TECHNISCHE UNIVERSITÄT MÜNCHEN

Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt

Fachgebiet für Waldinventur und nachhaltige Nutzung

Livelihood strategies and agricultural diversification in a leading hotspot area: a multilevel analysis in the Sumaco Biosphere Reserve, Ecuadorian Amazon

Segundo Bolier Torres Navarrete

Vollständiger Abdruck der von der Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktors der Forstwissenschaft (Dr. rer. silv.)

genehmigten Dissertation.

Vorsitzende:	Prof. Dr. Annette Menzel
Prüfer der Dissertation:	1. Prof. Dr. Thomas Knoke
	2. Prof. Dr. Carola Paul
	3. Priv.-Doz. Dr. Sven Günter

Die Dissertation wurde am 15.10.2018 bei der Technischen Universität München eingereicht und durch die Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt am 15.02.2019 angenommen.

Abstract

Currently, there is a growing interest in science and practice to understand the relationship between rural livelihoods and forest resources in tropical areas. In fact, previous studies have shown that rural households generate their livelihoods through a diverse range of activities to "survive and prosper", such as agriculture, hunting, fishing, the harvesting of timber and non-timber products, grazing cattle and lately off-farm and non-farm activities. However, not all households in a given area experience homogeneous livelihood strategies, especially in areas inhabited by indigenous and migrant settlers, where the variable of ethnicity alongside assets can affect not only the types of income-generating activities, but also the income levels for each activity and intensity of the adopted practices.

This thesis analyses rural livelihood strategies and their relationship with agricultural diversity and forest conservation and was carried out in an area of biological and cultural interest located in the central northern part of the Ecuadorian Amazon in the Sumaco Biosphere Reserve (SBR). The data were collected using the methodology of the Poverty and Environment Network (PEN-CIFOR). The study used the Sustainable Livelihood Framework (SLF) and multivariate econometric models at the household level. The results show the summary of four documents published with empirical data collected in the SBR, the four published topics were carefully selected considering the research questions, which are basically oriented to study the socio-economic determinants of livelihood strategies, agricultural diversification, use of timber and the potential of a traditional agroforestry system used at the local level. The main findings are as follows.

In the first document, the proportion of household incomes was used in a Principal Components Analysis (PCA), whose results were computed in a Cluster Analysis (CA), thus determining four livelihood strategies (LS) based on: forest, crops, livestock and wages. Additionally, using a Multinomial Logistic Model (MLM), it was determined that ethnicity and human, physical and natural capital are key determinants in terms of a producer choosing one of these LS. While using a Tobit model, it was determined that ethnicity significantly affects income levels positively or negatively. For example, in a LS based on agricultural crops, on average a Kichwa household (locally dominant ethnic group) earns US$ 223 more than a migrant settler household (population colonizing the area since the 1960s). In contrast, in a livestock-based LS, a settler migrant household typically earns US$ 472 more than a Kichwa one.

In the second document, the socioeconomic determinants of the legal and illegal use of timber were analysed. It is one of the earliest quantitative studies considering the legal and illegal logging as two different groups of analysis. Using a Multinomial Probit Model (MPM), it was determined that ethnicity

(Kichwa or migrant settlers) had no influence on the likelihood of harvesting timber (either legally or illegally). However, an important finding is that the annual volume harvested by Kichwa households averaged 8.7 m^3/year on an average surface of 8.9 hectares of primary forest, which is considerably lower than the average harvested by migrant settler households which is 36 m^3/year (four times higher) on an average of 8.4 hectares. In addition, illegal logging is more likely in households that do not have off-farm income, that maintain large areas of forest and reside far from urban areas. Meanwhile, the legal extraction of wood is carried out mainly by households with better economic conditions, who have legalised land tenure, but do not have off-farm income. Finally, households that do not harvest timber have a high probability of being poor, receiving income outside the farm, having small areas of land in primary forest and living near towns or villages.

The third document analyses the effect of ethnicity and livelihood strategies on the degree of diversification of the cultivated agricultural area based on the results obtained in paper one. A Multinomial Logistic Model MLM was applied in order to determine the triggering factors for agricultural diversification, considering three levels as a dependent variable. The levels were determined using the Shannon equity index *(E)* in a range of: low diversification (<25%), medium diversification (25-75%) and high diversification (>75%). The MLM determined that the variable of ethnicity (in this case Kichwa) significantly influences the adoption of highly diversified agricultural systems and that households engaged in livestock-based LS or wage-based LS are more likely to adopt agricultural systems with low diversification and with a high tendency to specialise in monoculture activities. At the same time, households engaged in crop-based LS and forest-based LS are more likely to adopt more diverse farming systems.

In the fourth paper of this thesis, a local agroforestry system called "*Chakra*" which is utilised in the study area in a traditional and modified way, was analysed. Over the years, this system has incorporated the cultivation of income-generating plants such as cocoa and coffee. The document analyses the potential of this traditional system based on the cultivation of cocoa as a possible alternative for sustainable production and adaptation to climate change. It discusses some suggestions for extension agents and policy makers for promoting environmentally friendly production systems, income improvement, food security and forest conservation.

Through this research, it was possible to demonstrate the importance of ethnicity and human, physical and natural capital in terms of choosing some kind of rural LS, and that ethnicity is a significant variable to determine the livelihood's effectiveness in terms of economic income. In spite that ethnicity is not significant when deciding whether logging or not, it is quite important in terms of intensity of logging. This is an important finding for forest management and conservation that must be considered in further interventions. Therefore, in regions inhabited by different ethnic groups, a reasonable recommendation is to consider LS and ethnicity in order to promote agrarian/forestry policies, incentives and technology transfer towards sustainable production systems and forest management. If policies are implemented neglecting these important aspects, they could generate failures in the medium term and long term due to landowners' preferences. The results also suggest the need for future studies related to ethnicity and the optimal land-use portfolios based on LS. As well as, the relation between ethnicity and access to markets and compensations payments addressing forest conservation and management must be further analysed to assess their real impact on rural livelihoods.

Keywords: Livelihoods, sustainable production, forest conservation, econometrics.

Zusammenfassung

In Wissenschaft und Praxis besteht ein zunehmendes Interesse, die Beziehung zwischen den Lebensgrundlagen im ländlichen Raum und Waldressourcen in den Tropen zu verstehen. Frühere Studien haben gezeigt, dass ländliche Haushalte ihren Lebensunterhalt mit einer Vielzahl wirtschaftlicher Aktivitäten wie Landwirtschaft, Fischerei, Nutzung von Holz- und Nichtholzprodukten und in steigendem Maße auch außerbetrieblichen und nicht landwirtschaftlichen Tätigkeiten bestreiten. Allerdings sind die Strategien der Haushalte zum Lebensunterhalts in einem bestimmten Gebiet sehr heterogen. Dies gilt besonders für Siedlungsgebiete indigener Gruppen und Siedler, wo die ethnische Zugehörigkeit und das verfügbare Kapital nicht nur die unterschiedlichen Formen Einkommen schaffender Aktivitäten beeinflussen können, sondern auch das Einkommensniveau für jede Aktivität und Intensität.

Die vorliegende Dissertation analysiert Strategien der ländlichen Bevölkerung zum Lebensunterhalt (LS) und ihre Beziehung zur landwirtschaftlichen Diversifizierung und Walderhalt in einem Gebiet von hohem biologischen und kulturellen Interesse, im Sumaco Biosphärenreservat (SBR)im ecuadorianischen Amazonas. Die Daten wurden mithilfe der Methodik des “Poverty and Environment Network“ (PEN-CIFOR) erhoben. Die Studie verwendete den konzeptionellen Ansatz zur Analyse des nachhaltigen Lebensunterhalts (Sustainable Livelihood Framework SLF) unter Anwendungmultivariater ökonometrischer Modelle auf Haushaltsebene. Die vorliegende Dissertation fasst die Ergebnisse von vier Publikationen zusammen, welche auf empirischen Daten basieren, die im SBR erhoben wurden. Die vier zu Grunde liegenden Themen wurden zur Beantwortung von Forschungsfragen ausgewählt, die darauf ausgerichtet sind, die sozioökonomischen Determinanten der Existenzgrundlagenstrategien, die landwirtschaftliche Diversifizierung, die Nutzung von Holz und das Potenzial eines traditionellen Agroforstsystems auf lokaler Ebene zu untersuchen. Die wichtigsten Ergebnisse sind:

Im ersten Artikel wurde die Struktur des Einkommens mittels Hauptkomponentenanalyse (PCA) in Kombination mit einer Clusteranalyse (CA) analysiert. Dabei konnten vier Strategien zum Lebensunterhalt auf der Grundlage der Nutzung von Holz, landwirtschaftlichen Nutzpflanzen, Vieh sowie außerbetrieblicher Arbeit bestimmt werden. Darüber hinaus wurde mithilfe eines multinomialen logistischen Modells (MLM) festgestellt, dass ethnische Zugehörigkeit -, physisches, natürliches und Human-Kapital Schlüsselfaktoren für die Wahl der Strategien zum Lebensunterhalt sind. Durch Anwendung eines Tobit-Modells wurde festgestellt, dass ethnische Zugehörigkeit einen signifikanten Zusammenhang mit dem Einkommensniveau aufweist. Beispielsweise verdient ein Kichwa-Haushalt (lokal dominierdende Ethnie) in einer auf Landwirtschaft ausgerichteten Strategie zum

Lebensunterhalt 223 US$ mehr als ein Siedler-Haushalt (Bevölkerung, die seit den 60er Jahren das Gebiet kolonisiert). Im Gegensatz dazu verdient aber ein Siedlerhaushalt in einer auf Viehhaltung basierenden Strategie 472 US$ mehr als ein Kichwa-Haushalt.

In einem zweiten Artikel wurden die sozioökonomischen Determinanten legaler und illegaler Holznutzung analysiert. Diese Studie zeichnet sich dadurch aus, dass sie offensichtlich als erste die illegale Verwendung von Holz als eigenständiges Merkmal der Analyse berücksichtigt. Unter Verwendung eines Multinomial-Probit-Modells (MPM) wurde festgestellt, dass Ethnizität (Kichwa oder Siedler/Mestizen) keinen Einfluss auf die Wahrscheinlichkeit der Holznutzung eines Haushalts hat. Ein wichtiges Ergebnis ist jedoch, dass das jährliche Nutzungsvolumen der Kichwa-Haushalte durchschnittlich 8,7 m^3/Jahr auf einer durchschnittlichen Primärwaldfläche von 8,9 Hektar betrug. Dies ist deutlich weniger als der Durchschnitt der Siedlerhaushalte mit 36 m^3/Jahr (viermal höher), auf durchschnittlich 8,4 Hektar. Darüber hinaus ist illegaler Holzeinschlag wahrscheinlicher in Haushalten, die kein zusätzliches Einkommen außerhalb der Landwirtschaft haben, die große Waldflächen besitzen und weit von städtischen Gebieten entfernt liegen. Legaler Holzeinschlag hingegen wird in erster Linie von privaten Haushalten mit günstigeren wirtschaftlichen Ausgangsbedingungen durchgeführt, die ihren Landbesitz legalisiert haben, jedoch nicht mit einem Einkommen außerhalb der Landwirtschaft rechnen können. Haushalte, die kein Holz ernten, eine hohe Wahrscheinlichkeit für Armut aufweisen und ihr Einkommen aus nicht-landwirtschaftlichen Tätigkeiten bestreiten, besitzen lediglich kleine Flächen im Primärwald und leben näher an Ballungszentren.

In einem dritten Artikel wurde der Effekt von Ethnizität und Lebensunterhaltstrategie auf den Grad der Diversifizierung der landwirtschaftlich genutzten Fläche analysiert. Im Rahmen eines multinomialen Logistikmodells (MLM) wurden unter Verwendung des Shannon-Diversitätsindex (E) drei Diversifizierungsklassen der landwirtschaftlichen Nutzfläche von geringer Diversifikation (<25%), durchschnittlicher Diversifikation (25-75%) und hoher Diversifikation (>75%) als abhängige Variable getestet. Ethnizität (in diesem Fall Kichwa) beeinflusst die Häufigkeit stark diversifizierter landwirtschaftlicher Systemen signifikant. Haushalte, die mit einer Viehhaltungs-Strategie oder außerlandwirtschaftlichen Tätigkeiten in Verbindung stehen, wenden eher landwirtschaftliche Systeme mit geringer Diversifizierung an, mit hoher Tendenz, sich auf Monokulturen zu spezialisieren. Haushalte mit auf Landwirtschaft basierenden Strategien und Holznutzung, wenden mit größerer Wahrscheinlichkeit stärker diversifizierte landwirtschaftliche Systeme an.

Im vierten Artikel der Dissertation wurde das lokale agroforstwirtschaftliche System "*Chakra*" analysiert, welches im Untersuchungsgebiet auf eine traditionelle und modifizierte Art und Weise

angewendet wird. In dieses System wurde im Lauf der Zeit der Anbau von Cash-Crop Pflanzen wie Kakao oder Kaffee integriert, die helfen Einkommen zu generieren. Das Dokument analysiert das Potenzial dieses traditionellen Systems in Kombination mit dem Anbau von Kakao als mögliche Alternative für eine nachhaltige Produktion unter besonderer Berücksichtigung der Anpassung an den Klimawandel. Es erörtert einige Implikationen für Akteure der Entwicklungszusammenarbeit und politische Entscheidungsträger hinsichtlich umweltfreundlicher Produktionssysteme, Einkommensverbesserung, Ernährungssicherheit und Waldschutz.

Anhand dieser Dissertation konnte die Bedeutung der ethnischen Zugehörigkeit sowie des physischen, natürlichen und des Human-Kapitals bei der Entscheidung für eine Strategie zum Lebensunterhalt im ländlichen Gebiet nachgewiesen werden. Die ethnische Zugehörigkeit ist eine wichtige Variable, um die Art und Weise der Einkommensgenerierung zu analysieren. Die Tatsache, dass die ethnische Zugehörigkeit nicht signifikant ist für die Entscheidung, Holz zu nutzen, jedoch stattdessen die Intensität der Holznutzung wesentlich beeinflusst, ist eine wichtige Erkenntnis für die Waldbewirtschaftung und den Naturschutz und sollte bei Maßnahmen zum Schutz des Naturwaldes berücksichtigt werden. Daher ist es zu empfehlen, in Gebieten, in denen unterschiedliche ethnische Gruppen wohnen, die jeweiligen Strategien zum Lebensunterhalt und Ethnizität zu beachten. Weiterhin sollten an die unterschiedlichen Ausgangsbedingungen angepasste Politikinstrumente für Land- und Forstwirtschaft, Anreizsysteme und Technologietransfers für nachhaltige Produktionssysteme und Waldbewirtschaftungsstrategien gefördert werden. Mittel- bis langfristig könnten Fehlentwicklungen auftreten, wenn politische Regulierungen oder Anreize angewendet werden, die jedoch die genannten Aspekte nicht berücksichtigen. Die Ergebnisse belegen den weiteren Bedarf an Studien über optimale Landnutzungs-Portfolios, basierend auf (unterschiedlichen) Lebensgrundlagen sowie weitere Analysen über den Einfluss von ethnischer Zugehörigkeit, Zugang zu Märkten und Ausgleichszahlungen auf die Erhaltung und Bewirtschaftung von Wald als Lebensgrundlage in ländlichen Gebieten.

Schlüsselwörter: Lebensgrundlagen, nachhaltige Produktion, Waldschutz, Ökonometrie.

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Resumen

Actualmente existe un creciente interés en la ciencia y en la práctica para entender la relación entre medios de vida rurales y los recursos forestales en áreas tropicales. De hecho, previos estudios han demostrado que hogares rurales desarrollan sus medios de vida en un diverso rango de actividades para "*sobrevivir y prosperar*", como la agricultura, caza, pesca, aprovechamiento de productos maderables y no maderables, pastoreo y últimamente actividades no agrícolas fuera de la finca. Sin embargo, no todos los hogares en una misma área experimentan estrategias de vida homogéneas, especialmente en sitios de asentamientos indígenas y migrantes colonos, donde la variable etnia y los capitales pueden afectar no solo en los tipos de actividades generadoras de ingresos, sino también en los niveles de ingresos por cada actividad e intensidad de la práctica adoptada.

Esta tesis analiza estrategias de vida rurales y su relación con la diversidad agrícola y la conservación forestal, en un área de interés biológico y cultural localizado en la parte centro norte de la Amazonía Ecuatoriana en la Reserva de Biosfera Sumaco (RBS). Los datos fueron colectados usando la metodología de la Red de Pobreza y Ambiente del (PEN-CIFOR). El estudio usó el marco conceptual de medios de vida sostenibles (SLF, por sus siglas en inglés) y modelos econométricos multivariados a nivel de hogares. Los resultados muestran el resumen de cuatro documentos publicados con datos empíricos colectados en la RBS, los cuatro temas publicados fueron cuidadosamente seleccionados considerando las preguntas de investigación, que básicamente están orientadas a estudiar las determinantes socioeconómicas de las estrategias de vida, diversificación agrícola, aprovechamiento de madera y el potencial de un sistema agroforestal tradicional usado a nivel local. Entre los principales hallazgos tenemos:

En un primer documento se usó la proporción de ingresos económicos en un análisis de componentes principales (ACP), cuyos resultados se computaron en un análisis de conglomerados (AC), determinándose cuatro estrategias de vida basadas en: madera, cultivos agrícolas, ganadería y empleos. Adicionalmente, usando un modelo logístico multinomial (MLM) se determinó que la etnia y los capitales humanos, físicos y naturales son determinantes claves para que un productor elija alguna de estas estrategias de vida. Mientras que usando un modelo Tobit, se determinó que la etnicidad afecta significativamente de manera positiva o negativa en los niveles de ingresos, por ejemplo, en una estrategia de vida basada en cultivos agrícolas, un hogar Kichwa (grupo étnico localmente dominante) ganaría US$ 223 más que un migrante colono (población que ha colonizado el área desde la década de 1960); En contraste, en una estrategia de vida basada en ganadería un hogar de migrante colono ganaría US$ 472 más que un Kichwa.

