Local Baseline Knowledge for Conservation and Restoration of Degraded Ecosystems in Ecuador

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Cover: Deforestation in the north of Cristobal Colón, land on its way to cattle pasture and oil palm plantations, Esmeraldas Ecuador

Photo: Ing. Marcelo Estévez, 2005

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Abstract

Deforestation and land-use changes are a major threats to native ecosystem in many tropical countries, including Ecuador– one of the biodiversity hotspots in the world. In tropical Andean countries, natural ecosystems change over small spatial scales. Thus, conservation and restoration initiatives, strongly require ecological baseline information about local ecosystems history, spatial distribution, integrity, trophic interactions, successional dynamics, home range, health and as well as considering the local ethobiogical and ethnoecological knowledge. The present work was done in order to generate initial ecological base-line information in three locals and one sub-regional landscape. The major findings are: (1) 'Forest Gap Phase Dynamic Reference Method' inside three successional stages in old grow reference forest and secondary forest regrowth, was able to generate baseline information about the ecosystem structure, composition and biomass in a local Choco-Darien rainforest (NW Ecuador); (2) Traditional Ecological Knowledge showed good synergy with ecological science-based approaches (e.g. regeneration survey in forest gaps) to identify native tree species useful for human beings and wildlife; (3) Inter-crown pixel information from hyperspatial aerial imagery enabled identification of 54% of families, 53% of genera and 56% of species sampled from the ground with a high predictive success of primary and secondary forest indicators species; (4) The home range of endemic brown-headed spider monkeys (*Ateles fusciceps*) was evaluated in the NW of Ecuador, and it was found that this species is in critical danger of extinction, due high levels of hunting and habitat loss specially outside protected areas; (5) anthropogenic disturbances, mainly grazing, in an Andean páramo ecosystem equally affected the species composition of the grassland and bushland communities with marked changes in their soil properties. Overall, these and other methods and results can be used to generate "Local ecosystem base line information", and initiate the idea of establishing a "Local ecosystem health centre" in each village, coordinated by natural and social science researchers, technicians and local population members, with a solid ecological background, who will be responsible to maintain available update information, coordinate or facilitate conservation and restoration efforts, as the establishment of ecological corridors, to reconnect local and sub regional fragmented ecosystems.

***Keywords**:* Referential ecosystems, Ethno-ecology, Ecosystem health center, Ecuador

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Dedication

To God, to all my family, friends and also to all who live respecting and contributing to maintain the holistic integrity and dynamic presence in natural ecosystems.

Jesus spoke to them again saying. I am the light of the world. The one who follows me will not walk in darkness, but will have light and life.

Jn.8,12.

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Ana Mariscal, Mulualem Tigabu, Per Angelstam, Patrice Savadogo, Mika Peck, David Neill, Carl Salk, Carl Soulsbury, Walter Palacios, Soldati Francesca, Per Christer Odén. (2016). Local reference ecosystem for restoration of degraded Neotropical rainforest landscapes (manuscript).

II Ana Mariscal, Mulualem Tigabu, Patrice Savadogo, David Neill, Harold Greeney, Mika Peck, Julian Trappe, Per Christer Odén. (2016). Regeneration status and role of Traditional Ecological Knowledge for degraded cloud forest ecosystem restoration in Ecuador (manuscript).

III Peck Mika, Ana Mariscal, Padbury Martin, Cane Tim, Kniveton Dominic and Chinchero Miguel Angel. (2012). Identifying tropical Ecuadorian Andean trees from inter-crown pixel distributions in hyperspatial aerial imagery. *Applied Vegetation Science* 15(4), 548-559.

IV Peck Mika, Thorne James, Ana Mariscal, Baird Abigail, Tirira Diego and Kniveton Dominic. (2011). Focusing Conservation Efforts for the Critically Endangered Brown-headed Spider Monkey (*Ateles fusciceps*) Using Remote Sensing, Modeling, and Playback Survey Methods. *International Journal of Primatology* 32(1), 32:134–148.

V Ana Mariscal, Patrice Savadogo, Mulualem Tigabu, Carl Soulsbury, Per Christer Odén. (2016). Species composition and soil properties of Ecuadorian páramo ecosystem under grazing disturbance (manuscript).

Papers III-IV are reproduced with the permission of the publisher

The contribution of Ana Mariscal (AM) to the papers included in this thesis was as follows:

I AM designed the field methodology, collected and analyzed the data with support from the co-authors. AM wrote the manuscript with valuable inputs from the co-authors. My overall contribution was 85%.

II AM initiated the idea, designed the study and collected the data. AM wrote the manuscript with assistance from the co-authors with data analysis and valuable inputs. My overall contribution was 85%.

III AM contributed in planning, collecting, processing of information, and review of the manuscript. My overall contribution was 40%.

IV AM contributed in organizing, planning, collecting data in the field, data processing and reviewing the article review. My overall contribution was 40%.

V Patrice Savadogo initiated and designed the study. AM involved in data collection and analysis. AM wrote most of the manuscript with valuable inputs from the co-authors. My overall contribution was 75%.

Abbreviations

ALLPA	Regeneración ecológica y cultural en el Ecuador
CEDENMA	Ecuadorian Committee for Nature and Environment Defense
CONAIE	Confederation of Indigenous Nationalities of Ecuador
DBH	Diameter at breast height
FUNAN	Antisana Foundation
GADC	Cosanga, autonomous decentralized government
GADP	Píntag, autonomous decentralized government
DEFRA	Darwin Initiative
IHCC	Intermedium high closed canopy
INEC	National Institute of Statistics and Censuses Ecuador
UNESCO	United Nations Educational, Scientific and Cultural Organization
IUCN	International Union for Nature conservation
PACHAKUTIK	Pachakutik Plurinational Unity Movement
PRIMENET	Primate conservation network
MAGAP	Agriculture Ministry of Ecuador
MAE	Environmental Ministry of Ecuador
MCC	Mature close canopy
RFGD-Method	Referential Forest Gap Phase Dynamic Method
SF	Secondary forest
SENESCYT	Secretary of Science and Technology of Ecuador
SLU	Swedish University of Agricultural Sciences
TEK	Traditional Ethnoecological Knowledge
UK	United Kingdom
VHR	Very high resolution proximal canopy remote sensing imagery
WWF	World Wildlife Fund

1 Introduction

1.1 General background

Healthy ecosystems deliver essential goods and services for human society. Tropical forest ecosystems are well-recognized as biodiversity hotspots – housing 44% of all plant species world-wide and 35% of vertebrate species within an aggregate expanse of 2.1 million km^2 or 1.4% of the Earth's land surface (Myers et al. 2000). Among the leading hotspots is the Tropical Andes, which spans from western Venezuela to northern Chile and Argentina, and includes large portions of Colombia, Ecuador, Peru, and Bolivia. According to Myers et al. (2000), this hotspot is the richest and most diverse, with 45 000 plant species (20 000 being endemic) and 3 389 vertebrate species (1 567 being endemic). The Choco-Darien region in Western Ecuador is also one of the biodiversity hotspots, housing 9 000 plant species (1625 being endemic). Tropical forests also play a key role in climate regulation, hydrological cycle and soil conservation (Jobbágy and Jackson 2000, Valencia et al. 2004). It is estimated that tropical forests store 471 ± 93 Pg C, which is equivalent to 55% of the carbon stored in Earth’s forests (Pan et al. 2011).

Deforestation and land-use change have been, and still are, major threats to the native ecosystem degradation and loss of ecosystem benefits such as water supplies and carbon sequestration in the tropical highlands and lowlands. During the period between 2010 and 2015, tropical forests are being lost at a rate of 5.5 M ha y^{-1} (Keenan et al. 2015). This destruction of tropical forests is accounted to high carbon losses both above and below ground. The greenhouse gas (GHG) emissions resulting from deforestation are estimated at 1.6 ± 0.4 Gt C y^{-1}, which is about 27% of the global carbon that is released from fossil fuel combustion estimated to be 6 Gt C in 1990 (Malhi et al. 2002).

Three quarters of the emissions from deforestation are from the loss of aboveground biomass, and a quarter is due to soil C decomposition (Melillo et al. 1996, Malhi, Meir and Brown 2002, Houghton et al. 2001). In addition, CO_2 emissions from forest degradation increased significantly from 0.4 Gt CO_2 yr^{-1} in the 1990s to 1.1 Gt CO_2 yr^{-1} in 2001–2010 (Federici et al., 2015).

In Ecuador, deforestation and forest degradation has dated back to the colonial period when native forests were unscrupulously exploited for timber, which was later exacerbated by increasing human population (from 4 million in 1950 to more than 16 million in 2016) and a poor forest development policy that promotes reforestation programs using exotic species (Mecham 2001, Sarmiento 2002, Farley 2007). In addition, a resettlement policy promoted by governmental institutions, especially in the Amazon and the Andean Choco Regions, between 1960 and 1990 has resulted in further clearance of the natural forests (Southgate, Sierra and Brown 1991, Sierra 2001, Perreault 2002, Laurance et al. 2004). Consequently, several conservation and restoration initiatives have been launched over the past few decades, which are highlighted in the subsequent section.

1.2 Conservation and restoration initiatives in Ecuador

Ecuador has been recognized globally as a ‘mega-biodiverse’ country which harbors various global conservation priorities (Dodson and Gentry 1991, Sierra et al. 1999), with its four natural regions (Costa, Andean, Amazonian and Galapagos), eight vegetation associations, 19 intermediate vegetation associations and 72 vegetation types (Sierra et al. 1999). This extraordinary diversity has attracted the attention of many international and national conservationists. The early days of conservation awareness resulted in the creation of spectacular national parks, notably the declaration of a National Park for several islands in the Galapagos between 1936 and 1939 (Black 1973). Non-governmental environmental organizations (NGOs) interested in nature conservation have flourished over time; the oldest being Charles Darwin’s foundation established in 1959 by the IUCN (International Union for Conservation of Nature) and UNESCO (the United Nations Educational, Scientific and Cultural Organization) to study and protect the Galapagos archipelago (Black 1973). This was followed by the establishment of nature foundation (Fundación Natura) in 1978 with the supports of the World Wildlife Fund (WWF) and IUCN for promoting the National Park System and urban conservation education program.

The mid-1980s marked the conservation movement known as the CONAIE (Confederation of Indigenous Nationalities of Ecuador) and the socio-political frame work “Sumak kawsay” (good living) formed the base for the establishment of “PACHAKUTIK” (Pachakutik Plurinational Unity Movement) in Ecuador. Together with other Andean Countries, this represents a planetary-wide movement which seeks to respect and heal the Earth by reforming human relations at all levels so as to promote holistic maintenance of ecosystems and to secure a ecosystems for future generations (Mecham 2001, Radcliffe 2012). In addition to the CONAIE framework, several foundations were set up, such as: CEDENMA (Ecuadorian Committee for Nature and Environment Defense), Maquipucuna, Jatun Sacha, Amigos de la Naturaleza, Sociedad Francisco Campos, Pedro Vicente Maldonado, Arcoiris, Amerindia, Aves y Conservación, Acción Ecológica, EcoCiencia, Mazán, Pachamama, Antisana, ALLPA, Jocotoco, Cambugán, Ecominga (FUNAN 2002, Justicia 2007, ECOLAP-MAE 2007, MAE 2007, Radcliffe 2012, Krause 2013).

