainous areas of natural forests and even nature reserves. The spatial distribution of rubber plantation in Hainan Island showed in (**Figure 10**).



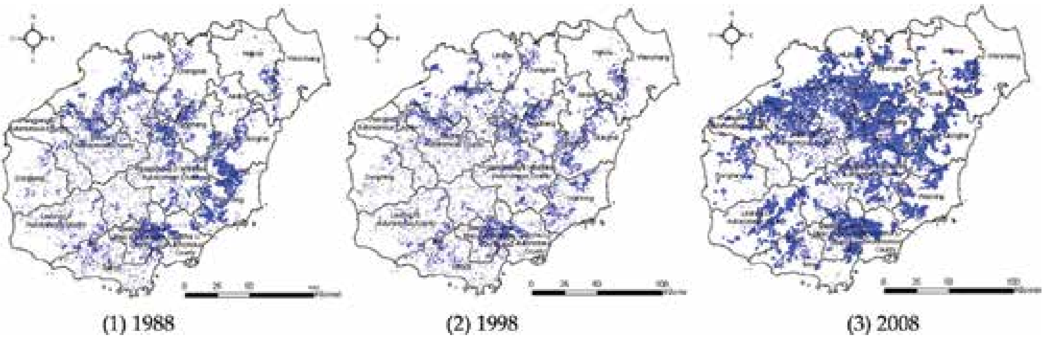
(1) 1988 (2) 1998 (3) 2008

Figure 8. Spatial distribution of natural forest in Hainan Island. (1) 1988; (2) 1998; (3) 2008.



(1) 1998 (2) 2008

Figure 9. Spatial distribution of pulp plantation in Hainan Island. (1) 1998; (2) 2008.



(1) 1988 (2) 1998 (3) 2008

Figure 10. Spatial distribution of rubber plantation in Hainan Island. (1) 1988; (2) 1998; (3) 2008.

3.1.2. Change analysis of natural forest, rubber and pulp plantations

3.1.2.1. Newly increased natural forest distribution pattern analysis in 1988–2008

1. Newly increased natural forest distribution pattern.

The differences in the spatial distribution of natural forests in 1988, 1998, and 2008 (**Figure 11(1)–(3)**) are mainly concentrated on three large areas, namely Danzhou, Qiongzhong, and Baisha, which showed the change in characteristics, for example, increasing-decreasing-increasing, and the same applied for Changjiang Li Autonomous County and Dongfang County. The boundaries of Qionghai and Wanning counties (cities) are increasing continuously, while others such as Sanya City show continuously reducing state.

2. Rubber plantations-natural forest pattern changes.

As a whole, the rubber plantation converted into natural forests from 1988 to 2008 showed fragmentation character, except parts of Qionghai, Wanning, and Qiongzhong that have block area from 1988 to 1998 and from 1998 to 2008 (**Figure 12(1)–(3)**). Most of the changes are located in the central mountainous area and its surrounding areas, but the spatial distribution is uneven, such as Qiongzhong and Ledong County. To analysis the total changed area, the area changes of 1988–2008 (29,200 hectares) are more significant than the changes of 1988–2008 (28,000 hectares) and 1998–2008 (12,000 hectares).

3. Distribution pattern of other forest converted into natural forest.

The total area of other forest (mainly farmland, grassland, etc.) converted into natural forests is small and shows sporadic distribution (**Figures 13** and **14**).

3.1.2.2. Spatial pattern of newly increased pulp plantation in 1988–2008

1. Spatial pattern of newly increased pulp plantation.


(1) 1988-1998

(2) 1998-2008

(3) 1988-2008

Figure 11. Newly increased natural forest distribution pattern: (1) 1988–1998; (2) 1998–2008; (3) 1988–2008.

(1) 1988-1998

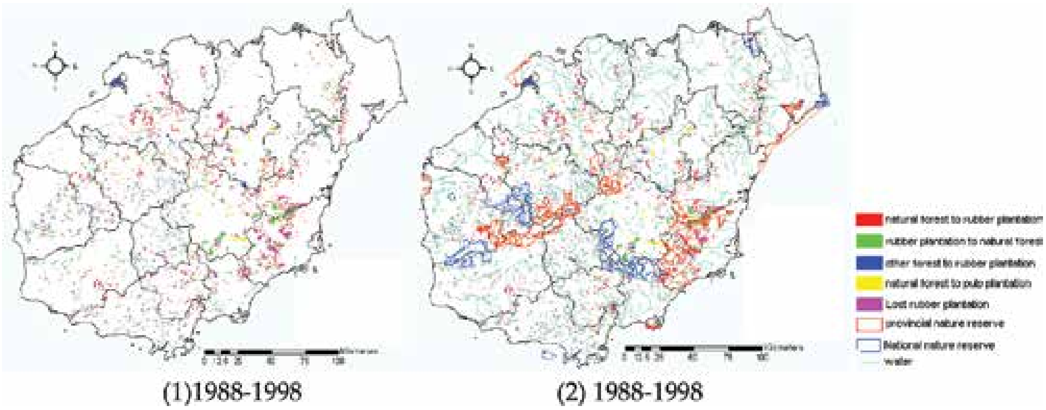
(2) 1998-2008

(3) 1988-2008

Figure 12. Spatial distribution of rubber plantation converted into natural forest: (1) 1988–1998; (2) 1998–2008; (3) 1988–2008.

As can be seen from **Figure 15**, the area of newly increased pulp plantation was relatively small (11,400 hectares) during 1988–1998, which mainly distributed at Danzhou, Qiongzhong, Baisha, Tunchang Counties. The area increased greatly to 193,800 hectares during 1998–2008. The most obvious is the formation of zonal areas along the northern coastal plains of the east, Changjiang, Danzhou, Lingao, Chengmai, the south of Haikou, and Wenchang. It contains 43.7% of the increased area. The strip-shaped forest zone also plays a role in the windbreak and sand fixation. The distribution of pulp plantation in other areas mainly showed small patches, mostly distributed in the central mountainous area and its surrounding area, with a small amount of distribution along the eastern coast.

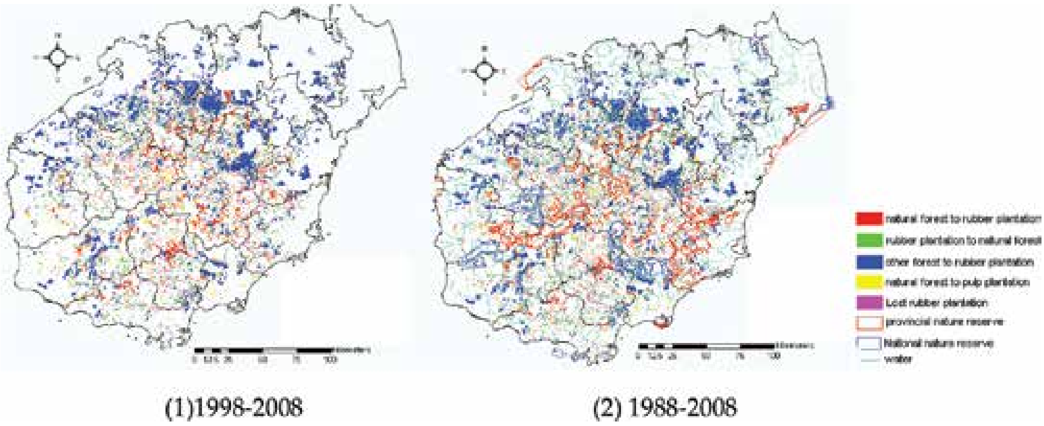
2. Spatial pattern of natural forest converted into pulp plantation.



(1)1988-1998

(2) 1988-1998

Figure 13. Distribution pattern of other forest converted into natural forest: (1)1988–1998; (2) 1988–1998.



(1)1998-2008 (2) 1988-2008

Figure 14. Mutual transformation of natural forest and rubber pulp plantation: (1)1998–2008; (2) 1988–2008.

(1) 1988-1998 (2) 1998-2008 (3) 1988-2008

Figure 15. Spatial distribution pattern of newly increasing pulp plantation. (1) 1988–1998; (2) 1998–2008; and (3) 1988–2008.

From 1988 to 1998, the conversion of natural forests into pulp plantation was mainly distributed in Qiongzhong, Danzhou, and Tunchang counties in the northern part of Zhongshan District, with a relatively small area (0.29 million hectares). From 1998 to 2008, the total area (50–200 hectares) increased obviously, which mainly distributed in the central mountainous regions. The center of the change obviously migrated to the south. Apart from the obvious increase in three counties and cities mentioned above, they were also distributed in the Dongfang, Ledong and Sanya counties, and their area diffusions were significant.

3. Spatial pattern of rubber plantation converted into pulp plantation.

The change from rubber plantation to pulp plantation was very small (0.02 million hectares) in 1988–1998, mainly in Tunchang County in the northern area of central mountainous. The area (90,000 hectares) increased significantly from 1998 to 2008 mainly in the junction area of northwest Danzhou and northeastern Wenchang – Haikou (city).

4. Spatial pattern of other ecosystem types converted into rubber plantation.

The spatial distribution of other ecosystem types (farmland, tea garden, grassland, etc.) varied from 1988 to 1998, mainly in small blocks distributed in Danzhou, Qiongzhong, Baisha, Tunchang counties and cities. It increased significantly during 1998–2008, accounting for 67.5% of the total increase area (193,800 hectares), forming strip-shaped areas along the northern coastal plain of the east, Changjiang, Danzhou, Lingao, Chengmai, south of Haikou, and Wenchang County (city). Others are distributed in the central mountainous areas and the coastal plains.

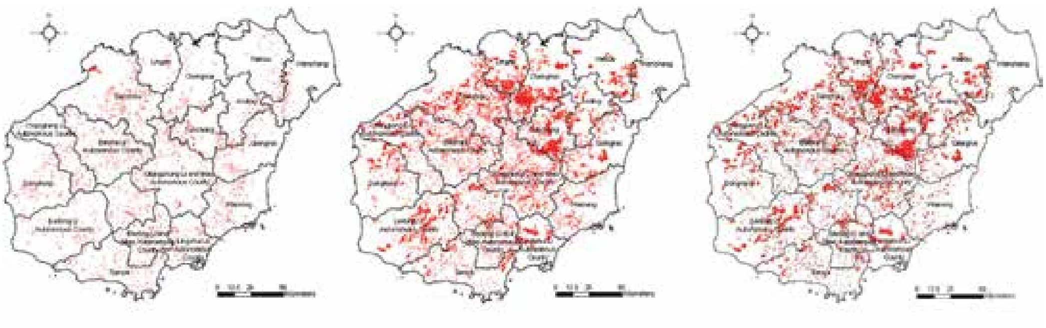
3.1.2.3. The pattern changes of newly increased rubber plantation

1. The pattern of newly increased rubber plantation.

   The newly increased rubber plantation mainly evenly distributed in the central mountainous area and its surrounding area during 1988–1998. The total area (51,400 hectares) is small. From 1998 to 2008, the area (467,300 hectares) has a great increase in the central mountainous area and its surrounding area. It extends inward and outward along the central mountainous area, especially in the northeast of Tunchang, Chengmai, Lingao, Haikou, and other counties even into sheet shape. The area during 1988–2008 changes is not obvious compared with 1998–2008 (**Figure 16**).

2. The pattern changes of natural forest to rubber plantation.

   The area of newly increased natural forests converted into rubber plantations (0.37 million hectares) is small and spatially dispersed during 1988–1998, as can be seen from **Figure 17(1)**. It is mainly around the central mountainous area. From 1998 to 2008, the area of natural forest into rubber plantation changed significantly (110,900 hectares), and the increase mainly concentrated in the central mountainous area and the surrounding areas, showing the Qiongzhong, Tongshi, Baisha County as the center, the pattern of radiation to Sanya, Baoting, Ledong, Danzhou, and other counties (cities). From 1988 to 2008, the change of the total area (96,800 hectares) was not as obvious as that of 1998–2008 except for the changes in Qiongzhong, Tongshish, Baisha County (city) as the center of the region, the distribution of Sanya and Ledong (city) changes is also obvious.



(1) 1988-1998 (2) 1998-2008 (3) 1988-2008

Figure 16. The spatial pattern of newly increased rubber plantation. (1) 1988–1998; (2) 1998–2008; and (3) 1988–2008.

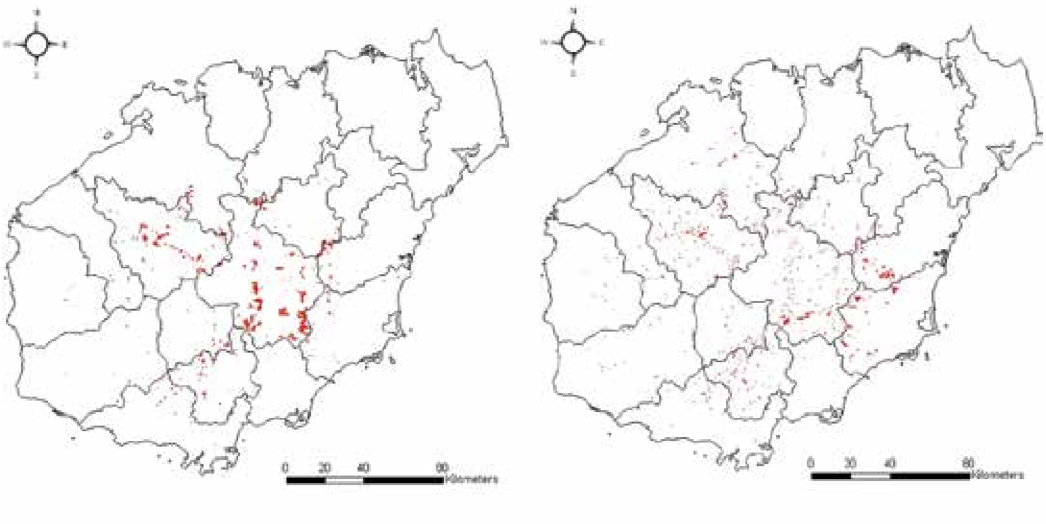

(1) 1988-1998 (2) 1998-2008 (3) 1988-2008

Figure 17. The spatial pattern of natural forest to rubber plantation. (1) 1988–1998; (2) 1998–2008; and (3) 1988–2008.

3.1.2.4. Spatial pattern of newly increased other types of ecosystems

The increased pattern changes of other types, such as orchards, farmland, grassland, and so forth, are mainly concentrated on the central region of Qiongzhong, Baisha Counties (**Figure 18**).

The major ecosystems in Hainan Island (natural forests, rubber plantation, pulp plantation, farmland, etc.) have been significantly changed in space from 1988 to 2008. Natural forests increased significantly from 1988 to 1998 and the spatial distribution expanded outward from the central mountainous areas, that is, infiltration and expansion from the central mountainous area to the surrounding land. The changes in the central mountainous area were obvious.



1998-2008 (2) 1988-2008

Figure 18. Spatial pattern of newly increased other types ecosystems: (1) 1998–2008 and (2) 1988–2008.

The rubber plantation was partly replaced by pulp plantation. The rubber plantation was mainly distributed around the platform around the central mountainous area. The rubber and pulp plantations invaded the natural forest in central mountainous area. During 1998–2008, the natural forest decreased significantly, and the main performance was from the terrain around the hills to the central mountain, which sharply declines. The rubber plantations are mainly distributed in the vicinity of water, extending to four directions from southeast to northwest, of which northeast is the most obvious. The pulp plantation area increased greatly, forming a banded area (acting as a shelterbelt) from the northwest to the north. The pulp plantation also expanding obviously in other areas, infiltrating in nature reserves, farms, the southern Sanya area, and so forth. The north and west of pulp plantation distribution was larger than the south and east in general. Large area of natural forest was replaced by pulp and rubber plantation.

3.2. The change of different forests during 1988–2008

The total area of tropical forest in the study area increased during 1988–2008. The area of tropical forest covered about 68.57% of the study area in 1988, and then covered about 71.89% of the study area in 2008, with the increase approximately 8% during 1988–2008.

Natural tropical forest always covered the largest area of land use type within the study area, increasing slightly (6.65%) in the first decade (1988–1998), and then decreasing sharply (13.69%) in the second decade (1998–2008). Generally, the area of natural tropical forest tended to decrease, despite obvious fluctuations during the study period.

The area of economic forest obviously expanded from 1988 to 2008. Of the economic forest, rubber plantations covered the largest area, but decreased slightly (3.79%) during the economic recession of 1988–1998; then, it experienced a rapid increase in conjunction with the renascent market economy during 1998–2008. A few scattered pulp plantations existed before 1988. Pulp wood was planted widely after 1988, eventually covering about 0.7×10^4 hectares by 1998 and about 7.09×10^4 hectares by 2008 (**Table 1**).

Landscape-scale transformation of various forest types obviously occurred. From 1988 to 1998, natural forest in the piedmont was converted into scattered rubber plantation, ultimately covering 9.57×10^4 hectares by 1998. During the next decade (1998–2008), an additional 9.72×10^4 hectares natural forest was converted into economic forest (rubber and pulp

Year	Natural forest (10^4 hectares)	Rubber plantation (10^4 hectares)	Pulp wood areas (10^4 hectares)	Total forest area (10^4 hectares)
1988	73.48	22.57	*	95.91
1998	82.66	17.28	0.70	100.64
2008	63.29	35.91	7.09	107.29

*Hainan Island had sporadic eucalyptus in 1988, but eucalyptus was grown for timber, not for pulp.

Table 1. Area of natural forest and economic forest during 1988–2008.

wood plantations), which led directly to a corresponding decrease in the extent of natural tropical forest. At the same time, up to 6.26% of natural forest and up to 3.09% of economic forests were converted to other land uses.