En un segundo documento se analizó las determinantes socioeconómicas del aprovechamiento legal e ilegal de madera. Este estudio se distingue en que es al parecer, el primero en considerar el aprovechamiento ilegal de madera como una característica independiente de análisis. Usando un modelo multinomial probit (MPM), se determinó que la etnicidad (Kichwa o colonos/mestizos) no tuvo influencia sobre la probabilidad de que un hogar aproveche madera o no. Sin embargo, un hallazgo importante es que el volumen anual aprovechado por los hogares Kichwa fue en promedio de 8.7 m^3/año sobre una superficie promedio de 8,9 hectáreas de bosque primario, considerablemente menor que el promedio aprovechado por hogares colonos 36 m^3/año (cuatro veces mayor) sobre un promedio de 8,4 hectáreas. Además, que la extracción ilegal de madera es más probable en hogares que no tienen ingresos fuera de finca, que mantienen grandes áreas en bosques y residen lejos de las áreas urbanas. Mientras que la extracción legal de madera se realiza fundamentalmente por hogares con mejores condiciones económicas, que han legalizado la tenencia de la tierra, pero que no cuentan con ingresos fuera de la finca. Finalmente, los hogares que no extraen madera tienen altas probabilidades de ser pobres, recibir ingresos fuera de la finca, poseer pequeñas áreas en bosque primario y vivir cerca de centros poblados.

En un tercer documento se analizó el efecto de la etnicidad y las estrategias de vida determinadas en el primer documento, sobre el grado de diversificación del área agrícola cultivada. Los principales resultados de un modelo logístico multinomial (MLM), que asignó como variable dependiente tres niveles de diversificación del área agrícola determinados mediante el uso del índice de equidad de Shannon *(E)* en un rango de: baja diversificación (<25%), media diversificación (25–75%) y alta diversificación (>75%), el MLM determinó que la variable etnia (en este caso Kichwa) influye significantemente en la adopción de sistemas agrícolas altamente diversificados. Y que hogares relacionados con la estrategia de vida basada en ganadería o empleos fuera de la finca son más probables de adoptar sistemas agrícolas de baja diversificación, con alta tendencia a la especialización en actividades de monocultivos. Mientras que los hogares enganchados en las estrategias de vida basadas en cultivos agrícolas y en aprovechamiento de madera son más probables de adoptar sistemas agrícolas más diversos.

En un cuarto documento de la tesis se analizó un sistema agroforestal local denominado "*chakra*", manejado en la zona de estudio de manera tradicional y modificada. Sistema que con el paso de los años se le ha incorporado el cultivo de plantas generadoras de ingresos económicos como cacao o café. El documento analiza el potencial de este sistema tradicional basada en el cultivo de cacao como una posible alternativa de producción sostenible y adaptación al cambio climático. Discutiendo

algunas implicaciones para extensionistas y generadores de políticas hacia sistemas de producción ambientalmente amigables, mejoramiento de ingresos, seguridad alimentaria y conservación forestal.

A través de esta investigación fue posible evidenciar la importancia de la etnicidad y de los capitales humanos, físicos y naturales en las decisiones para optar por algún medio de vida rural; y que la etnia es una variable significativa para determinar su efectividad en términos de ingresos económicos en cualquiera de los medios de vida que ellos elijan. El hecho de que la variable etnia no es significante al momento de decidir si aprovechar madera o no, pero si en la intensidad del aprovechamiento maderero, es un hallazgo importante para el manejo y conservación forestal a considerarse. Por lo tanto, en regiones habitadas por diferentes etnias, se sugiere considerar las estrategias de vida y la etnicidad para promover políticas agrarias/forestales, incentivos y transferencia de tecnología hacia sistemas de producción sostenibles y manejo de bosques que, si bien pudieran ser adoptadas por factores de empujes (regulaciones políticas o incentivos), podrían también generar fracasos a mediano plazo si se las aplica sin considerar estos aspectos. Los resultados también sugieren futuros estudios relacionados con la etnicidad y el portafolio óptimo del uso del suelo con enfoque en las estrategias de vida, así como también entre la etnicidad y el acceso a mercados y compensaciones que contribuyan a la conservación y manejo del bosque y de los medios de vida rurales.

Palabras clave: Medios de vida, producción sostenible, conservación forestal, econometría.

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1. Introduction

1.1. Problem Statement

The relationship between forest and livelihood strategies of local dwellers is still not completely understood in tropical countries (Wunder et al. 2014, Sunderlin et al. 2005). Nevertheless, scientific evidence suggests that the disappearance of natural forests, among other reasons, negatively affects the livelihoods of the populations that depend on the forest products and services (Maruyama & Morioka 1998, Brosius 1997). Sunderlin et al. (2005) have recognized three basic types of interaction between livelihoods and forest change: from hunting and gathering, to either itinerant agriculture or permanent agriculture at the forest frontier. Currently, most of the rural populations in tropical forests are in the last two categories (Sunderlin et al. 2005).

Land use change caused by subsistence-based agriculture and small-scale timber logging has transformed the landscape in the tropics (FAO 2016), with economic, social and ecological effects. Smallholder agricultural activities have been widely identified as one of the primary source of deforestation and forest degradation (Davidson et al. 2012). Whilst on one hand, tropical forest ecosystems are the most important source for biodiversity worldwide (Barthlott et al. 2005), on the other hand they play an important role for the livelihoods of over one billion people (Chao 2012, Quang and Sato 2008, WRI 2005), which may account for about 22% of total rural household income (Angelsen et al. 2014, Vedeld et al. 2007), whereas smallholder agricultural activities contribute to around 41% (Angelsen et al. 2014). Thus, it is necessary to find practical ways to meet local populations' demands, while still allowing for forest protection and conservation.

This particular issue is important in Ecuador, one of the world's most biodiverse countries (Mittermeier et al. 1998, Myers 1988). At the same time, the nation has a very high deforestation rate, where about 90% of the deforested area in the last two decades has been converted into croplands and pastures (Sierra 2013). In the Ecuadorian Amazon Region (EAR) which comprises about 48% of Ecuador's total surface area, land-use patterns are mostly the same. The EAR has a distinctive land-use history due to several migration processes. It is currently inhabited by migrant settlers and indigenous populations who differ in their conservationist behavior and market integration (Lu et al. 2010, Gray et al. 2008). Settlers are generally reported to use extensive land clearing for commercial agriculture, while indigenous people prefer smaller agricultural areas (Gray et al. 2008). It is generally believed that indigenous people have cultural norms and values that promote the conservation and sustainable use of resources (Stocks et al. 2007). However, diverse studies have demonstrated that indigenous people have access to a market economy, and that they also engage in unsustainable practices including extensive cattle ranching, cash crops and timber logging (Porro et al. 2014, Gray et al. 2008, Godoy et al. 2005, Rudel et al. 2002). It is evident that there is no clear behavior pattern based on ethnicity regarding land-use among local dwellers in this area. There is a gap in knowledge that this study seeks to fill. Conducting a socioeconomic and cultural cross-sectional research may provide an opportunity to better understand the livelihood strategies adopted by both migrant settlers and indigenous people (Kichwa). This could enhance understanding about how ethnicity and asset endowments may create different impact in terms of income levels and intensity of practices, depending upon the interest group.

Given this context, this research addresses four aspects related to: a) the determinants of livelihood strategies (LS) choices and income levels, considering ethnicity and assets (human, social, natural, physical financial and capital); b) the socioeconomic determinants of legal and illegal smallholder logging, assessing the role of ethnicity on logging patterns and treating legal and illegal logging as two different categories of analysis; c) the patterns of agricultural diversification, focusing on the role of ethnicity and the livelihood strategies the household follow; and d) the assessment of a local traditional agroforestry system used by indigenous populations as a possible agricultural alternative. The four aspects are particularly relevant due to four key reasons. First, three data sets covering both migrant settlers and indigenous population have been used, which allows one to assess the role of ethnicity on the level of income and intensity of each farm activity. Second, an interesting combination of multivariate techniques is used in each category of analysis. Third, in the EAR, as well as in other rural areas in Amazonian countries, there is evidence of a tendency to employ monoculture systems based on pastures and crops, which creates economic and socio-environmental impacts, evidencing the relevance of studies in agricultural diversification. Fourth, both household and contextual influences through the Sustainable Livelihood Framework (SLF) (Ellis 2000, Bebbington 1999, Scoones 1998) are considered, which is appropriate as it identifies the household as the main factor of farm-activity decision making and provides policymakers with specific information to design sustainable development and forest conservation policies.

1.2. Tackling the Problem

There is currently a gap in our understanding of how households' socioeconomic and cultural characteristics such as ethnicity, asset endowments and land use practices influence the adoption of livelihood strategies and their implication for poverty reduction, agricultural diversification and forest conservation in a biological *hotspot* area (Myers et al. 2000, Myers 1988), inhabited by indigenous populations and migrant settlers who arrived 50 years after colonization (Sellers et al. 2017, Mena et al. 2006). To examine these issues, three data bases from household surveys of forest landowners in the buffer and transition zone of the Sumaco Biosphere Reserve (SBR) were analyzed, on the basis of the SLF, using the following research conceptual framework (Figure 1).

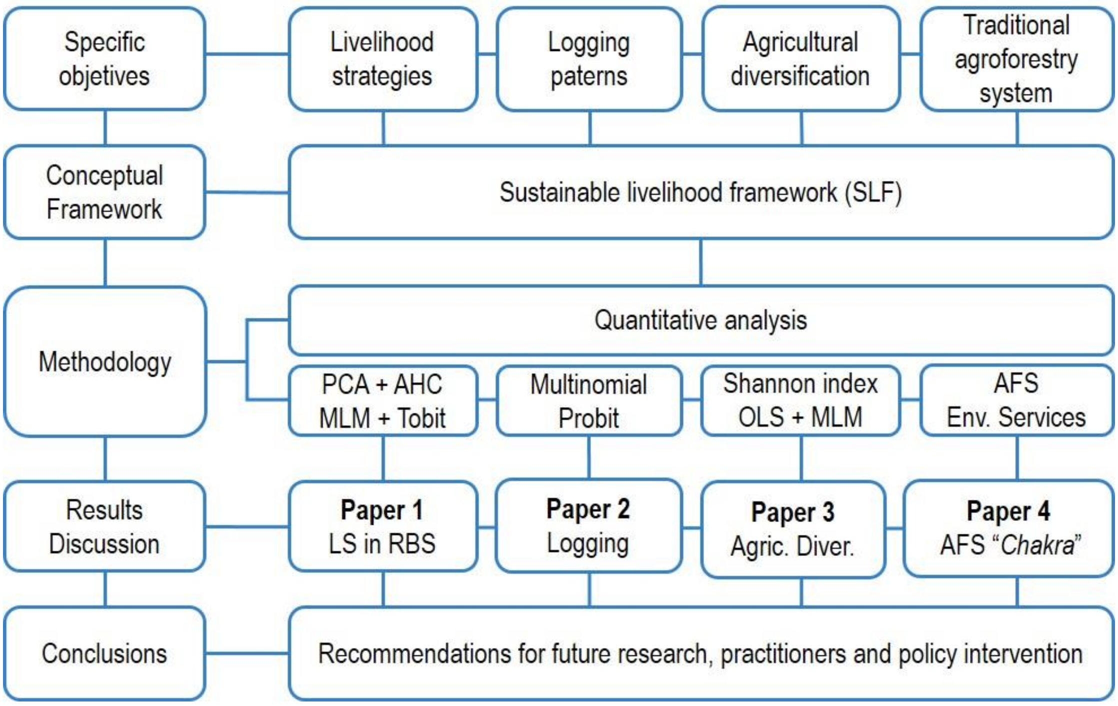

Figure 1. Conceptual framework of the research. Notes: LS livelihood strategies. PCA principal components analysis. AHC agglomerative hierarchical clustering. OLS ordinary least square. MLM multinomial logit model. AFS agroforestry system. Source: Author, 2018.

1.3. Objectives and Hypotheses

The aim of this thesis was to analyze the determinants of livelihood strategies and their relationship with sustainable development and forest conservation, using the SLF and multivariate econometric models at the household level in the Ecuadorian Amazon Region.

The thesis pursues the following specific objectives:

1. To determine the Livelihood Strategies (LS) employed by indigenous (Kichwa) and migrant settler populations and examine the factors associated with households' LS choice, as well as to evaluate the effect of ethnicity on households' incomes in each livelihood strategy.
2. To examine household livelihood strategies and timber logging, as well as the socioeconomic determinants of legal and illegal smallholder timber harvesting using an econometric model.
3. To determine agriculture diversification according to each livelihood strategy using the Shannon diversity index of agriculture (crops and livestock) and evaluate the effect of LS and ethnicity on degree of agricultural diversification using a range of high, medium and low diversification determined from the Shannon equitable index.
4. To analyze the contribution of the *chakra* as an appropriate agroforestry system to mitigate climate change, food insecurity and poverty.

This thesis is driven by the following hypotheses:

1. Ethnicity has strong influence on the households' livelihood strategy (LS) decision making, and will also affect the level of household income in the determined LS.
2. Ethnicity has no effect on the likelihood of harvesting timber either legally or illegally.
3. Agricultural diversity is affected by ethnicity and the livelihood strategies that a household pursues with consequences on socioeconomic variables.

1.3. Papers Contributions

Four papers form the core part of this thesis, which help to understand the role of livelihood strategies, including the small-scale agricultural systems in the EAR and how they relate to forest conservation (Table 1).

Table 1. List of publications on which the dissertation is based

List of publications	Summary	Division of labor
Bolier Torres, Cristian Vasco, Sven Günter, and Thomas Knoke. 2018. Determinants of agricultural diversification in a hotspots area: evidence from colonist and indigenous communities in the Sumaco Biosphere Reserve, Ecuadorian Amazon. In: *Sustainability* Vol. 10(5), 1432: 1-21.	The publication analyzes the drivers of agricultural diversification, using the Shannon index of crop area as a dependent variable in a OLS model, while an MLM was used to assess a household's degree of diversification based on Shannon equitable index (*E*).	Concept: BT, TK, SG Design: BT, TK Data collection: BT, CV Data analysis: BT, CV Article writing: BT, CV, SG, TK
Bolier Torres, Sven Günter, Ricardo Acevedo and Thomas Knoke. 2018. Livelihood strategies, ethnicity and rural income: The case of migrant settlers and indigenous populations in the Ecuadorian Amazon. In: *Forest Policy and Economics* Vol. 86(2018): 22-34.	This paper examines the livelihood strategies (LS) of two ethnic groups and explores their implications for forest conservation. We analysed the influence of ethnicity on the households' adoption of LS, and on the level of household income.	Concept: BT, TK, SG Design: BT, TK Data collection: BT Data analysis: BT, RAC Article writing: BT, SG, TK
Cristian Vasco, Bolier Torres, Pablo Pacheco, Verena Griess. 2017. The socioeconomic determinants of legal and illegal smallholder logging: Evidence from the Ecuadorian Amazon. In: *Forest Policy and Economics* Vol. 78 (2017): 133-140.	This paper analyzes the socioeconomic determinants of legal and illegal smallholder timber harvesting. We used a multinomial probit to assess the role of ethnicity and socioeconomic variables on logging patterns.	Concept: CV, BT, PP Design: CV, BT Data collection: BT, PP Data analysis: CV, BT Article writing: CV,BT, PP,VG
Torres Bolier, Oswaldo Jadán Maza, Patricia Aguirre, Leonith Hinojosa and Sven Günter. (2015). The Contribution of Traditional Agroforestry to Climate Change Adaptation in the Ecuadorian Amazon: The Chakra System. In: Leal Filho Walter (Ed.), *Handbook of Climate Change Adaptation. Springer-Verlag Berlin Heidelberg*. 1973-1994 pp.	This publication presents the contribution of the "*chakra*," a traditional agroforestry system, on climate change mitigation and adaptation, as well as on biodiversity conservation in communities of the EAR. The paper provides solid evidence that the latter might be possible through traditional agroforestry system.	Concept: BT Design: BT Data collection: OJ, BT Data analysis: BT, OJ, SG Writing the article: BT, LH, PA, SG, OJ

BT: Bolier Torres; TK: Thomas Knoke; SG: Sven Günter; RAC; Ricardo Acevedo; CV: Cristian Vasco; PP: Pablo Pacheco; VG: Verena Griess; PA: Patricia Aguirre; OJ: Oswaldo Jadán; LH: Leonith Hinojosa.

2. State of Research

This chapter shows relevant information described in recent literature about the antagonism between forest conservation and livelihoods, which are the main driver of land-use change and how these activities contribute to subsistence-based farmers. The chapter also contains information about the main livelihood activities practiced in the study area such as timber logging, cattle ranching and cash cropping, key elements for this research work. By reviewing this information, it has been possible to understand how local dwellers interact with the resources available to them in terms of using goods and services from the forest, the level of conservation of the resource, and the degrees of sustainability achievable based on the population's dependence on natural areas.

2.1. Rural Livelihoods and Forest Resources

From 2000–2010 there was a global net forest loss of 7 million hectares and a net gain in agricultural land of 6 million hectares per year in tropical countries (FAO 2016). In the tropics and subtropics, large-scale commercial agriculture accounts for about 40% of deforestation and subsistence-based agriculture 33%. While shifting cultivation and timber harvesting have been identified as a major threat to biodiversity and forest encroachment (FAO 2016, Peres et al. 2006, Asner et al. 2005), they also represent important economic activities for subsistence-based farmers and thus, the relationship between these two aspects must be better understood, especially for the formulation of policies aiming to promote forest conservation, food security and income for farmers.

There is a global consensus that deforestation is a process triggered by different causes on various scales. According to Kaimovitz and Angelsen (1998), the causes of deforestation can be proximate (direct) or underlying (indirect). Among proximate causes, one can include farming expansion (crops and livestock) (Rudel et al. 2009, Mena et al. 2006), timber logging (Vasco et al. 2017, Mejía et al. 2015), mining and infrastructure, which are all human activities with direct impacts on forest cover. Meanwhile, underlying causes of deforestation are related to macro-level interactions of political, social, economic, technological and cultural factors (Kissinger et al. 2012, Geist and Lambin 2001).