By 1990s the number of social and environmental NGOs had already reached over 400 (Justicia 2007, ECOLAP-MAE 2007) and continue to grow over the past decades. The notable feature of some of the environmental organizations, was purchasing land and setting it aside for conservation purposes within a human-dominated landscape. However, this approach was later challenged by some as it fails to take into account the local communities socio-economic conditions. Organizations as: Fundación Maquipucuna, established in 1988, and Fundación Jatun Sacha stablish in 1989, together with other local communities and organizations, had been trying to promote at the local community level environmental education activities and the generation of alternatives as local ecotourism related activities, which is subsequently proven to be one of the most effective means to conserve natural ecosystems (Justicia 2007). Today, Ecuador is the first country in the world to declare the rights of nature in its constitution through popular referendum in the year 2008 (articles 71-74). The declaration guarantees the rights of natural ecosystems to exist, to be maintained and be respected their ecological and evolutionary processes and the need to find alternatives to restore degraded ecosystems (Becker, 2011, Radcliffe, 2012)

Although the conservation movement in Ecuador has a relatively long history, active restoration of degraded ecosystems is still lagging behind. Most efforts to forest restoration involve planting of a few native and/or exotic species based on experiences elsewhere. However, the choice of tree species for restoration planting can influence both the rate and trajectory of restoration processes and determine the success of the projects. Ideally, the species selected for restoration endeavors should tolerate the prevailing environmental conditions of the degraded site, and have diverse ecological importance and traditional economic and non-economic values. In areas where restoration practice is at its infancy stage, the lack of knowledge about suitable species is always a challenge. In recent years, this lack of knowledge has triggered interests among researchers and practitioners to look into rapid and reliable methods of generating information for establishing local reference ecosystem. This accentuates the need for defining a locally suitable landscape unit that can serve as reference and planning unit for conservation, productive and restoration purposes.

Given the biological ecosystems and environmental degradation crisis and as well considering the potential to generate future conservation and restoration initiatives, the main question here is: How individuals and social groups, especially at the local landscape level, could possible contribute effectively to reduce the natural ecosystem degradation? In order to generate alternatives to face this problems, first it is needed: An integrate nature frame perspective, as the one that we are suggesting in (Figure. 1), in which the human population can be perceive that is one of the species, which are part of the inorganic and organic global and universal nature components, and part of it had been characterized by experts, from different disciplines and from different periods of time, considering different levels of organization and spatial distribution. In addition, each sub regional and local landscape has its own unique geoclimatic conditions, biological components and history (Figure 1). Thus, scale is an important issue in ecological studies, and from experience a local ecosystem analysis unit of 100 km^2 seems reasonable, which in the case of Ecuador corresponds to an area higher to the average parish (administrative unit) at which collective landscape planning occurs.

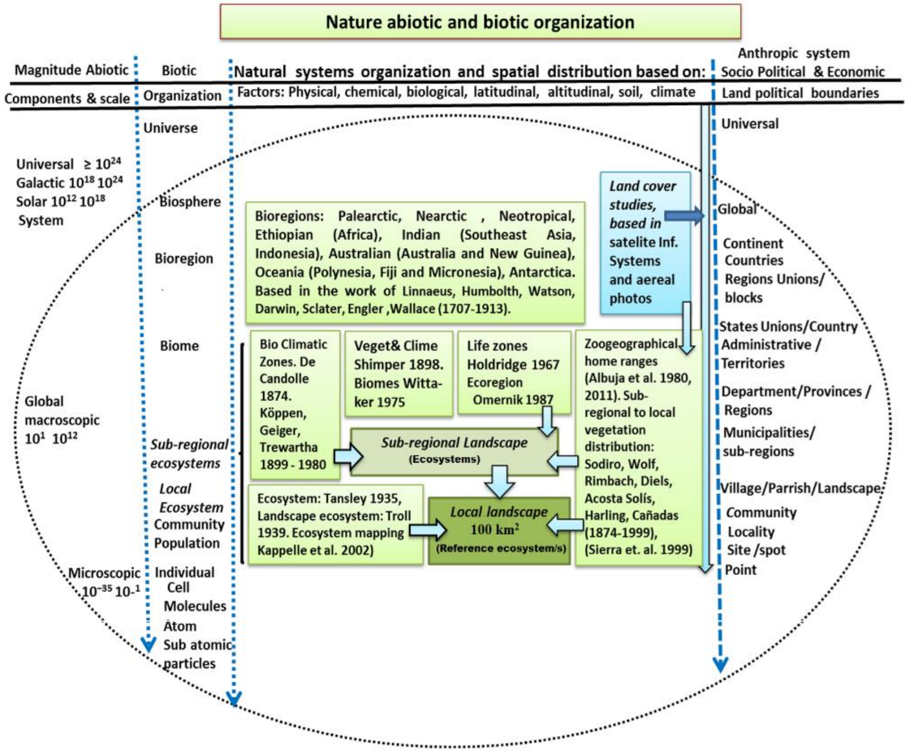

Fig. 1. Integrated nature perspective considering different scales of biotic, abiotic and social levels of organization and the local landscape context in which one or several reference ecosystem could be present

The spatial scale of analysis depends on the biological system and the study purposes under consideration (Andreasen et al. 2001, Kappelle et al. 2003). Classification schemes, such as the “Holdridge life zone system" or the "Köppen-Trewartha climate classification" (Holdridge 1967, Kottek et al. 2006) codify spatial- and bio-climatic basis of the Earth’s broad-scale vegetation. A Holdridge life zone system applied in Ecuador (Figure. 2), found the presence of 24 to 25 life zones (Vivanco et al. 1963, Cañadas 1983). These models are able provide important and valuable information for conservation and restoration efforts, but have certain limitations. In particular, they do not allow fine scale classification of local ecosystems within different latitudinal- and altitudinal ranges of environmental and biological processes that are present in sub regional and landscape scales (Harris 1973, Lugo et al. 1999, Sierra et al. 1999, Bailey 2002, Kottek et al. 2006).

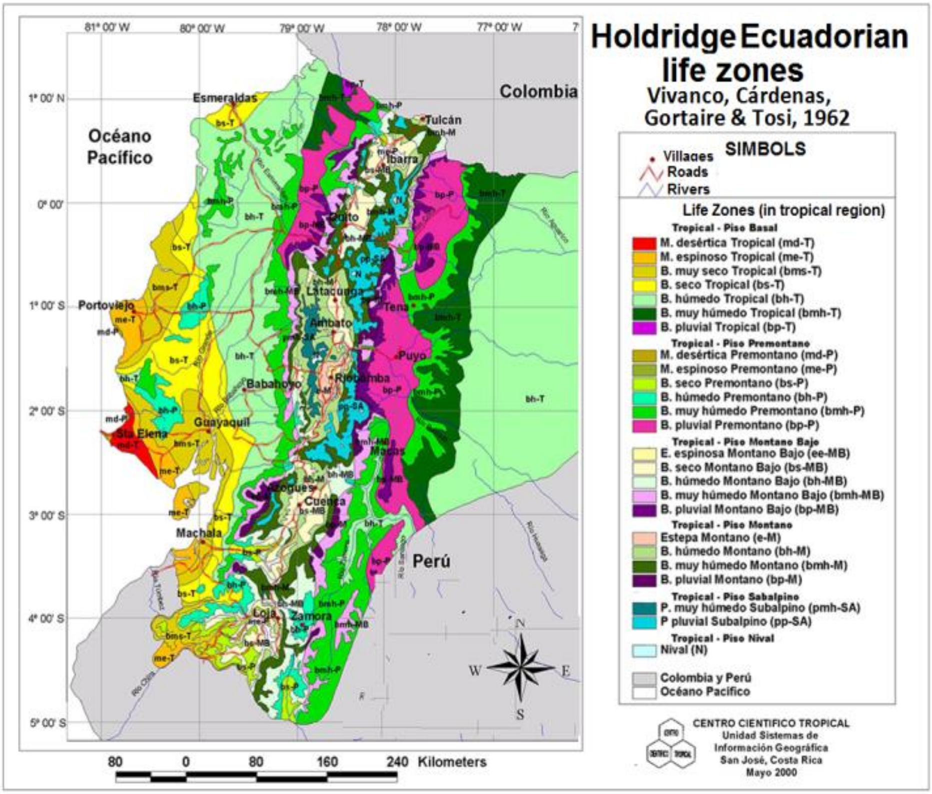

Fig. 2 Ecuadorian life zones map based in Holdridge bioclimatic zones (Vivanco et al. 1962).

1.3 The need for local ecosystem base-line information

The diversity of ecosystems in Ecuador coupled with changes in natural ecosystems over small spatial scales, particularly in areas with steep altitudinal gradients and marked microclimatic variability; mean it is paramount that the base-line information should be based on local ecosystem within the broader landscape. This locally relevant information can be generated in various ways. First and foremost, studying old growth primary ecosystems as forest remnants can provide sufficient information about its composition, structure, function and dynamics. Secondary regrowth is also a vital source of information about the potential of passive restoration (natural regeneration of degraded forests). There is ample evidence that shows the importance of secondary forests as templates for restoration and refuge of biodiversity in fragmented landscapes (Lamb, Stanturf and Madsen 2012, Lamb 2012).

Important base-line information about a given local ecosystem should include the following indicators: spatial distribution, ecosystem components, dynamics, trophic interactions and, health, as well as the local ethobiological and ethnoecological knowledge (Table 1). For capturing this information, a new 'Forest Gap Phase Dynamic Reference Method' was developed and tested in this thesis. Essentially, the method entails analyzing forest tree component integrity (structure, composition and biomass, and dynamics) inside three successional stages of old growth primary forest (gaps, intermediate and mature closed canopy) and secondary regrowth. Advances in remote sensing and GIS have made assessment of various aspects of ecosystems at a broader local and sub-regional landscape context for the study of a biological organism as mammals which are adapted to different forest ecosystems located in different altitudinal ranges of variation as the tropical lowland rainforest and cloud forest. In this thesis, both satellite images and hyperspatial aerial imagery were employed to identify tree species and delimiting home range distribution of an endemic brown-headed spider monkey.

Table 1. Factors and their indicators that should be considered during collection of baseline information about a given local reference ecosystem.