The spatial conversion of forest was also seen because of the transformation of different forest types. The remaining natural tropical forests tended to occur only at higher elevations and on steeper mountain tops, that is, the average distances to farms and transportation corridors increased. This occurred because some natural tropical forests at lower elevations, and with less steep slopes that were previously closer to farms and transportation corridors, were transformed into economic forests during 1988–2008. The increasing extent of economic forests might result in a loss in the value of ecosystem services [17]. Generally, forest transition theory assumes that increasing forest cover indicates that environmental conditions are improving [18], but the increasing forest cover in our study area does not necessarily mean that biodiversity and natural ecosystems are recovering (**Figure 19**).

3.3. The response of forest transformation to economic development and protection policies

Regional market trends contribute to the conversion from natural forests to economic forests (rubber, pulp forests, etc.). Rubber and pulp plantations expanded because of new regulations and increased demand from consumers. For example, the demand for rubber kept increasing slowly, and this led to low prices between 1988 and 1998. In addition, most rubber plantations were planted on government-operated farms, typically covering large areas, whereas small landholders were not involved significantly in rubber plantations until 1995. Thus, the conversion of natural tropical forests into rubber plantations in the piedmont had been only sporadic during 1988–1998. However, the market demand for rubber increased sharply after 1999, leading to higher prices, which encouraged smaller landholders to become deeply involved in rubber plantations after 1999. Therefore, the demand for rubber in the open market might be an important factor in driving the change of different forest types during 1988–1998 (**Figure 20**).

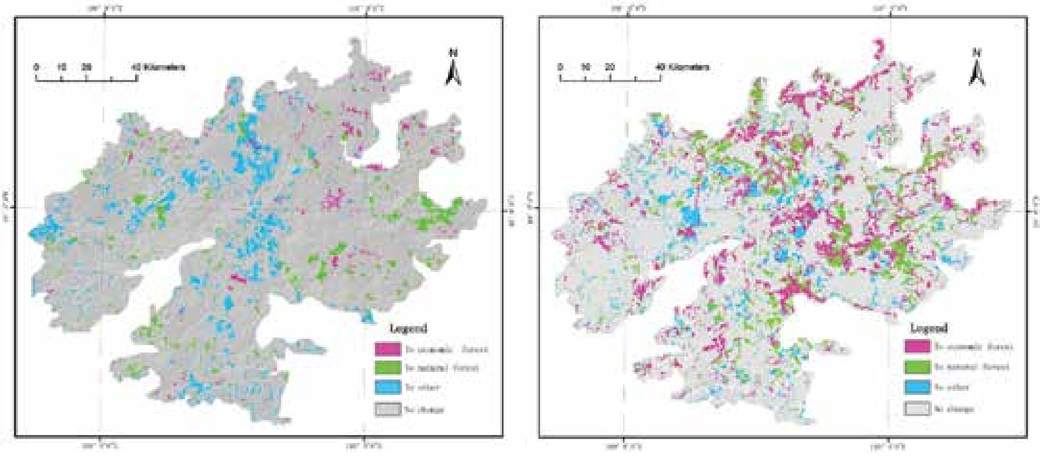


Figure 19. The transformation of different forest types in 1988–1998 (left) and 1998–2008 (right).

Figure 20. Chinese natural rubber demand and price changes.

The Chinese Government has strongly encouraged the planting of pulp plantations with the goal of developing a domestic wood pulp industry that could meet growing domestic demand. The government provided substantial capital subsidies in the form of low interest rate loans, discounted loans, and extended repayment periods for loans from state banks [19].

Thus, new plantations of economic forests greatly reduced the available space for natural tropical forests; therefore, the area of natural tropical forest decreased by 2008. Protection policies and the establishment of reserves delayed the transformation of some forests. In the early 1950s, policies encouraged the establishment of rubber plantations. Several nature reserves were established in Hainan Island starting in 1976. Currently, nine national nature reserves cover 11.20×10^4 hectares, while provincial nature reserves cover 13.84×10^4 hectares. Generally, both national nature reserves and provincial nature reserves limited the expansion of rubber plantations. The transformation of rainforests to plantation forests was suppressed by these protection policies, and especially by the existence of natural reserves during 1988–1998 (**Table 2**).

Different types of reserves provide different levels of protection. The national nature reserves play important roles in protecting natural forest. During 1988–2008, in the national reserves, the area of natural forest increased steadily while the area of economic forest decreased slightly. However, provincial natural reserves play an ineffective role in protecting natural forest because local and provincial government agencies support economic growth over the conservation of natural resources. Therefore, some natural forests in provincial reserves were replaced by economic forests during the same period (**Table 2**).

Reserves type	1988	1998	2008
National reserves	16.31%	10.96%	7.22%
Provincial reserves	14.24%	8.80%	16.77%

Table 2. The percentage of plantation forests in different natural reserves in 1988–2008.

Generally, the main forces driving the transformation of forest types seem to be protection policies and economic development. Some natural forests were protected by the established nature reserves, and protection policies suppressed the transformation process. Furthermore, the development of economic forests, such as rubber and pulp plantations, propelled the transformation between different forest types, even in provincial reserves formally under the protection policies during 1998–2008. Generally, the spatial extent of natural forests decreased significantly from 1998 to 2008. Although some protection efforts have been attempted, such as the "Natural Forest Protection Project," the establishment of nature reserves, and the closing of hillsides to facilitate afforestation, our results suggest that some of these protection measures were poorly implemented. From another viewpoint, economic development exerted an enormous influence on the tropical forests of Hainan Island and reduced the effects of these protection efforts. Extensive areas of natural tropical forest in Hainan Island have been converted into economic forest. Local politicians are evaluated strongly on their support of economic development. This encourages them to support economic development at the expense of environmental protection. Changing policies related to local government officials could increase protection for natural landscapes.

To resolve the conflict between development and protection, a balance between economic development and forest protection needs to be found based on monitoring data [20]. The establishment of ecological compensation mechanisms might contribute to providing local communities with some economic benefits in exchange for forest protection [21].

3.4. Response of forest transformation to environmental factors

The dynamics of major ecosystems are the result of the combination of economic drivers and state-related policies. The following sections will be comprehensive analysis of the relationship between the spatial patterns of main ecosystem in Hainan Island with terrain, traffic, water sources, settlements, and nature reserves.

3.4.1. Relationship between distribution pattern of natural forest and topography

The process of natural forest change in Hainan Island is a process of human disturbance. It is a process of gradually approaching to the southern of the central mountains, that is, the natural forest follows the process of approaching from plains, terraces, and hills to mountains successively. Its altitude also follows the change from low to high. With the increase of the terrain, the average patch area tends to increase. The following is an example of the relationship between natural forest distribution and topography in 1998 (**Table 3**).

From **Table 3**, natural forests were mainly distributed in the central mountainous area, closely related with the terrain. The next distribution area was the terrace, and the coastal plain was sparsely distributed. This shows that natural forests are closely related to the terrain. One thing to note is that mangroves and other natural forests distributed in coastal areas need to increase protection.

3.4.2. Relationship between natural forest distribution pattern and water system

Under the analysis of water system (**Figure 21**), the natural forest near the hilly area or in relatively low altitude, where water system developed, is gradually replaced by other types of vegetation. The relationship between the natural forest distribution in the central mountainous

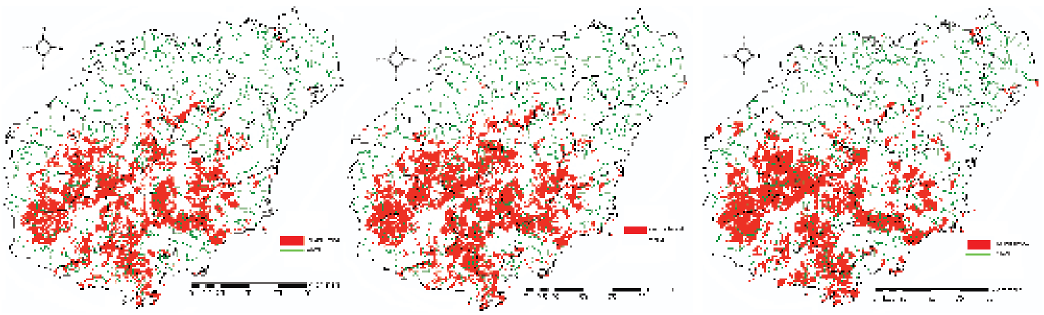
Region	Natural forest area(km^2)	Core area	patch numbers	Mean patch area(km^2)	Spatial pattern and terrain
Haikou City	1.634		5	0.32671	Coastal plains, low topography
Lingao County	1.535		2	0.76742	Coastal plains, low topography
Chengmai County	151.905		19	7.99502	Coastal plains, low topography
Wenchang City	5.021		6	0.83677	Coastal plains, low topography
Anding County	61.784		15	4.11895	Northeast terraces, plains, the terrain is relatively low
Pizhou City	273.933		49	5.59048	Coastal plains and terraces
Tunchang County	173.980		37	4.70216	North Central Plains, hills
Baisha Li Autonomous County	1078.765		54	19.97714	Central mountains, terraced hills
Qiongzhong Li and Miao Autonomous County	1403.166		56	25.05654	Central mountainous area
Changjiang Li Autonomous County	487.069		50	9.74138	Terrace and coastal plains
Qionghai City	190.571		22	8.66231	Terrace and coastal plains
Wanning City	532.908		46	11.58496	Coastal plains
Wuzhishan City	809.595		17	47.62325	Central mountainous area
Dongfang City	794.933		25	31.79732	Central mountains, terraced hills, coastal plains
Ledong Li Autonomous County	1121.411		50	22.42821	Central mountains, terraced hills, coastal plains
Baoting Li and Miao Autonomous County	549.121	431.76	12	45.76008	Central mountainous area
Lingshui Li Autonomous County	358.404	257.45	26	13.78476	Terraced hills
Sanya City	910.537	591.3	54	16.86180	Terrace - coastal plains

Table 3. Relationship between different ecosystems and topography.

area and water system is not as obvious as the terrain. That is, the distribution of water systems is not the main reason for the distribution of natural forests in this area.

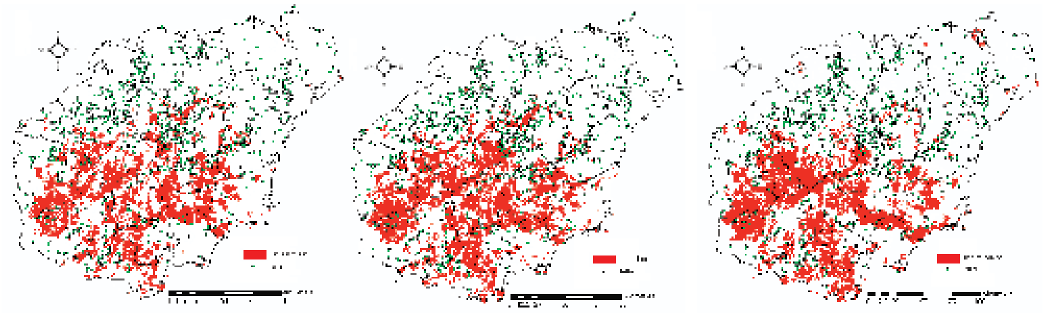
3.4.3. Relationship between the natural forest distribution pattern and farms

As can be seen from the distribution pattern of the farms (**Figure 22**), most of the farms are located in the hills, terraces, and coastal plains, while the central mountainous areas have relatively small densities. However, the natural forest patches in the farmland are obviously fragmented. In other words, near the farm, the destruction strength of natural forest is big, otherwise it is small. It can be seen that the distribution of farms directly affects the spatial pattern of natural forests and has obvious negative impacts on the distribution of natural forests.



(1) 1988 (2) 1998 (3) 2008

Figure 21. Relationship between natural forest distribution and water system. (1) 1988; (2) 1998; and (3) 2008.



(1) 1988 (2) 1998 (3) 2008

Figure 22. Relationship between natural forest distribution patterns and farms. (1) 1988; (2) 1998; (3) 2008.

3.4.4. Relationship between natural forest distribution and traffic route distribution

The traffic conditions directly affect the spatial distribution pattern of natural forests (**Figure 23**). The areas with convenient transportation are mainly distributed in plains, terraces, and hilly areas. The patches of natural forests on both sides of the traffic line showed fragmented trend. That is, the destruction of natural forests is serious where the traffic line is dense, the terrain is relatively flat, and the distribution of residents and farms is wide. Therefore, the distribution of traffic lines is closely related to the distribution of natural forests.

3.4.5. Relationship between natural forest distribution and nature reserve distribution

In order to better protect the cherished species, there are many provincial and national nature reserves have been successively set up in recent years (**Figure 24**). In this area, 88.71% of the National Nature Reserve area is covered by natural forest in 2008, 94.03% in 1998, and 82.71% in 1988, while the surrounding area of the reserves is often replaced by other features, especially the provincial nature reserves. The natural forest has become an island, such as Hainan Jiaxin Provincial Nature Reserve, Liulianling Provincial Nature Reserve, and so forth. This shows that the establishment of nature reserves played a positive role in the protection of natural forests but also exposed hidden worries of other types of ecosystems to natural forests.

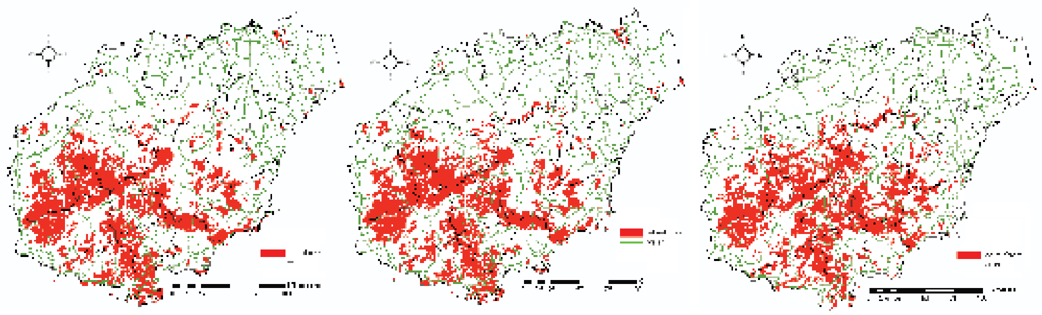

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Figure 23. Relationship between natural forest distribution and traffic route distribution. (1) 1988; (2) 1998; (3) 2008.

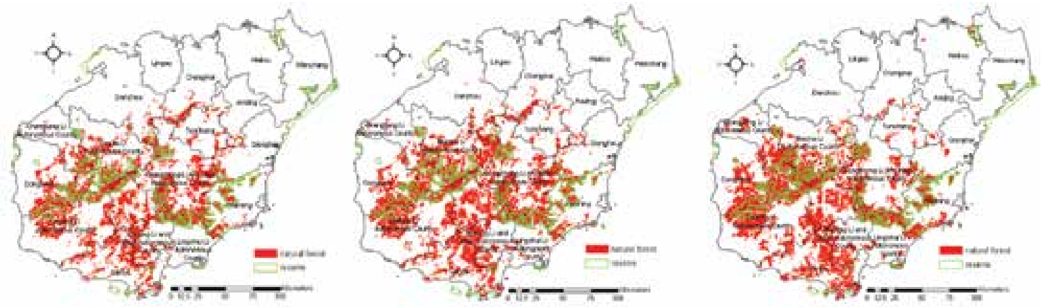

(1) 1988 (2) 1998 (3) 2008

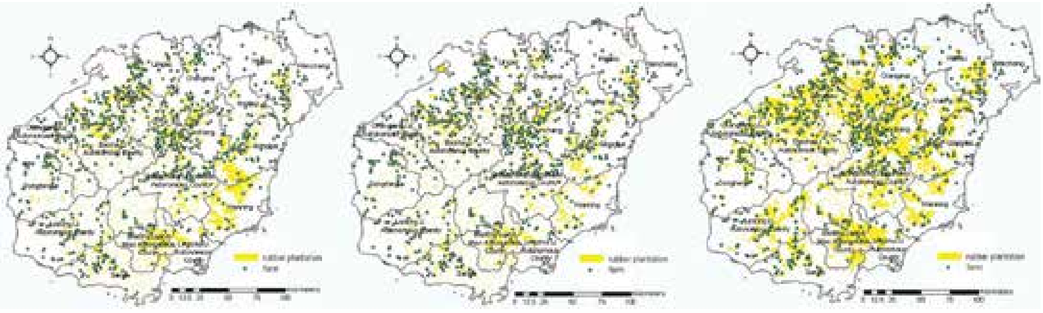
Figure 24. Relationship between natural forest distribution and nature reserve distribution. (1) 1988; (2) 1998; (3) 2008.

3.4.6. Relationship between rubber plantations and farms, traffic lines, water distribution

Figures 25 and **26** are the spatial distribution maps of rubber plantations and settlements in 1988, 1998, and 2008. The farms were mainly distributed in the western and northern parts of Baisha, Zhanzhou, Tunchang and southwest Sanya, Ledong and other counties and cities. Its distribution is more in northwest, north and less in southern, coastal plains in short. Most of the rubber plantations are located near 3–5 km to the farms and settlements, showing that the distribution of farms, settlements, and rubber plantations are closely related. According to the abovementioned analysis, most of the traffic lines in settlements and farms are well developed and are relatively close to the water source. Therefore, it can be considered that most of the rubber plantations were relatively close to the traffic and water source. Therefore, the distribution of water systems, traffic lines, and farm concentration is frequent areas for deforestation and rubber plantations.