In the EAR, a region inhabited by a large growing indigenous population and subsistence-based migrant settlers, small-scale agriculture is the main cause of deforestation and land-use change (Sierra 2013, Bremner et al. 2009, Gray et al. 2008, Bilsborrow et al. 2004). As a consequence, conflicts converge in this region between biodiversity conservation and the use of natural resources (Finer et al. 2008). Large-scale commercial agriculture is not common in the EAR so far, with few oil palm plantations in the Northern Ecuadorian Amazon (NEA). This particular characteristic shows the opportunity to improve small-scale subsistence farms for both migrant settler and indigenous populations, for example through the implementation of sustainable agricultural practices embracing social, economic and environmental aspects (Pretty 2008) and to promote farmer organizations. However, more scientific information is required, especially regarding the determinants of the adoption of sustainable production systems in order to facilitate the development of public policies to improve the rural livelihoods of small-scale farmers.

2.2 Household Livelihood Strategies

Several approaches can be employed to analyze sustainable development and how people can influence the use of natural resources. One of them is the conventional approach, which aims to increase productivity, incomes and employment into single occupations and does not consider livelihoods (Ellis 2000). Another approach is the SLF, an important theoretical approach that integrates concepts of development and conservation (Ellis 2000, Ellis 1999, Ellis 1998, Scoones 1998), facilitating the analysis of rural livelihood strategies. The SLF was first promoted by the Department for International Development (DFID), a British government department, in the late 1990s (Ashley and Carney 1999). This approach has been used by previous studies to describe the LS in rural areas (Torres et al. 2018a, Walelign 2017, Walelign 2016, Porro et al. 2015, Trung Thanh 2015, Zenteno et al. 2013) at household level.

The main objective of the SLF is poverty reduction (Ashley and Carney 1999). But it is necessary to understand differences in LS among different groups of households that pursue homogeneous schemes of livelihoods. In fact, these LS are determined by both assets (human, social, natural, physical and financial) and external factors that households use in their on- and off-farm activities, which comprise a diverse portfolio of activities for survival and improving standards of living (Torres et al. 2018a, Walelign 2017, Nielsen et al. 2013, Davis et al. 2010, Ellis 1999, Ellis 1998).

Nowadays, LS are considered a dynamic and adaptable concept (Walelign and Jiao 2017, Walelign 2017, Trung Thanh 2015, Nielsen et al. 2013), defined by Walelign (2017) as a “livelihood ladder”. This extended concept suggests that a livelihood strategy could change depending on livelihood asset endowment and the accumulation of assets (e.g. land, livestock and productive implements), as well as the occurrence of positive events such as remittance or finding a salaried job (Walelign 2017), characteristics that represent entry or exit barriers (Barrettet al. 2001). External contexts and social groups also effect LS.

Relating the SLF described to the current context of the Sumaco Biosphere Reserve (SBR), located in the northern and central part of the Ecuadorian Amazon Region (EAR), the latest infrastructure development in the EAR acts as an external factor that could reduce obstacles to people adopting better LS, thus facilitating the social movement of indigenous populations historically isolated from the formal economy. Additionally, the continuing growth of non-farm employment with oil companies and ecotourism may provide uncommon local income-generating opportunities that could reduce pressure on the forest. Nevertheless, in territories inhabited by migrant settlers and indigenous populations, beside asset endowments, it is also necessary to assess the effect of ethnicity not only on the adoption of livelihoods, but also on the intensity of land-use practices adopted and the profitability they can achieve by carrying out similar practices.

2.3. Smallholders Timber Logging

The sustainable livelihood approach has also been used in the contexts of smallholder decisions concerning timber harvesting at both local (Vasco et al. 2017, Mejia et al. 2015) and global levels. It was revealed that timber is one of the main sources of income for people living in tropical forest landscapes, accounting to around 22% of rural income at a global level (Angelsen et al. 2014, Vedeld et al. 2007) and 28% for Latin American countries (Angelsen et al. 2014). These authors recommend the use of the SLF to facilitate the analysis of individual and community context, as well as of the external factors related to the households. Under the SLF, the rural household is the decision-making unit which makes decisions depending on the different endowments of natural assets (land properties, water, forest resources, crops and pasture areas), social assets (membership to associations, interpersonal networks, help received and trust in neighbors), human assets (level of education, household size, skills and health), physical assets (goods, implements and mobile phone), and financial capital or its substitutes (cash, access to credits and savings). Access to these assets and the way in which they are combined shape households LS and the relationship the strategy has with the environment (Bebbington 1999, Scoones 1998).

In this context, the SLF it is also a reference approach for addressing unusual investigations due to difficulty in obtaining reliable information, as is the case for smallholder logging (either legally or illegally). As a matter of fact, the literature presents two main views in explaining smallholder participation in legal or illegal forest operations. The first is related to the high transaction costs connected to legal timber harvesting, such as the processes for achieving transportation permits as well as payment of taxes. Besides this, obtaining the permit requires the construction of a management plan that must also be paid to a forestry operator. These cost inhibit many smallholders from entering the formal sector and, at the same time, push them to participate in illegal logging (Mejia et al. 2015). Only wealthier smallholders are able to pay high transaction costs for obtaining the permit required for forestry operations (Pacheco et al. 2008). The second picture found in timber harvesting literature suggests that smallholders voluntarily choose to exploit timber illegally based on a domestic cost-benefit analysis, in which selling timber illegally is found to be worth the risk of being detained and having the product confiscated (Amacher et al. 2009, Perry et al. 2007).

In other approaches, smallholder logging decisions are shaped mainly by the opportunity cost of time and access to forest resources (Amacher et al. 2009). In this context, logging is more likely to occur if the opportunity cost of labor time is high, the lost utility of non-timber labor is low or the marginal utility of income is high. Consequently, a higher opportunity cost of labor time reduces the likelihood of selling timber since household utility can be met more easily via other means (e.g. agricultural and non-farm income). According to Agrawal (2005), forest regulation also shapes the decision of smallholders as to whether to harvest timber in compliance with forest regulation or outside the law, also suggesting that in the absence of forest regulation, smallholders may overexploit and deplete forest resources. Although in recent years there has been scientific research about timber harvesting, there is a lack of scientific information about the socioeconomic determinants of smallholder timber logging decisions, even more involving determinants of illegal logging, one of the common figures of timber exploitation in tropical regions, due to the lack of control of downstream activities. Therefore, to progress towards sustainable forest management, it is necessary to analyze these matters at the level of the site (Sunderlin et al. 2005), to facilitate public policies at a national level.

2.4. Smallholders' Agricultural Diversification

Within the literature on agricultural diversity and income, the studies generally focus on estimating the determinants of diversity. In fact, several studies found a positive relationship between household income and agricultural diversification (Barrett et al. 2001, Ellis 2000, Ellis 1998). Consequently, the diversification of agricultural activities is considered to be an important strategy for dealing with poverty, economic crisis, risk management, internal/external shocks (Michler and Josephson 2017, Pellegrini and Tasciotti 2014, Knoke et al. 2012, Ellis 2000, Ashley and Carney 1999), natural disturbances, climate change (McCord et al. 2015, Tilman et al. 2011, Altieri 2004), food security and dietary diversity (Jones et al.2014, Altieri 2004). The SLF is a theoretical approach for examining the degree of agricultural diversification and crop incomes and their relationship with the livelihood strategies adopted. The SLF relates to the idea of how poor people in rural areas construct their livelihoods and the importance of structural and institutional issues (Ashley and Carney 1999).

Despite increased industrialization in agriculture, millions of small-scale famers in rural areas still use diversified agricultural systems to produce sustained yields for their subsistence needs (Altieri 2004, Denevan 1995). Previous local empirical studies have examined agricultural diversification and its relationship with households' livelihoods in a wider context. In fact, traditional agricultural systems have been developed by traditional farmers whose management and practice often result in both food security and agrobiodiversity conservation (Altieri 2004) and can be used as a strategy to promote food security, the production of sustainable commodities and increased rural incomes (Torres et al. 2018b) tackling some of the main challenges at a global level, especially in tropical countries (Paul and Knoke 2015, Tilman et al. 2011, Tilman et al. 2002). Nevertheless, understanding how small-scale farmers make their decisions regarding whether or not to diversify their production, considering individual, household and community variables is crucial in order to design and implement strategies for ensuring the sustainability of agriculture, agroforestry and other land-use practices.

3. Study Area: General Context and Sampling Design

3.1. Study Area

This research was carried out in the Sumaco Biosphere Reserve (SBR), which was declared as a biosphere reserve by UNESCO's Man and Biosphere program (MAB) in 2000 (Valarezo et al. 2002). Its core area of conservation is the Sumaco Napo-Galeras National Park (PNSNG), which was established in 1994[1] with 205,751 hectares (Ministerio del Ambiente del Ecuador (MAE), 2013). The SBR is located in the northeastern part of the EAR. Portions of its territory are located in the Napo, Orellana, and Sucumbíos provinces, bordering four important protected areas: Cayambe Coca National Park, Llanganates National Parks, Antisana Ecological Reserve and Colonso-Chalupas Biological Reserve (Figure 1).

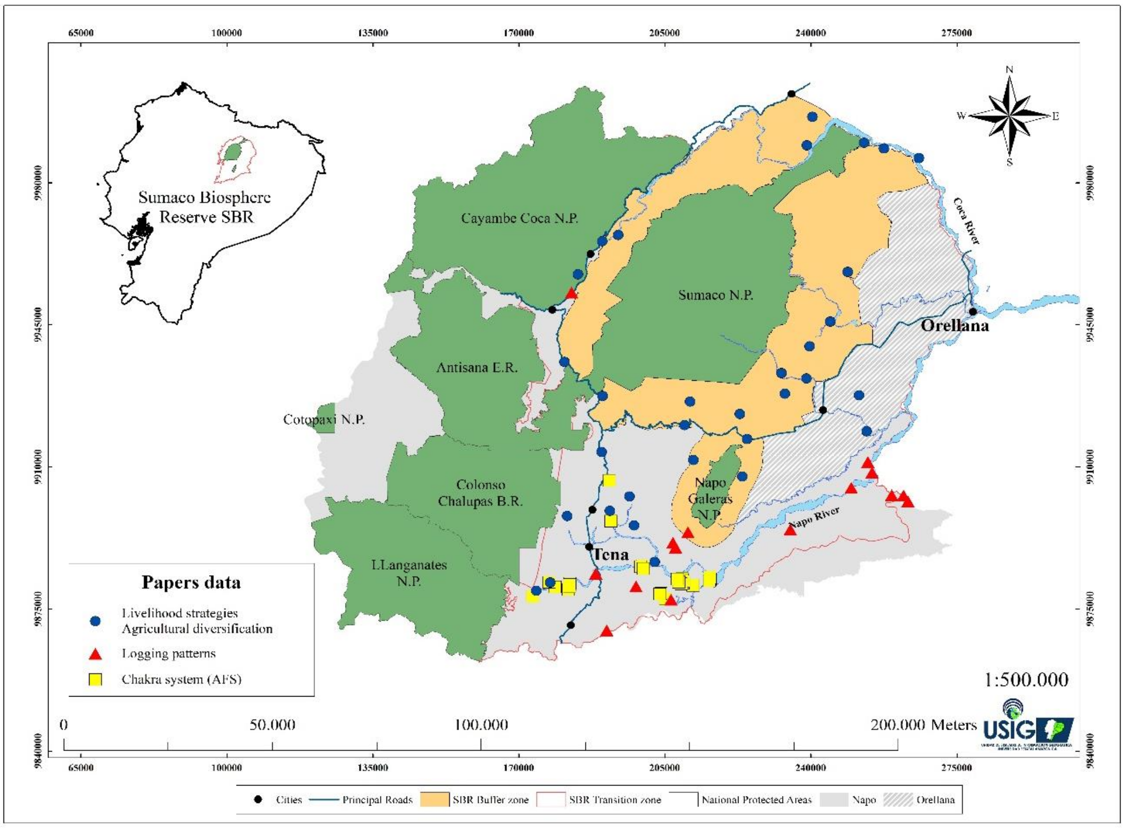

Figure 2. Ecuador and the study area, the Sumaco Biosphere Reserve. The blue dots show the communities studied for papers 1 and 3. The red triangles represent the communities studied in paper 2. The yellow boxes correspond to the sites studied in paper 4. Source: Author, 2018.

[1] Resolution No. 9, March 2nd, 1994 – Official registration No. 47 of June 28, 1994, INEFAN-Ecuador

3.2. Land Use Characteristics

The main land uses in the study area are pasture for cattle (Figure 3a), small-scale timber logging (Figure 3c) and the cultivation of cocoa, coffee, naranjilla, maize, and rice, in addition to staple crops, such as cassava, plantain, bananas and peach palm, most of them in traditional *Chakra* agricultural system (Figure 3b).

Figure 3. a) Pastures for cattle ranching; b) the traditional Chakra agroforestry system; c) small-scale timber logging. Source: Author, 2018.

The agricultural system is made up of mainly pasture for cattle and some cash and staple crops. These trends are similar to those found in other parts of the Ecuadorian Amazon (Torres et al. 2018b, Vasco et al. 2015, Lerner et al. 2014, Torres et al. 2014a, Bilsborrow et al. 2004). However, there is a slight difference in the agricultural systems of the indigenous Kichwa and the migrant settlers: for the majority of the Kichwa population, the most common agricultural system is the *chakra* (Coq-Huelva et al. 2017a, Coq-Huelva et al. 2017b, Torres et al. 2015, Torres et al. 2014b), while for most of the migrant settlers the agricultural system is made up of mainly cash crop sales and pastures for cattle ranching (Torres et al. 2018a, Vasco et al. 2015, Torres et al. 2014a, Bilsborrow et al. 2004).

3.3. Land-Use Changes and Deforestation

Although the SBR is part of the biodiversity hotspot called the Uplands of Western Amazonia (Myers et al. 2000, Myers 1988), this region also faces high rates of deforestation, like many other areas of high biodiversity which are under threat from habitat destruction (Mittermeier et al. 1998). From 2008 to 2013 the SBR lost 93,853 hectares of native forest that were designated for other uses (MAE-GIZ, 2013). This represents a 10.80% shift to other land uses over a five-year period. From the data of this study at a general level across the SBR, the changes tended to increase areas of secondary forests, pastures, and abandoned areas (Figure 4). The materials used in this investigation were satellite images from Landsat 7 and Aster.

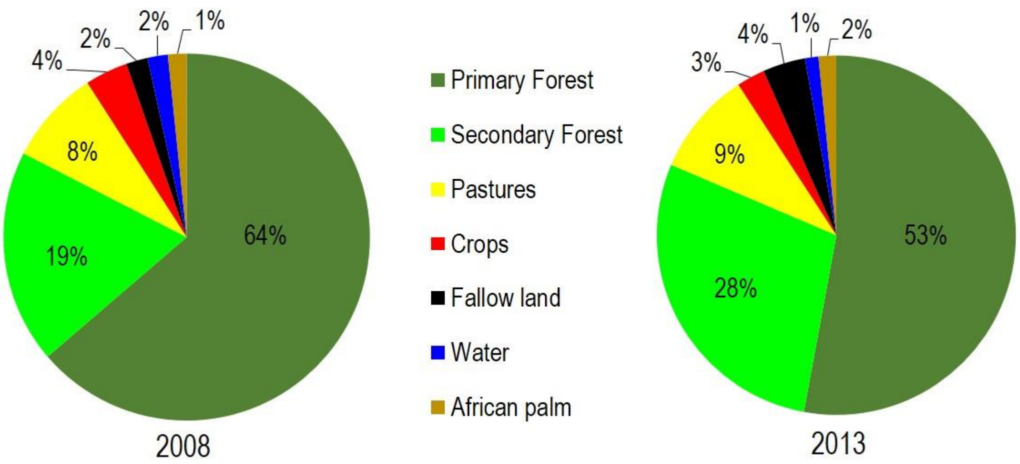

Figure 4. Land use change in the Sumaco Biosphere Reserve during the years 2008-2013.

Source: Adapted from multi-temporal study periods 2002-2007 and 2008-2013 using satellite images from Landsat 7 and Aster (MAE-GIZ, 2013).

3.4. Sampling Design, Data Collection and Additional Data Set

The main data of this research used the PEN (Poverty and Environment Network) methodology of data collection developed by CIFOR (Angelsen et al. 2014). This approach includes four quarterly household questionnaires, two annual household surveys (separated by twelve months) and, two community-level annual surveys. Questionnaires were administered to a sample of 186 households in 32 communities (21 Kichwa and 11 migrant). Communities were randomly selected in 2007 from a total of 300 villages inside the buffer and transition zone of the SBR, representing 12% of all communities (Table 2; Figure 2). The use of this approach ensures a fair representation of the communities and improves the accuracy of the results (Cavendish 2003). This data was used to develop papers 1 and 3 of this dissertation (Figure 2).

Table 2. Main characteristics of the communities selected for the household survey within the Sumaco Biosphere Reserve, 2008.

Community	Elevation m.a.s.l.	Ethnic group	Year stablished	Population	Major agricultural activities
Arapino	538	Kichwa	2001	120	Agriculture, agroforestry
Avila Viejo	596	Kichwa	1980	400	Agriculture, agroforestry
Campo Alegre	420	Settler	1563	490	Agriculture, cattle
Cascabel 2	343	Kichwa	1989	300	Agriculture, timber
Centro K. Río Guacamayos	628	Kichwa	1988	300	Agriculture, agroforestry
Cinco de Octubre	325	Kichwa	1990	60	Agriculture, agroforestry
Cosanga	2004	Settler	1955	700	Cattle, fish ecotourism
Diez de Agosto	377	Kichwa	1975	80	Agriculture, agroforestry
Gonzalo Diaz de Pineda	1625	Settler	1961	350	Cattle, monoculture
Guayusaloma	1997	Kichwa	1993	108	Agroforestry, cattle
Juan Pio Montufar	497	Settler	1984	700	Agriculture, timber
Makana Cocha	325	Kichwa	1970	130	Agriculture, timber
Mushullacta	936	Kichwa	1988	600	Agriculture, agroforestry
Pacto Sumaco	1519	Settler	1987	600	Agroforestry, cattle
Pandayacu	472	Kichwa	1972	550	Agriculture, agroforestry
Playas del Rio Coca	566	Kichwa	2000	124	Agriculture, agroforestry
Pununo	414	Settler	1968	250	Timber, Agriculture
San José de Payamino	304	Kichwa	1500	325	Agriculture, agroforestry
San Pablo	349	Kichwa	1962	500	Agriculture, agroforestry
San Vicente de Huaticocha	621	Settler	1994	220	Cattle, agriculture
San Vicente de Parayacu	825	Kichwa	1963	22	Agriculture, agroforestry
Santa Elena de Guacamayos	1646	Settler	1980	135	Cattle, agriculture, fish
Santa Rosa	1493	Settler	1960	350	Cattle, agriculture
Sardinas	1706	Settler	1948	600	Cattle, agriculture
Serena	544	Kichwa	1910	280	Agriculture, agroforestry
Shandia	514	Kichwa	1953	320	Agriculture, agroforestry
Supayacu	395	Kichwa	1998	55	Agriculture, agroforestry
Tambayacu	699	Kichwa	1953	500	Agriculture, agroforestry
Union y Progreso	761	Settler	1988	150	Agriculture, cattle
Verde Sumaco	324	Kichwa	1941	290	Agriculture, agroforestry
Villano	821	Kichwa	1972	370	Agriculture, agroforestry
Wamani	1174	Kichwa	1970	700	Agroforestry, cattle

Source: Adapted from Torres et al. (2008).