Factor	**Indicators**
Abiotic	Geographic, climate, site conditions
Biotic integrity	Biological components structure, abundance, composition, biomass
Dynamic	Internal dynamic processes and natural disturbances
Interactions	Trophic Food web interactions, matter and energy flow
Spatial distribution	Species, population/s distribution and home range/s
Anthropic Knowledge	Human socio-economic history (Anthropic induced disturbance)
Conservation	Ethno biological (botanical, zoological) and ecological knowledge
	Social, Public, private conservation , restoration efforts
Health	Signals and symptoms of ecosystem, components health, vulnerability, sickness, damage, degradation, collapse, species extinction, presence exotic and invasive species

Ethnic studies are used information about how local societies make sense of their surrounding environment, understand what is important to support their daily life which is part of their social identity (Cerón and Montalvo 1998, Becker and Ghimire 2003, Zarger and Stepp 2004). The social knowledge about their surrounding nature components including the local animal and plants had been studied by some research disciplines: (1) Ethnobiology, which is referred to human cultures uses and relationships with biological organism as: bacteria, fungi, plants and animals (Castetter 1944, Hunn 2007); (2). Ethnobotany, study the human cultures uses and relationships with plants (Acosta-Solís 1992, Cerón and Montalvo 1998, Cerón 2002, Palacios 2005, De la Torre, Muriel and Balslev 2006, De la Torre et al. 2008); (3). Ethnozoology, study the human cultures uses and relationships with animals (Alves 2012) and (4) Ethnoecology, are related with the human cultural interaction and adaptation to their surrounding ecosystems (Mueller et al. 2010, Nabhan 2009, Ouma, Stadel and Okalo 2016, Becker and Ghimire 2003). In addition ethnoecological studies, like the current one, can potentially generate information about the local communities members' ecological knowledge, the local animal-plants interactions, and other information which is an essential part of the local ecosystem baseline information and can be used to guide local and sub-regional conservation and restoration efforts considering human and wildlife needs.

Furthermore, the contribution of traditional ethnoecological knowledge in conservation, generation of economical alternatives with low ecological impact has been well recognized and utilized over the past few decades (Gadgil, Berkes and Folke 1993, Berkes, Colding and Folke 2000, Lykke, Kristensen and Ganaba 2004). TEK had been defined as a "cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment"(Gadgil et al. 1993). Unlike indigenous knowledge (focusing on particular ethnic group or indigenous people), TEK focuses more on a local culture and interactions with their biotic and abiotic environment (Gadgil et al. 1993, Becker and Ghimire 2003, Nabhan 2009, Warren and Rajasekaran 1993), ranging from cursory awareness about the social responsibility to maintain healthy ecosystems as a fundamental base for the maintenance of the social health, wellbeing and cultural values, norms and beliefs.

Traditional ethnoecological knowledge is a dynamic process that co-evolves with the ecosystem and the needs of local communities, thus serving as an information base for a society, facilitating communication and decision making, and as a foundation for local institutions. However, its present or potential contribution in restoration ecology has not been well studied. As a result, the integration of traditional knowledge in restoration planning still remains undervalued in many parts of the world, including Ecuador. The general premise for the role of traditional ethnoecological knowledge in restoration is that traditional people often interact with a landscape at a much larger scale and over longer periods of time, thus it can provide valuable information relevant to restoration ecology in less time and at a lower cost.

A recent review also demonstrates that traditional ethnoecological knowledge can contribute in process of ecological restoration, through species selection for restoration planting to monitoring and assessment of restoration outcomes (Uprety et al. 2012). Although all traditional practices and belief systems are not always ecologically sound and adaptive due to changing conditions, becoming stagnant and irrelevant over time (Charnley, Fischer and Jones 2007), there is supporting evidence that demonstrates the synergy between TEK and science-based approaches (Gadgil et al. 1993, Berkes et al. 2000, Becker and Ghimire 2003). Combining all these pieces of ecological and local population knowledge about their natural ecosystems components and interactions could be consider as part of the local natural ecosystem restoration toolkit to guide practitioners in the future to restore degraded ecosystems.

2 Objectives

The general objective of the studies presented in this thesis was to generate initial basic examples of three local and one sub-regional base-line information about Ecuadorian lowland rainforest ecosystem, a cloud forest and an Andean páramo which could be used to supports the generation of further information and monitoring process and as well as in future conservation and restoration efforts; thereby enhancing the generation of ecosystem benefices from the local to the global society. The studies focused on methodological aspects for generating the local relevant information and examining the legacy of previous event and as well as made the effort to predict the main performance of the studied ecosystem under different future scenarios, as the trophic catastrophic events as a stream period of wind, flooding, earthquakes etc. The specific objectives of the studies were:

1. Evaluate the reference gap phase dynamics method as a snapshot approach to characterize local reference ecosystem components in Choco-Darien lowland rainforest in Ecuador (Paper-I);

2. Examine the regeneration status in forest gaps in cloud forest remnants based in the use of the gap phase dynamics approach and to explore the importance of traditional ethnoecological knowledge (TEK) to generate relevant information for restoration (Paper-II);

3. Investigate the potential of very high resolution (VHR) proximal canopy remote sensing for taxonomic identification of trees and in primary and secondary forest remnants in a Ecuadorian Andean montane cloud forest (Paper-III);

4. Identify the sub-regional distribution and local home range average abundance of the remaining populations of the endemic critical endanger brown spider monkey (*Ateles fusciceps*) considering also other aspects as habitat suitability and hunting risk (Paper-IV); and

5. Examine the legacy of anthropic disturbance (grazing) on the páramo ecosystem under grassland and bushland habitats and their associated changes in soil conditions (Paper-V).

3 Materials and Methods

3.1 Study sites

The studies were carried out in three ecosystems in Ecuador (MAGAP et al. 2014), tropical lowland rainforest, Andean montane cloud forest and páramo, in five sites (Figure 3). The lowland rainforest, where local reference ecosystem attributes were characterized, is located between 0º20'867" N, 79º02'756" W, in Imbabura (Garcia 160 Moreno Parish) and Esmeraldas (Eloy Alfaro Parish) provinces. This site is part of the Choco Darien landscape complex in the NW Ecuador, where the spatial distribution and local home range of brown-headed spider monkey was investigated as well. The mean annual rainfall is 2804 mm and the mean annual temperature is 24.8 °C (MAE 2007). The forests, especially in Esmeraldas province, have been subjected to anthropic disturbance since 1959 period when network of roads and the train line were expand to this sub region.

The montane cloud forests, where surveys of natural regeneration and ethobiogical and traditional ethnoecological knowledge were conducted, are located in Cosanga, Napo province on the East of the Andean cordillera (0°30'39'' N, 77°50'39'' W), whereas the site where taxonomic identification of trees in primary and secondary forest by hyperspatial imagery technique was conducted in a cloud forest, located in Santa Lucia Reserve in Pichincha province (0°7′30″ N, 78°40′30″ W) in wester Andean Ecuadorian. The annual rainfall average ranges in the studied cloud forest ranged from 2500 to 3500 mm and the case of Cosanga the mean monthly temperatures range from 15-17 °C; and the climate is best described as cool and rainy. The forest soil is dominantly Cambisol with spatial heterogeneity in water logged conditions.

The fieldwork in the páramo ecosystem was conducted in Píntag parish (0°24′ 9″ N, 78°21′55″ W) located South East of the province of Pichincha within the Metropolitan District of Quito. It is part of the buffer zone of Antisana ecological reserve, endowed with the best provincial moors and the main source of water supply for south Quito. The Antisana ecological reserve is located in a biodiversity hotspot considered for Ecuador by the WWF. It contains almost half of the plant species known to exist in Ecuador, many of them unique to this region. The Píntag parish is about 2400-4500 m a. s. l and shared by the community of San Augustine. Its climate is clearly differentiated along an altitudinal gradient. The high altitude (3400-3900 m) is characterized by low temperatures, even below zero temperature, because of proximity to snowcapped Antisana. The mid altitude (3000-3400 m) has average temperature ranging between 20°C in the morning and 10°C in the night; while the low altitude (2700-3000 m) has average temperature ranging from 23°C in the morning to 13°C in the night. The South East of the Parish has a cold climate, while the north is a little bit warmer because of proximity to the Chillos Valley.

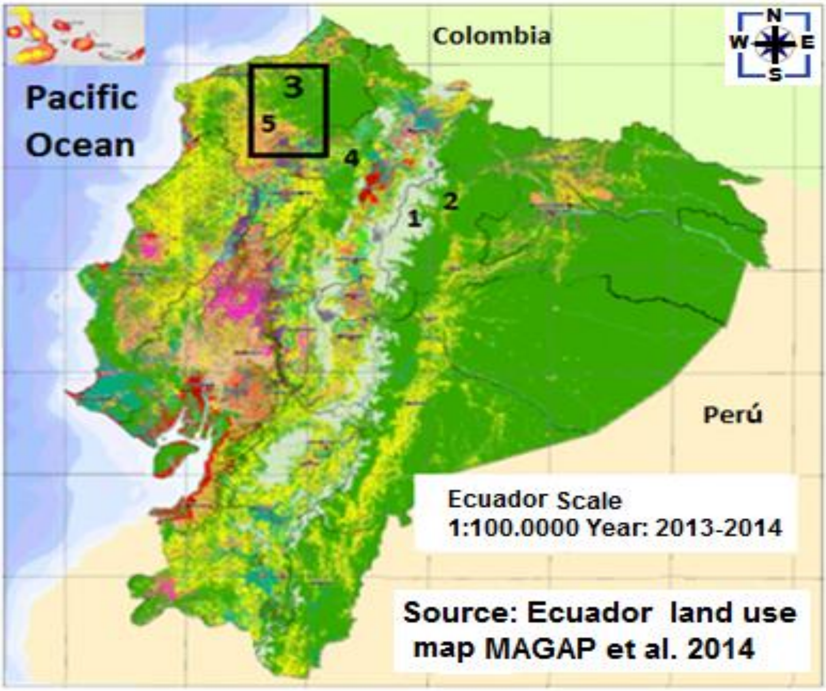

Figure 3. Location of the study sites in Ecuador; 1: Páramo in Píntag Parish, 2: Cosanga in Napo province, 3: Choco Darien lowland and highland landscape, 4: Santa Lucia reserve in Pichincha province, and 5: Imbabura and Esmeraldas provinces.

3.2 Data collection and analyses

3.2.1 Characterization of local reference forest ecosystem

To characterize ecosystem structure and function, three old growth primary forest remnants and secondary regrowth were randomly chosen from a forest landscape unit of 100 km^2 in Guayacanes, Tres de Septiembre and León Febres Cordero. Each selected area was on average 30 ha and divided into three sub-blocks of 10 hectares each and within each sub-block six transect lines (150 x 30 m) were established. The successional stages were assessed in forest patches inside the transect lines, or with at least 50% of the area inside the transect (Runkle 1992), and three stages were selected in the old growth primary forests: gap, intermediate high closed canopy and mature closed canopy. Once the inventory of the successional stages within each forest remnant were concluded, 27 biggest patches in the primary forests and 18 in secondary regrowth representing at the least 75% of characteristics of the succession stages were randomly selected. The area of each successional stage was 0.27 ha and the corresponding total area per primary forest remnant sampled was 3.24 ha.

To facilitate data collection, three nested sample plots (5 m^2, 10 m^2 and 30 m^2) were established in patches of each successional stage along four equal sections, starting from the northern direction and following the clockwise direction. In small plots (5 m^2), all woody individuals from 50 cm to 5 m in height were identified and counted by species while in 10 m^2 plots all woody species with ≥ 5 cm dbh were identified and the number of individuals of each species was counted. In 30 m^2 plots, all woody species with dbh ≥ 10 cm were identified, and the dbh of all living woody stems, height to the first branch, the total tree height were measured. In the same plots, the number of standing and lying deadwood was recorded. The diameter and length of the standing and lying deadwood with more than 1 m length were measured. In case of deadwood trunks with central holes, the two opposite side of the trunk borders were measured and summed to obtain single diameter. For fallen logs, the length was measured at two or more sections in which the log was considered inside the respective plot. The decomposition stage of the deadwood was categorized into three classes: (1) initial (fresh bark and wood with visible natural color), (2) middle (bark and trunk appeared darker in color, begun to decompose and covered with moss, lichen, fungi) and (3) rotten or advanced stage (semi-soft and rotten wood with obvious signs of disintegration).