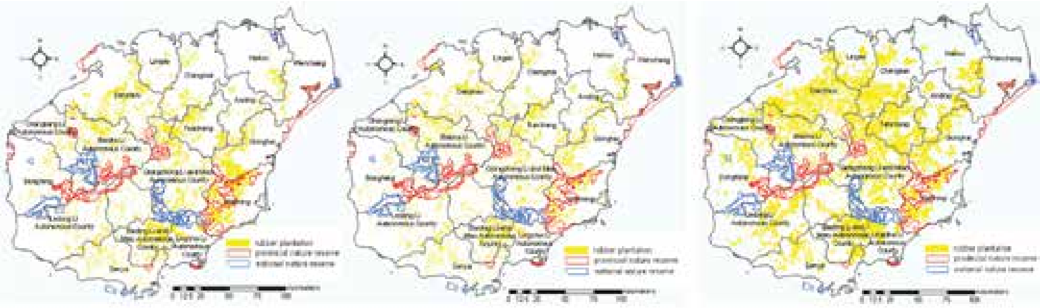
3.4.7. Relationship between pulp plantation with farm, traffic lines, and water distribution

The space distribution of pulp plantations shows small block-like but relatively wide distribution. There are a large number of distributions in the vicinity of farms, traffic lines, and waters, as well as widely distributed in coastal plains, central mountains, and terraces, which mostly



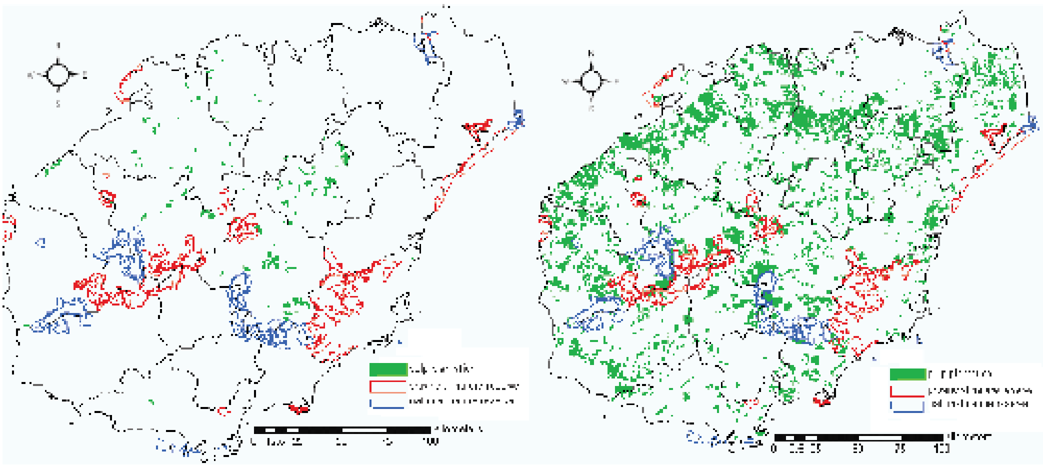
(1) 1988 (2) 1998 (3) 2008

Figure 25. Relationship between rubber plantations and farms, traffic lines, water distribution. (1) 1988; (2) 1998; and (3) 2008.



(1) 1988 (2) 1998 (3) 2008

Figure 26. Relationship between rubber plantation area change with other woodlands and nature reserves. (1) 1988; (2) 1998; and (3) 2008.



(1)1988-1998 (2)1998-2008

Figure 27. Relationship between pulp plantation area change with other woodlands and nature reserves. (1)1988–1998 and (2)1998–2008.

distributed less than 25 degrees slope. It can be seen that the regularity of pulp plantation spatial distribution is not obvious.

3.4.8. Relationship between pulp and rubber plantation with nature reserves

In recent years, natural forest reserves have been established one after another to protect natural forests and other species (**Figure 27**). In National Nature Reserve area, the area 11.29% in 2008, 5.197% in 1998, 17.29% in 1988 was covered with rubber plantation and pulp plantation. This shows that nature reserves play a protective role in natural forests. At the same time, rubber forests and pulp and paper forests gradually penetrate into nature reserves and gradually replace natural forests.

4. Conclusions

The results emphasize that forest monitoring could incorporate remote sensing imagery of specific periods and an object-based decision tree method to identify forest change. The object-based information extraction based on the decision tree method proved applicable and effective in identifying the main forests with complex surface features in a tropical evergreen ecosystem. Based on the results of forest information extraction, it is determined that the tropical forests of the central Hainan Island suffered a significant change during 1988–2008. Initially, the spatial extent of natural tropical forest increased slightly and then experienced a considerable decrease during 1998–2008. Larger amounts of natural tropical forest were replaced by economic forests, resulting in an expansion of economic forests (rubber and pulp plantations). Forests also shifted spatially during 1998–2008. Elimination of some natural tropical forests in the lower piedmont, due to economic development, caused the average location of the remaining tropical forest shift to higher altitudes. The transformation of forests was driven mainly by protection policies and economic development, but economic development exerted a much stronger influence and minimized the protection efforts. Transportation corridors, farmland, slope, and elevation were also important intrinsic dynamics that affected the transformation of tropical forests.

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A Re-Examination of the Validity of the "Separative and Exclusive Conservation Model": Insights from an Ethnobiological Study in Maluku, East Indonesia

Masatoshi Sasaoka

Additional information is available at the end of the chapter

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Abstract

This chapter aims to examine the validity and desirability of "separative conservation model," a conservation model, which tries to separate human use areas from wildlife habitats to protect "intact nature." In mountain areas of central Seram, East Indonesia, local people have created and maintained various types of human-modified forests (HMFs) through arboriculture. Among them, some of damar forests and forest gardens are distributed inside the Manusela National Park in central Seram. Principally, the Indonesian national park management authority has adopted the "separative conservation model" and basically forbids local arboricultural activities for creating HMFs by cutting wild trees inside a national park. In this chapter, I first describe how the locals have formed HMFs through arboricultural and how resources provided from those HMFs support local livelihood. After that, I describe local knowledge on behavior of a flagship species of Wallacea Moluccan cockatoo and its habitat utilization. Then, I evaluate how some types of HMFs function as habitats for the Moluccan cockatoo by analyzing transect survey data. Finally, I provide implications for future conservation and research.

Keywords: human-modified forests (HMFs), separative and exclusive conservation model, Moluccan cockatoo, arboriculture, participatory transect survey, Manusela, Seram

1. Introduction

A historical anthropologist D.K. Latinis called the subsistence system in Wallacea, including Maluku, Eastern Indonesia, an "arboreal-based economy" [1] because its residents meet most of their needs through arboreal resource utilization. In the mountain area of central Seram, East Indonesia, where I have been conducting environmental sociological research on local wildlife use, local people are highly dependent on arboreal resources. They have created and maintained various types of human-modified forests (HMFs) through “arboriculture.” “Arboriculture” here means the utilization, cultivation and protection of useful arboreal plants. At first glance, mature natural forests in central Seram look like “intact forests,” which experience little impact from human activities. In fact, however, there are many HMF patches scattered in the forest area.

Some of those HMFs are located inside a national park. In central Seram, there is the Manusela National Park, which was established in 1989. It has an area of 189,000 ha, covering about 10 percent of the terrestrial area of the Seram Island. One of its main purposes is to help conserve a flagship species in Wallacea, the Moluccan cockatoo (*Cacatua moluccensis*) (**Figures 1** and **2**). The cockatoo is endemic to Seram Island. It is believed that the population of this world’s largest white parrot is decreasing due to illegal trapping for pet trade and the destruction of habitat (mainly the destruction of lowland rainforests). Therefore, it is listed in Convention on `International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix 1 and protected under Indonesian law [2].

Basically, the Manusela National Park management authority (Balai Taman Nasional Manusela) has adopted a “separative and exclusive conservation model” (hereafter, “separative model”) for its park management. The separative model here means a conservation model that separates human-use areas from wildlife habitats and excludes human activities from protected areas to protect “intact nature.” Behind this model lies the implicit assumption that what should be conserved is “intact nature,” which is not disturbed by humans, and local people are a (potential) threat to nature. In the mountain areas of central Seram, local people have

Figure 1. A flagship species in Wallacea, the Moluccan cockatoo. Note: Photo by Kai Bancer.

Figure 2. A Moluccan cockatoo drawn on a sign near the national park border. Note: It says 'protect us!' The cockatoo is drawn at the center of the national park's logo and is the primary symbol for the entire park.

created and maintained damar forests (*Agathis dammara*-dominated forests for resin extraction) and forest gardens (mixed tree gardens with fruit trees). Some of these HMF patches are distributed inside the national park. Even though the park management authority seems to give its tacit approval to the locals to manage the HMFs, according to existing Indonesian laws that regulate national park management, HMFs' creation is by cutting wild trees inside a national park.

However, tropical forests in Seram have a long history of human interaction [3]. Large parts of the forest areas inside the national park have been affected by human intervention, including arboricultural practices.

While staying in an upland community on central Seram, I heard from some villagers that Moluccan cockatoos do not live only in kaitahu ("primary" or mature secondary forests situated far from the village settlement and primarily used as hunting and trapping grounds) but are also frequently seen in damar forests and forest gardens. According to the villagers, besides kaitahu, those HMFs are important places for the birds to forage and rest.

Manusela National Park is managed not only for the purpose of protecting Moluccan cockatoo's habitats. However, conservation of the parrot is undoubtedly one of the most important expected functions of Manusela National Park. If, as the villagers mentioned, damar forests and forest gardens truly contribute to providing important habitats for the cockatoo, and if we attach great importance to its conservation, it would be inappropriate to apply a conventional separative model that strictly excludes any human intervention, especially arboriculture, inside the park.

Based on the earlier section, in this chapter, I discuss the validity of a separative model in the context of Seram by evaluating the importance of HMFs as a habitat of a flagship species, the Moluccan cockatoo. This chapter is organized as follows. After explaining the research site and our data collection methods, in the results section, I first describe how the locals have formed HMFs through arboricultural practices and how resources provided from those HMFs support local livelihood. I also describe local knowledge on the Moluccan cockatoo's behavior, its habitat utilization and distribution. I then evaluate how some types of HMFs are functioning as habitats for the Moluccan cockatoo by analyzing transect survey data. Finally, I provide implications for future conservation and research.

2. Methods

2.1. Study area: Amanioho and Manusela National Park

Seram island is the largest island in the Moluccas (18,410 km^2), East Indonesia, extending approximately 60 km from north to south and approximately 340 km from west to east. The island is located at the north of Ambon, the provincial capital.

This study was conducted in an upland community (given the fictitious name of Amanioho) in the forested interior of central Seram (**Figure 3**). In central Seram, there is a certain amount of forest degradation and deforestation in the lowlands in the northern coastal areas. This is caused by cacao plantations, shrimp farms and transmigration programs as well as commercial logging of meranti (*Shorea* spp.) and merbau (*Intsia bijuga*). In addition, a large forest area in the northern coastal lowlands was cleared for oil palm plantation in 2009. Nevertheless, large tracts of mature natural forest remain in other rural areas in central Seram, especially in the interior mountainous area.

Amanioho is situated in the forest interior of central Seram. In 2012, the population of Amanioho was approximately 320 (60 households). Since there is no navigable roadway, it is necessary to walk to the coastal area where markets are situated. On foot, the journey from Amanioho to the north coast takes between 2 and 3 days, whereas the journey to the south coast takes 1 day (**Figure 4**).

The main economic activities include sago palm (*Metroxylon sagu*) cultivation, banana and root crop agriculture, hunting and trapping and gathering forest products such as edible plants, rattan and wild honey. These activities are primarily conducted for subsistence [4, 5]. The villagers also engage in seasonal migrant work, such as harvesting cloves in the southern coastal area from September to November, and they occasionally sell non-timber forest products (NTFPs) such as parrots and honey in the coastal areas [6].

The village settlement of Amanioho is situated approximately 2–3 km from the nearest boundary of the Manusela National Park. Nearly half the territory of Amanioho is inside the park. As mentioned above, the locals have created and maintained HMFs through arboriculture, and some of the HMF patches are located inside the national park.

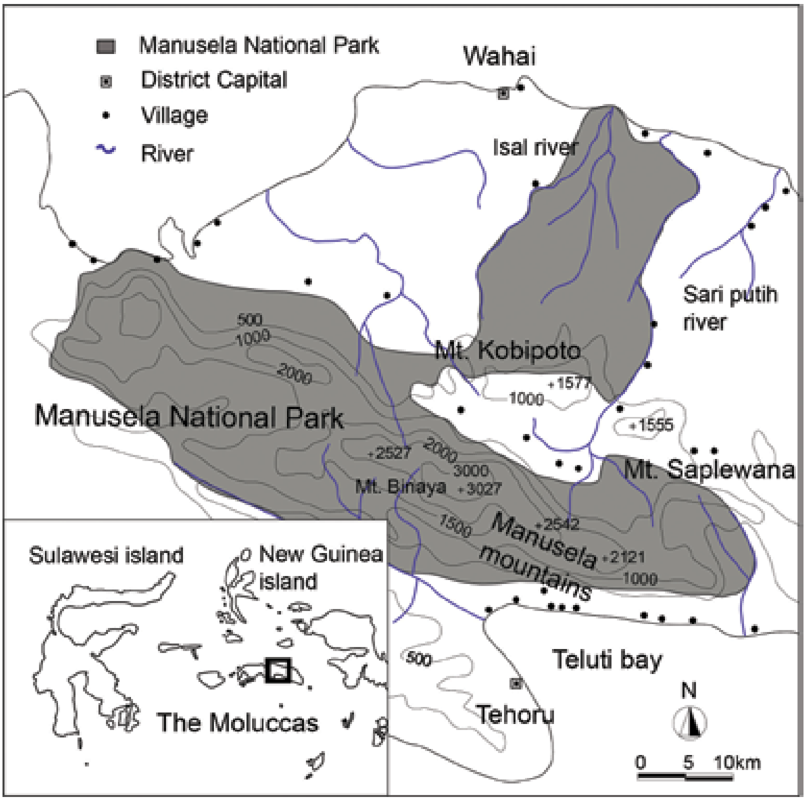

Figure 3. Manusela National Park in central Seram, East Indonesia.

Indonesian Act No.5/1990, concerning conservation of the living natural resources and their ecosystems, and Government Regulation No. 68/1998, on nature sanctuaries and nature conservation areas, stipulate that national parks are managed through a zoning system, and activities that change the ecological integrity of the core zone are forbidden.

Even though the national park management system in Indonesia basically applies a separative conservation model, it also has a mechanism that partially allows local people to use resources inside a national park. The Indonesian national park zoning system comprises several types of zones as shown in **Table 1**. In traditional zones and special zones, the local people can harvest resources under certain conditions (e.g., prohibition on natural tree cutting).

According to the Ministerial Decree on guidelines for the zoning of national parks (p.56/Menhut-II/2006), public consultation involving stakeholders including local people is needed in the process of zonation. Designation of zones in Manusela National Park was implemented in 2011. As shown in **Figure 5**, most of the park is designated as core zones and wilderness zones, where human activities are strictly limited for conservation. Several

Figure 4. The main street in Amanioho (A) and a distant view of Amanioho (B).

upland communities are situated in a peninsula-shaped enclave in Manusela valley. People of those communities are highly dependent on forest resources, and they historically used to use forest areas inside the national park. However, no "traditional zone" is established in the mountain areas where the local people harvest forest resources. The park management

Zone	Allowed activities	Local resource use	Not adjoining core zone
Core	Research, education, building non-permanent supporting facilities.		
Wilderness	Research, education, restricted tourism, building supporting facilities.		
Utilization	Tourism and tourism development, building supporting facilities.		v
Other zones			
Rehabilitation	Rehabilitation-related activities.		
Religious, cultural and historical	Rituals, cultural/historical sites maintenance.		
Traditional	Resource use (NTFPs) in a traditional way.	v	
Special	Accommodating facilities and infrastructure (e.g. roads and electricity), resource/ land use for livelihood.	v	v

Sources: Ministerial Decree 'P.19/Menhut-II/2004 on collaborative management of nature reserves and protected areas, and Ministerial Decree'P.56/Menhut-II/2006 on guidelines for zoning of national parks.

Table 1. Zonation of National Parks in Indonesia.

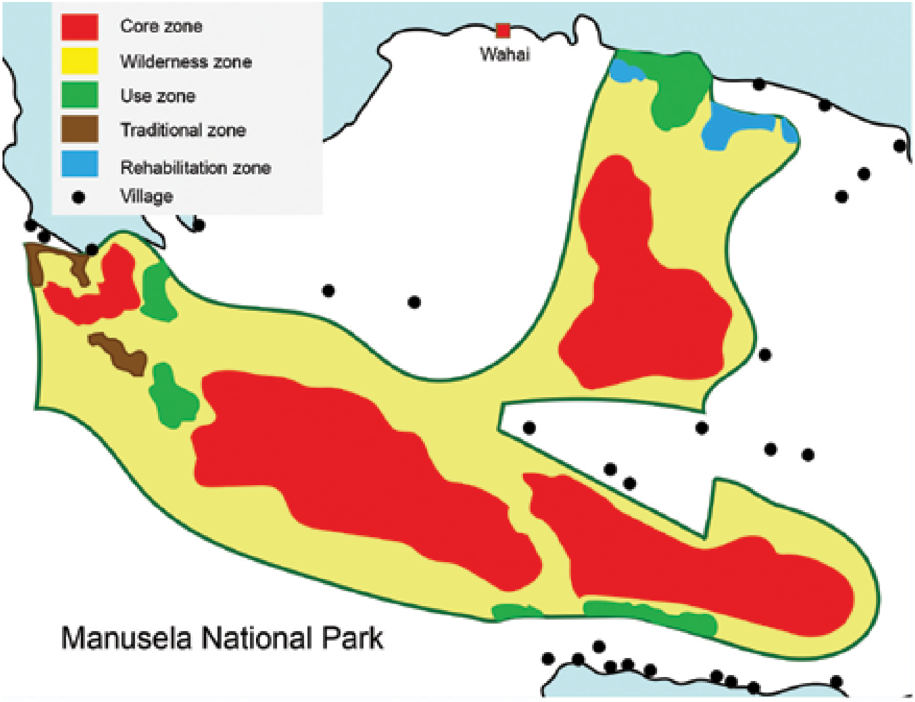

Figure 5. Manusela National Park in central Seram, East Indonesia. Note: Author (MS) drew the map based on 'Peta Zonasi Taman Nasional Manusela, Kabupaten Maluku Tengah, Provinsi Maluku (Zonation map of the Manusela National Park, Central Maluku, Maluku province) (Balai Taman Nasional Manusela, 2011).

authority did not provide sufficient opportunities for the Amanioho people to communicate their aspirations during zone planning.