Two additional data sets were also used for papers 2 and 4. Data for paper 2 was also collected in the SBR, Napo province, in 2012 (see Figure 2, where red triangles represent the communities studied in the paper) under a Letter of Agreement between the Universidad Estatal Amazónica (UEA), Ecuador, and The Center for International Forestry Research (CIFOR), Indonesia as a part of the EU-funded project "Policy and Regulatory Options to recognize and better integrate the domestic timber sector in tropical countries" (PRO-FORMAL). Meanwhile, data for paper 4 was collected in the southern part of the SBR, specifically in the Tena and Archidona cantons within the Napo province during 2012 (see Figure 2, where yellow boxes show the sites studied in the paper).

4. Materials and Methods

4.1. Methodological Approach

In order to investigate the LS and their relationship with forest conservation, approaches based on the SLF and some multivariate techniques were applied to the Ecuadorian Amazon context, considering indigenous populations and migrant settlers in the SBR. First, in sub-chapter 4.2 a short theoretical description of the principal component analysis and agglomerative hierarchical clustering are presented and their suitability to group households' LS, as well as of the multivariate approaches regarding a multinomial logit model (MLM) to establish the determinants of a household's livelihood choices and a Tobit model to determine the effects of ethnicity on household income (Torres et al. 2018a). Afterwards, sub-chapter 4.3 describes the multinomial probit model (MPM) as a technique to analyze the likelihood of extracting timber (Vasco et al. 2015). This is followed by sub-chapter 4.4 which describes the Shannon index as a tool for agricultural diversification purposes, as well as the application of ordinary least squares (OLS) and MLM to measure the determinants and degree of agricultural diversification respectively (Torres et al. 2018b). Finally, sub-chapter 4.5 includes the methodological description of a case study about an appropriate agricultural system called *Chakra* and its contribution to food security, biodiversity conservation and climate change mitigation and adaptation (Torres et al. 2015).

4.2. Multivariate Approach to Determine Livelihood Strategies

Two multivariate techniques used to determine livelihood strategies are described: Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering (AHC).

4.2.1. Principal Components Analysis (PCA)

The PCA is an orthogonal linear transformation that relates the data to a new coordinate system. After the transformation, the projection with the greatest variance lies on the first coordinate, followed by other coordinates in order of variance size. *X* is defined as a matrix, where each of the *n* rows represents an individual case from the sample and each of the *p* columns represents a particular feature of that case. The transformation is a set of p-dimensional vectors with the weights wk = (w1 , … , wp)k that map each row vector xi of X to a vector of principal component scores ti = (t1 , … , tk)i given by tki = xi wk. The advantage of such a transformation is that not all the principal components need to be retained. Keeping only the first L principal components, produced by only using the first L loading vectors (Bengio et al. 2013), means a reduced dimensionality, which helps one to visualize and process high-dimensional datasets while still retaining as much of the variance in the dataset as possible. Thus, the percentages of the nine revenue sources for each household were used in the PCA to show the relative importance of each source to total household incomes and to reduce the dataset into non-correlated principal components (PCs). The PCA was performed using the R package FactoMineR (Husson & Pages, 2013).

4.2.2. Cluster Analysis (CA)

To define the number of groups an AHC was performed on results from the PCA. In the agglomerative approach, each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy. The criterion for choosing the pair of clusters to merge at each step is based on the optimal value of an objective function as follows:

$$d_{ij} = \left\| x_i - x_j \right\|_2 \quad (1)$$

Where; d_{ij} is the squared Euclidean distance between points x_i and x_j are two observations in our sample. In every iteration, the AHC finds the pair of clusters that leads to minimum increase, min *(d_{ij})*, in total within-cluster variance after merging. For this purpose we used the function of hierarchical clustering principal component (HCPC) of FactoMineR with a Euclidean metric and the Ward's minimum variance method (Husson & Pages, 2013), which can produce a histogram showing the increase in inertia as the cluster number is increased. Thus, in this study, the five major components resulting from the PCA were used. This accounted for 70.15% of the cumulative variance of the original data, which was considered sufficient to develop the AHC (Torres et al. 2018a).

4.2.3. Determinants of Household's Livelihood Choices (CA)

Multinomial logit regression is the most common model used to carry out an analysis of dependent variables with more than two unordered outcomes (Wooldridge 2002). In this thesis report, the dependent variables are the four LS (cluster results) and the model contained eight explanatory variables: ethnicity, age of household head, education of household head, altitude, distance to city, household’s access to credit and household total land. Thus, the results of the MLM are specified in terms of the probability of an outcome occurring given the independent variables (Torres et al. 2018a). The model was performed in the following way:

$$\Pr(Y_i = K - 1) = \frac{e^{\beta_{K-1} \cdot X_i}}{1 + \sum_{k=1}^{K-1} e^{\beta_k \cdot X_i}} \quad (2)$$

Where; K is the number of LS alternatives (in this case four), one of which is the main source of income of an individual i, X is a vector of independent variables and β is a vector of coefficients whose magnitude and direction are of fundamental interest to this study.

4.2.4. Effects of Ethnicity on Household Income

The Tobit regression is a useful methodology when a non-trivial (important) number of observations of the sample have the value of 0 (Wooldridge, 2002), which is the case for the four dependent variables analyzed here. In Torres et al. (2018a) the Tobit regression was executed, where the dependent variables of interest are the incomes obtained from the forest, crop and livestock production, and paid work outside the farm (referred to as wage labor). Predictors include the age, ethnicity, trust and education level of the head of the household, as well as household size, total land available for use, forest land, access to roads, distance to city and location in the SBR. Thus, we used a model of the following kind:

$$y_i^* = \boldsymbol{\beta x_i} + \varepsilon_i \qquad (3)$$

$$y_i = 0 \text{ if } y_i^* \leq 0$$

$$y_i = y_i^* \text{ if } y_i^* > 0$$

Where y_i is the total income from each category of household i, $\boldsymbol{\beta}$ is a vector of coefficients, $\boldsymbol{x_i}$ is a vector of the predictors described above; and ε_i is the nuisance term. The observable output variable y will equal 0 if the unobservable variable $y^* \leq 0$ and will take the value of y^* provided $y^* > 0$. Thus, the coefficients of the Tobit analysis indicate the extent to which a change of one unit in x can affect the latent variable y_i^*.

4.3. Factors Influencing Logging Patterns

Small-scale timber extraction is one of the principal activities in the study area and is one of the four LS determined by Torres et al. (2018a) in the SBR. Consequently, it is necessary to determine the socio-economic determinants of this activity. In this research, a multinomial probit model was used to estimate the likelihood of a household not harvesting timber, harvesting timber legally or harvesting timber illegally during the year preceding the data collection. This methodology is robust enough for identical irrelevant alternatives (IIA) (Wooldridge 2002). The model uses the following formula:

$$P_i^c = \Pr(TIMBER = c \mid X_i) \qquad (4)$$

$$= F(X_i \, \beta_i^c)$$

Where P^c is the probability of a household *i* to select one of the three categories *c* (not harvesting timber, harvesting timber legally and harvesting timber illegally over the 12 months preceding the survey). *X* is a vector of household head, household and community characteristics to be described later on, and βi is a vector of coefficients the size and direction of which are to be determined (see Vasco et al. 2017).

4.4. Approaches to Determining Agricultural Diversification

4.4.1. Shannon Index

Agricultural diversification is an important management strategy in sustainable agriculture (Altieri 2004), especially in areas like the SBR with a high level of biodiversity (Myers et al. 2000, Myers 1988). There are several approaches to measuring agricultural diversification. In the third paper of this thesis, Torres et al. (2018b) described the use of the Shannon diversity index, in an analysis of agricultural crop area diversification *(*H_{crop_area}*)*. This methodology is commonly used to assess species diversity (Magurran 1988). The complete formula of the H_{crop_area} used in this analysis is described as follows:

$$H_{crop\_area} = -\sum_{i=1}^{S}[(cropshare_i) \cdot ln(cropshare_i)], \quad (5)$$

Where: *S* is the number of crop area sources and $cropshare_i$ is the share of crop area from activity *i* in total household crop area. The Shannon index H_{crop_area} accounts for both the number of crops sources and their evenness. Based on this index *H*, the Shannon equitability index *E* is calculated as:

$$E_{crop\_area} = \left(-\frac{H_{crop\_area}}{\sum_{i=1}^{S}\left(\frac{1}{S}*ln\left(\frac{1}{S}\right)\right)}\right) X\ 100\ , \quad (6)$$

Where the denominator is the maximum possible *H,* and *E* ranges from 0 to 100, reflecting the share of the actual crop area diversification in relation to the maximum possible diversity of crop area. In addition, the number of crop areas (NCA), which involves the numbers of household crops and pasture, was also determined.

4.4.2. Modeling Livelihood Strategies and Agricultural Diversification

The determinants of farm diversification may differ from one geographical location to another (Amine and Brabez 2016, Minot et al. 2006). To investigate this field, there are several approaches. McCord et al. (2014) used an ordinary least squares (OLS) model to investigate the factors contributing to varying levels of crop diversification in a semi-arid irrigated agricultural system in Kenya. A recent study developed by Ochoa-Moreno (2018) used a Heckman two stage regression to analyze land-use diversification based on the Shannon index (*H*). The Heckman approach is appropriate when the sample contains large censored information (zero values), since the Heckman model considers households with censored information in the first stage (Probit regression), whilst in the second stage an OLS analyzes the rest of the uncensored information in the entire sample.

Given that outcomes of this research have a small proportion of zero values related to the number of crops and the Shannon equitable indices (E_{crop_area}) within the whole sample in the study area. Additionally, considering that this thesis analyzes the effect of LS previously determined (forest-based, Crop-based, Livestock-based, Wage-based) and ethnicity on degree of agricultural diversification, using a range of high, medium and low diversification determined from the Shannon equitable index, it was necessary to use a model that simultaneously identify the determinants of households' decision to choose which level of agricultural diversification should follow. Consequently, a Multinomial Logit Model (MLM) was employed to identify the factors associated with the households' degree of diversification choice. This methodology is appropriate for determining the influence of a selected set of explanatory variables on a dependent variable with more than two unordered outcomes (Wooldridge 2002). In this case, the model's dependent variable is the result of the diversification degree from the Shannon equitable indices (E_{crop_area}), with three determined agricultural diversification levels: high diversification (>75%), medium diversification (25–75%) and low diversification (<25%), which accounted for fifteen independent variables (See Torres et al., 2018b). The model is as follows:

$$\Pr(Y_i = K - 1) = \frac{e^{\beta_{K-1} \cdot X_i}}{1 + \sum_{k=1}^{K-1} e^{\beta_k \cdot X_i}} , \qquad (7)$$

Where: *K* is the number of diversity degrees (in this case three), one of which is the main level of diversification of an individual *i*, *X* is a vector of independent variables; and *β* is a vector of coefficients whose magnitude and direction are of fundamental interest to this study. The dependent variables are the three diversification levels: high, medium and low diversification. The model contained fourteen explanatory variables: forest-based LS, Crop-based LS, livestock-based LS, wage-based LS, ethnicity, age of household head, education of household head, household size, access to credit, forest land, total land, allocation, distance to city and distance to road.

Additionally, this thesis also employs the Ordinary Least Squares (OLS) model in order to provide extra support from the numbers of crops sources (NCS) and the Shannon index (H) to this approach. Since the outcomes have a small proportion of zero values as a fraction of the number of crops within the whole sample in our study area, a multiple regression using OLS is appropriate in these cases

(Asante et al. 2016, Jones et al. 2014, Fausat 2012). Thus, the OLS shows the determinant variable for each category versus the base category (in our case, crop-based strategy). We therefore used a model with the following formula:

$$Y_i = \beta X_i + \varepsilon_i \quad (8)$$

Where: Y is the numbers of crop sources *(NCS)*; the H_{crop_area}, X is a vector of individual and household characteristics; β is a vector of coefficients the direction and magnitude of which are of interest to this study; and ε stands for the disturbance term.

4.5. Examining a traditional agroforestry system

Trying to find a suitable agricultural system for the lower part of the SBR, the potential contribution of the traditional *chakra* system was examined, through a small multi-purpose research project, with the participation of two master's students. The research was carried out in the cacao corridor in the province of Napo in the northeastern part of the EAR (Figure 1), where fifteen circular temporary plots[2] of 1,600 m^2 under the chakra system were installed (Torres et al. 2015, Jadán, Torres and Günter 2012) to determine the number and diversity of tree species, the amount of carbon captured in each plot, the diversity of tree species and the practices that produce food and medicinal plants. Similarly, 8 circular temporary plots under the monoculture system and five in primary forestland were also selected for the purpose of comparison. The amount of underground biomass stored, floristic diversity and main arboreal plants in the *chakra* were examined. Additionally, interviews were conducted with producers. The project was supported by German cooperation (GIZ) in Ecuador.

[2] Was carried out by Jadán (2012) in form of Master Thesis under the author's supervision.

5. Results and Discussion

This chapter presents the main findings obtained from the four papers that are part of this dissertation thesis, in which a series of activities regarding livelihoods and nature conservation were analyzed on the basis of the sustainable livelihood framework (SLF) at a household level. The results of these case studies serve as recommendations for practitioners and policy makers promoting sustainable production and forest conservation and also contribute to the debate about the sustainable management and conservation of both forest and rural livelihoods.

5.1. Livelihood Strategies in the Ecuadorian Amazon Region[3]

5.1.1. Methodological Approach Used to Determine Livelihood Strategies

In this first part, the proportion of nine income sources (environmental resources, fishing in rivers, aquaculture, business activities, wages from employment, forestry uses, agricultural production, livestock production and other activities) was used in a PCA. Furthermore, the PCA considered components with loading values above 0.5. Thus, five principal components (PC) (wage, crops, forest, livestock and business) are the most influential for explaining a LS (Table 3).

Table 3. Component matrix from PCA of all percentage income source (n = 186) (adapted from Torres et al. 2018a).

Income portfolios	5 major components extracted				
	PC1	PC2	PC3	PC4	PC5
Wage	0.60	-0.23	-0.11	-0.65	-0.27
Other	0.57	0.56	0.22	0.14	0.12
Crops	-0.57	0.64	-0.38	0.02	-0.05
Forest	-0.55	-0.28	0.66	-0.14	-0.15
Livestock	0.19	-0.62	-0.30	0.67	-0.01
Fish	0.35	0.35	0.45	0.33	0.02
Business	-0.08	-0.29	0.17	-0.08	0.69
Aquaculture	0.03	0.06	-0.26	-0.25	0.62
Environmental	0.01	0.01	-0.37	0.01	-0.13
Eigenvalues	1.52	1.48	1.20	1.10	1.00
% of variance	16.89	16.52	13.33	12.26	11.13
Cumulative (%)	16.89	33.42	46.75	59.02	70.15

Component 1 has two main variables with positive signs (wage and other), and accounts for 17 % of the variance. Component 2 relates to crops and accounts for 16 % of the variance. Component 3 has a high loading value (forest) and explains 13 % of the variance. Component 4 has a positive sign and

[3] This sub-chapter is based on: Bolier Torres, Sven Günter, Ricardo Acevedo and Thomas Knoke. 2018. Livelihood strategies, ethnicity and rural income: The case of migrant settlers and indigenous populations in the Ecuadorian Amazon. *Forest Policy and Economics Vol. 86(2018): 22-34.*

high loading value (livestock) and makes up 12% of the variance and Component 5 relates to business and accounts for 11 % of the variance (Table 3).

In the second part of this analysis, the first five PC, which constituted 70% of the variance (Table 3 and Figure 5a), were used to compute the AHC. Thus, of the nine sources of portfolio income, five were decisive in establishing the four LS (forest, crops, livestock, and wage) (Figure 5b).

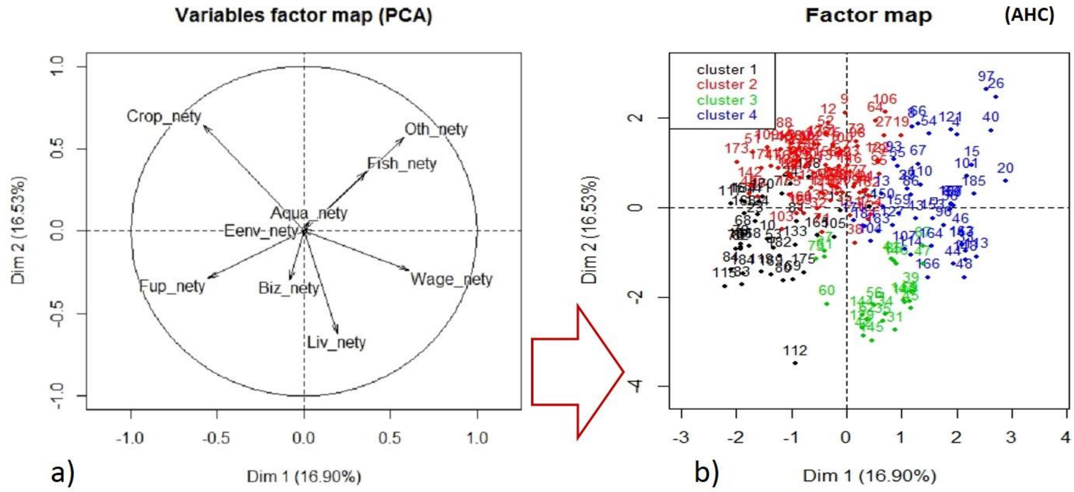

Figure 5. a) Graph of the variables factor map of the principal component analysis (PCA); b) Graph of the Agglomerative Hierarchical Clustering (AHC) (adapted from Torres et al. 2018a).