Aboveground biomass (AGB, kg) was estimated following the allometric equation developed by Chave et al. (2014), which is a generalized biomass equation that can be applied across different forest types, including both old primary and secondary forests (Chave et al. 2014). The allometric equation, a function of tree, diameter at breast height (dbh), tree height (H in m) and wood specific density (ρ in g/cm3), can be expressed as:

$$AGB = 0.0673 \times \rho \, (D^2H)^{0.976}$$

Values for wood specific density were extracted from the global wood density database (Zanne et al. 2009). For species that lacked a direct measurement of specific density in that database, genus-level averages were used wherever possible. In few cases where the species was not represented in the data base up to genus level, a site average value of wood specific density was used.

The below ground biomass (BGB) was also estimated using the following formula (Ravindranath and Ostwald 2008).

$$BGB = \mathrm{Exp}\,(-1.0587 + 0.8836 \times \ln(AGB))$$

Finally the two biomass components were summed up and then multiplied by 0.47 to get an estimate of the carbon stock.

Species richness and abundance of seedlings and trees, carbon stock, abundance of deadwood were computed for each plot, and General linear model Analysis of variance (ANOVA) was performed to examine difference among forest blocks and successional stages. Forest blocks (three primary forest remnants) and sub-blocks were treated as random factors and successional stages of the primary forests (gaps, intermedium high closed canopy, and mature closed canopy) and secondary succession in secondary regrowth as fixed factor. Means that exhibited significant differences among successional stages were compared using Tukey's test.

3.2.2 Regeneration and traditional ethnoecological knowledge

The regeneration survey in four montane cloud forest remnants was performed studying forest gaps, based on the use of the inventory method described above. In the center of each selected gap, a plot of 10 m × 10 m was established, and all woody species from 0.5-5 m in height was enumerated. Most of the species were identified *in situ* during the inventory, and those that were difficult to identify in the field were collected and taken to the National Herbarium of Ecuador for identification by taxonomy experts. Voucher specimens were deposited at the same herbarium. The number of individuals of disturbance indicator species, *Chusquea* spp. (bamboo), was also counted in each gap during the inventory.

Species richness and abundance of individuals were computed for each plot by growth habit (tree versus treelets), and two-way analysis of variance was performed to examine significant differences among cloud forest remnants and growth habits, considering the density of disturbance indicator species as a covariate. Means that exhibited significant differences were further compared using Tukey's test. Linear regression analysis was performed to explore the relationship between population density of disturbance indicator species and species richness and abundance.

For the survey of traditional ethnoecological knowledge, in-depth interviews of 48 informants, who were randomly selected from a list of the Cosanga Cattle producers association, which has 102 members, was conducted. During the interview, the following data were gathered: demographic data of the informants, land use history, knowledge of native tree species and their uses for humans and wildlife, species recommended for planting and future land use plan. The interview about species and their uses was conducted in two-steps. First, open questions were posed to every informant to compile a list of species and their full knowledge of different uses (e.g., medicine, food, timber, wildlife habitat). In the subsequent interview, a list of 28 species together with photos, selected based on the survey of cloud forest remnants and group discussion with conservation experts, was presented to the informants, and the informants were asked whether they know the species and to mention their importance for human and wildlife utility.

Data related to TEK were analyzed using descriptive statistics and quantitative indices. For each species, user-reports (UR), defined as the sum of number of informants (*i*) who mentioned the use of the species, *s*, in the use-category, *u*, was computed following Tardío and Pardo-de-Santayana (2008) as

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

The socio-ecological importance of each tree species was compared using three quantitative indices: Relative Frequency of Citation (RFC), Relative Importance Index (RI) and Cultural Value index (CV), which are robust quantitative methods in ethno-botanical studies (Tardío and Pardo-de-Santayana 2008, Reyes-García et al. 2007). Relative frequency of citation of a species (RFCs) was obtained by dividing the number of informants who mention the use of the species, also known as frequency of citation a species (FCs), by the number of informants participating in the survey (N) as expressed below:

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

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

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

$RFC_{s(max)}$ is the relative frequency of citation over the maximum, obtained by dividing FCs by the maximum value in all the species of the survey; i.e., $RFC_{s(max)}$ = FCs/max (FC). $RNU_{s(max)}$ is the relative number of use-categories over the maximum, obtained by dividing the number of uses of the species by the maximum value in all the species of the survey; i.e., $RNU_{s(max)} = NU_s$/ max (NU).

Cultural Value Index of a species (CV_s) was computed by combining the number of different uses reported for the species (NU_s), the relative frequency of citation of the species (FCs) and the sum of all the UR for the species (UR_{ui}) relative to the sum of all the UR for the species (NC) and the total number of informant, N as follows:

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

Theoretically, RFCs varies between 0, when nobody mentioned any use of the species, and 1 if all informants mention the use of the species. The RI index varies from 0, when nobody mentions any use of the plant, to 1 in the case where the plant was the most frequently mentioned as useful and in the maximum number of use-categories. CVs reaches theoretical maximum value when all the factors reached their maximum; i.e., if all the informants mention the use of the species (FCs = N) in all the use-categories considered in the survey (NUs = NC), thus the first two factors would be equal to 1 while the third factor would vary from 0 to NC.

3.2.3 Identification of trees using hyperspatial aerial imagery

A remotely controlled helicopter, with Canon Power Shot A650 12.1 megapixel digital camera (Canon, New York, NY, USA) with a remotely operated shutter mounted on a gimballed platform, was sent out on pre-determined flight paths to capture proximal canopy aerial imagery across the survey area. As geo-markers, foil balloons were raised into the canopy and placed reflective foil markers at various prominent or significant locations in the sampling area and recorded their coordinates using a GPS (Garmin CSx60, Garmin International Inc., Olathea, KS, USA). The flights took place between 11:00 and 14:00 hours to ensure that light conditions were similar for each group of images. Images were assessed for clarity and resolution, setting a maximum pixel size of 5 cm as a threshold for subsequent analysis. For the primary forest site, 17 aerial images were collected, covering a sampling area of 2.15 ha. Imagery for the secondary site covered an area of 2.47 ha for analysis.

Laminated printouts of individual high-quality images were used to ground-truth crowns in the imagery with crowns in the field. Ground-truth data were collected in both primary and regenerating secondary forest. Data for 1048 trees were collected from the field, with trees representing 73 species, 58 genera and 39 families. All samples were collected between altitudes of 1786 m and 1966 m. Each selected tree was identified and tagged with an individual number, and the following measurements were taken: height and crown diameter, diameter at breast height (DBH), slope angle, aspect, phenology (flowering status of the tree crown), GPS coordinates and altitude. Where possible, we identified trees to species in the field; otherwise samples were taken to National Herbarium of Ecuador (QNCE) in Quito. We identified potential canopy indicator species of forest successional stage by their relative abundance in the two forest types for species that represented a minimum of 5% of total samples.

With individual crowns represented across multiple images, a total of 396 individual crown samples were used in the analysis. Crown samples in aerial imagery represented 41 species, 31 genera and 21 families. Species abundance differs between those identifiable in aerial imagery and species represented on the ground. We explored the raw and standardized data sets for comparative continuities in composition using linear redundancy analysis in CANOCO (Plant Research International, Wageningen, Netherlands). We then used the classification and regression tree modelling procedures in SPSS (SPSS statistics, v. l 17.0.0, 2008; SPSS Inc., Chicago, IL, USA).

We chose tree-based classification methods as they generate decision tree outputs that closely resemble the traditional taxonomic keys used in botanical identification. For a model that provides a good fit, the decision tree generated allows a user (or algorithm) to identify the species of a new crown by following dichotomous or multi-way branches (nodes). Splitting decisions are based on values of crown image features that best explain the split at each level. We applied and compared the predictive ability of four tree growing methods: CHIAD, Exhaustive CHAID, CRT and QUEST. The CHIAD (chi-squared automatic interaction detector) method uses multi-way splits based on adjusted significance testing (Bonferroni testing, $p < 0.05$; Kass 1980) and the canonical axes (RDA Monte Carlo permutation test).

3.2.4 Mapping home range of brown-headed spider monkey

The endemic brown-headed spider monkey (*A. fusciceps*) is catalogued as critical endangered species according to the UICN red list (Cuarón et al. 2008, Mittermeier, Reynolds and Rodrigues-Luna 1997). To determine its home range, first we identified remaining forest via a LANDSAT mosaic and then applied species-specific criteria to delineate remaining forest with potential to maintain a population of brown spider monkey. As home range information is not available for this species, a value close to the largest recorded for similar species in the Ecuadorian Amazon was taken (Pozo 2001).

The sampled localities were selected from records of *A. fusciceps* collected between 1995 and 2008 (Tirira 1995–2008). By combining this historical distribution with ecological niche modeling and predicted hunting intensity, a species-specific landscape map was generated. In the forest under investigation, we conducted field surveys during the day (09:00–17:00 h), walking 4–6 km/d (day), depending on access to area and terrain. We walked on existing trails and transects with ≥3 people at 1–1.5 km/h to avoid disturbing primates. Every 500 m we played the standardized recorded vocalization for 1 min, turning every 15 s to broadcast to the 4 points of the compass. We waited for 15 min at each point to record any responses to the stimulus. We estimated density by dividing the number of responses to playback at each site by the actual area sampled by playback.

3.2.5 Grazing effect on the páramo ecosystem

A reconnaissance survey was first made to get an impression of the internal variation of the entire study area; subsequently two broad zones of páramo vegetation types, grassland and bushland, were identified. The selected sites had visible signs of biotic disturbance, including removal of ground cover by grazing animals, and vegetation disturbance by local people through the collection of some fire wood, cutting and lopping of shrubs, and dead stumps. Within each vegetation community, two 1.0 ha plots were established based on overall altitude and slope. The plots in the grassland was located at 4027-4045 m (with 20% slope) and 4081-4102 m (with 15% slope) elevation while that of the bushland were located at 3932-3959 m (with 27% slope) and 3962-4003 m (with 35% slope) elevation. Each 1.0 ha (Block) was further subdivided into 25 subplots of 20 × 20 m for assessment of vegetation composition.

The presence of herbs and woody plants were assessed within every second subplot for each 1-ha plot. All the new herbs and shrubs were identified, their diameter at breast height (dbh) in plants lower that 1.5 m the diameter measurement was perform around 75% of the plants total high, which was measured by cross-calipering and their height was measured using a graduated pole. Bushes, herbaceous species and grass tussocks were studied within nested plots of 5 × 5 m^2 and 2x2 m^2 sub-quadrats which were placed at the corners of each 20 × 20 m^2 subplot. We identified all species present and counted the number of individuals of herbaceous species. Voucher specimens of each species in the quadrat and sub-quadrat were collected, numbered, pressed and taken to the National Herbarium which belong to the Ecuadorian Museum of Natural Science for identification by comparing with identified plant specimens and storage. Nomenclature follows that of the published volumes of Latin America flora (Jorgensen and León-Yánez 1999, Ulloa and Neill 2005, León-Yánez et al. 2011).