2.2. Data collection

The following research methods were used. All interviews were conducted by the author using Bahasa (a common Indonesian language) mixed with the local language, *Sou upa*.

- Interviews: Key informants, groups, and working interviews were conducted regarding the formation and utilization of HMFs and on local knowledge of the Moluccan cockatoo's ecology. These interviews were conducted intermittently in October–November 2010, February 2012, September 2012 and March 2014.
- Resource inventory surveys: Through walking interviews with groups of several villagers, the names of plant and animal resources, the usefulness of which was recognized by the villagers, were listed. Focus-group interviews with four villagers (two men and two women) were also conducted to collect data on land usage, where various resources were collected and harvested. As for plant resources, specimens were collected and their scientific

names were identified at the Herbarium Bogoriense, the Indonesian center for science. Initial extensive survey work was conducted in 2003. Supplementary surveys were conducted through the interviews with three village men and two women to complement previous data in October–November 2010, February 2012, and September 2012.

- Food intake surveys: MS distributed self-administered sheets to 14 randomly selected households and asked those household members to record contents of meals they had (food items, land types where those food items are harvested, etc.) for 16 days in 2 research periods, respectively. Data was collected from February 6 to February 21, 2012 (fruiting seasons/wet season) and from September 6 to September 21, 2012 (outside fruiting seasons/dry season). During data collection, MS visited houses of the informants once every 2 days during the longest intervals to check the recorded data and clarified unclear data through interviews.
- Moluccan cockatoo site-mapping surveys: In February 2012, MS conducted a mapping survey to identify locations and forest types of cockatoo sites, that is, places where local villagers reported that the cockatoos are commonly seen or heard. MS interviewed 26 randomly selected villagers regarding the location and forest types of cockatoo sites. After the interviews, MS asked them to visit these sites with small GPS loggers (Trip Recorder 747Pro) to record the geographical coordinates of the cockatoo sites.
- Participatory parrot-transect surveys: These were simple parrot census surveys conducted to understand the cockatoos' HMF use patterns more precisely. MS asked four village males to walk along small forest trails at about 1 km/h with small GPS loggers at specified time periods (from 6:30 to 12:30 and from 14:30 to 18:00) and to record the forest types, when they entered each forest type, when they saw or heard cockatoos and, if possible, the number of cockatoos (**Figure 6**). Before conducting the surveys, the author held a half-day training program to teach the villagers how to record the data. Behavior of the cockatoos may be affected by time. For the purpose of avoiding over-concentration of data in a certain forest

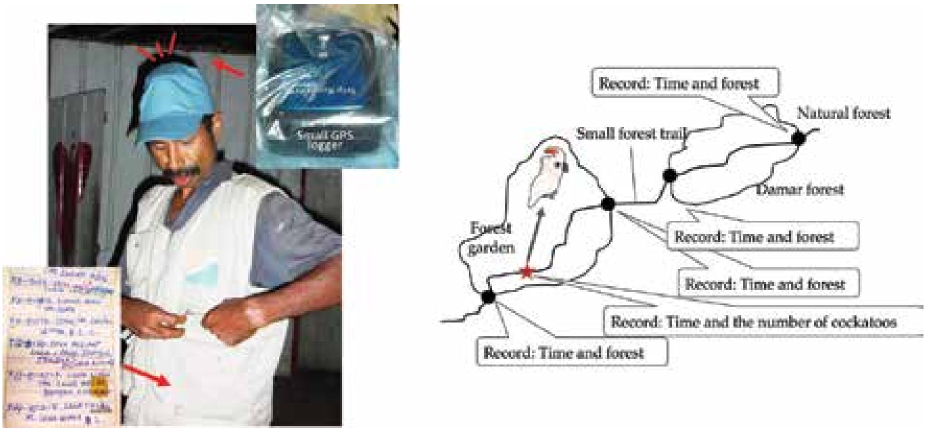

Figure 6. Participatory parrot-transect survey. One of the recorders of the participatory parrot-transect survey (left) and a schematic of the participatory transect survey (right).

type and time period, MS organized survey trips in the following manner. A single transect survey trip took 2 days. On the first day, the recorders walked along forest trails from disturbed forest areas with human-forest mosaics relatively near the village settlements to remote forest areas covered by primary/old natural growth, and they stayed overnight in the forest. On the second day, the recorders walked back along the same forest trails. Since rain may hinder parrot activities, we discontinued the survey during the monsoon. We conducted these surveys during durian (*Durio zibethinus*), jackfruit (*Artocarpus champeden*) and langsat (*Lansium domesticum*) fruiting seasons (in February 2012) and outside the seasons (in September 2012) to avoid a seasonal bias (**Tables 2** and **3**). Data collected by the participatory parrot transect surveys are not available to estimate the population density of the Moluccan cockatoo, but they are sufficient for evaluating relative abundances of the cockatoo in different types of forests.

Route	Length of transect (km)	Lowest altitude (m)	Highest altitude (m)	Number of times of survey	
				Fruiting season (Feb. 2012)	Non-fruiting season (Sep. 2012)
Route-1	9.4	860	1190	8	8
Route-2	11.3	800	990	6	10
Route-3	8.5	840	1410	10	10
Route-4	5.6	790	1140	10	10
			Total	34	38

Source: Fieldwork.

Table 2. Participatory transect surveys.

Forest type	Fruiting season (m) (Feb. 2012)	Percentage (%)	Non-fruiting season (m) (Sep. 2012)	Percentage (%)
Primary'/old secondary forest	123,989	45	157,887	47
Damar forest	39,616	14	51,322	15
Forest garden	42,973	16	39,674	12
NTFP collection forest	19,428	7	24,607	7
Old fallow forest	9031	3	9540	3
Bamboo grove	18,059	7	24,620	7
Cacao garden	5817	2	8825	3
Sago grove	18,177	7	20,083	6

Source: Fieldwork.

Table 3. Length of all surveyed transects (m).

3. Results

3.1. Formation and utilization of human-modified forests

The locals classified land types into at least 13 categories (**Table 4**). Land categories marked with X are HMFs formed through arboriculture.

Among the types, forest gardens and damar forests are important for interrelationships between humans and Moluccan cockatoos.

Land types (Folk categories)		HMFs	Descriptions
1.	Home garden and residential area (amania)		Residential land and home gardens with coconut palms, betel nut palms and various herbs.
2.	Intensive root crop – vegetable garden (lela)		Intensively managed garden, where the main crops are taro, cassava, sweet potato, vegetables, tobacco, sugar cane, etc.
3.	Extensive banana – taro garden (lawa aelo)		Extensively managed garden with banana and taro.
4.	Forest garden (lawa aihua)	X	Mixed tree garden with both fruit trees (durian, langsat, jackfruits, etc.) and wild trees.
5.	Sago grove (soma)	X	Sago palm (*Metroxylon sagu*) grove that supplies sago starch, which is a staple food for local people. Sago (*Metroxylon sagu*) grove. Local people also use sago groves as places to collect edible wild plants.
6–7.	Cultivatable land and fallow forest (lukapi)		Cultivatable land where huge roots of trees have decayed, and fallow forest that was formed in the ex-lela and ex-lawa.
	6. Young fallow forest (lukapi holu)	X	Fallow forests with relatively small young trees that can be cut down by a machete (parang).
	7. Old fallow forest (lukapi mutuani)	X	Fallow forests with relatively large trees that cannot be cut down by a machete.
8.	Itawa forest (Itawa harie)	X	Litsea mappacea-dominated forests that are used as a trapping ground for edible wild birds.
9.	Cacao garden (dusun cokorat)	X	Cacao (*Theobroma cacao*) -dominated gardens. Most of them spring up in fallow land.
10.	Bamboo forest (dusun bambu)	X	Bamboo grove formed through transplanting. Several species of bamboo are used as handicraft materials, fuel wood, and cookware. Bamboo shoot is also collected.
11.	Damar forest (kahupe hari)	X	Resin extraction forest dominated by the *damar* tree *(Agathis dammara*).
12.	NTFP collection forest (airima hari)	X	A forest located relatively close to village settlements, and they are used for collecting NTFPs such as construction materials, fuel woods, medical plants and wild edible plants.
13.	Primary'/old secondary forest (kaitahu)	X	A primary or mature secondary forest situated far from the village settlement and thought of as ground that is primarily used for hunting and trapping game animals. Artificial gaps are made for trapping cuscus.

Source: Fieldwork.

Table 4. Folk land categories.

Damar forests are dominated by *Agathis dammara*, which has been used for resin (damar is a fuel for lamps and kindling) collection. These are formed through selectively protecting seedlings as well as young trees that are growing naturally, and they are patchily distributed in primary and old secondary forests. Felling and barking of *Agathis dammara* is strictly forbidden.

Forest gardens are mixed fruit tree gardens with durians (*Durio zibethinus*), langsats (*Lansium domesticum*), jackfruits (*Artocarpus champeden*) and so on. Forest gardens are formed through planting and protecting seedlings as well as young trees growing in the wild; the seeds are mainly dispersed by wild bats. Forest gardens are patchily distributed in mostly old secondary forests. These HMFs are less intensively managed. As a result, forest gardens have no clear boundary and are mixed with many wild plants.

Figure 7 shows the number of plant resources and total use scores, which indicate the number of uses of the plant resources in each land category. This indicates that non-timber forest product (NTFP) collection forests, forest gardens and sago groves provide relatively diverse plant resources used for various purposes, including food and medicine. **Figure 8** shows the number of animal resources usually captured or commonly seen in each land type. This indicates that the locals utilize a variety of animal species that enter or live in these HMFs. The locals have created various types of HMFs, and this enables them to enjoy diverse plant and animal resource utilization.

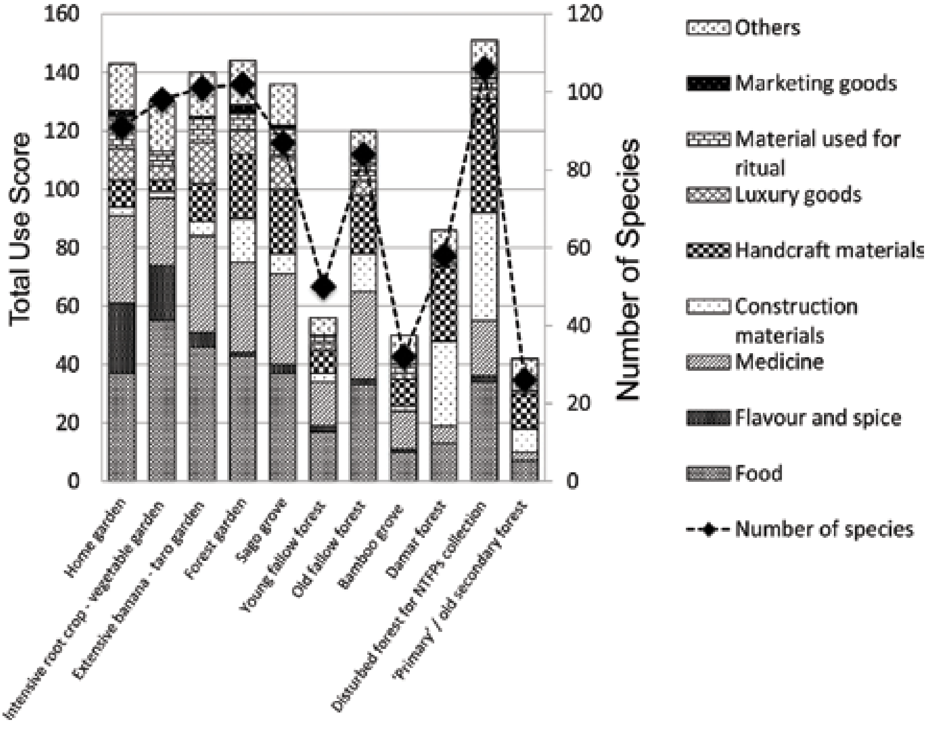

Figure 7. Plant resources. Source: Fieldwork. Note 1: The 'Total use scores' were counted based on the number of uses. For example, the total use score of cassava for food is 2 because besides its root, the leaves of cassava can also be eaten. Note 2: The data for the Itawa forest and cacao garden were deficient.

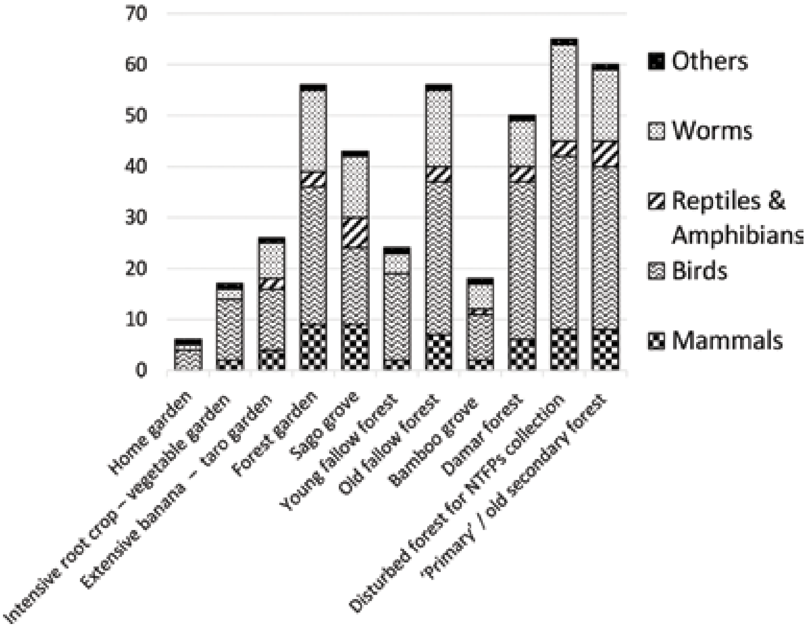

Figure 8. Animal resources. Sources: Fieldwork. Note 1: These animal resources are mostly used for food. Note 2: 'Others' includes snails and honey.

Here we look at how resources provided from HMFs support local diets. **Figure 9** shows the result of the food intake surveys. Bars indicate the number of food items that were consumed by 14 households during the 2 periods by land types. As shown in the graph, the local people harvest diverse food resources in various types of lands. During both survey periods, sago grove, old fallow forest and NTFP collection forest provided relatively many food resources. In the fruiting season for durian, jackfruit, langsat and so on, the locals consume lots of food resources harvested from forest gardens. Creation and maintenance of diverse HMFs contribute to enriching local diets.

3.2. Local knowledge of parrot ecology

3.2.1. Behavior and habitat utilization of Moluccan cockatoo

According to the villagers, during the night, the cockatoos roost in large trees, such as those locally called "kahari" (*Sloanea* sp.) and "raruka" (*Elaeocarpus rumphii)*, in primary and old secondary forests. After sunrise, they fly to feeding areas; they return to the same roosting sites before sunset.

In the morning and evening, they forage new shoots of rattan (*Calamus* spp.), swarms of moths in trunks of dead trees and fruits such as "kahari" and "raruka" in primary and old secondary forests (the fruiting seasons of "kahari" and "raruka" are unknown). They also forage other fruits such as "tatola" (*Homalanthus novoguineensis)*, "ulia" *(Spondias cytherea)* and "masapa" (*Syzygium* sp.) in old fallow forests and forest gardens; fruits of *Agathis dammara* in damar forests; and "hakia" (*Magnolia candollei)*, which also grows in damar forests. These trees do not have specific fruiting seasons. The cockatoos use these food resources all year.

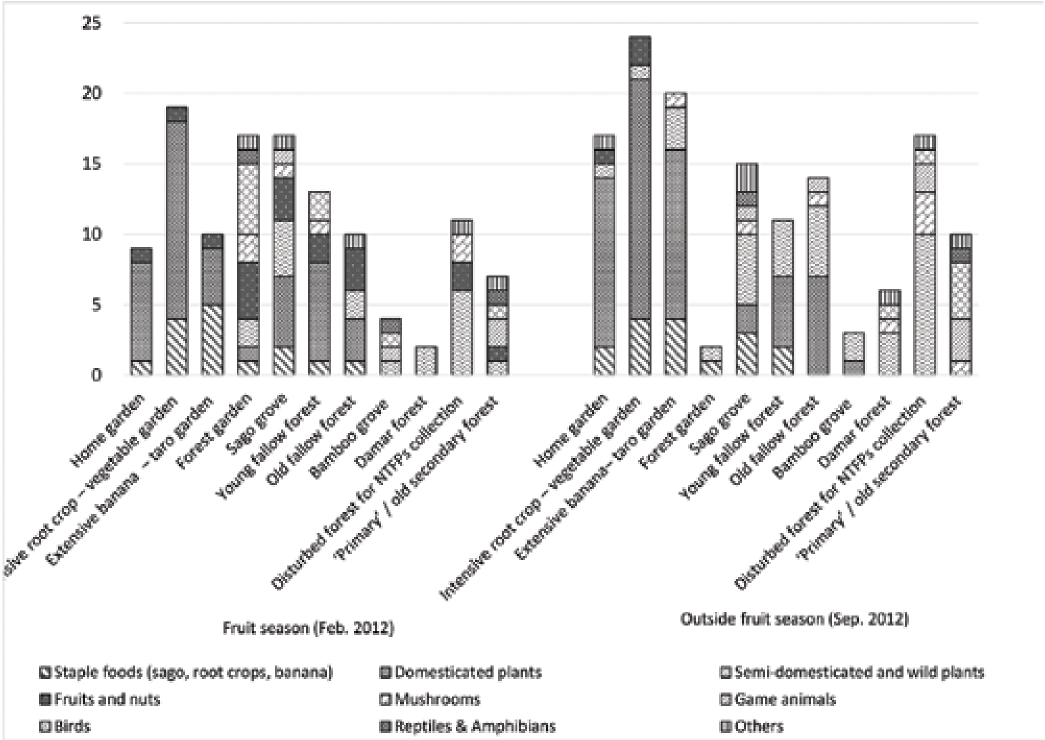

Figure 9. Number of food resources harvested in each land category. Source: Fieldwork. Note 1: Food resources consumed as a snack, luxury items (e.g. tea, coffee, tobacco, betel nuts etc.), spices, flavors and oil are not included. Note 2: 'Semi-domesticated plants' here mean (1) herbaceous and arboreal plants that are planted (transplanted) by humans and less intensively managed after planting, and (2) herbaceous and arboreal plants that grow naturally, but the growth of which is encouraged by humans through weeding, cutting underbrush and vines, etc.