The results of the AHC using the five PC facilitated the identification of four household categories based on LS (Figures 5a and 5b). The relative income for each activity in each category was used to name the four LS. For cluster 1, income from unprocessed timber resources constituted around 51% of total household income, consequently this LS was called ***"Forest-based"***. Cluster 2 consisted of households whose main sources of income came from crops; therefore, this group of households was identified as ***"Crop-based"***. For households in cluster 3, the main revenue was from livestock, totaling 62% of their income, therefore, this group was labeled ***"Livestock-based"***. Households in cluster 4 obtained substantial income in two categories, which together contributed about 75% of towards total revenue: 38% from off-farm wages and 37% from other non-agricultural income; hence, cluster 4 was named ***"Wage-based"***. (See Torres et al. 2018a).

5.1.2. Determinants of Livelihood Strategies Choices

The application of the MLM using the four LS determined by the PCA and AHC as dependent variables, showed that ethnicity (in this case migrant settlers), location and physical assets (total land) have strong effects on households to adopt a Livestock-based LS, one of the most remunerative LS in the study area. Meanwhile, human (household size), financial (access to credit) and physical assets are related to the adoption of a Forest-based LS. The MLM also demonstrated that physical assets are negatively associated with households engaged in a Crop-based LS, one of the least remunerative LS in the study area (Table 4).

Table 4. Multinomial logit model predicting the determinant of households' livelihood adoption (marginal effects). Wage-based LS (control) (adapted from Torres et al. 2018a).

Variables	Forest-based LS	Crop-based LS	Livestock-based LS	Wage-based LS
Kichwa (yes)	-0.464	0.150	-0.087**	-0.017
Age of household head	0.030	-0.000	-0.191	-0.027
Age squared	-0.000	-0.000	-0.000	0.000
Household size	0.170*	0.009	0.111	-0.026*
Education of head (years)	-0.008	-0.016	-0.194	0.009
Altitude (m)	-0.000	-0.001*	0.002***	0.000
Distance to city (mins.)	-0.005	0.002	-0.012**	-0.000
Access to credit	0.176**	-0.103	-0.103	-0.069
Total land (ha)	0.005***	-0.004*	0.065***	-0.001
Chi^2 (27)			113.24***	
Number of observations			186	
Pseudo R^2			0.23	
Log likelihood			-182.180	

Significance levels: *, **, *** are 90%, 95%, and 99%, respectively. Values in parentheses are standard deviations of the coefficients.

Another main finding is that ethnicity has a strong influence on the level of household income. The results show that the Kichwa ethnic group has a higher annual income by US$ 223 from a Crop-based LS in comparison to migrant settlers. In contrast, settlers on average earn US$ 472 more per year from livestock than indigenous households in a Livestock-based LS and 182 dollars more annually in Wage-based LS (Table 5). In this regard, the use of the Tobit regression model to analyze the effect of ethnicity on household income according to the four LS determined has one advantage, because this model also shows the probability of an increase or decrease in income in each LS if there is a change in the explanatory variables.

Table 5. Tobit regression model to determine the effect of ethnicity and assets on the main source of household income for each LS (marginal effects) (adapted from Torres et al. 2018a).

Variables	Forest-based LS	Crop-based LS	Livestock-based LS	Wage-based LS
Kichwa (yes)	-21.86	223.80**	-472.50***	-182.0***
Age of household head	21.73	-10.42	6.275	-7.24
Age squared	-0.30	0.06	-0.06	0.10
Household size	17.37	42.80***	15.73	12.76*
Education of head (years)	1.75	-1.43	-1.17	17.21**
High trust (yes)	-2.80	17.57	34.06	48.27
Inside buffer zone (yes)	-268.40**	-4.28	-119.80	-44.32
Remaining forest (%)	-3.53	-5.22	-3.76	3.81
Distance to city (mins)	0.05	0.31	-0.94	0.07
Total land (ha)	8.77**	3.65	4.37	-5.38*
Road access (yes)	28.80	155.40*	-140.80	40.40
Uncensored observation	110	158	115	137
Chi^2	23.95**	32.92***	29.99***	25.49**

Significance levels: *, **, *** are 90%, 95%, and 99%, respectively.

The findings obtained from the MLM and the Tobit regression corroborates the first hypothesis of this study, which is *H1: Ethnicity has strong influence on the households' adoption of livelihood strategies (LS), and will also affect the level of household income in the determined LS.*

5.1.3. Household Income Portfolio and Remaining Forest Land

In regions like the SBR that have high biodiversity and are inhabited by indigenous and migrant populations, it is important to consider income sources (cash and subsistence) and the remaining forest land, when analyzing LS at a household level. These features in the methodology helped to assess the importance of each activity on and off the farm, as well as the forest area endowment as natural capital. In fact, households engaged in a Wage-based LS and Forest-based LS comprised a greater proportion of the remaining forest land (65% and 64% respectively), compared to a Crop-based LS and Livestock-based LS with 60% and 53%, respectively. Households in a Livestock-based LS obtain higher incomes, but also have the smallest mean area of forest remaining on their land (Figures 6a and 6b). An explanation could be the conversion of forests into grassland is an extensive operation. This may be related to the tendency to convert primary forest to grassland over time in this study area (GIZ-MAE, 2013).

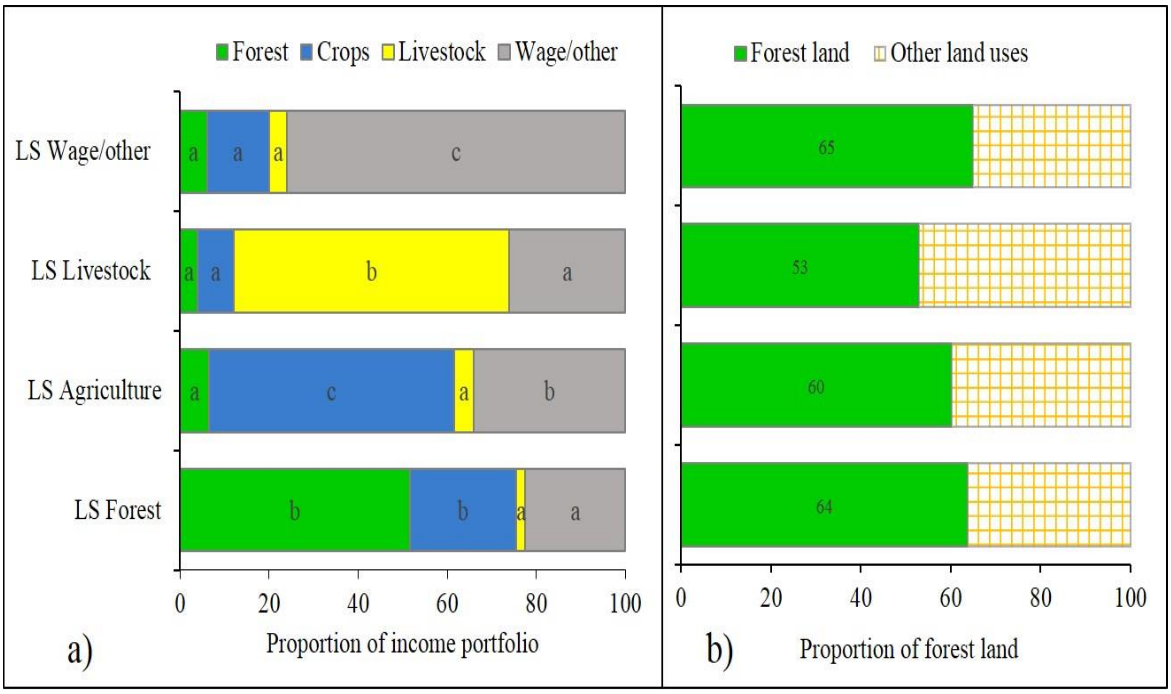

Figure 6. a) Graph of the land-use portfolio in the four LS; b) Graphic of the income portfolio among LS. Letters denote significant differences among LS based on the ANOVA test. *Source*: Author's own survey data PEN/RAVA - SBR, 2008.

5.1.4. Trends Towards Income Diversification

The results indicate that off-farm income (including jobs, businesses and other income such as remittances or land rent) are important income sources in the SBR. These off-farm activities comprise not less than 21% of total income of all LS, an average of around 40% of the whole sample and 75% in households engaged in a Wage-based LS from wage and other activities (Figure 7), confirming the trend towards income diversification in rural areas of the EAR (Mejia et al. 2015, Vasco Pérez et al. 2015, Izurieta et al. 2014, Gray et al. 2008). In this regard, ethnicity also has a significant effect on off-farm income, with the Kichwa on average earning US$ 182 less per year than their migrant settler counterparts. A possible explanation is that settlers tend to live closer to the main towns while the Kichwa usually reside in remote areas. This is probably due to *pull factors*, including higher demand for skilled and semi-skilled workers in oil companies and government offices (Murphy 2001). These findings are unlike prior research that has found that households in frontier areas are highly dependent on the extraction of natural resources (Walelign 2016, Porro et al. 2015, Zenteno et al. 2013).

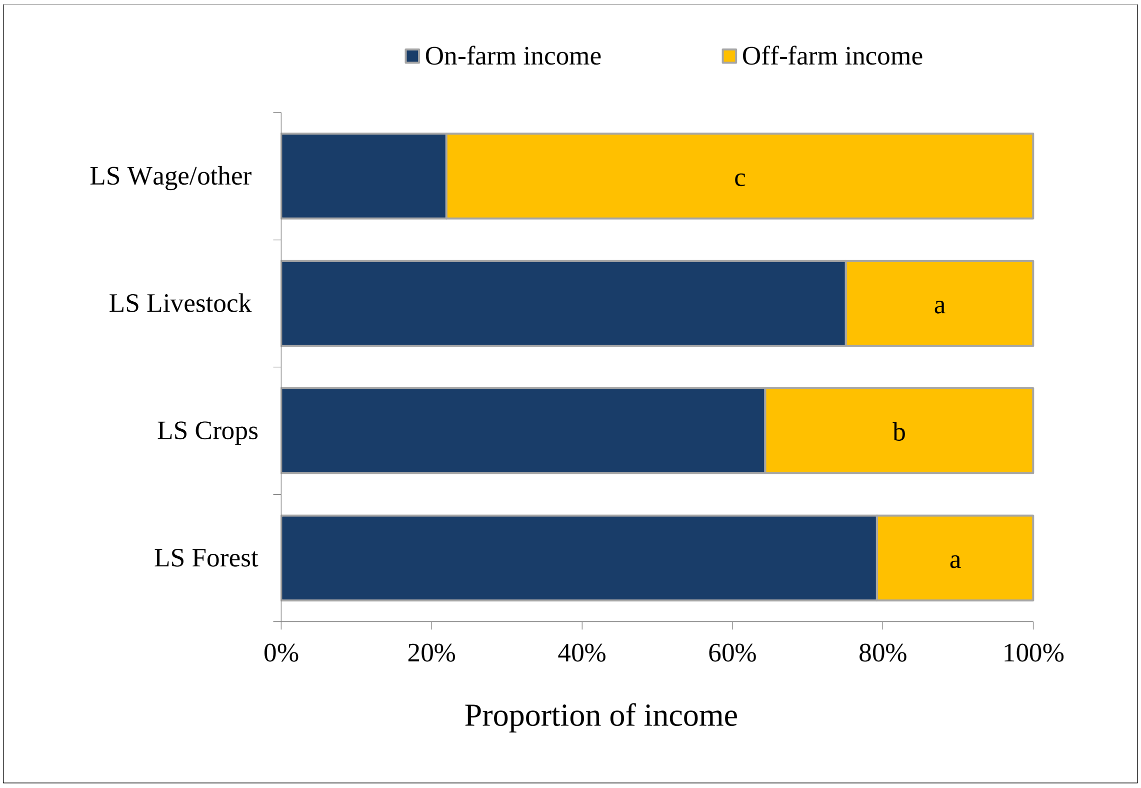

Figure 7. On-farm income and off-farm income by LS. Letters denote significant differences among LS based on the ANOVA test. Source: Author's own survey data PEN/RAVA - SBR, 2008.

5.2. Smallholders Logging Patterns in the Ecuadorian Amazon Region[4]

The main findings of this sub-chapter show the role of timber in smallholders' livelihoods strategies, the tree species harvested and the socioeconomic determinants of legal and illegal smallholder logging.

5.2.1. Smallholders' Livelihood Strategies and Timber Harvesting

Forest income (sales of unprocessed wood) is not the main income source for rural households in the SBR, representing around 14% of the whole sample of this study. However, in chapter 5.1, it is shown that households engaged in Forest-based LS obtain around 51% of their total income from unprocessed timber resources and this LS is used by almost 20% of the rural households in the SBR (see Torres et al. 2018a). This main finding confirms the theory that not all households in a given area experience homogeneous livelihood schemes (Walelign et al. 2016, Nielsen et al. 2013). Rather it shows the necessity of examining the socio-economic determinants of timber logging and the variety of forest tree species commonly extracted from households in the lower part of the SBR.

Figure 8. Small-scale timber logging in the lower part of SBR, Napo, Ecuador. Source: Author, 2017.

Undoubtedly the use and sale of unprocessed timber products provides some benefits to rural households in the EAR (Sellers et al. 2017, Vasco et al. 2017, Mejia et al. 2015, Vasco Pérez et al. 2015, Bilsborrow et al. 2004) given that timber harvesting is stimulated by a vigorous network of

[4] This sub-chapter is based on: Cristian Vasco, Bolier Torres, Pablo Pacheco, Verena Griess. 2017. The socioeconomic determinants of legal and illegal smallholder logging: Evidence from the Ecuadorian Amazon. *Forest Policy and Economics Vol*. 78(2017): 133-140.

intermediaries linked to markets in the cities (Mejia et al. 2015) who receive the highest income. Households obtain some benefits only when members of the household participate in the harvesting operation process, and they also depend on the market value of the species harvested (Mejía et al. 2015). Considering that one fifth of the population in in the SBR are engaged in Forest-based LS, it is also important to know what the main timber trees species (Table 7) harvested in this region are, given that they are one of the main ecosystem products used by the rural local people.

Table 6. Main timber tree species in term of m^3 harvested as reported by households in the lower part of the SBR, Napo, Ecuador.

Species	Family	Local Name
Otoba spp.	Myristicaceae	Doncel, coco
Virola spp.	Myristicaceae	Doncel, sangre de gallina
Cordia alliodora (Ruiz & Pav.) Oken	Boraginaceae	Laurel
Ochroma pyramidale (Cav. Ex Lam.) Urb.	Malvaceae	Balsa
Cedrela odorata L.	Meliaceae	Cedro
Guarea spp.	Meliaceae	Tucuta, colorado
Brosimum spp.	Moraceae	Sande rojo
Chrysophyllum sp.	Sapotaceae	Abio, Caimitillo
Ciba samauma (Mart.) K. Schum.	Bombacaceae	Ceibo
Ocotea spp.	Lauraceae	Canelo
Nectandra spp.	Lauraceae	Canelo
Hyeronima alchorneoides Allemão	Phyllanthaceae	*Mascarey, motilón, calum calum*
Dacryodes spp.	Burseraceae	Copal
Vochysia spp.	Vochysiaceae	Tamburo
Apeiba spp.	Malvaceae	*Corcho*
Terminalia oblonga (Ruiz & Pav.) Steud.	Combretaceae	*Yunyun*
Cedrelinga cateniformis (Ducke) Ducke	Mimosaceae	*Chuncho*
Chimarris spp.	Rubiaceae	*Hintachi*
Minquartia guianensis Aubl.	Olacaceae	*Guayacan*
Tabebuia chrysantha (Jacq.) G. Nicholson	Bignoniaceae	*Guayacan*
Cabralea cangerana (Vell.) Mart.	Meliaceae	*Batea caspi*
Cedrela spp.	Meliaceae	*Cedro*
Pollalesta discolor (Kunth) Aristeg	Asteraceae	*Pigue*
Cedrelinga cateniformis (Ducke) Ducke	Fabaceae	Seike, chuncho
Ceiba spp.	Malvaceae	Ceibo
Myroxylon balsamum (L.) Harms	Fabaceae	Bálsamo
Capirona decorticans Spruce	Rubiaceae	Capirona
Swietenia macrophylla King	Meliaceae	Caoba, ahuano

5.2.2. Determinants of Legal and Illegal Loggings

The main findings of the MPM show that: a) the households that do not extract wood from native forestland have a high probability of owning small areas in primary forestland, living near populated centers, receiving income outside the farm and being poor; b) illegal logging is more likely in households that maintain large areas of forestland, reside far away from urban areas and do not have off-farm income, c) the legal extraction of wood is mainly realized by households with better economic conditions, who have legal land tenure, but who do not have income from outside the farm.

The use of a multivariate analysis, in this case the MPM is appropriate since unlike other approaches (e.g. multinomial logit) it is robust enough for identical irrelevant alternatives (IIA) (Wooldridge, 2002) and the objective behind this analysis was to estimate the likelihood that a household does not harvest timber, harvests timber legally or has harvest timber illegally over a time-period of one year.

Table 7. Multinomial probit model to analyze the determinants of smallholder timber logging decisions (marginal effects) (adapted from Vasco et al. 2017).

	Does not harvest	Harvests illegally	Harvests llegally
Age household head	0.000	-0.023	0.022
Age squared	-0.000	0.000	-0.000
Primary education (0/1)	0.088	-0.029	-0.059
Secondary education (0/1)	0.002	0.117	-0.120
Kichwa (0/1)	-0.272*	0.098	0.174
Household size	-0.013	0.022	-0.008
Wealth	-0.054***	-0.032**	0.087***
Nonfarm income (0/1)	0.156**	-0.216**	-0.373**
Agricultural land (ha)	0.093	-0.103*	0.010
Área of forest land (ha)	-0.115***	0.099**	0.016
Total land area available for use (ha)	-0.002	0.003	-0.000
Legal land tenure (0/1)	-0.090	-0.088	0.179**
Crisis (0/1)	0.084	0.084	-0.168
Distance to market (city of Tena)	-0.336***	0.201**	0.134
Number of observations	124	124	124
Wald test		39***	

Note: *, **, *** stand for statistical significance at 10, 5 and 1% levels, respectively. (0/1) identifies dummy variables.