During the inventory, soil samples were collected from three below ground sub-plots within each plot at 0-5, 5-10, 10-25 and 25-50 cm using a soil-corer. The following soil properties were determined at the Laboratorio de Química Agrícola y suelos “Julio Penaherrera, Quito”: Organic matter was determined using the Loss-on-Ignition (LOI) method; Soil particle size distribution according to the procedure described by Day (1965); Soil pH-value using a glass electrode connected to a Digital ion analyzer (Digital pH/mv Meter, Model 701A); Total nitrogen using Kjeldahl procedure; Available Potassium by atomic absorption spectrometry; and Available Phosphorus using Bray-1 extract (Olsen and Dean 1965).

To characterize the floristic composition of grassland and bushland communities, species richness for each 1-ha plot was calculated. Similarity between vegetation communities was evaluated using Sørensen similarity index. Analysis of variance (ANOVA) was performed to examine significant differences in plot-wise species richness between and within vegetation communities. Two-way ANOVA was performed to examine significant differences in soil properties between vegetation communities and soil depth

4 Main results

4.1 Local reference ecosystem attributes

In the regeneration phase, a total of 132 species were recorded in all old growth primary lowland rainforest remnants; of which 55, 66 and 70 species were recorded in gaps, intermediate high closed canopy, mature closed canopy, respectively; while 59 species were recorded in secondary regrowth of disturbed forest. The species in the regeneration phase were represented by 723 individuals; of which 149 were found in the gaps, 181 in mature closed canopy and 188 in the secondary succession of disturbed forest and 205 in intermediate high close canopy. For tree species with dbh > 5 cm, 227 tree species, distributed over 52 families, was recorded in the primary forests, with total abundance of 1602 individual trees. A complete list of species together with their number of individuals is presented in Annex 1.

The total carbon stock of the old growth primary forest remnants was estimated to be 2112.5 t C/ha (with mean = 78 t C/ha) and that of secondary succession was 400.3 t C/ha (with mean 44.5 t C7ha). The total abundance of deadwoods was 725 pieces in the old growth primary lowland rain forest and 308 pieces in the regenerating forest. Overall, the abundance of lying deadwood was substantially higher (882 pieces) than the standing deadwood (151 pieces). With respect to decomposition state, 41% of the deadwoods were rotten, 32% in middle stage of decomposition and 27% in an initial stage of decomposition.
At plot-level, species richness, abundance and carbon stock of trees with dbh > 5 cm as well as abundance of deadwood varied significantly across successional stages ($p < 0.05$). Species richness, number of individuals and carbon stock per plot was higher in the intermediate high closed canopy than in the secondary succession plot of regenerating forests, whereas the abundance

of deadwood was higher in gaps and secondary succession plots than in intermediate high and mature closed canopy plots (Table 2).

Table 2. *Attributes of local reference ecosystems across different successional stages; where IHCC, MCC and SS stands for intermediate high closed canopy, mature closed canopy and secondary succession, respectively. For each ecosystem attribute, means across the row followed by different letter are significantly different.*

		Successional stage		
Attributes	Gap	IHCC	MCC	SS
Species richness	17 ± 2[ab]	21 ± 1[a]	16 ± 1[a]	14 ± 3b
No. of individuals	25 ± 2[a]	34 ± 2[b]	25 ± 1[a]	28 ± 3a
No. deadwood	38 ± 2[a]	2 ± 2[bc]	20 ± 2[c]	34 ± 6ab
Carbon stock	76.5 ± 9.7[ab]	83.0 ± 6.3[a]	75.3 ± 10.1[ab]	44.5 ± 9.6b

4.2 Traditional ethnoecological knowledge for local ecosystem restoration

A total of 32 species was reported by the informants as socio-ecologically important, with number of uses of a species ranged from one to a maximum of five (Annex 2). The total use-report values were 105-188 for 11 species, 61-93 for seven species and less than 50 for 14 species. Species with more than 25 citation frequency for both human and wildlife uses included *H. duquei, C. montanum, E. crassimarginata, O. insularis, S. prainiana, S. contortum, E. edulis, F. maxima* and *C. echinulatum*. In addition, seven species, *T. mollis, V. tomentosa, N. acutifolia, D. integrifolium, A. acuminate, W. macrophylla* and *A. latifolia*, were frequently cited as important for various human uses. Among species useful for wildlife, *C. echinulatum* was cited as important for both food and habitat (perching and nesting grounds) for various birds and small mammals. Ranking of native tree species useful for both human and wildlife using different indices exhibited minor inconsistency (Table 3). The relative importance index (RI) and cultural value index (CV), which took into account multiplicity of uses (number of use-categories mentioned for a species) consistently ranked *H. duquei, C. montanum, E. crassimarginata* and *S. contortum* as the most socio-ecologically important species; while the relative frequency of citation (RFC), which considered the spread of knowledge of useful species among informants, consistently ranked two species only, *H. duquei* and *E. crassimarginata*, as the most important species as the other indices. Most of the species recommended for future planting by informants complemented the regeneration survey, in which were recorded 154 species in gaps of remnant cloud forests with 10 rarest species (6 stems/ha).

Table 3. Ranking of species useful for humans and wildlife in Cosanga using relative frequency of citation (RFC), relative importance index (RI) and cultural value index (CV). Species are arranging in decreasing order of CV and species ranking based on each index.

	Indices			Ranking		
Species	RFC	RI	CV	RFC	RI	CV
Hyeromina duquei	0.979	0.900	2.191	1	1	1
Citharexylum montanum	0.740	0.878	2.036	6	2	2
Eugenia crassimarginata	0.833	0.826	1.627	2	3	3
Sapium contortum	0.698	0.756	1.105	7	4	4
Ocotea insularis	0.833	0.726	0.923	2	6	5
Vismia tomentosa	0.542	0.677	0.890	9	11	6
Ficus maxima	0.583	0.698	0.792	8	7	7
Ceroxylon echinulatum	0.469	0.739	0.767	11	5	8
Delostoma integrifolium	0.375	0.691	0.753	14	9	9
Erythrina edulis	0.771	0.694	0.723	4	8	10
Alnus acuminata	0.354	0.681	0.701	16	10	11
Tibouchina lepidota	0.510	0.561	0.424	10	15	12
Alchornea pearcei	0.365	0.586	0.386	15	13	13
Saurauia aff. Tomentosa	0.771	0.594	0.340	4	12	14
Nectandra acutifolia	0.417	0.513	0.283	13	17	15
Guarea kunthiana	0.323	0.565	0.242	17	14	16
Inga aff. Acuminate	0.302	0.554	0.219	20	16	17
Weinmannia macrophylla	0.323	0.465	0.176	17	21	18
Trichilia septentrionalis	0.198	0.501	0.106	22	18	19
Clusia lineata	0.167	0.485	0.087	23	19	20
Oreopanax palamophyllus	0.156	0.480	0.080	24	20	21
Turpinia aff. occidentalis	0.219	0.412	0.061	21	24	22
Hedyosmum luteynii	0.323	0.365	0.060	17	25	23
Cedrela montana	0.448	0.329	0.057	12	26	24
Critoniopsis occidentalis	0.083	0.443	0.018	25	22	25
Solanum cf. hypermegethes	0.042	0.421	0.005	26	23	26
Miconia glandulistyla	0.042	0.221	0.001	26	27	27
Jungleus (unidentified sp.)	0.021	0.211	0.000	28	28	28
Morus insignes	0.010	0.105	0.000	29	29	28
Nectandra sp.	0.010	0.105	0.000	29	29	28
Musmus (unidentified sp.)	0.010	0.105	0.000	29	29	28
Pandola (unidentified sp.)	0.010	0.105	0.000	29	29	28

The regeneration survey in forest gaps from four primary forest remnants showed significant differences ($p < 0.05$) in species richness and stem density among remnants of cloud forests and growth habits. The most important factor that influenced the regeneration of woody species was the abundance of bamboos (*Chusquea* sp.) – a well-known disturbance indicator species. Regression analysis revealed negative relationship between stem density of *Chusquea* and species richness (Fig. 4A) and abundance (Fig. 4B) of seedlings and saplings. Stem density of *Chusquea* explained 63% of the variation in species richness between plots (gaps), while it explained 48% of the variation in abundance of seedlings and saplings.

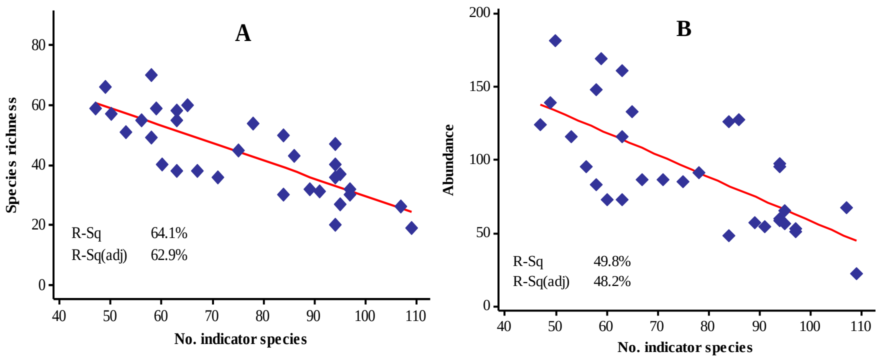

Figure 4. Relationship between stem density of disturbance indicator species and species richness (A) and abundance (B) of seedlings and saplings recorded in gaps of remnant cloud forests.

4.3 Identifying tree species composition by hyperspatial imagery

The aerial imagery represented 54% of families, 53% of genera and 56% of species sampled from the ground. Ordination (redundancy analysis) confirmed that inherent continuities, based on crown metrics, correlated with traditional species, genus and family groupings. Data were best described by histogram means in the green band. The best predictive model (CRT) generated a 47% probability of correct species identification for 41 species – with similar success at genus and family level. Predictive ability was highly species specific, ranging from zero for some taxa to 93% for *Cecropia gabrielis* Cuatrec. From the crown metrics tested, we found the mean pixel intensity in the green band was most effective in predicting species and species grouping of tropical mountain trees. This metric integrates species-specific differences in leaf density of crowns and reflectance in the green waveband. High predictive success for indicators of primary (*Cornus peruviana* J.F. Macbr.) and secondary forest (*Cecropia gabrielis* Cuatrec.) shows that VHR imagery can be used to identify species from pixel information to provide ecological information on successional status.

For the raw data set, the nominal environmental descriptors were significantly correlated with the first and all canonical axes (RDA Monte Carlo permutation test, $P < 0.001$). The sum of all canonical eigenvalues (variance explained) ranged from 31.8% for species to 26.2% for genera and 16.6% for family groupings, indicating that greater variability was introduced when grouping species into higher taxonomic units. For species, the first axis explained 26.7% of the variance, with subsequent axes explaining the remaining 5.1%. For genera 21.9% of variance is explained by the first axis with 4.3% explained by remaining axes, and for family taxonomic groupings 11% is explained by first axis with 5.6% explained by subsequent axes.