During the durian, jackfruit and langsat fruiting seasons, the cockatoos frequently fly to forest gardens to eat the fruits of these trees. They also frequently use damar forests to nest in hollows of large dead damar trees (**Table 5** and **Figure 10**).

3.2.2. Forest types and distribution of the cockatoo sites

The map in **Figure 11** indicates the "cockatoo sites" recognized by the randomly selected 26 villagers, as those where Moluccan cockatoos are frequently and commonly seen or heard. As shown on the map, the cockatoo sites are distributed over a wide area, including areas relatively near the village settlement and some of HMFs inside the national park. A total of 78 cockatoo sites were listed. Among them, 42 sites are damar forests, and 25 sites are forest gardens (including forest gardens mixed with *Agathis dammara* trees). Of those, 16 sites in damar forests and 3 sites in forest gardens are situated inside the national park (**Table 6**).

The result of the Moluccan cockatoo site-mapping surveys seems to indicate that the cockatoo uses damar forests and forest gardens as important parts of their habitats. However, it is still unclear whether those HMFs are truly functioning as important parrot habitats because of the

Forest type	Utilization	Season
Forest garden	• Eats fruits of durian, langsat, jackfruit	Jan–May
	• Eats tatola (*Homalanthus novoguineensis*), ulia (*Spondias cytherea*), and masapa (*Syzygium* sp.)	All year around
Damar forest	• Eats fruits of damar tree (*Agathis dammara*) and hakia (*Magnolia candollei*)	All year around
	• Nests in tree hollows of large dead damar tree	

Source: Fieldwork.

Table 5. Utilization of human-modified forests.

lack of objective and quantitative data. Therefore, I next analyze the relative abundances of Moluccan cockatoos by forest types.

3.2.2. Relative abundance of Moluccan cockatoos

A relatively high abundance of Moluccan cockatoos was observed in primary and old secondary forests during time period 1 and in damar forests during time periods 2 and 3 in both the fruiting (February 2012) and non-fruiting (September 2012) seasons. During the fruiting season, the cockatoos' abundance in forest gardens during time zones 2 and 3 is relatively high (**Table 7** and **Figure 12**). On the other hand, their presence in other forest types (NTFP collection forest, cacao garden, bamboo forest and sago grove) is very low in both seasons.

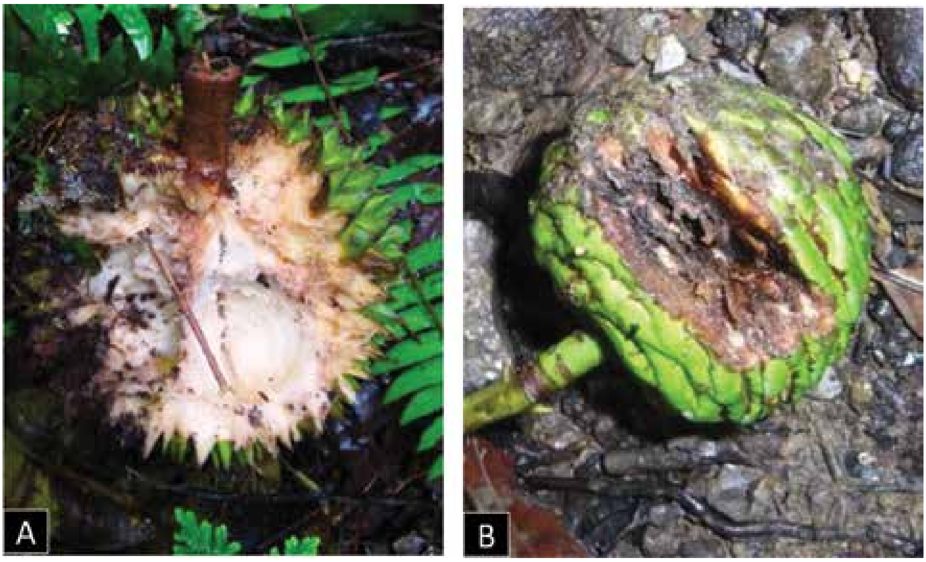

Figure 10. Feeding scars of Moluccan cockatoo on the fruit of durian (A) and *Agathis dammara* (B).

Forest types	Number of sites	Number of sites inside the National Park
Primary/old secondary forest	11	3
Damar forest	42	16
Forest garden	19	2
Forest garden mixed with damar trees	6	1

Source: Fieldwork.

Note: 78 cockatoo sites were identified through the interviews with 26 villagers (Feb 2012).

Table 6. The results of the cockatoo site surveys.

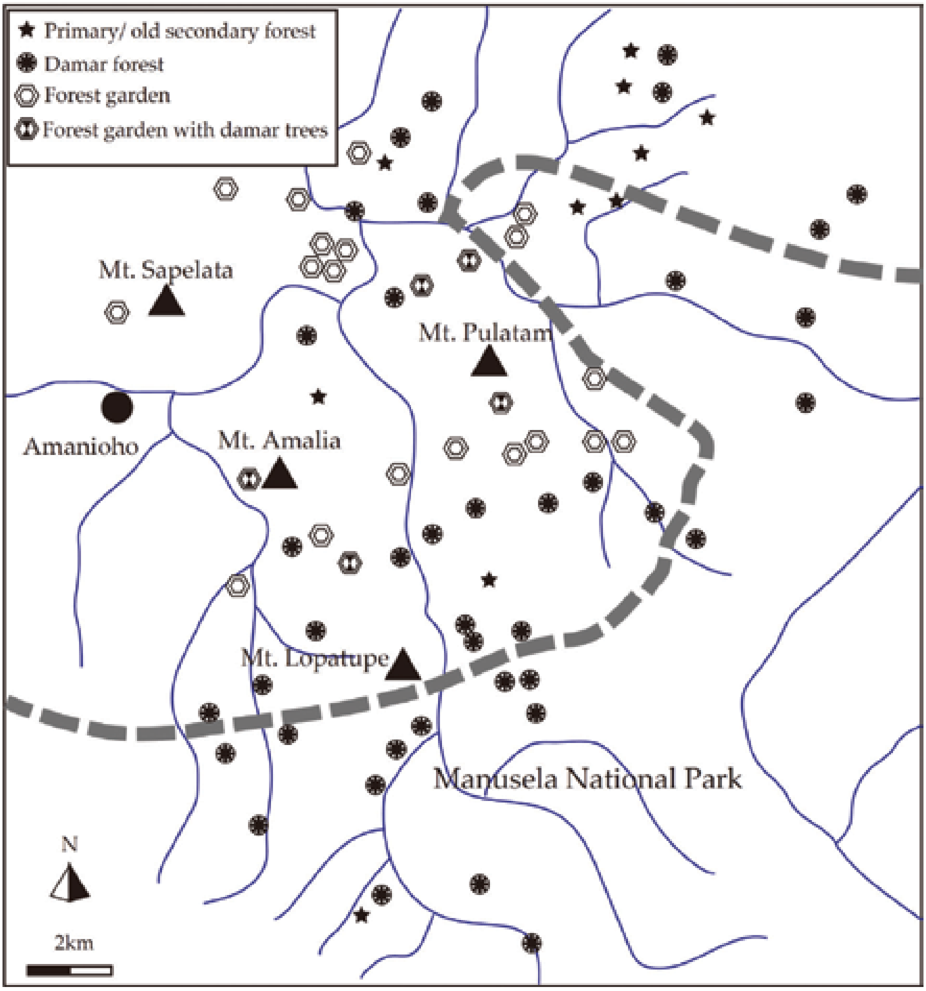

Figure 11. Sites where the Moluccan cockatoos are frequently seen or heard.

Forest type	Time zone-1 (6:30–8:00)	N	Time zone-2 (8:00–9:00)	N	Time zone-3 (9:00–10:00)	N	Time zone-4 (10:00–11:00)	N	Time zone-5 (11:00–12:30)	N	Time zone-6 (14:30–16:00)	N	Time zone-7 (16:00–17:00)	N	Time zone-8 (17:00–18:00)	N	P
Fruit season (Feb. 2012)																	
Primary/old secondary forest	2.88	27	0.94	25	0.21	28	0.24	27	0.00	33	0.72	26	0.21	20	0.12	15	0,001***
Damar forest	0.81	30	1.29	14	0.34	11	0.00	13	0.00	7	1.62	8	0.27	13	0.86	22	0,308
Forest garden	1.19	35	1.20	25	1.08	14	0.18	19	0.59	17	0.21	13	0.00	20	0.06	20	0,052*
NTFP collection forest	0.00	4	0.00	9	0.00	12	0.00	7	0.00	8	0.00	9	0.00	15	0.00	8	1000
Old fallow forest	0.00	15	0.00	6	0.00	3	0.00	3	0.00	6	0.00	3	0.00	6	0.00	9	1000
Bamboo grove	0.00	12	0.00	19	0.00	14	0.00	8	0.00	6	0.00	10	0.00	19	0.00	10	1000
Cacao garden	0.00	9	0.00	2	0.00	1	0.00	14	0.00	14	0.00	6	0.00	2	0.00	5	1000
Sago grove	0.30	21	0.00	14	0.00	9	0.00	10	0.00	18	0.00	18	0.00	6	0.00	14	0,286
P	0.009***		0.029**		0		1		0		0.044**		0		0		
Outside fruit season (Sep. 2012)																	
Primary/old secondary forest	2.29	34	1.08	24	0.47	25	0.45	33	0.10	39	0.26	24	0.51	29	0.43	28	0,010**
Damar forest	0.97	40	0.00	14	2.03	10	0.45	11	0.00	12	1.10	12	0.36	19	0.31	30	0,036**
Forest garden	0.18	31	0.30	22	0.85	12	0.73	11	0.00	19	0.00	17	0.09	17	0.00	17	0,747
NTFP collection forest	0.00	4	0.00	4	0.30	12	0.00	12	0.07	13	0.00	10	0.00	13	0.00	4	0,412

Forest type	Time zone-1 (6:30–8:00)	N	Time zone-2 (8:00–9:00)	N	Time zone-3 (9:00–10:00)	N	Time zone-4 (10:00–11:00)	N	Time zone-5 (11:00–12:30)	N	Time zone-6 (14:30–16:00)	N	Time zone-7 (16:00–17:00)	N	Time zone-8 (17:00–18:00)	N	P
Old fallow forest	0.00	11	1.05	17	0.00	2	0.00	3	1.07	9		0	0.00	9	0.00	12	0,763
Bamboo grove	0.00	17	0.18	22	0.00	11	0.00	10	0.00	15	0.00	9	0.00	16	0.00	20	0,726
Cacao garden	0.00	21	0.00	8	0.00	2	0.00	7	0.00	17	0.00	9	0.00	5	0.00	14	1000
Sago grove	0.00	25	0.00	11	0.00	20	0.00	5	0.06	27	0.00	19	0.00	3	0.00	18	0,809
P	0.000***		0.000***		0.008***		0		1		0.081*		0		0.054*		

Source: Fieldwork.

Note 1: Kruskal-Wallis test.

Note 2:*Significant level 10%;

**Significant level 5%;

***Significant level 1%.

Note 3: Relative abundance = [numbers of observed cockatoo]/[length of a transect unit].

Table 7. Relative abundances of Moluccan cockatoos (number/1000 m).

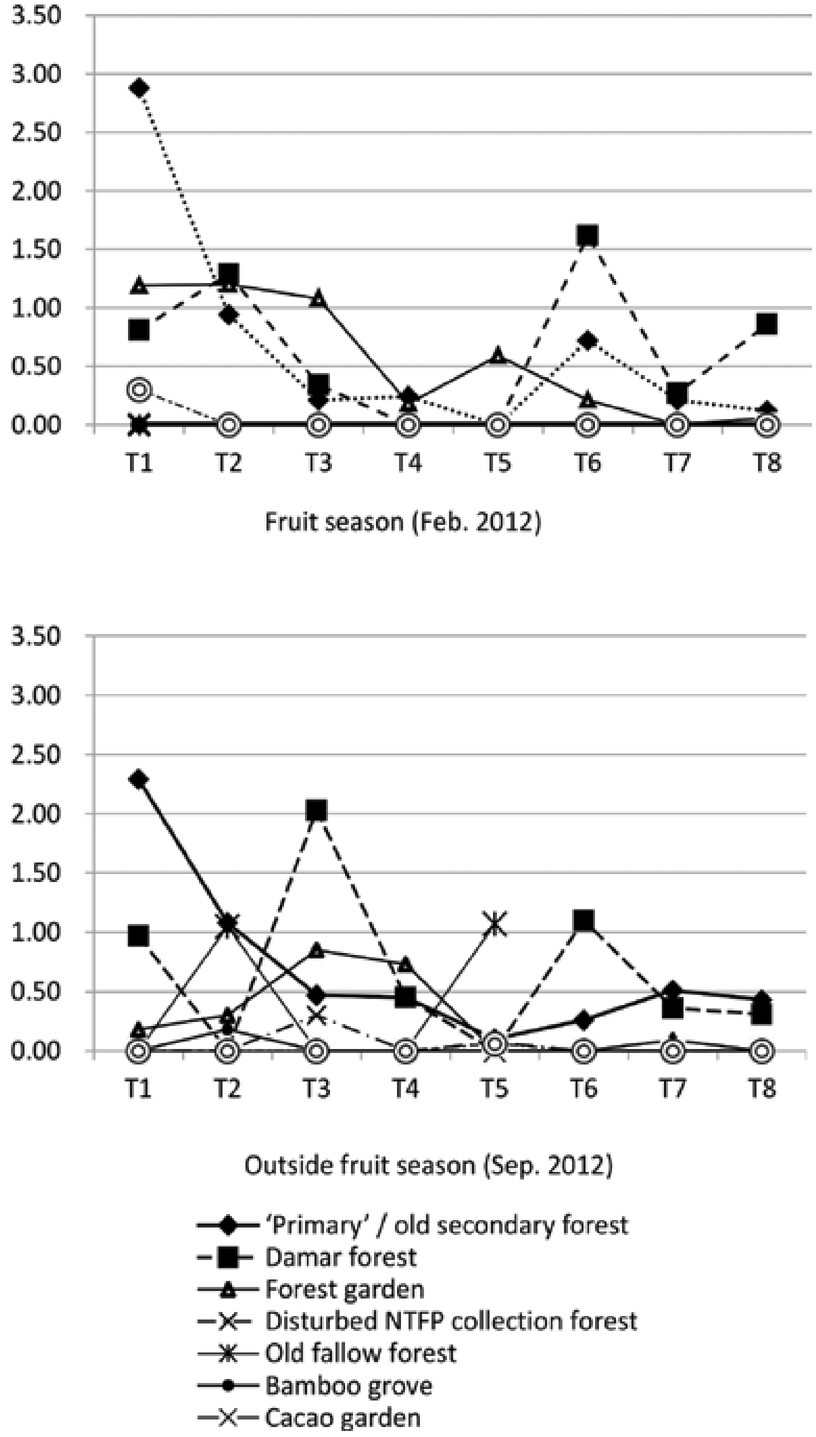

Figure 12. Relative abundances of Moluccan cockatoos in terms of forest type and time zone (number/1000 m). Source: Fieldwork. Note:T1, T2, T3, T4, T5, T6, T7 and T8 represent time zone 6:30–8:00, 8:00–9:00, 9:00–10:00, 10:00–11:00, 11:00–12:30, 14:30–16:00, 16:00–17:00, 17:00–18:00, respectively.

In the participatory transect surveys, I could not collect data after 18:00 (shortly before sunset) for a practical reason: the recorders were needed to prepare firewood for overnight camping. Therefore, cockatoo locations during the late evening are still unknown, but it can be presumed that the cockatoos' forest use patterns correspond to folk knowledge about parrot behaviors, as described earlier.

The data collected by the participatory transect surveys suggest that the cockatoos use primary and old secondary forests as shelters, roosting sites and feeding areas and that they frequently use HMFs as feeding sites (including damar forests, forest gardens and old fallow forest) during different time periods and seasons. Damar forests are used by the cockatoos all year, but the extent of their use of forest gardens tends to increase during the fruiting season.

4. Discussion

The locals under study have created and maintained diverse HMFs. Some of these are located inside the national park. The diverse HMFs enable the locals to enjoy a variety of forest provisioning ecosystem services. The HMFs appear to secure the livelihood of mountain people living in remote areas with poor access to local markets.

As indicated by the results of the cockatoo site surveys and the participatory transect surveys, among the various types of HMFs, NTFP collection forests, bamboo forests, cacao gardens and sago groves appear to be unsuitable habitats for the cockatoos, but less-intensively managed HMFs, such as damar forests and forest gardens, are suitable habitats.

If forest gardens and damar forests really contribute to providing important habitats for the cockatoo and if we attach great importance to the conservation of the cockatoo as part of national park management, it would be inappropriate to apply conventional national park management measures that strictly exclude any human intervention through agriculture (including arboriculture) inside the park.

In the northern coastal area of central Seram, there are coconut palm and cacao plantations as well as shrimp farms. In addition, transmigration programs and commercial logging have been conducted intensively since the 1990s [7]. These practices have caused forest degradation and deforestation in large areas of the lowland. An oil palm plantation company began operations in 2009.

Given that these large-scale development projects have destroyed and are destroying a large area of the forest, the park's importance in conserving regional biodiversity is undoubted. What I recommend here is more flexible park management measures that are consistent with local realities.