The results also show that indigenous households (in this case Kichwa) in the SBR are as likely to harvest timber (either legally or illegally) as their migrant settler counterparts. However, a prominent finding is that the annual volume harvested by Kichwa households averaged 8.7 m^3/year on an average surface of 8.9 hectares of primary forest, which is considerably lower than the average harvested by migrant settler households which is 36 m^3/year (four times higher) on an average of 8.4 hectares. These findings obtained from the MPM are significant enough to corroborate the second hypothesis of this study, that being H2*: Ethnicity has no effect on the likelihood of harvesting timber either legally or illegally.*

To conclude this section, the MPM also show that non-farm employment is negatively correlated with the likelihood of harvesting timber either legally or illegally. This suggests that fostering non-agricultural jobs in the EAR could work as one of the strategies in reducing deforestation (Torres et al. 2018a; Vasco et al. 2015). However, it is necessary to continue investigating the effectiveness of a strategy such as that, considering the livelihood strategies framework, as well as the diverse possibilities of rural income diversification, through schemes that generate non-agricultural jobs.

5.3. Determinants of Agricultural Diversification in the Ecuadorian Amazon Region[5]

The main findings of this sub-chapter show the leading agricultural incomes among households' livelihoods strategies, the agricultural diversification indices, the determinants of agricultural diversification and the potential of agricultural diversification to productively transform the EAR.

5.3.1. Agricultural Income Among Livelihood Strategies

In the SBR, aagriculture (crops and livestock) accounts for about 40% of total annual household income with an average of US$ 936 from at least eight agricultural products (Figure 9) in the whole SBR, reflecting that household income still depends, to a large extent, on agricultural income, as in many other parts of the EAR (Vasco et al. 2015, Torres et al. 2014, Murphy 2001). However, analyzing the four LS determined, agricultural (crops and livestock) income is only economically attractive for household engaged in a Livestock-based LS, with an average of US$ 2725 annually (Figure 10c), differing greatly to households in a Crop-based LS (US$ 884), Forest-based LS (US$ 704) and Wage-based LS (US$ 314) (Figures 10b, 10a and 10d respectively). (See Torres et al. 2018b).

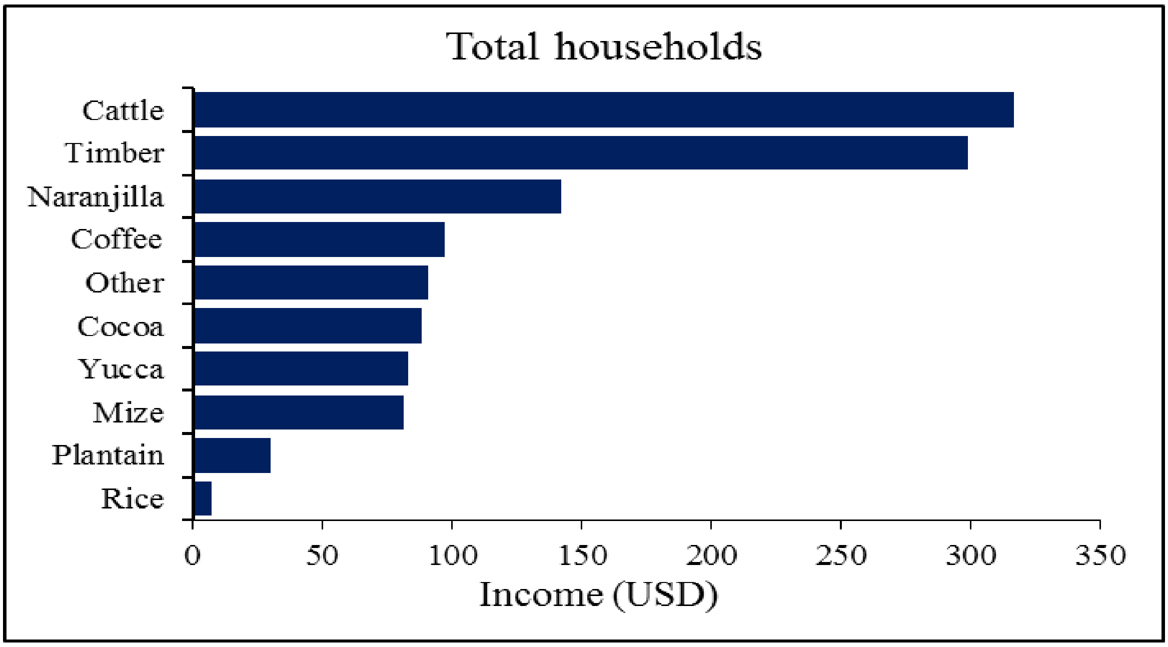

Figure 9. Breakdown of agricultural and forest household income by LS. Source: Author's own figures from survey data PEN/RAVA - SBR, 2008.

[5] This sub-chapter is based on: Bolier Torres, Cristian Vasco, Sven Günter and Thomas Knoke. 2018. Determinants of agricultural diversification in a hotspots area: evidence from colonist and indigenous communities in the Sumaco Biosphere Reserve, Ecuadorian Amazon. *Sustainability*.

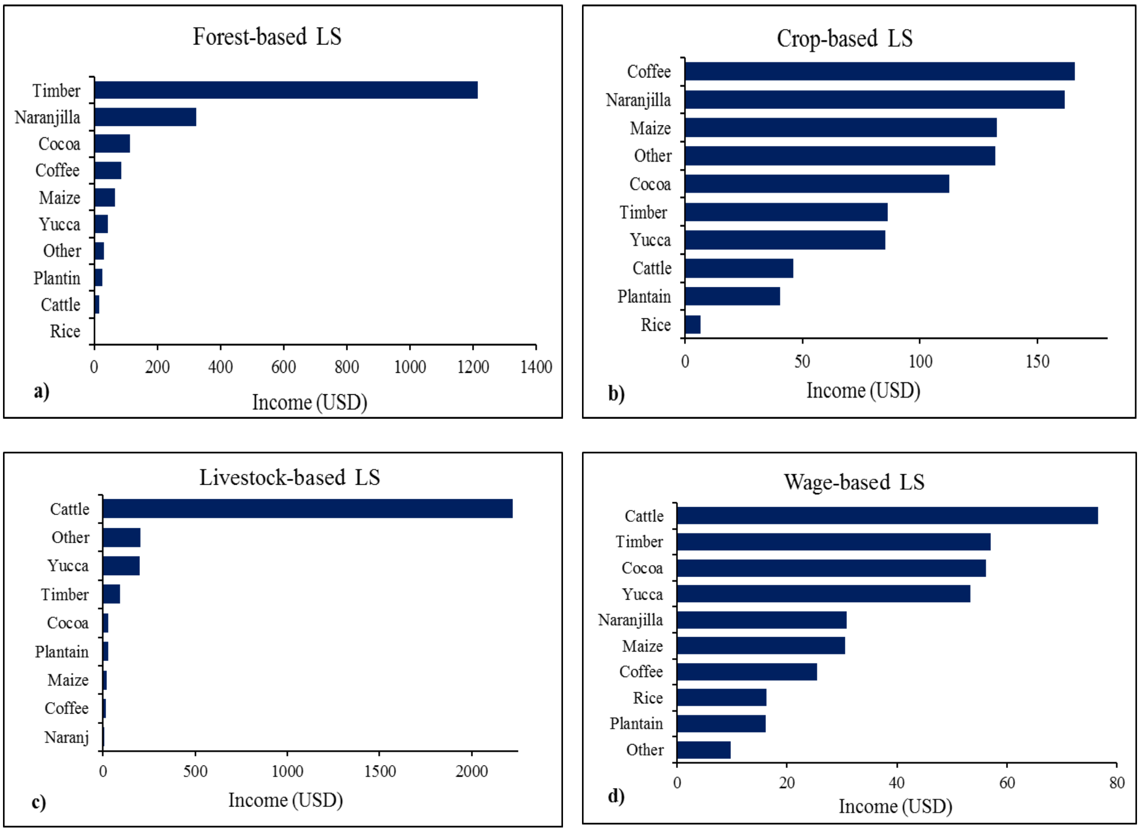

Figure 10. Annual average agriculture and forest household incomes across of the four livelihood strategies determined: a) Forest-based LS, b) Crop-based LS, c) Livestock-based LS, and d) Wage-based LS. Source: Author's own from survey data PEN/RAVA - SBR, 2008.

5.3.2. Agricultural Diversity Indices

An essential element for estimating the determinants of agricultural diversification is the calculation of an index. Thus, the Shannon index, a methodology commonly used to assess species diversity (Magurran 1988), is an optimal way of calculating agricultural diversification using the crop areas to perform the index (H_{crop_area}). Thus, the Crop-based LS showed the highest average index (0.94), followed by Forest-based LS (0.83) and Wage-based LS (0.61). Meanwhile the lowest index (0.20) was in households involved in Livestock-based LS (see Figure 11). The numbers of crop sources (NCS) was also used to measure diversification. The results reflect an average of 3.4 and 3.3 for number of crops per household in Crop-based LS and Forest-based LS, respectively, whilst the lowest average was obtained in households within the Livestock-based LS (1.8).

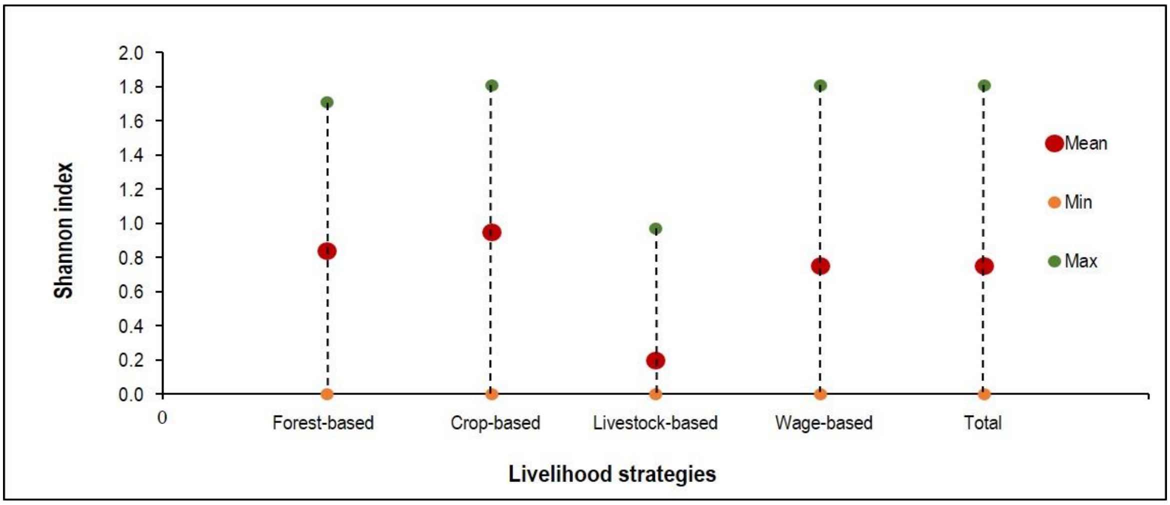

Figure 11. Annual average agriculture and forest household incomes across the four livelihood strategies determined: a) Forest-based LS, b) Crop-based LS, c) Livestock-based LS, and d) Wage-based LS. Source: Author's own from survey data PEN/RAVA - SBR, 2008.

5.3.3. Effect of Livelihood Strategies on Agricultural Diversification

To determine the level of agricultural diversification, I used the Shannon equitable index (E) in the crop area (see Equation 2 and Figure 12) over the 186 households. Three levels of agricultural area diversification were determined in a range of: low diversification (<25%), medium diversification (25–75%) and high diversification (>75%) (Figure 12). The use of this range facilitates the analysis of the households´ adoption of the degrees of agricultural diversification using an MLM.

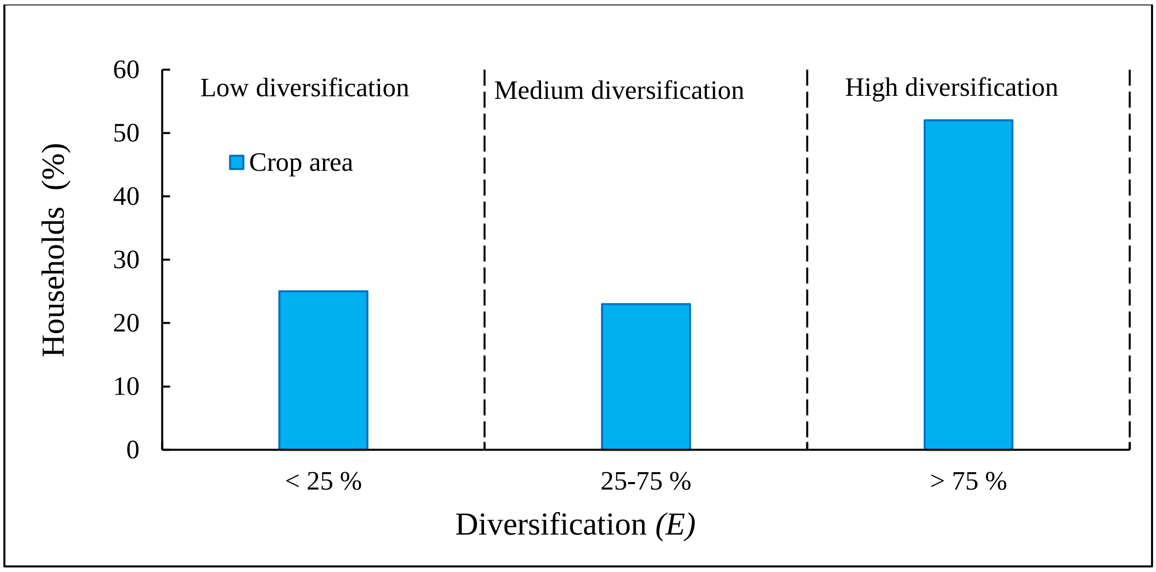

Figure 12. Percentage of households across the three levels of agricultural area diversification determined using the Shannon equitable index (E). Source: Author's own from survey data PEN/RAVA-SBR, 2008.

The MLM results shows the households' adoption of the three degrees of agricultural diversification determined from E (Figure 12), showing that ethnicity (in this case Kichwa) has a significant effect ($p < 0.001$) on the adoption of highly diversified agricultural systems. Meanwhile, smaller migrant settler households, which are not accessible by road and are engaged in Livestock-based LS, are more likely to adopt low agricultural diversification, with high trends towards specialization in monoculture activities. Households in the Livestock-based LS and Wage-based LS are less likely to have highly diversified agricultural areas, compared to households with Crop-based LS, whilst households in Livestock-based LS have a strong tendency to adopt low diversified crop areas. Household size and forest land are also likely related to the adoption of highly diversified crop areas. Low diversified households are located at short distances from urban areas.

Table 8. Multinomial logit model predicting the determinants of the degree of agricultural area diversification. (Marginal effects) (adapted from Torres et al. 2018b).

Variables	Agricultural area diversification					
	High diversification		Medium diversification		Low diversification	
Forest-based LS	-0.191	(0.128)	0.054	(0.116)	0.137	(0.149)
Livestock-based LS	-0.644***	(0.057)	-0.107	(0.084)	0.752***	(0.096)
Wage-based LS	-0.224*	(0.111)	0.044	(0.112)	0.179	(0.121)
Kichwa (yes)	0.414***	(0.112)	-0.058	(0.101)	-0.355**	(0.138)
Age of household head	-0.043	(0.028)	0.028	(0.025)	0.014	(0.020)
Age squared	0.000	(0.000)	-0.000	(0.000)	-0.000	(0.000)
Education of head (years)	-0.002	(0.016)	0.007	(0.013)	-0.004	(0.013)
Household size	0.033**	(0.016)	-0.001	(0.013)	-0.031**	(0.014)
Access to credit (yes)	0.088	(0.104)	0.035	(0.081)	-0.124	(0.087)
Forest land (ha)	0.023***	(0.008)	-0.018***	(0.005)	-0.005	(0.006)
Total land (ha)	-0.010	(0.006)	0.017***	(0.004)	-0.007	(0.005)
Inside buffer zone (yes)	-0.058	(0.121)	0.005	(0.095)	0.053	(0.092)
Distance to city (minutes)	-0.000	(0.000)	0.000	(0.000)	-0.000	(0.001)
Road access (yes)	0.057	(0.151)	0.280***	(0.077)	-0.338**	(0.160)
Numbers of observation	186					
Chi2 (28)	128.01***					
Pseudo R2	0.33					
Log likelihood	-126.38					

Significance levels: *, **, *** are 90%, 95%, and 99%, respectively. Values in parentheses are standard deviations of the coefficients.
Source: Authors computation from survey data PEN/RAVA - SBR, 2008.

Additionally, an Ordinary Least Square regression, using the Shannon indices and the NCS as dependent variables, was used to reinforce the analysis of the determinants of agricultural diversification at a household level.

The results of the OLS regression show three main findings. Firstly, ethnicity has a positive effect on both the diversification indices utilized (H_{crop_area} and NCS) in the SBR, demonstrating that Kichwa households have more agricultural diversity than migrant settlers (Table 8).

An explanation could be that the Kichwa population maintain their traditional agroforestry practices based on subsistence agriculture (Lu et al. 2010), using the *chakra* traditional agroforestry system, characterized not only as a polyculture (Vera et al. 2017, Coq-Huelva et al. 2017a) but also for its high floristic diversity (Coq-Huelva et al. 2017b, Jadán et al. 2016, Vasco et al. 2015). Secondly, road accessibility positively influences the number of crops and crop area diversification. This indicates that roads facilitate the transport of products to markets, which is consistent with the theory of von Thünen & Hall (von Thünen and Hall 1966) but it also could be related with forest clearing and the expansion of agriculture near roads (Angelsen and Kaimowitz 1999, Southgate et al. 1991).