4.4 Home range of brown-headed spider monkey

The potential historical North west sub-regional distribution of the brown-headed spider monkey based on Max-Ent modeling provided a high predictive success rate (13 out of 17 localities successfully predicted as present) and a highly significant distribution model ($p < 0.001$) based on the classification of 81% of the studied area. According to the model prediction, the remaining forest area capable of sustaining brown-headed spider monkey was 5872 km^2, of which protected areas covered 2172 km^2 while the unprotected forests covered an area of 3700 km^2, but within this area only 989 km^2 (23%) is under low hunting pressure and likely to maintain healthy population.

To overcome problems of sampling at low primate density and in difficult mountain terrain we developed a field survey technique to determine presence and estimate abundance using acoustic sampling. For sites under low hunting pressure, density of primates varied with altitude. The number of individuals/km^2 decreased from seven at 332 m a.s.l to one at 1570 m a.s.l. Playback field survey results showed that the mean minimum detectable density varies from 0.23 to 0.68 individuals/km^2. With the exception of the community of Leon Febres Cordero, where hunting levels were thought to be high, we observed higher densities of primates at lower altitude. Additionally it was also found that in one of the studied localities even visually observed monkeys not answer the call, presumably because they are afraid of humans. Based on hunting buffers of 9 km radius for lowland settlements and 3 km radius for highland settlements, a forested area of 2711 km^2, suitable for brown-headed spider monkey was impacted by high levels of hunting. Of particular interest was an area of 989 km^2 of unprotected forest, suitable habitat for brown-headed spider monkey, was relatively isolated from human populations and hunting pressure.

4.5 Legacy of disturbance on páramo ecosystem

The floristic composition of the bushland in San Agustín páramo was composed of 30 species, distributed over 16 families, while that of the grassland was composed of 33 species of 16 families. Overall, the two vegetation habitats exhibited a large similarity in species composition (Sørensen similarity index = 0.700-0.722); so also plots within each vegetation community (Sørensen similarity index = 0.811-0.840) despite differences in their positions on the páramo landscape (elevation and slope). However, there was a significant difference in mean species richness at plot level between vegetation communities ($F_{[3, 92]} = 30.48$; $p < 0.001$). The mean species richness per plot was higher for both plots of the grassland than that of the bushland while the plots within each vegetation type were statistically similar in terms of species richness (Figure 5).

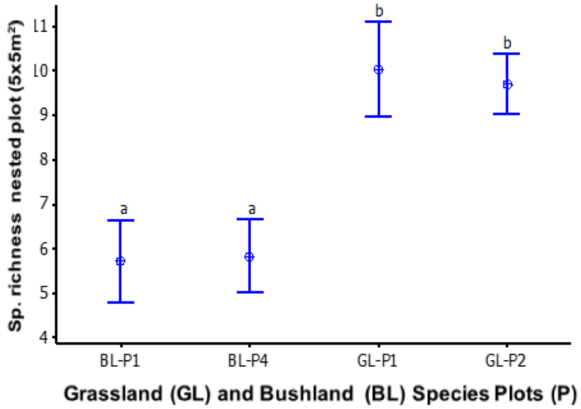

Figure 5. Species richness (no. of species per plot) of grassland (GL-P1 and P2) and bushland (BL-P1 and P4) plots differing in elevation and slope. The values are 95% CI of means

The soil textural fractions showed significant differences with respect to vegetation communities, soil depth or both, depending on the type of soil textural fraction; but no significant interaction effect was detected (Table zz). The proportion of the sand fraction was significantly ($F_{[1, 40]} = 7.38$; $p = 0.010$) higher for grassland than the bushland; the proportion of the silt fraction was significantly ($F_{[1, 40]}$ = 5.81; p = 0.021) lower for grassland than bushland and for lower soil depth (25-50 cm) than the upper 10 cm ($F_{[3, 40]}$ = 5.74; p = 0.002); and the proportion of the clay fraction was significantly ($F_{[3, 40]}$ = 19.61; p < 0.001) lower in the upper 10 cm soil depth than the lower soli depth. The organic matter content was significantly ($F_{[1, 40]}$ = 4.59; p = 0.038) higher for the bushland than the grassland, while it decreased significantly ($F_{[3, 40]}$ = 25.92; p < 0.001) with soil depth (Table 4).

Table 4. *Soil textural fractions and organic matter content in relation to vegetation communities and soil depth (mean ± SE). Means for each main effect followed by different letter (s) are significantly different.*

Soil textural fractions	Soil depth (cm)	Vegetation community Grassland	Bushland	Main effect (soil depth)
Sand (%)	0-5	36.5 ± 2.4	34.3 ± 1.2	35.4 ± 1.3a
	5-10	36.7 ± 2.6	35.0 ± 1.4	35.8 ± 1.4a
	10-25	38.3 ± 0.9	34.0 ± 2.0	36.2 ± 1.2a
	25-50	41.5 ± 1.8	36.3 ± 0.8	38.9 ± 1.2a
	Main effect (vegetation)	38.3 ± 1.0a	34.9 ± 0.7b	
Silt (%)	0-5	62.3 ± 2.5	64.3 ± 1.2	63.3 ± 1.3a
	5-10	61.7 ± 2.6	62.7 ± 1.5	62.2 ± 1.5a
	10-25	58.0 ± 0.9	61.8 ± 1.7	59.9 ± 1.1ab
	25-50	54.3 ±1.4	59.2 ± 1.2	56.8 ± 1.1b
	Main effect (vegetation)	59.1 ± 1.1a	62.0 ± 0.8b	
Clay (%)	0-5	1.3 ± 0.5	1.3 ± 0.3	1.3 ± 0.3a
	5-10	1.7 ± 0.4	2.3 ± 0.2	2.0 ± 0.2a
	10-25	3.7 ± 0.4	4.2 ± 0.4	3.9 ± 0.3b
	25-50	4.2 ± 0.4	4.5 ± 0.8	4.3 ± 0.4b
	Main effect (vegetation)	2.7 ± 0.3a	3.1 ± 0.4a	
OM content (%)*	0-5	18.4 ± 2.2	22.8 ± 1.7	20.6 ± 1.5a
	5-10	15.5 ± 0.7	15.7 ± 1.4	15.6 ± 0.8b
	10-25	11.7 ± 0.9	12.7 ± 0.7	12.2 ± 0.5c
	25-50	9.7 ± 0.5	11.6 ± 0.7	10.6 ± 0.5c
	Main effect (vegetation)	13.8 ± 0.9a	15.7 ± 1.1b	

* OM stands for organic matter

Soil pH, total carbon and nutrient contents also showed significant variation with respect to the bushland and grassland, soil depth or both (Table 5). The soil pH was significantly higher ($F_{[3, 40]}$ = 4.59; p = 0.007) in the upper 5 cm soil depth of the bushland than other soil depths in both grassland and bushland. The total soil carbon content was significantly ($F_{[1, 40]}$ = 4.59; p = 0.038) higher for bushland than grassland and significantly ($F_{[3, 40]}$ = 25.89; p < 0.001) decreased with increasing soil depth. The total nitrogen content was also significantly ($F_{[1, 40]}$ = 4.38; p = 0.043) higher for bushland than grassland and significantly ($F_{[3, 40]}$ = 26.09; p < 0.001) decreased with increasing soil depth.

The available phosphorus didn't differ significantly between vegetation types, but it was significantly ($F_{[3, 40]} = 26.09$; $p < 0.001$) higher in the upper 5 cm soil depth than in the lower 10-50 cm soil depth. The concentration of potassium was significantly ($F_{[1, 40]} = 17.77$; $p < 0.001$) higher for bushland than grassland soil, and it was significantly (F[3, 40] = 9.79; $p < 0.001$) higher in the upper 10 cm soil depth than in the lower soil depth.

Table 5. *Soil nutrient contents in relation to vegetation communities and soil depth (mean ± SE). Means for each main effect followed by different letter (s) are significantly different.*

Soil nutrients	Soil depth (cm)	Vegetation community Grassland	Bushland	Main effect (soil depth)
Soil pH	0-5	9.74 ± 1.16	12.04 ± 0.88	10.89 ±0.78^{a}
	5-10	8.20 ± 0.39	8.29 ± 0.76	8.24 ± 0.41^{b}
	10-25	6.18 ± 0.45	6.69 ± 0.35	6.43 ± 0.28^{c}
	25-50	5.11 ± 0.25	6.14 ± 0.35	5.62 ± 0.26c
Main effect (vegetation)		7.31 ± 0.49^{a}	8.29 ± 0.56^{b}	
Total C content (%)	0-5	9.74 ± 1.16	12.04 ± 0.88	10.89 ±0.78^{a}
	5-10	8.20 ± 0.39	8.29 ± 0.76	8.24 ± 0.41^{b}
	10-25	6.18 ± 0.45	6.69 ± 0.35	6.43 ± 0.28^{c}
	25-50	5.11 ± 0.25	6.14 ± 0.35	5.62 ± 0.26c
Main effect (vegetation)		7.31 ± 0.49^{a}	8.29 ± 0.56^{b}	
Total N content (%)	0-5	0.92 ± 0.11	1.14 ± 0.08	1.03 ± 0.07a
	5-10	0.78 ± 0.04	0.78 ± 0.07	0.78 ± 0.04b
	10-25	0.59 ± 0.04	0.63 ± 0.03	0.61 ± 0.03c
	25-50	0.49 ±0.02	0.58 ± 0.03	0.53 ± 0.02c
Main effect (vegetation)		0.69 ± 0.05a	0.78 ± 0.05b	
Available P (ppm)	0-5	8.38 ± 0.70	8.57 ± 0.89	8.48 ± 0.54a
	5-10	6.62 ± 0.60	5.03 ± 0.94	5.83 ±0.58^{ab}
	10-25	5.05 ± 0.83	5.18 ± 1.86	5.12 ± 0.97b
	25-50	6.85 ± 2.42	2.67 ± 0.23	4.76 ± 1.32b
Main effect (vegetation)		6.73 ± 0.68^{a}	5.36 ± 0.67^{a}	
Conc. K (cmol/g)	0-5	0.25 ± 0.01	0.32 ± 0.04	0.29 ± 0.02a
	5-10	0.22 ± 0.02	0.31 ± 0.04	0.26 ±0.02^{ab}
	10-25	0.18 ± 0.01	0.24 ± 0.02	0.21 ±0.01^{bc}
	25-50	0.16 ± 0.01	0.21 ± 0.01	0.18 ± 0.01c
Main effect (vegetation)		0.20 ± 0.01a	0.27 ± 0.02b	

5 Discussion

Terrestrial ecosystems are under constant disturbance by natural and anthropogenic forces (Turner et al. 2003). Generally, disturbance is defined as any relatively discrete event in time that disrupts an ecosystem, community, or population structure and changes resource availability as well as the physical environment (White and Pickett 1985). It is ubiquitous, inherent, unavoidable, and affect all levels of biological organization from individuals through ecosystems and landscapes with varying consequences at each hierarchical level. The series of earthquake that recently hit Ecuador is a good example of sudden and dramatic changes in ecosystems/landscape by natural disturbance forces. On the other hand, an inherent disturbance, such as natural tree fall, is a typical disturbance integral to a given forest ecosystem, resulting in subtle and gradual change in ecosystem structures and functions (Perera and Buse 2004). Natural disturbances are the primary causes of patchiness in ecosystems (Turner et al. 2003) and are evolutionary forces that have shape the adaptation of biota exposed to them.