As long as locals engage in less-intensive and small-scale arboriculture, it is unlikely that their subsistence activities will negatively impact biodiversity in the park. Therefore, it would be desirable to establish special zones where locals can practice arboriculture in the park under certain conditions (e.g., limited to subsistence purposes).

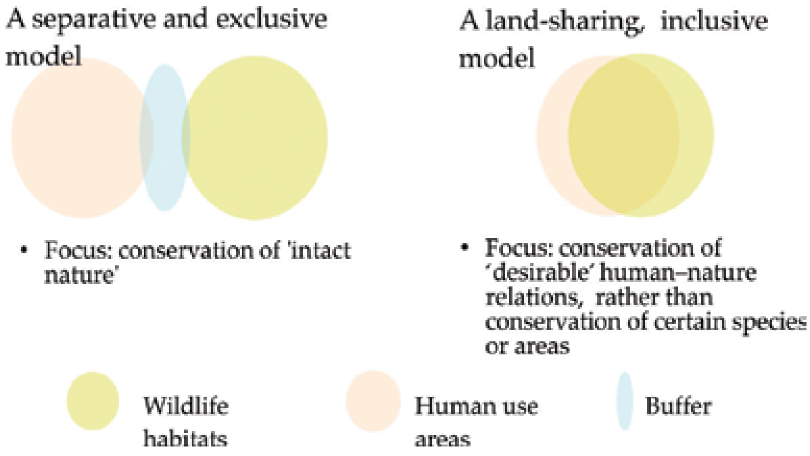

Figure 13. A new conservation paradigm versus the conventional paradigm.

To promote such a flexible system, a shift of management paradigm, away from the conventional separative model that strictly separates areas of human activity from conservation areas to a new one that focuses on human-wildlife relationships formed in human-modified landscapes (**Figure 13**) is necessary.

Space for less-intensively managed HMFs is diminishing through the process of "polarization of landscapes," where rural forest areas are divided into "development areas" used intensively for agricultural production and resource exploitation on the one hand and "conservation areas" for protecting "intact nature" on the other hand. We still know little about the roles of less-intensively managed HMFs in conserving flagship species and maintaining local biodiversity. Therefore, the conservation value of HMFs needs to be assessed.

Acknowledgements

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Masatoshi Sasaoka is an Associate Professor at the Graduate School of Letters, Hokkaido University, Japan, who is interested in environmental sociological studies on the local utilization of wildlife in the tropics, resource management and conservation based on local ecological knowledge and policy of forest resource management and biodiversity conservation.

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Chapter 8

Physicochemistry and Utilization of Wood Vinegar from Carbonization of Tropical Biomass Waste

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Additional information is available at the end of the chapter

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Abstract

Pyroligneous acid also called wood vinegar is an aqueous liquid produced from pyrolysis of lignocellulose waste and biomass. In general, the pyrolysis types are classified base on heating rate mainly either fast or slow pyrolysis. The characteristic and properties of wood vinegar are primarily influenced by the type of carbonaceous feedstocks as well as the production techniques. Wood vinegar is a complex mixture of polar and non-polar chemicals with various molecular weights and compositions. Its major constituent is water (80–90%). Some physical properties; such as pH, specific gravity, dissolved tar content are, respectively, within the range of 2–4, 1.005–1.016 g/mL, 0.23–0.89% wt, and color, odor and transparency have been reported. In addition, the degree of ^{o}Brix was ranged between 1.7 and 6.6. Besides water, the chemical compositions of wood vinegars consisted of acetic acid with the largest component (30.45–70.60 $mg.mL^{-1}$). A high number of phenol derivatives have been found and those in higher concentrations were 4-propyl-2-methoxyphenol (5–11 $mg.mL^{-1}$) followed by 2-methylphenol (2–4 $mg.mL^{-1}$). Wood vinegar has been regarded as a natural product, which claimed to be capable in several fields of application. In agriculture, wood vinegar has been used in vegetable cropping in order to combat disease, pest control, improve growth and fruit quality, seed germination accelerator as well as herbicide. In pharmaceutical and medical applications, it is used for the preparation of detoxification pad while in veterinary and animal production, incorporation of the wood vinegar in feed could promote acidity in large intestine to inhibit growth of enteropathogenic microbes. In food processing, wood vinegar has a characteristic smoke flavor, and also exhibits microbial growth inhibition. In addition, several investigators reported that bio-oil and wood vinegar obtained from fast pyrolysis and carbonization showed a high potential on organic wood preservative. In summary, the wood vinegar prepared from the tropical wood and/or biomass waste is widely beneficial. The chapter attempts to provide essential knowledge relevant to physicochemical characteristics of wood vinegar and its applications.

Keywords: wood vinegar, carbonization, physicochemistry, tropical biomass, utilization

1. Introduction

Pyroligneous acid also called wood vinegar is an aqueous liquid produced from pyrolysis of lignocellulose waste and biomass. They are formed by rapidly and simultaneously depolymerizing and fragmenting cellulose, hemicellulose, lignin and other constitutes of biomass. Those biopolymers were broken into smaller molecule with high temperature under air less atmospheres. The crude condensate smoke during pyrolysis was so called bio-oil. In order to prepare wood vinegar, this liquid is stand in a closed container for at least 3 months and decanted from sedimentation tar of bio-oil. The transparent solution in upper phase is practical wood vinegar. It has a special smoky odor and color is light yellow to brown depending on feedstock properties and pyrolysis system used for preparing it. The wood vinegar was very complex solution; the major proportion was water (80–90%) and minor proportion was more than 200 species of organic compounds. Recently, wood vinegar has been wildly applied for various proposes such as medicinal, smoky aroma, food and platelet aggregation and anti-dermatophyte activity in pharmaceuticals [1, 2]. In particular, in organic agriculture, a great number of toxic-chemicals were replaced by wood vinegar, a natural product, which has been used to combat disease and pests, stimulate plant growth, improve the quality of fruit, accelerate the speed of plant seed germination and serve as herbicides [3]. However, the physicochemistry and biological activity of wood vinegar are affected by many factors such as chemical composition of biomass, pyrolysis system and refining method.

2. Definition of wood vinegar

The crude liquid obtained by condensation of an output, gas phase and smoke, during charcoal production process is called bio-oil. After standing the crude liquid in a closed container at ambient temperature for about 3 months, it will be separated into 2 phases. A clear solution of upper phase is wood vinegar or pyroligneous acid, while the lower phase is tar sediment. The acid has smoky odor, and color may vary from light yellow to dark brown (**Figure 1**).

3. Factors influencing properties of wood vinegar

Wood vinegar is a complex mixture of polar and non-polar compounds that varies widely in their property among samples that may be observed. These are primarily influenced by the type of carbonaceous feedstocks as well as production techniques.

3.1. Feedstock

In general, cellulose (42–45%), hemicellulose (28–35%), and lignin (16–33%) are major constituents of the plant cell wall, which are primary components of wood, while water-soluble and organic-soluble compounds are the minor compounds [4]. The biopolymers and minor compounds are arranged in a complex structure as illustrated in **Figure 2**. It should be noted that

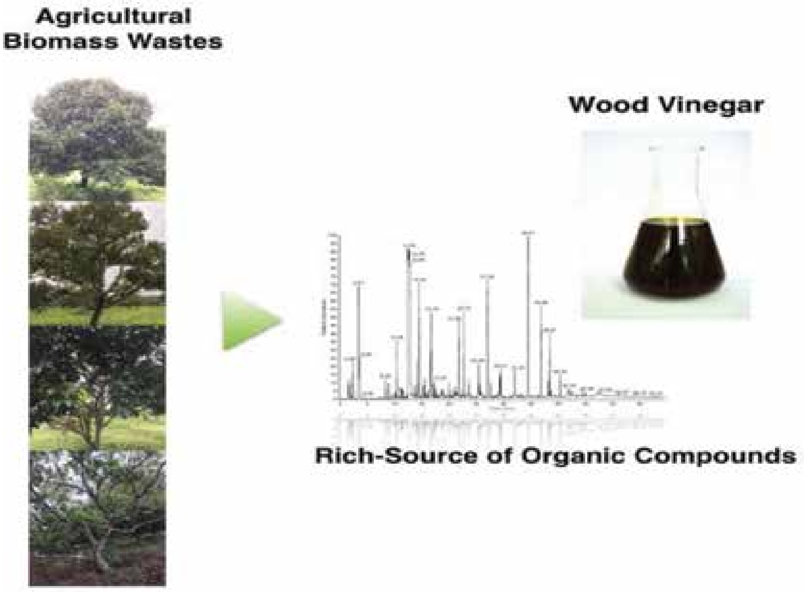

Figure 1. Wood vinegar from agricultural biomass waste.

variations in proportion of the constituents are not only depends on the plant species, but are also influenced by other factors such as habitat, age, part of the tree, etc. Hence, it could be deduced that variations in composition of feedstock used for the preparation of wood vinegar might give rise to different properties of the product.

Cellulose is a long-chain linear polymer of glucose that contains crystalline arrangements with smaller amorphous regions. There are arranged as micro-fibril which contributes to the structural component of the cell wall. In general, a similar content at approximately 43% wt is found in both hardwood and softwood [6].

Hemicellulose is shorter or branched amorphous polymer of five-or six-carbon sugars which naturally are associated with cellulose and lignin to from the matrix. The sub-units of hemicellulose in hardwoods and herbaceous plants such as wheat straw, cornstover and switch grass consist mainly of D-xylose, whereas D-mannose, D-xylose and D-galactose are the principal constituents in softwood [7].

Lignin, the third cell wall component, is a three-dimensional polymer formed from phenyl propane units with many different types of linkages between the building blocks. The main building blocks in the biosynthesis of hardwood and softwood lignin are different in structure. In softwoods, guaiacyl lignin is predominantly found resulting from polymerization of a higher fraction of conifer phenyl propane units. In hardwood, guaiacyl-syringyl lignin is present . It is a copolymer between coniferyl and sinapyl phenyl propane units where sinapyl unit fraction is higher than that in softwood lignin [8].

The water-soluble and organic-soluble compounds may be extracted from the lignocellulose biomass. For instance, the organic-soluble compounds in wood include terpenes, fats, waxes, phenolic compounds, hydrocarbons and sugars, while the water-soluble compounds are

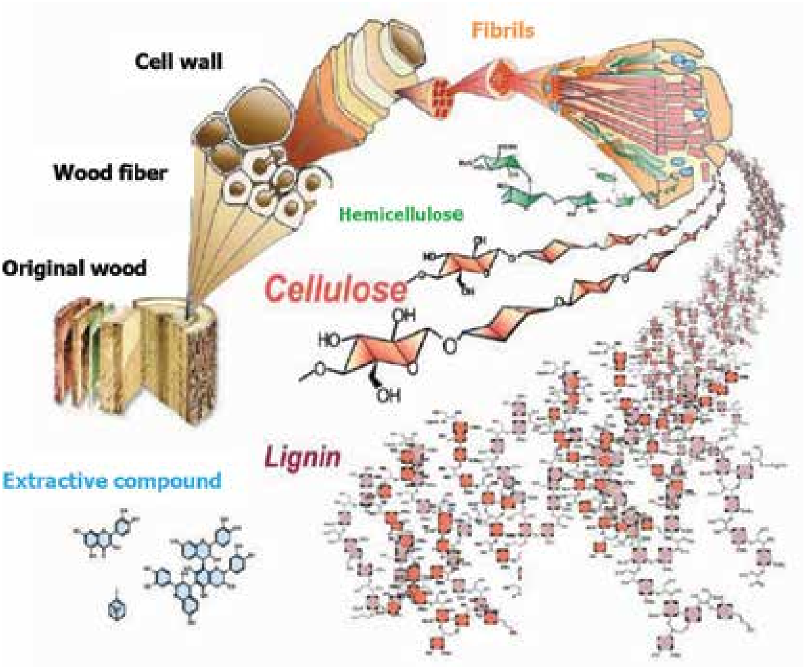

Figure 2. Composition of wood, illustrating the structure of lignocellulosic biomass [5].

sodium and potassium salts. In general, herbaceous biomass typically contains significant amounts of inorganic salts and organic-soluble compounds which may be found at approximately 15 and 20%wt, respectively. In contrast, in common woods, there are usually lower content which the inorganic salts and organic-soluble compounds may be found at approximately 0.3–0.4%wt and 2–3%wt, respectively [9].

3.2. Pyrolysis processes and preparation of wood vinegars

Pyrolysis is mainly technology used to produce wood vinegar with thermal degradation of organic material. According to this system, the larger molecules were transformed to smaller with high temperature and air less condition. Pyrolysis technology has been continuously developed to support various purposes. In general, the pyrolysis types were classified based on heating rate mainly fast and slow pyrolysis.

Fast pyrolysis is an advance process in which biomass is rapidly heated to moderate temperature of around 500°C and short residence time of typically less than 2 seconds. Fast pyrolysis kinetic of wood constituents determined the rate of thermal breakdown as presented in **Figure 3**. Hemicelluloses are fast decomposed in temperature range from 200 to 300°C and cellulose is the least stable polymer decomposed from 300 to 400°C. Lignin exhibits intermediate thermal degradation behavior from 250 to 500°C. Thermal decomposition studies on separated lignin will not necessarily match the pyrolysis behavior of this component when it is present in the original biomass [10]. Typical product yields, dry wood basis, consisted of liquid, char and gas at 75, 12 and 13% respectively [11]. The main objective of developing fast pyrolysis is to generate an enhanced fuel for generating heat and power. Fast pyrolysis technology has long been developed as a thermochemical conversion technology to produce high yields of bio-oil from biomass [4].

Slow pyrolysis is a simple technology that has been practiced by the ancient Chinese. It has long been known as carbonization. The reaction is a thermal conversion process where wood or other biomass material is slowly heated in the absence of air or oxygen up to final temperature of about 500°C. In slow pyrolysis, hemicelluloses are degraded in temperature range from 200 to 260°C, cellulose at 240–350°C and lignin at 280–500°C [12]. Charcoal is most important product with about 30% of wood slow pyrolysis. It has long been used for heating, cooking, and industrial purposes. Bio-oil content was about 30% and gas content was about 35%.

In Asia, slow pyrolysis was used to prepare charcoal. With the current increasing concern in regard to environment issues, the smoke from charcoal making could be called a pollutant. The wood vinegar produced by smoke from charcoal making has many benefits such as stimulating vegetables and plant growth, anti-harmful microorganisms [10]. Today, however, there is much diversity of charcoal wood including thinned wood, sawdust and backboard dust produced by sawmills, bark, windfall trees, dead trees, waste wood from agriculture and demolished buildings, bamboo, straw and rice husks. Different charcoal wood requires a different carbonization kiln but the principle of charcoal-making, i.e. baking charcoal wood by regulating the airflow, remains the same for all types of kilns. Similarly, the principle of recovering bio-oil has remained unchanged. To recover bio-oil, the chimney is placed above the smoke outlet of the charcoal kiln while a container is placed in the lower end of the chimney to collect the dripping, condensed liquid.

The color of the smoke produced in the carbonization of wood changes depending on the progress of this process. These are used as an impotent indicator to recover bio-oil. When carbonization starts, the white smoke first appears. This is wet smoke because the water

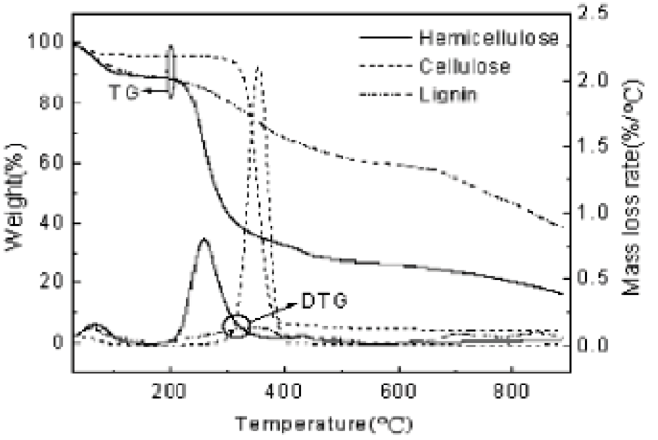

Figure 3. Fast pyrolysis kinetics of hemicellulose, cellulose, and lignin: TG = thermogravimetry; DTG = differential thermogravimetry [10].

contained in charcoal wood comes out as steam. At this stage, temperature inside kiln and the smoke out of the chimney are about 300 and 80°C, respectively. After that the color of the smoke changes to a mixture of white and yellowish brown with an irritating burning smell then the color changes back to white within a short time. The white smoke reappears and the smell changes to a sweet smell. The temperature inside kiln and the smoke out of the chimney is lower than 300°C and range from 80 to 150°C. This stage recommends as the optimal condition to recover bio-oil [13].

On wood vinegar preparation, the crude bio-oil solution is kept in a closed container and stands at ambient temperature for about 3 months. The solution then will be separated into 2 phases; the clear upper phase that is wood vinegar is drained off, while the lower phase is called tar sediment.

4. Physicochemical properties of wood vinegars

Wood vinegar is a complex mixture of polar and non-polar chemicals with varying molecular weights and compositions, which depends upon feedstock and processing condition. Some physical properties such as pH, specific gravity, color, odor, dissolved tar content, ignition residue and transparency have been reported. Due to the presence of organic acids such as acetic acid, formic acid and propionic acid, the acidity of wood vinegar is often in the range of pH 2–4. Total soluble tar contents were found within a range of 0.23–0.89% wt. The specific gravity and °Brix was reported within a range of 1.005–1.016 g/mL and 1.7–6.6, respectively [3, 14].