Table 9. Ordinary Least Squares (OLS) regression predicting the determinant of crop area diversification (adapted from Torres et al. 2018b).

Variables	*NCS*	H_{crop_area}
Forest-based LS	−0.513 (0.292)	−0.195 * (0.093)
Livestock-based LS	−1.786 *** (0.329)	−0.642 *** (0.097)
Wage-based LS	−0.833 *** (0.244)	−0.263 *** (0.086)
Kichwa (yes)	0.825 *** (0.287)	0.351 *** (0.096)
Age of household head	−0.001 (0.052)	−0.006 (0.018)
Age squared	−0.000 (0.000)	0.000 (0.000)
Education ofhousehols head (years)	−0.022 (0.030)	−0.002 (0.010)
Household size	0.017 (0.030)	0.015 (0.010)
Access to credit (yes)	0.203 (0.201)	0.046 (0.065)
Forest land (ha)	−0.021 (0.012)	0.003 (0.004)
Total land (ha)	0.052 *** (0.011)	0.007 * (0.003)
Inside buffer zone (yes)	−0.202 (0.241)	−0.062 0.078)
Distance to city (mins)	−0.001 (0.001)	0.000 (0.000)
Road access (yes)	0.765 *** (0.265)	0.196 ** (0.093)
Number of observations	186	186
F	12.44 ***	20.12 ***
R^2	0.375	0.406

Notes: *, **, *** stand for significance at 90%, 95%, and 99%, respectively. Standard deviations are in parentheses.

Thirdly, land size is another significant factor affecting the H_{crop_area} and NCS in the SBR, which is consistent with previous research, reporting a strong correlation between this variable and crop diversification (Asfaw et al. 2018, Makate et al. 2016), showing that larger farms are more diversified in terms of number of crops and crop areas. In summary, these results in the SBR suggest a profile of highly diversified farmers. Households belonging to the Kichwa ethnic group with large families, remnants of forest land and engagement in Crop-based and Forest-based LS are more likely to adopt highly diversified agricultural systems.

In light of the results obtained, the third hypothesis of this study, has proven to be robust. *H3: Agricultural diversity is affected by ethnicity and the livelihood strategies that a household pursues with consequences on socioeconomic variables.*

5.3.4. Potential for Sustainable Productive Transformation

Only for those households engaged in Livestock-based LS, the relationship between pasture areas and livestock income is economically efficient. Meanwhile, for households involved in the remaining LS the opposite is true: for example, the average pasture area for those households in the Forest-based LS was 43%, whilst their proportion of income from livestock was only 1.5% (see Figures 13a and 13b). This shows the need for policy recommendation related to the productive transformation agenda. These existing characteristics of households engaged in Forest-based LS, Crop-based LS and Wage-based LS with significant unproductive areas in pastures (see Figures 13a and 13b), could be used as a strategy to facilitate farmers' accepting to convert less efficient or abandoned pasture areas into more sustainable production systems. These households could be the potential target group for promoting land conversion and the production of sustainable commodities.

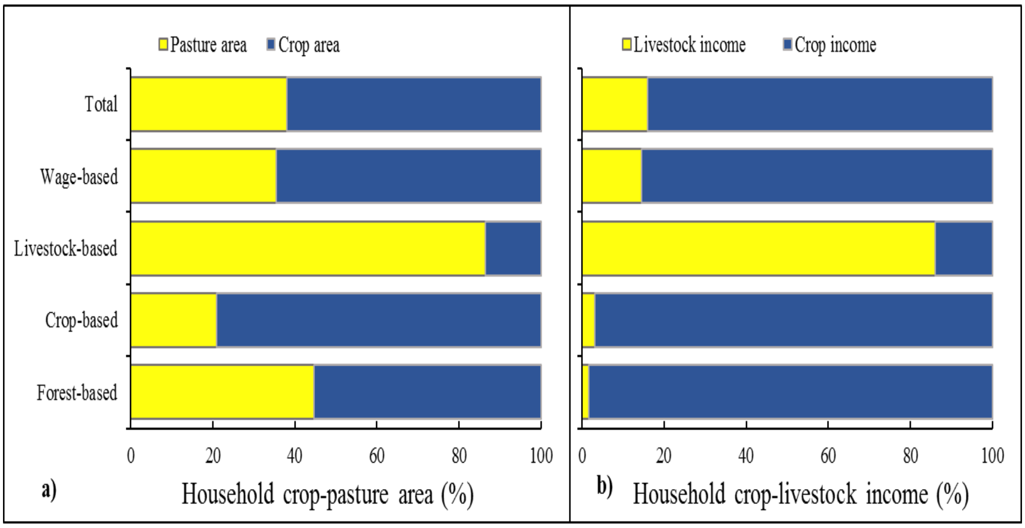

Figure 13. Percentage average of: a) household crop and pasture area, b) crop and livestock annual household incomes across the four livelihood strategies. Source: Author's own from survey data PEN/RAVA - SBR, 2008.

5.4. Analyzing a Traditional Agricultural System – The Chakra[6]

So far, this research has shown the land use income portfolio across the LS and the importance of agricultural diversification in a *hotspot* area. However, some traditional land uses provide significant

[6] Bolier Torres, Oswaldo Jadán, Patricia Aguirre, Leonith Hinojosa and Sven Günter. 2015. The contribution of traditional agroforestry to climate change adaptation in the Ecuadorian Amazon: The chakra system. In: Leal, W. (ed.), *Handbook of Climate Change Adaptation.*

ecosystem services that are also valuable at local, regional and global levels. Given that the SBR is mostly inhabited by Kichwa populations, who have an essential cultural value, it is important to evaluate and rescue some agricultural traditions. In fact, the majority of Kichwa households are engaged in the Crop-based LS (see Torres et al. 2018a), with 5.8 ha of croplands areas on average, keeping more diversified farms than their migrant settler counterparts (Torres et al. 2018b), due to the use of a traditional agroforestry system locally called *chakra,* based mainly on cocoa and coffee crops. In this sub-chapter, I show the *chakra's* potential as an appropriate agricultural system for the fragile Amazonian soils, as well as for the provision of ecosystem services.

5.4.1. The *Chakra* System in the Ecuadorian Amazon Region

The traditional agroforestry *chakra* system (Figure 14) is the most common productive land-use for the Kichwa population in the EAR (Coq-Huelva et al. 2017a, Coq-Huelva 2017b, Torres et al. 2014), characterized by its high level of biodiversity, fruit trees and timber-yielding trees (Vera et al. 2017, Coq-Huelva et al. 2017a, Torres et al. 2015, Jadan et al. 2015). The *chakra* in the SBR is also considered a polyculture (Coq-Huelva et al. 2017a, Vera et al. 2017) where the principal crops are cocoa (*Theobroma cacao* L.), coffee (*Coffea canephora* Pierre ex A. Froehner), and guayusa (*Ylex guayusa* Loes) (Krause and Ness 2017, Sidali et al. 2016). These crops grow alongside plants used for medicine, spiritual rituals, making crafts and other consumption purposes (Coq-Huelva et al. 2017a), according to Torres et al. (2015) there are nearly 12,500 ha of cacao cultivated in the chakra system in the buffer and transition zone of the SBR, with the size of *chakra* plots ranging from 0.5–4 ha. Culturally, the *chakra* also serves as spaces where traditional knowledge has been transmitted from generation to generation.

5.4.2. The Contribution of the *Chakra* System to Tree Diversity Conservation

In a *chakra* system, timber-yielding and fruit trees can be found in distances of between 15 to 20 meters apart due to the fact that a *chakra* system does not have systematic practices for planting trees. Instead, trees grow in a process of natural regeneration from the dispersion of seeds caused by wind or from the diversity of the fauna present in the system. Tree species in the *chakra* system show the highest level of diversity (Table 9), providing ecosystem services for local populations and in some ways biodiversity conservation.

Table 10. Main timber yielding trees found in the traditional chakra system with cocoa in the SBR, Napo, Ecuador (adapted from Torres et al. 2015).

Species	Family	Local Name
Cordia alliodora (Ruiz & Pav.) Oken	Boraginaceae	Laurel
Cedrela odorata L.	Meliaceae	Cedro
Cedrelinga cateniformis (Ducke) Ducke	Mimosaceae	Seike, chuncho
Ciba samauma (Mart.) K. Schum.	Bombacaceae	Ceibo
Myroxylon balsamum (L.) Harms	Fabaceae	Bálsamo
Cabralea cangerana (Vell.) Mart.	Meliaceae	Batea caspi
Capirona decorticans Spruce	Rubiaceae	Capirona
Minquartia guianensis Aubl.	Olacaceae	Guayacán
Tabebuia chrysantha (Jacq.) G. Nicholson	Bignoniaceae	Guayacán
Nectandra cissiflora Nees	Lauraceae	Canelo amarillo
Ocotea amazónica (Meisn.) Mez	Lauraceae	Canelo amarillo
Swietenia macrophylla King	Meliaceae	Caoba
Clusia ducuoides Engl.	Clusiaceae	Pungara
Vochysia biloba Ducke	Vochysiaceae	Tamburo
Gustavia macarenensis Philipson	Lecythidaceae	Paso
Pollalesta discolor (Kunth) Aristeg	Asteraceae	Pigüe
Terminalia Amazonia (J.F.Gmel) Exell	Combretaceae	Roble Yumbingue
Otoba parvifolia (Markgr.) A.H. Gentry	Myristicaceae	Sangre de Gallina
Caryodendron orinocense H. Karst.	Euphorbiaceae	Maní de árbol

Figure 14. Typical chakra system with cocoa plants in SBR, Napo, Ecuador. Source: Author, 2014.

5.4.3. The Contribution of the *Chakra* System to Food Security

One of the principal challenges for researchers and practitioners is increasing agricultural production without damaging the environment (Paul and Knoke 2015, Tilman et al. 2011, Tilman et al. 2002). The traditional *chakra* system based on a cocoa plantation could address these challenges in the EAR by increasing food security and incomes without damaging the environment. In this sense, the main edible plants found in the cacao-based chakra in the SBR are: Cassava (*Manihot sculenta* Crantz*),* chinese potato/taro [*Colocasia esculenta* (L.) Schott], Inca peanut (*Plukenetia volubilis* L.), banana and plantain (*Musa* spp.), corn (*Zea mayz* L.), peanuts (*Arachis hypogaea* L.), naranjilla (*Solanum quitoense* Lam.), lemongrass [*Cymbopogon citratus* (DC.) stapf], chili (*Capsicum annuum* L.) and wild coriander (*Eryngium foetidum* L.). These species together with the main species of fruit trees, shrubs and palms shown in Table 10 are commonly found in a cocoa-based chakra and contribute to the preservation of local food culture.

Table 11. Main species of fruit trees, bushes and palms that store carbon and are used for consumption in Chakras with cocoa in the SBR, Napo, Ecuador (adapted from Torres et al. 2015).

Scientific name	Family	Local name	Use					
			Edible	Medicinal	Spiritual	Craft	Drink	Material
Bixa orellana L.	Bixaceae	Achiote	x	x		x		x
Theobroma bicolor Humb. & Bonpl.	Sterculiaceae	Cacao blanco	x	x				
Grias neuberthii J.F. Macbr	Lecythidaceae	Pitón	x	x				x
Ilex guayusa Loes	Aquifoliaceae	Guayusa		x	x		x	x
Sanago racemosum (Ruiz & Pav.) Barringer	Grossulariaceae	Panka grande		x	x			
Gustavia macarenensis Philipson.	Lecythidaceae	Paso	x	x				x
Gustavia longuifolia Poepp. ex O. Berg	Lecythidaceae	Paso						
Pouteria caimito Radlk.	Sapotaceae	Caimito	x	x				x
Micropholis melinoniana Pierre	Sapotaceae	Caimitillo	x	x				x
Micropholis venulosa Pierre	Sapotaceae	Caimitillo						
Artocarpus altilis (Parkinson) Fosberg	Moraceae	Frutipan	x	x				x
Brugmansia arbórea (L.) Lagerh	Solanaceae	Floripondio		x	x			
Persea americana Mill.	Lauraceae	Aguacate	x	x				x
Bactris gasipaes Kunth	Arecaceae	Chonta duro	x	x		x	x	
Mauritia flexuosa L.f.	Arecaceae	Morete	x		x	x	x	
Iriartea deltoidea Ruiz & Pav.	Arecaceae	Pambil	x	x		x		x
Inga edulis Mart.	Fabaceae	Guaba	x	x				x
Pouroma spp.	Urticaceae	Uva del monte	x				x	x
Annona cherimola Mill.	Anonnaceae	Chirimoya	x	x			x	x
Psidum guajava L.	Myrtaceae	Guayaba	x	x			x	x

5.4.4. The Contribution of the *Chakra* System to Climate Change Adaptation and Mitigation

The main findings in this topic suggest that in comparison with primary forest in the study area, cocoa-based *chakras* store 42% of C (334 Mg C ha^{-1}) and 56 Mg C ha^{-1} more than cocoa in monocultures considering C in total biomass, C in necromass and C in soil (Jadan et al. 2015, Torres et al. 2015). This reveals the potential of the cocoa-based *chakra* system in mitigating climate change, considering the approximately 12,500 ha of cocoa-based *chakra* farms in the SBR (Torres et al. 2015).

6. Conclusions

Based on the findings presented in this research, it was feasible to draw the following conclusions:

The use of multivariate techniques (PCA and AHC) are suitable for determining proportion of income source to facilitate grouping the livelihood strategies. Moreover, the SLF improves the analysis, because it involves economic and social variables at household levels as well as variables that characterize the community easily to obtain econometric results and hypothesis testing. In this context, four LS in the SBR were found based on: forest income, crop production, livestock production and wage labor.

Ethnicity does affect the level of household income. Even though both migrant settlers and indigenous populations practice cattle ranching, migrant settlers' income from livestock is higher than that of indigenous households. In contrast, belonging to the Kichwa ethnic group does increase average annual income from crops. These findings made it possible to conclude that ethnicity is an important variable when analyzing livelihoods. Irrespective of the livelihood strategy that a rural household employs in tropical areas, ethnicity will affect income levels due to several factors such as customs and traditions, education levels, management systems and, market access. These characteristics must be taken into account when designing development and conservation policies, for example one must consider the variable of education and technical assistance in order to reduce the differences of human and social capital as factors that could limit the technology transfer.

Based on the fact that ethnicity has no effect on the likelihood of harvesting timber either legally or illegally and that migrant settlers harvest four times as much timber as Kichwa households in the SBR, these results also highlight the importance of the variable ethnicity in livelihoods. One recommends that government organizations and practitioners should focus on: supporting smallholders by simplifying the process for obtaining a legal logging permit, by encouraging the procurement of deeds to land (especially among indigenous peoples) as a way of promoting legal logging, and by fostering non-agricultural jobs as one of the strategies to reduce deforestation. Scientific evidence supports this point, so it is necessary to orient public policies in this way to encourage forest conservation.

To improve the analysis of household agricultural diversification in tropical rural areas, there is a potential for grouping households into LS. This approach facilitates categorization in levels of diversification using a diversification index, making it easier to analyze the socio-economic and cultural determinants of agricultural diversification. The results of this work reflect that policy makers should devise multiple approaches for the different livelihood strategies used by households in the EAR, as well as taking into account the variable ethnicity. For example, establishing differences in the application of development policies and the provision of incentives for forest conservation or incorporation of sustainable production systems.

Finally, this work argues that the use of the traditional *chakra* system facilitates agricultural diversification. Hence, the promotion of the diversified *chakra* system should be encouraged in the EAR, whilst encouraging diversification in the pastoral system used mostly by households in Livestock-based LS. Diversification is necessary on a landscape level to cope with society's multipurpose demands. In this way, the last conclusion of this document is that *chakra* system display interesting environmental advantages and could contribute to private or communal land use portfolio stability and provide additional subsistence and societal benefits. The use of the *chakra* system based on commercial crops in the lower part of the SBR could also provide diversified ecosystem services that can only be recuperated through the recognition of local knowledge. Furthermore, it is within the Chakra system that decisions concerning harmonized landscapes, territory and locally constructed processes of adaptation to climate change are made every day. In this sense, *chakra* with cocoa or coffee could be integrated as productive-wildlife corridors, connecting patches of primary or secondary forests while generating household income. However, research is required if this land-use system can be competitive under full access market conditions or if compensation regimes might be necessary.

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Bolier Torres, Cristian Vasco, Sven Günter, and Thomas Knoke. 2018. Determinants of agricultural diversification in a hotspots area: evidence from colonist and indigenous communities in the Sumaco Biosphere Reserve, Ecuadorian Amazon. In: *Sustainability* Vol. 10(5), 1432. https://doi.org/10.3390/su10051432

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9. Acknowledgements

I am thankful to Professor Dr. Thomas Knoke and Dr. PD. Sven Günter for their valuable support, and supervision during my research throughout the PhD period during my four research stances in Munich and Hamburg. I am also grateful to Professor Dr. Carola Paul and Professor Dr. Annette Menzel for their worthy contributions. Thank you to my colleagues Fabian Härtl, Luz María Castro and Santiago Ochoa for reading and commenting on the manuscript. I am as well very thankful for the methodological support during the field campaign to PEN/CIFOR and RAVA network and the WWF's Education for Nature Program for additional support during the final phase, which made my research possible. Also thanks to my coauthors for the strong support during the preparation of the manuscripts that encompass this dissertation.

I would also like to thank all my colleagues from the Institute of Forest Management of the TUM specially to, Liz Valle-Carrión, Katharina Meserer, Elizabeth Gosling, Patrick Hildebrandt, Ricardo Acevedo, Stefan Friedrich, Mengiste Kindu, Thomas Schneider, Horst Kolo, Martin Döllerer, Michael Du and also to the efficient secretaries Violeta Aramayo and Silvia Dejon for their valuable advice, support and friendship. All of you contributed to enjoyable times during all the stances of my PhD.