Thus, any attempt to generate information about reference ecosystem should take into account this natural ecosystem dynamics. In this regard, the proposed reference gap phase dynamic method is a useful approach to quickly generate essential baseline information for formulating ecologically sound conservation and restoration strategies. The results for the old growth primary forest also show that species richness, number of individuals and carbon stock per plot differ along successional stages; being higher in the intermediate high closed canopy than in the secondary regrowth plot. Owing to its effects on nutrient levels, light regimes, substrate types, and dominance patterns, a disturbance may favor increased colonization by some species while it disfavors others (Gibson and Brown 1991, Jonsson 1993). Forest succession theories underscore that the positive effect of disturbance depends on its magnitude and availability of succession primers. According to the Intermediate Disturbance Hypothesis, too much disturbance leads to the loss of late successional species, whereas too little leads to the exclusion of species adapted to colonize ecosystems immediately after disturbance, thus an intermediate disturbance regime enables community co-existence (Connell 1978, Molino and Sabatier 2001, Sheil and Burslem 2003). Whereas the recruitment limitation hypothesis emphasizes that although disturbances in mature forests increase the choices of available niches, these would not necessarily be filled by the most adapted species, but rather by species whose propagules are sufficiently abundant at the right time and at the right place (Hubbell et al. 1999, Chazdon, Colwell and Denslow 1999). Overall, such functional adaptations underlie the mechanisms of ecosystem response to disturbance, which contribute to ecosystem resilience.

In tropical Andes, characterized by altitudinal gradient and marked climate variability, areal imagery can be a valuable methodology to generate relevant information about successional stages. Our result has shown that relatively simple pixel distribution descriptors for the three visible (RGB) bands in VHR aerial imagery can provide information to predict the identification of taxonomic species and species groupings of trees. In addition, high rates of success for crown samples of *Cornus peruviana* J.F. Macbr. Both *C. gabrielis* and *C. peruviana*, which are indicators of primary and secondary forests; confirms that using relatively simple pixel descriptors can provide important ecological information on the successional status of Andean mountain forest within the altitudinal range investigated. A successful method of remote identification of tree species within a tropical forest canopy would allow rapid landscape-scale analysis of a number of forest characteristics that have been studied at smaller scales for many years, such as flowering patterns (Hubbell 1980), and the mapping of distributional and diversity patterns (Gentry 1992).

An understanding of forest composition would, in turn, enable more accurate assumptions to be made regarding habitat suitability (Hyde et al. 2005) in terms of quality, keystone species, fragmentation and their respective effects on the biodiversity of the forests (Hill and Curran 2003, Leigh Jr et al. 2004). The increased knowledge in these areas would enable more informed conservation planning and management (Margules and Pressey 2000, Pouliot et al. 2002). The advancement of drone technology may be an opportunity in the future to apply crown-level identification to survey the changing composition of large tracts of forest and monitor degradation of forests, for example by identifying selective illegal logging of high-value or endangered timber species.

Anthropogenic activities, such as land use change and unscrupulous exploitation of natural resources, are by far the major disturbance factors that dramatically alter ecosystem structure and function. For instance, increasing hunting pressure close to Cotacachi-Cayapas Ecological Reserve has restricted the potential home range of critically endangered but endemic brown-headed spider monkey. Also we found out that in the southern block of the study area the spider monkey is already locally extinct. Regrettably, we didn’t observe any brown-headed spider monkey in the southern block of the study area; suggesting that either the species is locally extinct or forced to migrate.

In Ecuador, deforestation and forest degradation has dated back to the colonial period when native forests were unscrupulously exploited for timber, which was later exacerbated by increasing human population (from 4 million in 1950 to more than 16 million in 2015) and wrong forest development policy that promotes reforestation programs using exotic species (Mecham 2001, Sarmiento 2002, Larrea 2006, Farley 2007). In addition, resettlement policy promoted by governmental institutions, especially in the Amazon and the Andean Choco Regions, between 1960 and 1990 has resulted in further clearance of the natural forests (Southgate et al. 1991, Sierra 2001, Perreault 2002, Laurance et al. 2004). Consequently, several restoration initiatives have been launched by local community and private land owners, as well as non-governmental and governmental organizations over the past few decades (FUNAN 2002, GADPC 2012, Gómez De la Torre 2011).

However, most efforts to forest restoration involve planting of few native and/or exotic species based on experiences elsewhere due to lack of locally relevant knowledge about native species in the area. Emerging evidence shows that traditional ecological knowledge can fill crucial gaps in our ecological understanding (Mueller et al. 2010, Nabhan 2009, Ouma, Stadel and Okalo 2016, Becker and Ghimire 2003). The results from the survey of TEK presented in this thesis also are consistent with the general premise that TEK can provide valuable information about the relationship between local people and their natural environments, which is relevant to restoration and conservation in less time and at a lower cost. The informants identified 32 species that are culturally important; of which 25 species are reported to be useful as food for wildlife and three species as valuable perching and nesting grounds. Such information is vital for selection of native species for planting in conservation zones, including corridors that connect forest remnants, as erecting bird perches facilitates seed dispersal along the landscape (Holl 1998, Shiels and Walker 2003).

Human activities have not spared even the high altitude tropical alpine (páramo) ecosystem, despite its immense socio-ecological importance. The páramo ecosystem is an important component of the Andean biodiversity hotspots, housing the richest tropical mountain flora in the world (Smith and Cleef 1988, Luteyn and Churchill 1999, Hofstede et al. 2014); regulates hydrological cycle due to the high water retention capacity of páramo soils (Podwojewski and Poulenard 2000, Buytaert et al. 2006); and sequesters a large amount of organic C due to long and slow rate of decomposition of its thick layer of organic matter (Hribljan et al. 2016).

Grazing represents the main land use practice in the Ecuadorian páramo (Sarmiento 2002, Podwojewski et al. 2002). In San Augustine area alone, around 200 cows and 100 horses are freely grazing in the páramo. Fire had been part of the land management practice in the páramo to improve grassland productivity (Schmidt and Verweij 1992, Suárez and Medina 2001). The legacy of these disturbances is apparent from the substantial decline in the number of plant species, the replacement of the tussock grass vegetation by short carpet grass vegetation, and an increase of bare land (Podwojewski and Poulenard 2000, Podwojewski et al. 2002). The results presented in this thesis also provide some insight about the grazing effect on soil properties; particularly the decline in the accumulation of organic matter and total soil carbon, which in turn may disrupt ecosystem functions – energy flow and nutrient cycling.

6 Conclusions and future research

The studies presented in this thesis examined different approaches for generating base-line information about local reference ecosystem in Ecuador. Based on the findings the following conclusions can be drawn. (1) The proposed reference gap phase dynamic method is a useful approach to quickly generate baseline information about ecosystem components, functions and health at a local landscape level. This baseline information is vital before during and after passive or active restoration interventions in a specific landscape for planning future conservation actions, monitoring future changes in natural ecosystems; and comparing the state of several forest ecosystems within a landscape; thereby prioritizing restoration and conservation sites. (2) Secondary regrowth in gaps of disturbed cloud forests is limited by the rampant colonization of gaps by bamboo species and micro-habitat conditions created by topographic and soil conditions. (3) TEK can contribute to ecological restoration through species selection for restoration planting; and there is synergy between TEK and science-based approaches (e.g. regeneration survey); thus TEK can be an important entry-point to design locally adapted restoration interventions. (4) Simple pixel distribution descriptors for the three visible (RGB) bands in VHR aerial imagery can provide information to predict traditional taxonomic species and species groupings of trees, and to study successional stages. (5) Combining satellite image analysis and field survey using acoustic method, the home range of the endemic brown-headed spider monkey could be delimited; and to sustain a healthy population of this primate, the current home range within the ecological reserve needs to be expanded. (6) The Ecuadorian páramo vegetation communities are composed of largely similar species with few individuals; suggesting high grazing pressure that has spread from the relatively low elevation bushland to high elevation grassland. The soils of the páramo vegetation communities are composed of mainly sand with limited amount of organic matter. The soil C content, total N content and

K concentration in the soils of the páramo are regulated by microclimatic factors (low temperature) and the vegetation types through their influence on the rate and type of organic residue incorporated into the soil system.

In light of these findings the following recommendations are made: (1) further studies are needed to generate baseline information related to ecosystem functions that are not addressed here using the RGPD-method so that the versatility of the method will be further improved; (2) attempts should be made to regulate the population density of bamboo to create more growing space for seedlings in gaps of cloud forests; (3) incorporation of TEK in conservation and restoration planning is vital, as the local people have a wealth of knowledge about their local ecosystems; (4) to maintain a healthy population of brown-headed spider monkey, conservation action should focus on unprotected lowland forest to the south and west of the Cotacachi-Cayapas Ecological Reserve, where hunting pressure is still low and population density of the species is the greatest; and (5) degraded páramo ecosystem should be prioritized for conservation to improve the potential of páramo soils to sequester more organic carbon and contribute to climate change mitigation. Finally, establishment of *"Local ecosystems health center"* in each local village or parish would be considered to advice and coordinate conservation and restoration efforts in the future as well as to serve as a source of locally relevant information.

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Annex 1. A complete list of woody species recorded in Choco-Darien lowland rain forests, Ecuador.

Woody species	Total No. individuals
Wettinia quinaria (O.F. Cook & Doyle) Burret	*198*
Otoba novogranatensis Moldenke	*84*
Non -identified species 26	*72*
Guettarda hirsuta (Ruiz & Pav.) Pers.	*57*
Theobroma gileri Cuatrec.	*44*
Protium ecuadorense Benoist	*42*
Cecropia obtusifolia Bertol.	*40*
Cecropia garciae Cuatrec.	*39*
Eschweilera caudiculata R. Knuth	*39*
Gustavia dodsonii S. A. Mori	*38*
Eschweilera rimbachii Standl.	*29*
Vismia laterifolia Ducke	*29*
Swartzia haughtii R.S. Cowan	*25*
Gloeospermum grandifolium Hekking	*24*
Lecythis ampla Miers	*22*
Inga silanchensis T.D. Penn.	*21*
Cordia aff. mexiana I.M. Johnst.	*20*
Matisia malacocalyx (A. Robyns & S. Nilsson) W.S. Alverson	*19*
Prestoea acuminata (Willd.) H. E. Moore	*19*
Bauhinia pichinchensis Wunderlin	*18*
Matisia longipes Little	*18*
Otoba gordoniifolia (A. DC.) A. H. Gentry	*18*
Carapa guianensis Aubl.	*17*
Psychotria gentryi (Dwyer) C.M. Taylor	*16*
Dussia lehmannii Harms	*15*
Brosimum utile subsp. occidentale (Kunth) Pittier	*14*
Tabernaemontana amygdalifolia Jacq.	*14*
Posoqueria maxima Standl.	*13*