The major proportion in wood vinegar is water (80–90%) that is a result of feedstock dehydration. Water is usually miscible with the oligomeric lignin-derivative components because of the solubilizing effect of other polar hydrophilic compounds, low-molecular-weight acids,

Sample	**Physical and chemical parameters**								
	pH	**SG (g.mL^{-1})**	**TAC[b] (% by weight)**	***p*Ka**	**Total soluble tar (% by weight)**	**Degree Brix**	**λ_{max} (nm)**	**A_{max}**	**Water content (% by weight)**
L. leucocephala 1	3.40	1.006 ± 0.000	4.47 ± 0.01	4.70	0.37 ± 0.02	3.80 ± 0.10	274.50	154.00 ± 5.00	91.13 ± 0.27
L. leucocephala 2	3.10	1.007 ± 0.000	4.61 ± 0.02	4.70	0.57 ± 0.01	4.60 ± 0.10	270.80	375.50 ± 6.20	84.54 ± 0.02
A. indica 1	3.40	1.004 ± 0.000	3.28 ± 0.03	4.70	0.37 ± 0.02	3.00 ± 0.10	273.40	150.50 ± 5.00	91.50 ± 0.06
A. indica 2	3.20	1.005 ± 0.000	3.16 ± 0.04	4.70	0.58 ± 0.03	3.40 ± 0.10	271.00	298.00 ± 6.50	93.48 ± 0.15
E. camaldulensis 1	3.10	1.006 ± 0.000	4.62 ± 0.04	4.70	0.57 ± 0.02	4.60 ± 0.10	272.60	221.00 ± 5.00	89.44 ± 0.25
E. camaldulensis 2	3.50	1.008 ± 0.000	3.62 ± 0.03	4.70	0.49 ± 0.02	3.40 ± 0.10	270.80	393.00 ± 8.00	90.37 ± 0.20
H. brasiliensis	2.90	1.012 ± 0.000	4.92 ± 0.02	4.70	0.96 ± 0.03	6.00 ± 0.20	268.00	467.00 ± 7.00	85.30 ± 0.50
D. asper	2.90	1.010 ± 0.000	4.92 ± 0.02	4.70	0.71 ± 0.01	5.60 ± 0.20	269.20	470.00 ± 6.00	81.44 ± 0.26

Table 1. Physicochemical property of eight wood vinegars from five wood species [15].

Compound	**Concentration (mg.mL^{-1})**							
	***L. leucocephala* 1**	***L. leucocephala* 2**	***A. indica* 1**	***A. indica* 2**	***E. camaldulensis* 1**	***E. camaldulensis* 2**	***D. asper***	***H. brasiliensis***
Organic acidic								
Acetic acid	40.26 ± 1.02	55.98 ± 1.22	37.38 ± 0.04	35.26 ± 0.15	65.29 ± 0.02	32.49 ± 0.08	69.34 ± 0.17	70.60 ± 0.20
Alcohol derivatives								
Methanol	3.92 ± 0.04	8.12 ± 0.27	3.85 ± 0.66	3.80 ± 0.07	3.62 ± 0.03	6.13 ± 0.14	4.43 ± 0.09	4.52 ± 0.05
n-Propanol	ND	ND	ND	ND	ND	0.02 ± 0.00	ND	ND
n-Butanol	ND	ND	ND	ND	ND	ND	ND	ND
∑ Alcohol derivatives	3.92	8.12	3.85	3.80	3.62	6.15	4.43	4.52
Furfural and furan derivatives								
2-Furfuraldehyde	0.45 ± 0.00	3.06 ± 0.01	0.60 ± 0.02	4.06 ± 0.02	2.24 ± 0.01	5.23 ± 0.01	2.69 ± 0.03	0.67 ± 0.01
Methyl-2-furoate	0.18 ± 0.01	0.74 ± 0.01	0.08 ± 0.00	0.37 ± 0.01	0.41 ± 0.01	0.87 ± 0.01	0.62 ± 0.02	0.13 ± 0.01
2-Methylfuran	0.23 ± 0.01	0.54 ± 0.01	0.27 ± 0.00	0.31 ± 0.01	0.39 ± 0.01	0.34 ± 0.00	0.79 ± 0.02	0.55 ± 0.03
∑ Furfural and furan derivatives	0.86	4.34	0.95	4.74	3.04	6.44	4.10	1.35
Phenol derivative								
Phenol	0.94 ± 0.01	0.95 ± 0.01	0.75 ± 0.01	0.54 ± 0.02	0.45 ± 0.01	1.01 ± 0.01	0.67 ± 0.01	0.46 ± 0.02
2-Methylphenol	3.82 ± 0.02	2.85 ± 0.01	2.76 ± 0.01	1.57 ± 0.01	2.07 ± 0.01	3.17 ± 0.01	2.16 ± 0.11	4.06 ± 0.06
3-Methylphenol	1.67 ± 0.01	0.78 ± 0.68	0.68 ± 0.00	0.69 ± 0.01	0.61 ± 0.00	1.28 ± 0.05	0.05 ± 0.00	0.32 ± 0.0
4-Methylphenol	0.11 ± 0.00	0.19 ± 0.01	0.07 ± 0.00	0.13 ± 0.01	0.04 ± 0.00	0.16 ± 0.00	0.09 ± 0.00	0.04 ± 0.00
2-Ethylphenol	0.03 ± 0.00	0.03 ± 0.00	ND	0.02 ± 0.00	ND	0.03 ± 0.00	0.06 ± 0.00	0.03 ± 0.00
2,6-Dimethylphenol	ND	0.03 ± 0.00	ND	ND	ND	0.05 ± 0.00	0.42 ± 0.00	ND
2,5-Dimethylphenol	0.29 ± 0.01	0.10 ± 0.00	0.17 ± 0.01	0.07 ± 0.00	0.13 ± 0.01	0.24 ± 0.00	0.20 ± 0.00	0.12 ± 0.00
2,4-Dimethylphenol	ND	0.26 ± 0.22	ND	0.21 ± 0.01	ND	ND	ND	ND
2,3-Dimethylphenol	0.06 ± 0.00	0.04 ± 0.00	ND	0.03 ± 0.00	ND	0.04 ± 0.00	0.05 ± 0.00	ND
∑ Phenol derivatives	6.92	5.23	4.43	3.26	3.30	5.98	3.70	5.03
Methoxyphenol derivatives								

Compound	**Concentration (mg.mL^{-1})**							
	***L. leucocephala* 1**	***L. leucocephala* 2**	***A. indica* 1**	***A. indica* 2**	***E. camaldulensis* 1**	***E. camaldulensis* 2**	***D. asper***	***H. brasiliensis***
4-Propyl −2-methoxyphenol	6.90 ± 0.05	8.92 ± 0.03	5.88 ± 0.03	6.43 ± 0.03	5.54 ± 0.02	5.54 ± 0.02	11.56 ± 0.04	9.56 ± 0.01
4-Methyl-2-methoxyphenol	1.51 ± 0.01	3.09 ± 0.01	0.24 ± 0.00	1.51 ± 0.02	0.89 ± 0.01	1.27 ± 0.01	2.59 ± 0.06	2.23 ± 0.01
4-Ethyl-2-methoxyphenol	1.46 ± 0.02	3.10 ± 0.02	0.20 ± 0.01	1.85 ± 0.01	0.91 ± 0.01	1.34 ± 0.02	2.81 ± 0.02	2.33 ± 0.01
Guaiacol	0.40 ± 0.00	0.42 ± 0.00	0.66 ± 0.01	1.17 ± 0.01	0.51 ± 0.01	0.36 ± 0.01	1.33 ± 0.04	4.28 ± 0.02
Eugenol	0.27 ± 0.01	0.21 ± 0.02	ND	2.41 ± 0.02	0.06 ± 0.00	0.21 ± 0.01	5.23 ± 0.02	2.16 ± 0.02
Syringol	1.20 ± 0.02	2.01 ± 0.01	0.93 ± 0.01	3.15 ± 0.02	2.62 ± 0.02	3.88 ± 0.01	3.57 ± 0.02	0.06 ± 0.00
Acetovanillone	ND	ND	ND	ND	ND	ND	0.18 ± 0.00	ND
∑ Methoxyphenol derivatives	11.74	17.75	7.91	16.22	10.53	12.60	27.27	20.62
∑ Total phenol derivatives	18.66	22.98	12.34	19.48	13.83	18.58	30.97	25.65
1,2 Dihydroxybenzene	ND	ND	ND	ND	0.18 ± 0.00	ND	0.18 ± 0.01	ND

Table 2. Chemical compositions of eight wood vinegars from five wood species [15].

alcohols, hydroxyaldehydes, and ketones, mostly originating from the decomposition of carbohydrates.

The minor proportions of 10–20% wt are water-soluble organic compounds. These comprise of acids, alcohols, aldehydes, ketones and sugars. It appears that acetic acid is the highest proportion [14] in this fraction. The other components are also found, for instance, phenols and monolignols (quaiacol and syringol) which are degradation products from lignin. Levoglucosan, levoglucosenone, furfural, substituted furan, are derived from cellulose. The simpler organic molecules are converted from fats, mucilage, wax, alkaloids, and terpenoids. For inorganic salts and metallic complex are commonly reduced to ash.

The physicochemical characteristics of eight wood vinegars from the carbonization of five wood species—*Leucaena leucocephala* (Katin), *Azadirachta indica* (Sadao), *Eucalyptus camaldulensis*, *Hevea brasiliensis* (rubber wood) and *Dendrocalamus asper* (bamboo), which were produced by heating wood samples up to 400°C in a Thai-Iwate kiln showed the pH of 2.9–3.5, total soluble tar of 0.325–0.963% by weight and total soluble tar not more than 3%. The values of the specific gravity of only two products, from rubber wood (1.012 g mL^{-1}) and bamboo (1.010 g mL^{-1}) were within the acceptance criteria of quality assessments of Japan's standards, **Table 1** [15]. Chemical compositions of wood vinegars consisted of acetic acid as the largest component (30.45–70.60 mg mL^{-1}). A high number of phenol derivatives (16 compounds) were found and those in higher concentrations were 4-propyl-2-methoxyphenol (5–11 mg mL^{-1}) followed by 2-methylphenol (2–4 mg mL^{-1}), **Table 2**.

However, it has been showed that wood vinegar is unstable during prolong storage or aging process. The viscosity of the mixture gradually increases and phase separation is slowly occurs. Apart from sedimentation of a high-density particle and colloidal matter, this might be a result from the series of chemical reaction such as an aldol condensation reaction between aldehydes and alcohols, and self-aggregation of aldehydes with those of reactive oligomers. In addition, the metallic components may also play important role as reaction catalysis [16].

5. Quality of wood vinegars

As mentioned earlier, there are wide variations in the property of wood vinegar due to its mixture of many compounds with different concentrations. However, Japan Pyroligneous Liquor Association, an industrial body for pyroligneous liquor trader sets 7 parameters in order to standardize a good quality of the product. These are included pH value of around 3.0, standard specific gravity around 1.010–1.050, color should be a pale yellow, bright brown or reddish brown, has a marked smoky odor, the dissolved tar content should not more than 3%, ignition residue should not more than 0.2%, and exhibit transparency without suspended solid matter [13]. However, Fagernäs et al. [12] stated that the commercialized wood vinegar in European Unions (EU) has not been accepted because quality is widely varies. Accordingly, attention should be paid to obtain knowledge base on the preparation processes and quality control using a practical and cheap procedure.

The quality assessments of wood vinegars in Thailand were determined according to criteria from the Japan standard with slightly modification. Eight wood vinegars from the carbonization of five wood species—*Leucaena leucocephala* (Katin), *Azadirachta indica* (Sadao), *Eucalyptus camaldulensis*, *Hevea brasiliensis* (rubber wood) and *Dendrocalamus asper* (bamboo) grown in Thailand, which produced by heating wood samples up to 400°C in a Thai-Iwate kiln showed that all wood vinegar samples appeared to be good quality in terms of odor, color and transparency. An acetic acid concentration from the eight samples whose presence was indicated by pKa at 4.7 (**Table 1**) was mainly responsible for the pH values as shown in the good correlations of plots between pH and acetic acid concentrations (Correlation coefficient, R = 0.92). The specific gravity showed good correlations with total soluble tar and degree Brix (R = 0.87 for both); in turn the degree Brix showed good correlation with the total soluble tar (R = 0.87). Thus, the degree Brix which was easy to determine could be used as a general indicator of total soluble tar. The amount of total soluble tar signified the presence of phenolic compounds, of which previous studies suggested antifungal activity and usefulness as wood preservatives. In addition, phenolic compounds were also confirmed by the ultraviolet absorption maximum (λmax) at 268–274 nm, [15].

6. Semi-purification of wood vinegars

The crude wood vinegar, bio-oil, is very complex solution contained with at least 200 constituents. Some of those components can be prone to such complex reaction as oxidization and polymerization. Physicochemical characteristics of wood vinegar produced from different sources even between producing batch in the same source have very high variability. It will bring to the inconsistency on the utilization efficiency. Therefore, if wood vinegar is to be a future source of natural chemicals production with consistence activity, an effective separation method must be developed to generate semi-purified bioactive components. Several methods such as standing, filtering, distillation and solvent extraction have been developed for semi-purified and classified components. In order to obtain more specific and consistent property of product, the wood vinegar may be fractionated into semi-purified product. These could be achieved by several techniques such as sedimentation, filtration, chromatography, distillation and solvent extraction.

6.1. Standing method

This is used to prepare wood vinegar from crude bio-oil. It is simplest and most highly efficient method that keep crude bio-oil standing in a container. When left standing, the unstable constituents in raw wood vinegar are oxidized or polymerized to precipitate, suspend or adhere to the inner wall of the container. The thin oily film on the surface of the liquid and transparent wood vinegar separate on the middle phase must be discarded and the suspended as well as precipitated matters are filtered to produce transparent wood vinegar. When the standing and filtering processes are repeated several times, stable, transparent wood vinegar is obtained. While the standing method requires a long time, it is easy and inexpensive compared to other methods and good results are assured. In practice, wood vinegar is easily separated from whole bio-oil and a viscous oligomeric lignin-containing fractions setting at the bottom by standing at least 3 months [12].

6.2. Filtration

Filter like filter paper is used to remove the precipitated as well as suspended matters. The filtering of freshly recovered bio-oil cannot fully remove unwanted constituents, causing the appearance rely on filtering method. To obtain transparent wood vinegar, combining the filtering with the standing method is necessary. In the filtering process, the oil and suspended matters in wood vinegar gradually clog the filter paper or filter, lengthening the filtering time. In order to prevent this, frequent changes of the filter paper or filter are necessary. The appearance of suspended matter in transparent wood vinegar after future standing means that unstable constituent remains requiring further filtering.

6.3. Column chromatography

The principle of column chromatography is that substances are separate based on their different adsorption capabilities on stationary phase. Large polar compounds are contained in wood vinegar. In general, highly polar molecules are easily adsorbed in the stationary phase, while weak polar molecules are not. Thus, the process of column chromatography involves adsorption, desorption, re-adsorption, and re-desorption. Silica gel is commonly used as the stationary phase, and an eluent is selected based on the polarity of compounds from wood vinegar. Paraffin eluents, such as hexane and pentene, are used to separate aliphatic compounds. Aromatic compounds are usually eluted with benzene or toluene. Some other polar compounds are obtained by elution with methanol or other polar solvent [17–19].

6.4. Distillation

Distillation is a common separation technology in the chemical industry. This method separates the components successively according to their different volatilities, and it is essential for the separation of liquid mixtures. In general, there are two distillation systems i.e. the normal pressure and reduced pressure distillation. In both systems, compounds are separated by mean of the deference boiling points

The carbonizing wood vinegar has water content of as high as 80–90% with a rather small difference in boiling point between the remaining 10% of organic matters. Therefore, the boiling of wood vinegar starts below 100°C under atmospheric pressure, and then the distillation continues up to 250–280°C, whereupon 35–50% of residue is left [20].

Distillation method is quite effective to concentrate wood vinegar and also to remove substance with particularly low and high boiling points. However the distillation process cannot entirely remove unwanted polymer. It is more practical to use this method after unwanted polymer in crude vinegar removed by standing method., However, it should be carefully because the heating to boil sample may be induce the oxidation and polymerization in which bring to losing bioactivity of any components.

6.5. Solvent extraction

Liquid–liquid extraction method so called solvent extraction, involves the selective transfer of a substance from one liquid phase to another. Usually, an aqueous solution of the sample is extracted with an immiscible organic solvent. Thus the solute A distributed between an aqueous and an organic solvent:

$$K_D = \frac{\lfloor \mathbf{A} \rfloor \mathbf{solvent}}{\lfloor \mathbf{A} \rfloor \mathbf{aquase}}$$

where square bracket denote concentration and K_D is known as the equilibrium distribution of partition coefficient which is independent of total solute concentration. It should be note that constant temperature and pressure are assumed and that A must exist in exactly the same from in both phases. Equilibrium is established when the chemical potentials (free energies) of the solute in the two phase are equal and is usually achieve within a few minutes by vigorous shaking. The value of KD is a reflection of the relative solubility of the solute in the two phases [21].

Solvent extraction or liquid–liquid extraction has been introduced for semi-purification active compounds from wood vinegar mixture. This technique is used for the separation of compounds with different partition or relative solubility between the 2 solvent phases. Commonly, an aqueous solution of the sample is extracted with an immiscible organic solvent. By selecting appropriate polarity of the solvents for extraction, such as hexane, diethyl ether, ethyl acetate, acetone, water etc., the desired products may be obtained. In order to obtain the higher purity of bioactive compounds from wood vinegar, Oasmaa et al. [22] suggested that step-by-step extraction on the basis of polarity order may be employed. Some reports showed that phenolic compounds and organic acids were extracted from wood vinegar using ethers and dichloromethane [12, 23, 22]. However, they found that a considerable amount of the high polarity and volatile compounds have been lost because of co-evaporation of the compounds at solvent drying step.

In another phenomenon, synergistic function was characterized to be the mode of action of wood vinegar. The most researchers have long suggested that phenolic and organic acid were active component. However, the new report in 2011 presented other unidentified components has high possibility to be active compounds [24]. The highly classified efficiency method to identified components is very necessary. It will bring to the right answer about what is important bioactive compound of wood vinegar and then it might be used as biochemical markers to quantify wood vinegar quality.

7. Utilization of wood vinegar

7.1. The organic agriculture

Utilizing chemical fertilizers was not only imposing heavy loads and pollution on the environment but also threatening our health. Long-term application of chemical fertilizers exposed the following problem: exhaustion of soil organics, lower conservation of water and nutrition, deterioration of the soil structure and heavy losses of water and soil. Excessive chemical fertilization not only polluted the soil, water and air but also kept most residues in vegetables, which decreases the quality and security of our food supply. Therefore, it was very important to find and develop natural material for vegetable production. Wood vinegar was highly suitable for use in organic agriculture. Since wood vinegar were naturally organic compounds. A great number of toxic-chemical in agriculture was replaced by wood vinegar, natural product, which has been used to promote growth and yield for field cultivation crops such as rice, *Oriza sativa* [25], sweet potato, *Ipomoea batatas* [26], sugar cane, *Saccharum officinarum* [27], melon, *Cucumis melo* [28]. In addition it also used to improve the quality of fruit, combat disease and pests, accelerate the speed of plat seed germination and serve as herbicides [3, 28, 29].

7.2. Alternative medicine

Wood vinegar was believed to promote equilibrium and greater healing in the body. Toxin could be accumulated in the body from a number of sources such as chemical pesticide and fertilizers from food, polluted air and as a by-product from our metabolism. The result of continued accumulation of toxin was poor health as manifested by weakness, pains and aches, disease and sickness. Common examples of illnesses caused by bodily toxins were gout, arthritis, rheumatism, and back pains. Therefore, regular removal of toxins from our bodies may result in good health. Wood vinegar from carbonization was used in preparation of detoxification pad available in Japan, America, Korea and China. The direction of using detoxification pad is by placing at the bottom of both feet before going to bed. The detoxification pad will directly attach to the reflex points on the feet. It was believed to promote equilibrium and greater healing in the body. The sap sheet was believed to help by cleaning out waste and toxic material that were excreted in the form of the sweat under the feet. However, a clinical study of the effectiveness of using sap sheet or detox pad are under investigation.

Wood vinegar was utilized as prebiotics which are defined as non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and activity of one or a limited number of bacteria in the colon, and thus improve host health. Consumption of food containing less fiber, more meat and carbohydrate, and toxin may reduce good bacteria in large intestine. Wood vinegar was a source of short chain fatty acids that help to promote acidity in large intestine, resulting in inhibition of the growth of bad bacteria, enteropathogenic bacteria [30], and protozoa, *Cryptosporidium parvum* [31], and stimulate the growth of prebiotics, *Enterococcus faecium* and *Bifidobacterium thermophilum* [32]. In addition, it also reduces the absorption of alkaline carcinogen, enhancing calcium and magnesium absorption and increase blood circulation.

The distilled wood vinegar could inhibit allergic reaction, in particular, Type I allergic reaction by oral admiration. This solution was indicated for preventing allergic rhinitis, hay fever, allergic conjunctivitis, atopic dermatis, allergic asthma, urticarial and food allergy [33].

7.3. Food processing

Foods are subjected to many environmental condition such as temperature changes, oxidation and exposure to microbes, which can change their original composition. Foods also cause illnesses because of their susceptibility to contamination during production, processing and storage. Food-borne illnesses are under reported and are often a common, and sometimes life-threatening, problems for millions of people around the world [34].

Food additives play a key role in maintaining the food quality and characteristic that consumers demand, keeping food safe. They may be classified by one of six primary functions they serve: preservation, improvement in nutritional value, addition or replacement of color, addition or replacement of flavor, improve texture or processing aids [35]. Recently, synthetic food additive l has been reduced demand worldwide because greater consumer awareness. Therefore, natural food additives have become popular [36]. Many natural additives and preservatives have been widely used in food such as spices, herb, essential plant oils and wood vinegar.

Wood vinegar is food additive obtained from nature to use as additives and preservative functions. It can be used in processed food to prevent microbial growth by phenols and shot chain organic acids containing in vinegar [37]. In addition the smoke flavors extracted from Wood vinegar had application to food as a safety product [33]. Moreover, the U.S. Food and Drug Administration (FDA) allows using pyroligneous acid for smoke flavoring and preservation of food such as ham, bacon, sausage, fish and cheese.

7.4. Wood preservative potential of wood vinegar

7.4.1. Economic impact of wood and related industries

As world population is progressively growing, the demand of using wood for several purposes is also increasing. In contrast, due to worldwide concern on forest conservation, the availability of natural timber is limited and/or no longer available. Therefore, the timber from economic plants such as cedar, pine, maple, and rubber (*Hevea brasiliensis*) are an alternative. Among of them, with particular in Thailand, rubber wood has become a major raw material in the furniture industry, wood composites and panel products such as particle board, block board and medium density fiberboard [38].

Rubber plantations (*Hevea brasiliensis* Muell. Arg) are found in more than 30 countries around the world. The total planting area is approximately 9 million hectares with almost 90% are in Asia, and about 75% of this is in Thailand, Indonesia and Malaysia. Rubber trees reach their prime of latex production within 25 years, after which it is no longer of economical to use [38]. Several years ago, the expired rubber trees were simply burnt in the fields, prior to plant a new stock, or used as firewood for making bricks and also for the production of charcoal briquettes.

During the last two decades, however, the rubber wood has become an important source of timber, particularly for furniture. It is also extensively used to manufacture wood composites and panel products such as particleboard, block board and medium density fiberboard [38]. Recently, in tropical countries like Thailand and Malaysia, rubber wood has gained much importance as substitute for conventional timber. The rubber wood potential in exterior use has been hampered by its high susceptibility to biological degradation, while the growth of sapstain and surface mold on rubber wood poses serious problems for its utilization. The fungi that damaged rubber wood consist of three major groups: the white-rot, brown-rot and sap-staining fungi [39, 40].

7.4.2. Biochemistry of wood biodegradation mechanisms

In nature, cellulose, lignocellulose and lignin are major sources of plant biomass. Therefore their recycling is indispensable for the carbon cycle. Many organisms are capable of degrading and utilizing biopolymer as carbon source and energy sources. However the organisms predominantly responsible for lignocellulose degradation are fungi and the most rapid degraders in this group are basidiomycetes. The ability to degrade lignocellulose efficiently is thought to be associated with a mycelial growth habit that allows the fungus to transport scares nutrients such as nitrogen. Each polymer is degraded by fungi which produce a battery of enzymes that work synergistically. There are two types of extracellular enzymatic systems; the hydrolytic system, which produces hydrolases that are responsible for polysaccharide degradation; and a unique oxidative and extracellular lignolytic system, which degrades lignin and opens phenyl rings. Consequently, many free radicals are produced for disrupting wood cell wall [41].

Cellulose biodegradation is synergistic interaction between cellulolytic and non-cellulolytic microorganisms leading to complete degradation of cellulose. Cellulose degrading enzymes are produced with different specificities working together namely cellulases. They are composed of a mixture of enzyme protein with different specificities to hydrolyze the ß-1,4-glycosidic bonds. Cellulose degrading enzymes can be classified into three major enzyme activity classes; endoglucanase or endo-1,4-glucanase, cellobiohydrolase and ß-glucosidase. Endoglucanase initiate attack randomly at multiple internal sites in the amorphous regions of the cellulose fiber, which opens-up site for subsequent attack by the cellobiohydrolase. It removes monomer and dimer from the end of the glucan chain. ß-glucosidase hydrolyzes glucose dimer and in some cases cellulose oligosaccharides to glucose. To function correctly, those three enzymes must be stable in the extracellular environment and may form a tertiary complex with the substrate [42]. Generally, endoglucanase and cellobiohydrolase synergistically hydrolyse cellulose. However, the detail of mechanisms involved in the process are still unknown [41].

Hemicellulose biodegradation: the complete degradation of hemicellulose requires the cooperative action of variety of hydrolytic enzymes. Their action on substrates can be classified as endo-1,4-ß-xylanase and generates oligosaccharides from the cleavage of xylan and xylan 1,4-ß-xylosidase produces xylose from oligosaccharides. In addition, degradation of hemicellulose needs other enzymes such as xylan esterases, ferulic and p-coumaric esterases, α-1-arabinofuranosidases, and α-4-0-methyl glucuronosidases, acting synergistically to efficiently hydrolyze wood xylans and mannans. O-acetyl-4-0-methylglucuronxylan is one of the most common hemicellulose, which was initially degraded by endomannases to rupture the polymer and then acetyl glucomannan esterase removes acetyl groups and α-galactosidases eliminates the galactose residue. Finally, ß-mannosidase and ß-glycosidase break down the endomannase-generated oligomeric ß-1,4 bonds [41, 42].

Lignin biodegradation, is an oxidative process, which phenol oxidases form white-rot are used as major enzymes to degrade lignin. Among those enzyme, lignin peroxidase (LiP), manganese peroxidase (MnP) and laccases have been studied. LiP and MnP oxidize the substrate by two consecutive one-electron oxidation steps with intermediate cation radical formation [43]. LiP degrades non-phenolic lignin units, whereas MnP generates Mn^{3+} which acts as a diffusible oxidizer on phenolic or non-phenolic lignin via lipid peroxidation reactions. Laccase (blue

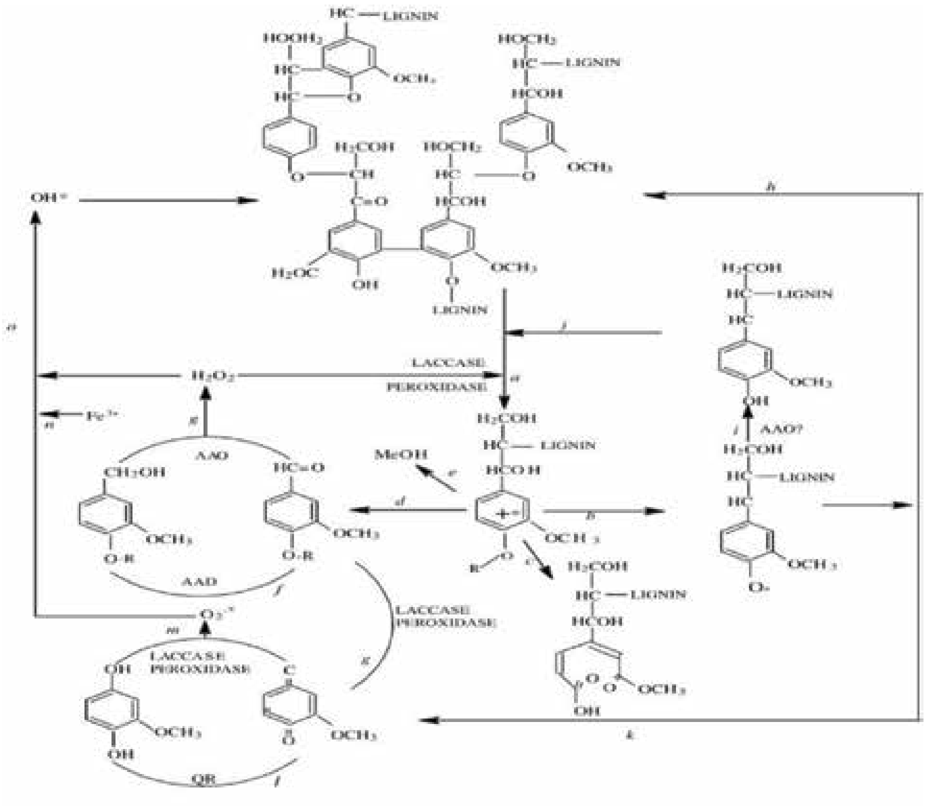

Figure 4. Biodegradation pathways of lignin by white rot fungi [41].

copper oxidases) catalyze the one-electron oxidation of phenolic and other substrate having rich electrons [43].

As shown in **Figure 4**, laccases or ligninolytic peroxidase such as LiP and MnP produced by white rot fungi, which generated aromatic radical by oxidizing the lignin polymer (a). These progress in different non-enzymatic reaction including C4-ether breakdown (b), aromatic ring cleavage (c), C_{α}-$C_{ß}$ breakdown (d), and demethoxylation (e). The aromatic aldehydes release from C_{α}-$C_{ß}$ breakdown of lignin or synthesize *de novo* by the fungus (g,f) are the substrates for H_2O_2 generation by aryl-alcohol dehydrogenases (AAD) in cyclic redox reaction. Phenoxy radical from C-4 ether breakdown can repolymerize on the lignin polymer (h) if they are not first reduced by oxidases to phenolic compound (i). The phenolic compounds formed can be repeatedly reoxidized by laccases or peroxidase (j). Phenolic in radical form can also be subjected to C_{α}-$C_{ß}$ failure (k) yielding *p*-quinones. Quinones from g and k split oxygen activation in redox cycling reactions with quinone reductases (QR), laccases and peroxidase (l,m). This reaction reduced ferric iron present in wood (n), either by superoxide cation radical or directly by the semiquinone radicals. In addition, it reoxidized with concomitant reduction of H_2O_2 to a hydroxyl free radical OH^{x} (o) and then it is a very mobile and very strong oxidizer that can initially attack the lignin (p) in the first stages of wood decay when the small size of pores in the still-intact cell wall prevents the penetration of lignolytic enzymes. Then the enzymes described above oxidize lignin. In the final steps, simple products from lignin degradation enter through the hyphae of fungal into intracellular and are incorporated catabolic routes.

7.4.3. Synthetic wood preservation

In comparison with the other structural materials such as concrete, steel and plastic, wood is of biological origin which is considered to be the lesser durability, whereas it poses the higher tensile strength. This problem is principally due to its susceptible to fungi and termites. To increase service life, therefore, preservative treatment using some chemical is introduced in wood industries. It has been concluded that there are 3 major groups of fungi involving to the problem, namely: white-rot, brown-rot and sap-staining fungi [39, 40].

On the basis of solubility, chemicals use in wood preservative may be classified into water soluble type (water-based) and organic soluble type (oil-based). Because copper is an excellent broad spectrum fungicidal property, low mammalian toxicity, relatively low price (Hingston et al. [45]), and is mostly water soluble compound, it is used as a primarily ingredient in wood preservative formulation. These include chromate copper arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), chromate copper boron (CCB), chromate copper phosphate (CCP), alkaline copper quaternary ammonium (ACQ) and copper azole, etc. Among them, CCA appeared to be the most potent wood preservative mixture because it posed a wide range of effects on fungi, termite, bacteria and marine borers, but its use is restricted in many countries [44]. In Thailand, CCB has been accepted for using as wood preservative.

7.4.4. Environmental friendly wood preservative from wood vinegar

As health and environmental concern, the conventional chemicals used in wood treatment are considered to be toxic agents. Therefore, an alternative eco-friendly preservative is underway of research. Some investigators reported that the settled tar of bio-oil from fast pyrolysis showed a high potential to use as organic wood preservative [4, 45], [48]. They also suggested that phenolic compounds seem to play an important role to inhibit growth of wood-degrading fungi.

Recently, some investigators reported that bio-oil and wood vinegar prepared from fast pyrolysis have high potential to be used as wood preservative, and they suggested that phenolic compounds seem to play an important role on growth inhibition and decay resistance test of fungi [4, 45, 46]. Moreover, wood block treated with the filtrates obtained from the slurry fuel of several woods such as sugi (*Cryptomeria japonica*) and acacia, (*Acacia mangium*) exhibit resistance against brown-rot fungus (*Fomitopsis palustris*) and white-rot fungus (*Trametes versicolor*). However, the filtrates did not increase the durability of wood blocks against subterranean termites (*Coptotermes formosanus*) [45]. Also, it has been showed that the liquid from pyrolysis of solid wood and wood-based composite such as particleboard, plywood and medium density fiber board with phenol or urea type adhesive have a high potential to inhibit growth of wood-degrading fungi. Bio-assay test shown that the liquid form wood-based composites bonded with phenol-type adhesive at the higher temperature and the liquid from the composites with urea-type adhesive at lower temperature showed a high antifungal activity [46].

In addition, decay and termite resistance of wood treated with tar oil obtained from commercial pyrolysis product of macadamia nutshells has been investigated. It was found growth of white-rot fungi *Trametes versicolor*, sap-staining fungi *Pleurotus ostreatus*, brown-rot fungi *Fomitopsis palustris* on wood specimens which had been applied with the tar oil 460 at kg/m^{-3}, was effectively inhibited [47].

8. Conclusion

Wood vinegar is prepared from pyrolysis of lignocellulose waste and biomass by fast and slow pyrolysis. The characteristics and properties of obtained wood vinegar are influenced by the type of feedstocks and production techniques. The vinegar is a complex mixture of polar and non-polar chemicals compositions, in which water, acetic acid and phenols are main proportions. Some physical properties such as pH (2–4), specific gravity within (1.005–1.016 g/mL), color, odor, dissolved tar content (0.23–0.89% wt.), and transparency have been evaluated as quality index of wood vinegar product. Wood vinegar, as a natural product, has beneficial applications in wildly fields; including agriculture, pharmacy and biomedicine, veterinary and animal production, food processing and wood preservative.

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Tropical forests occupy only one-tenth of the world's land area but are home to more than half of the world's flora and fauna. They comprise extremely complex labyrinth of ecological interactions. The astounding richness and biodiversity of tropical forests are rapidly dwindling. There is a fear that the burgeoning human population and industrialization, where a majority of these tropical forests are found, may lead to the clearing or modification or may be a complete disappearance of the remaining tropical forests within few decades. This has severely altered the vital biogeochemical cycles of carbon, phosphorus, nitrogen, and so on and has led to the change in global climate and pristine natural ecosystems. Hence, there is an urgent need to protect, restore, conserve, and improve the forest resources before they are irrevocably lost. In this second edition of the book *Tropical Forests*, the chapters share the above issues and help in understanding, educating, and creating awareness on the role of "tropical forests" for the very survival of mankind, climate change, and the diversity of biota across the globe. This book will be of great use and could be useful to students, scientists, ecologists, population and conservation biologists, and forest managers across the globe.

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