Virola reidii Little	*13*
Cecropia sp.1	*12*
Coccoloba obovata Kunth	*12*
Geonoma cuneata H. Wendl. ex Spruce	*12*
Inga sapindoides Willd.	*12*
Inga sp.2	*12*
Discophora guianensis Miers	*11*
Pachira patinoi (Dugand & Robyns) Fern. Alonso	*11*
Agouticarpa williamsii (Standl.) C. Persson	*10*
Faramea fragrans Standl.	*10*
Guarea kunthiana A. Juss.	*10*
Sapium stylare Müll. Arg.	*10*
Coussapoa contorta Cuatrec.	*9*
Grias peruviana Miers	*9*
Inga spectabilis (Vahl) Willd.	*9*
Licania celiae Prance	*9*
Pouteria aff. collina (Little) T.D. Penn.	*9*
Allophylus floribundus (Poepp.) Radlk	*8*
Apeiba membranacea Spruce ex Benth.	*8*
Conostegia aff. centronioides Markgr.	*8*
Geissanthus longistamineus (A. C. Sm.) Pipoly	*8*
Ossaea sp.	*8*
Brosimum utile subsp. occidentale	*7*
Cecropia hispidissima Cuatrec.	*7*
Tovomita nicaraguensis (Oerst., Planch. & Triana) L.O. Williams	*7*
Brosimum utile subsp. occidentale C.C. Berg	*6*
Guettarda platyphylla Müll. Arg.	*6*
Inga carinata T.D. Penn.	*6*
Inga lallensis Spruce ex Benth.	*6*
Sorocea jaramilloi C.C. Berg	*6*
Turpinia occidentalis (Sw.) G. Don	*6*
Brosimum guianense (Aubl.) Huber	*5*
Chrysochlamys dependens Planch. & Triana	*5*
Guarea glabra Vahl	*5*
Inga involucrata R.S. Cowan	*5*

Pouteria multiflora (A. DC.) Eyma	*5*
Quararibea aff. asterolepis Pittier	*5*
Sapium laurifolium (A. Rich.) Griseb.	*5*
Symphonia globulifera L. f.	*5*
Trichilia septentrionalis C. DC.	*5*
Casearia arborea (Rich.) Urb.	*4*
Chrysochlamys membranacea Planch. & Triana	*4*
Conostegia montana (Sw.) D. Don ex DC.	*4*
Conostegia sp.	*4*
Croton tessmannii Mansf.	*4*
Inga sp.1	*4*
Matisia aff. malacocalyx (A. Robyns & S. Nilsson) W.S. Alverson	*4*
Matisia grandifolia Little	*4*
Matisia soegengii Cuatrec.	*4*
Plinia sp.	*4*
Ruagea glabra Triana & Planch.	*4*
Tovomita weddelliana Planch. & Triana	*4*
Virola sebifera Aubl.	*4*
Alchornea grandis Benth.	*3*
Alchornea sp.	*3*
Andira macrotryrsa Ducke	*3*
Apeiba membranaceae Spruce ex Benth.	*3*
Carapa aff. guianensis Aubl.	*3*
Caryodaphnopsis theobromifolia (A.H. Gentry) van der Werff & H.G. Richt.	*3*
Dacryodes cupularis Cuatrec.	*3*
Dendrobangia boliviana Rusby	*3*
Eschweilera pittieri R. Knuth	*3*
Guatteria sp.1	*3*
Hedyosmum scaberrimum Stand.	*3*
Hernandia lychnifera Grayum & N. Zamora	*3*
Hippotis stellata C.M. Taylor	*3*
Inga acuminata Benth.	*3*
Inga chocoensis Killip ex T.S. Elias	*3*
Kutchubaea urophylla (Standl.) Steyerm.	*3*
Maytenus macrocarpa (Ruiz & Pav.) Briq.	*3*

Nectandra guadaripo Rohwer	*3*
Ossaea macrophylla (Benth.) Cogn.	*3*
Randia armata (Sw.) DC.	*3*
Sterculia apeibophylla Ducke	*3*
Sterculia colombiana Sprague	*3*
Abarema racemiflora (Donn. Sm.) Barneby & J.W. Grimes	*2*
Bertiera sp.1	*2*
Cecropia reticulata Cuatrec.	*2*
Cestrum megalophyllum Dunal	*2*
Conostegia aff. apiculata Wurdack	*2*
Conostegia cf. montana (Sw.) D. Don ex DC.	*2*
Cordia cf. mexiana I.M. Johnst.	*2*
Eschweilera pachyderma Cuatrec.	*2*
Eugenia florida DC.	*2*
Ficus sp.	*2*
Helicostylis tovarensis (Klotzsch & H. Karst.) C.C. Berg	*2*
Inga sp.3	*2*
Myrcia cf. splendens (Sw.) DC.	*2*
Naucleopsis naga Pittier	*2*
Ossaea brenesii Standl.	*2*
Palicourea acanthacea Standl. ex C.M. Taylor	*2*
Palicourea mexiae Standl.	*2*
Palicourea sp.	*2*
Perebea xanthochyma H. Karst.	*2*
Phragmotheca mammosa W. S. Alverson	*2*
Piper obliqum Ruiz & Pav.	*2*
Pleurothyrium cinereum van der Werff	*2*
Pleurothyrium sp.	*2*
Poulsenia armata (Miq.) Standl.	*2*
Pourouma aff. bicolor Mart.	*2*
Pouteria cf. collina (Little) T.D. Penn.	*2*
Rollinia pittieri Saff.	*2*
Saurauia lehmannii Hieron.	*2*
Siparuna gentryana Renner	*2*
Sloanea sp.1	*2*

Stephanopodium angulatum (Little) Prance	*2*
Stephanopodium longipedicellatum Prance	*2*
Synechanthus warscewiczianus H. Wendl.	*2*
Talisia macrophylla (Mart.) Radlk.	*2*
Vismia gracilis Hieron	*2*
Vismia sprucei Sprague	*2*
Alchornea cf. grandis Benth.	*1*
Alchornea cf. leptogyna Diels	*1*
Andira inermis (W. Wright) Kunth ex DC.	*1*
Beilschmiedia aff. costaricensis (Mez & Pittier) C. K. Allen	*1*
Bertiera sp.2	*1*
Brosimum utile (Kunth) Pittier	*1*
Bunchosia aff. deflexa Triana & Planch.	*1*
Bunchosia argentea (Jacq.) DC.	*1*
Byrsonima ligustrifolia A. Juss.	*1*
Calyptranthes sp.	*1*
Cecropia sp.2	*1*
Clarisia biflora Ruiz & Pav.	*1*
Clusia lineata (Benth.) Planch. & Triana	*1*
Clusia venusta Little	*1*
Compsoneura mutisii A.C. Sm.	*1*
Conostegia attenuata Triana	*1*
Cordia aff. lomatoloba I.M. Johnst.	*1*
Cordia cf. lomatoloba I.M. Johnst.	*1*
Cordia sp.	*1*
Coussapoa herthae Mildbr.	*1*
Coussarea latifolia Standl.	*1*
Cyathea delgadii Sternb.	*1*
Drypetes sp.	*1*
Elaeagia cf. karstenii Standl.	*1*
Endlicheria aff. browniana Mez	*1*
Endlicheria aff. browniana Mez	*1*
Endlicheria aff. formosa A.C. Sm.	*1*
Endlicheria formosa A.C. Sm.	*1*
Eugenia aff. florida DC.	*1*

Eugenia cf. myrobalana DC.	*1*
Eugenia sp.	*1*
Faramea sp.	*1*
Ficus brevibracteata W.C. Burger	*1*
Ficus cf. brevibracteata W.C. Burger	*1*
Ficus cf. cuatrecasana Dugand	*1*
Ficus mutisii Dugand	*1*
Fusispermum minutiflorum Cuatrec.	*1*
Guarea sp.	*1*
Guaripa aff. myrtiflora (Standl.) Lundell	*1*
Guatteria amazonica R.E. Fr.	*1*
Hedyosmum scaberrimum Standl.	*1*
Henriettella verrucosa O. Berg ex Triana	*1*
Hippotis stellata C. M. Taylor	*1*
Hippotis stellata C.M. Taylor	*1*
Hippotis stellata C.M. Taylor & Rova	*1*
Inga aff. coruscans Humb. & Bonpl. ex Willd.	*1*
Inga aff. spectabilis (Vahl) Willd.	*1*
Inga pezizifera Benth.	*1*
Inga sp.4	*1*
Inga venusta Standl.	*1*
Inga villosissima Benth.	*1*
Lozania mutisiana Schult.	*1*
Matisia sp.	*1*
Meliosma aff. occidentalis Cuatrec.	*1*
Miconia brachybotrya Triana	*1*
Mollinedia sp.	*1*
Myrcia aliena Mc. Vaugh	*1*
Naucleopsis sp.	*1*
Nectandra aff. membranacea (Sw.) Griseb.	*1*
Nectandra guadaripo	*1*
Nectandra purpurea (Ruiz & Pav.) Mez	*1*
Nectandra sp.	*1*
Neea cf. spruceana Heimerl	*1*
Notopleura sp.	*1*

Ocotea floccifera Mez & Sodiro	*1*
Oenocarpus bataua Mart.	*1*
Pleurothyrium cf. gigantum van der Werff	*1*
Pourouma sp.1	*1*
Pouteria aff. torta (Mart.) Radlk.	*1*
Pouteria collina (Little) T.D. Penn.	*1*
Pouteria sp.	*1*
Psychotria allenii Standl.	*1*
Pterocarpus aff. officinalis Jacq.	*1*
Raulvolfia leptophylla Rao	*1*
Rollinia sp.1	*1*
Sapium marmieri Huber	*1*
Sloanea sp.2	*1*
Sloanea stipitata Spruce ex. Benth.	*1*
Sterculia cf. colombiana Sprague	*1*
Swartzia aff. haughtii R.S. Cowan	*1*
Tabernaemontana panamensis (Markgr.,Boit. & L. Allorge	*1*
Trema micrantha (L.) Blume	*1*
Vantanea occidentalis Cuatrec.	*1*
Virola aff. calophylla (Spruce) Warb.	*1*
Vismia aff. lateriflora Ducke	*1*
Zanthoxylum aff. mauriifolium Reynel	*1*
	1602

*Ann*ex 2. Frequency of citation (FC) of a species by use category (together with number of uses (NU) as well as overall FC and use-report (UR). TF = timber and furniture; PF = poles for fencing, MH = medicines and herbs, FO = fruits and ornamentals, FW = fuelwood, WF = food for wildlife, WH = habitat for wildlife.

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

Hedyosmum luteynii	0	0	19	0	0	12	0	19	12	2	31
Turpinia aff. occidentalis	10	10	0	0	0	11	0	10	11	3	31
Critoniopsis occidentalis	5	5	0	0	5	3	0	5	3	4	18
Solanum cf. hypermegethes	3	3	0	0	3	1	0	3	1	4	10
Miconia glandulistyla	0	3	0	0	0	1	0	3	1	2	4
Jungleus (unidentified sp.)	1	0	0	0	0	1	0	1	1	2	2
Nectandra sp.	1	0	0	0	0	0	0	1	0	1	1
Morus insignes	1	0	0	0	0	0	0	1	0	1	1
Musmus (unidentified sp.)	0	1	0	0	0	0	0	1	0	1	1
Pandola (unidentified sp.)	1	0	0	0	0	0	0	1	0	1	1