I would like to express deep gratitude to my lovely family Gabriela, Amelia and Fanny. You have been my constant love and support. I thank my parents Bolívar and Hilda and siblings Alicia, Emma, Yenny, Alexandra, Bolívar and Alfredo, nephews and nieces who have lovingly been able to motivate me to give of my best. Special thanks to my friends and colleagues in Ecuador who sometimes by sharing a cup of coffee or lunch have been able to transmit some interesting ideas to improve my work. I would also like to thank the Romero-Aguilar family and relatives for the valuable moments shared with warmth and affection during this time.

Finally, I am very thankful to the institutional and financial support of the Universidad Estatal Amazónica.

10. Appendix

10.1. Publication 1

Bolier Torres, Sven Günter, Ricardo Acevedo-Cabra and Thomas Knoke. 2018. Livelihood strategies, ethnicity and rural income: The case of migrant settlers and indigenous populations in the Ecuadorian Amazon[7]. In: *Forest Policy and Economics* Vol. 86(2018): 22-34. https://doi.org/10.1016/j.forpol.2017.10.011

[7] The original source of this Elsevier article is the journal of Forest Policy and Economics, permission for publication in a Thesis/Dissertation is not required for authors.

Publication 1

Forest Policy and Economics 86 (2018) 22–34

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

Livelihood strategies, ethnicity and rural income: The case of migrant settlers and indigenous populations in the Ecuadorian Amazon

Bolier Torres[a,b,], Sven Günter[c], Ricardo Acevedo-Cabra[d], Thomas Knoke[a]

[a] Institute of Forest Management, Department of Ecology and Ecosystem Management, TUM School of Life Sciences Weihenstephan, Technische Universität München, 85354 Freising, Germany
[b] Facultad de Ciencias de la Vida, Universidad Estatal Amazónica, Pastaza, Ecuador
[c] Thünen Institute of International Forestry and Forest Economics, 21031 Hamburg, Germany
[d] Department of Mathematics, Technische Universität München (TUM), 85748 Garching, Germany

ARTICLE INFO

Keywords:
Forest conservation
Sustainable development
Indigenous
MLM
Tobit

ABSTRACT

This paper examines the livelihood strategies (LS) of two ethnic groups and explores their implications for forest conservation. We used data from household and community surveys covering migrant colonists and indigenous (Kichwa) people in the Sumaco Biosphere Reserve (SBR) in the central northern Ecuadorian Amazon. Data were collected using the Poverty and Environment Network methodology of the Center for International Forestry Research (CIFOR-PEN). To estimate LS, income proportions of farm portfolios were used in a Principal Components Analysis (PCA) followed by an Agglomerative Hierarchical Clustering (AHC). The results identify four LS based on: forest income, crop production, livestock production and wage labour (off-farm income). The results of a multinomial logit model (MLM) showed that ethnicity has strong influence on their choice of LS, and households with higher physical asset holdings are more likely to engage in more remunerative LS in both ethnicities. Tobit regression show that the ethnic group of Kichwa has US$ 223 higher annual income from Crop-based LS in comparison to colonists. In contrast, colonists earn, on average, US$ 472 per year more from live-stock than indigenous households in livestock-based LS and 182 dollars annually more in wage-based LS. Households with greater human capital are more engaged in Wage labour-based LS. Interestingly, residing within the buffer zone of the SBR reduces forest income by US$ 268 in Forest-based LS. The relative remaining forest land is not significantly related to LS. Potential implications of the different activities and composition of household assets in each LS are discussed in order to draw conclusions for equitable development and forest conservation.

1. Introduction

In the last two decades, several studies have examined the links between forests and rural livelihoods (de Sherbinin et al., 2008; Hogarth et al., 2013; Porro et al., 2015; Sunderlin et al., 2005; Thanh et al., 2015; Yemiru et al., 2010; Zenteno et al., 2013). For instance Vedeld et al. (2007) analyzed 54 case studies in 17 tropical countries (seven from Latin America) and found that, on average, 22% of rural income came from forest environment. Seven years later, and in a global analysis using standardized methodologies, Angelsen et al. (2014) found that forests contribute 22% of rural income at the global level and 28% for Latin American countries (seven cases). Babigumira et al. (2014) also identified a relationship between rural livelihoods and forest clearing. In any case, millions of people around the world rely on forests for their livelihoods (Vedeld et al., 2007), and the services they provide (Pan et al., 2011). Therefore, the relation between rural households' livelihoods and forest ecosystems is certainly of interest, with substantial global and political implications.

At the local level, various empirical studies have showed that rural households in tropical countries generate their livelihood strategy (LS) from a diverse range of economic activities (Ellis, 2000; Scoones, 1998), such as: farming (Walelign et al., 2016a; Porro et al., 2015; Thanh et al., 2015), fishing (Sirén and Machoa, 2008), hunting (Sirén, 2012; Sirén et al., 2006; Vasco and Sirén, 2015), producing timber and non-timber forest products (Duchelle et al., 2014; Mejía et al., 2015; Prado et al., 2013; Timko et al., 2010) herding (Lerner et al., 2014; McGroddy et al., 2015; Pacheco and Poccard-Chapuis, 2012; Rudel et al., 2015) and off-farm activities (Holden et al., 2004; Vasco et al., 2015). These studies

Corresponding author at: Institute of Forest Management, Department of Ecology and Ecosystem Management, TUM School of Life Sciences Weihenstephan, Technische Universität München, 85354 Freising, Germany
E-mail address: btorres@uea.edu.ec (B. Torres).

http://dx.doi.org/10.1016/j.forpol.2017.10.011
Received 20 March 2017; Received in revised form 12 September 2017; Accepted 10 October 2017
1389-9341/

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analyze a variety of the activities that households perform to “survive and prosper” inside forest landscapes (de Sherbinin et al., 2008). All of these activities are essential, given their significant contribution to rural living conditions. However, most of them lead to the ongoing conver-sion of forest to agricultural or grazing lands.

Most researchers have analyzed livelihoods considering the study sites as a whole (Kamanga et al., 2009; Pacheco, 2009; Prado et al., 2013), in some cases separating by ethnicity (Bilsborrow et al., 2004; Gray et al., 2008; Lu et al., 2010; Vasco et al., 2015). However, not all households in a given area experience homogeneous livelihood schemes (Walelign et al., 2016b; Nielsen et al., 2013). To a certain degree, li-velihood assets combined with external factors in rural areas promote some patterns in how households obtain their income, with these pat-terns being recognized as livelihood strategies (LS) (Ellis, 1999). Sev-eral approaches are available to group households into LS, in many cases, using two complementary multivariate statistical techniques: principal component analysis (PCA) to reduce the datasets into un-correlated principal components scores (Kuivanen et al., 2016) and clustering methods, e.g. hierarchical (Walelign, 2016; Kuivanen et al., 2016; Thanh et al., 2015; Zenteno et al., 2013; Yemiru et al., 2010), k-means (Soltani et al., 2012) and latent class clustering approach (Walelign and Jiao, 2017; Jiao et al., 2017; Walelign et al., 2016a; Nielsen et al., 2013).

We investigate these issues in the context of the Sumaco Biosphere Reserve (SBR), an area of about one million hectares located inside the Tropical Andes in the north central Ecuadorian Amazon (Fig. 1), which is considered to be a “leading hotspot” for biodiversity and endemic species (Myers et al., 2000).

The northern and central part of the Ecuadorian Amazon has ex-perienced a process of rapid colonization since the 1960s due to: a) the enactment of Agrarian Reform Laws (1964 and 1972) which promoted the colonization of forest lands; b) the discovery of significant oil re-serves by the consortium Texaco-Gulf in 1967 and, c) the construction of roads into previously inaccessible areas by oil companies (Bilsborrow et al., 2004; Pichon, 1997). These factors have led to intense defor-estation and land-use change (Mena et al., 2006), as well as fragmen-tation of farms due to population growth (Bilsborrow et al., 2004; Pan et al., 2007; Pan and Bilsborrow, 2005). This has driven both the Kichwa and migrant settlers to adopt market-oriented livelihood ac-tivities (Gray et al., 2008; Izurieta et al., 2014), including off-farm ac-tivities which have become the main income source in the Amazon (Torres et al., 2014; Vasco et al., 2015).

Regarding livelihoods and nature conservation, during prior dec-ades, Ecuador has made several efforts towards achieving sustainable development goals. In 2008, Ecuador became the first country to grant legal rights to nature, due to the presence of social environmentalist movements and the power of indigenous organizations who in-corporated politicized versions of indigenous beliefs about the en-vironment and the way of life, inducing the kichwa term sumak kawsay[1] or living well (in Spanish: buen vivir) (Akchurin, 2015; Gudynas, 2011). As a result, a National Plan of Development referred also as the National Plan for Living Well was developed in Ecuador (Walsh, 2010). These efforts also bring more opportunities to progress towards sus-tainable development, such as understanding and relating the im-portance of this national plan to improve livelihoods and conservation in the Ecuadorian Amazon.

In this study we try to address these urgent questions for sustainable development on the basis of the sustainable livelihood framework (SLF). Despite prior studies, there is a lack of empirical information on the role of ethnicity on income in determined LS, in particular for Andean-Amazon countries. We address this gap using a data set cov-ering both indigenous (Kichwa) and migrant settler populations. To the best of our knowledge, this is the first quantitative research in an Amazon country that considers the effect of ethnicity on the households' adoption of LS, the level of income within different LS and the impact of these LS on forest conservation.

With this background, we hypothesize that ethnicity has strong in-fluence on the households' adoption of LS, and will also affect the level of household income in the determined LS. Hence, this study aims at a) de-termining the LS emerging from indigenous (Kichwa) and settler po-pulations, b) examining the factors associated with households' LS choice, and c) evaluating the effect of ethnicity and assets on household incomes in each LS. Finally, the implications of LS for equitable de-velopment and forest conservation are discussed.

2. Theoretical framework

Sustainable Livelihood Framework (SLF) is an important theoretical approach to analyze rural LS and their implications for forest con-servation (Ashley and Carney, 1999; de Sherbinin et al., 2008; Ellis, 2000; Scoones, 1998 and Soltani et al., 2012). Rural LS in tropical countries are determined by both external factors and the mix of assets (human, social, natural, physical and financial capital) that households use in their on- and off-farm activities, to develop a diverse portfolio of activities for survival or improving their standards of living (Walelign and Jiao, 2017; Nielsen et al., 2013; Davis et al., 2010; Ellis, 1999, 1998). In this context, forest income and income diversification are special characteristics of rural LS in poor countries (Ellis, 2000). Off-farm income usually provides higher earnings than small-scale agri-culture (Davis et al., 2010; Reardon, 2001). The core objective of SLF is poverty reduction (Ashley and Carney, 1999). To achieve this goal in tropical rural areas, it is necessary to understand differences in LS be-tween different groups of households. The SLF was first promoted by the Department for International Development (DFID), a United Kingdom government department, in the late 1990s (Ashley and Carney, 1999). This approach has been used by previous studies to describe the LS in rural areas (Walelign, 2016; Thanh et al., 2015; Porro et al., 2015; Zenteno et al., 2013). In this study we consider LS as a dynamic and adaptable concept (Walelign and Jiao, 2017; Jiao et al., 2017; Nielsen et al., 2013) that could change depending of livelihood assets, external context and social groups. We use quantitative data to analyze LS emerging from indigenous (Kichwa) and settler populations under the SLF.

3. Materials and methods

3.1. Study area

The area of SBR was declared as a biosphere reserve by UNESCO's Man and Biosphere program (MAB) in 2000 (Valarezo et al., 2002). Its core area of conservation is the Sumaco Napo Galeras National Park (PNSNG), which was declared 1994[2] with 205,751 ha (Ministerio del Ambiente del Ecuador (MAE), 2013). The SBR is divided between the provinces of Napo (62%), Orellana (35%) and Sucumbíos (3%). It is an interesting site to investigate LS and their relation to forest conserva-tion because: a) the area is ancestrally inhabited by indigenous popu-lations, with almost 50 years of colonization; b) as a biodiversity “hotspot” under severe threat (Mittermeier et al., 1998), it is critically important to recognize LS that have major impacts on forest cover; and

c) the current status as a UNESCO Biosphere Reserve promotes biodi-versity conservation, sustainable development, education and research, as a means of reconciling humans and nature (Unesco, 1996).

1 For more on the concepts of sumak kawsay (in Spanish “buen vivir”), see Gudynas (2011), and Walsh (2010).

2 Resolution No. 9, March 2nd, 1994 – Official registration No. 47 of June 28, 1994, INEFAN-Ecuador.

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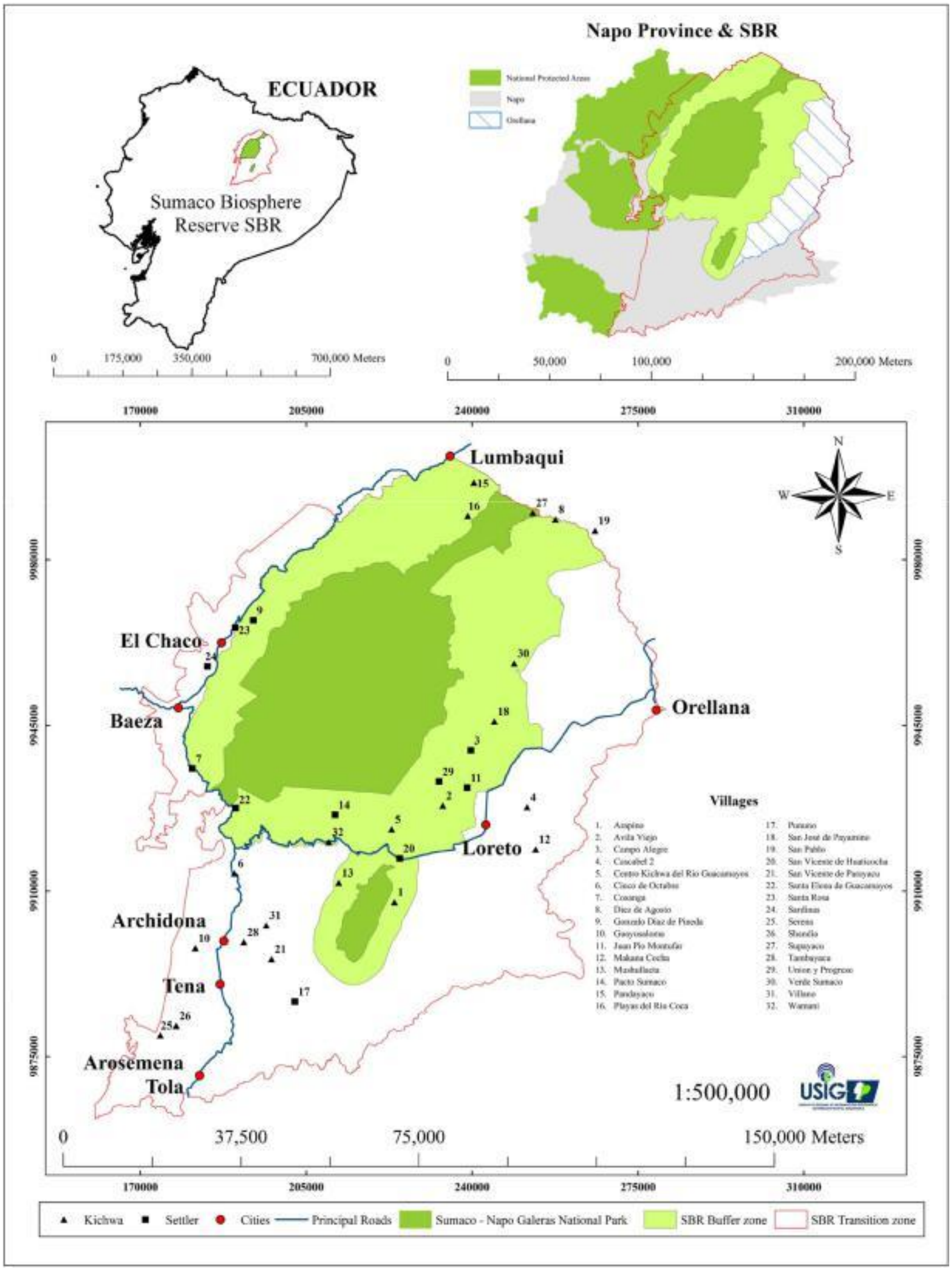

Fig. 1. Ecuador and the study area; location of the Sumaco Biosphere Reserve and the protected areas in Napo province; locations of the 32 communities included in the survey, Napo 2008.

3.2. Sampling and data collection

This study is part of the Poverty and Environment Network (PEN) and the Amazon Livelihoods and Environment Network (RAVA), and used the methodology developed by CIFOR-PEN to systematically col-lect data to assess rural livelihoods' dependency on environmental re-sources (Angelsen et al., 2014; Angelsen et al., 2011). The methodology comprises intensive fieldwork in selected research sites, defined as

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Table 1
Main characteristics of the villages selected for the household and community surveys within the Sumaco Biosphere Reserve, 2008.
Source: Analysis from survey data PEN/RAVA – SBR, 2008.

No.	Village	Social group	Local government	Year established	Population	Number of households
1	Arapino	Kichwa	Loreto	2001	120	30
2	Avila Viejo	Kichwa	Loreto	1980	400	76
3	Campo Alegre	Settler	Loreto	1563	490	70
4	Cascabel 2	Kichwa	Loreto	1989	300	80
5	Centro Kichwa Rio Guacamayos	Kichwa	Loreto	1988	300	37
6	Cinco de Octubre	Kichwa	Archidona	1990	60	8
7	Cosanga	Settler	Quijos	1955	700	120
8	Diez de Agosto	Kichwa	Orellana	1975	80	10
9	Gonzalo Diaz de Pineda	Settler	El Chaco	1961	350	101
10	Guayusaloma	Kichwa	Tena	1993	108	30
11	Juan Pio Montufar	Settler	Loreto	1984	700	140
12	Makana Cocha	Kichwa	Loreto	1970	130	28
13	Mushullacta	Kichwa	Archidona	1988	600	90
14	Pacto Sumaco	Settler	Archidona	1987	600	80
15	Pandayacu	Kichwa	G. Pizarro	1972	550	100
16	Playas del Rio Coca	Kichwa	G. Pizarro	2000	124	29
17	Pununo	Settler	Tena	1968	250	40
18	San José de Payamino	Kichwa	Loreto	1500	325	60
19	San Pablo	Kichwa	Orellana	1962	500	120
20	San Vicente de Huaticocha	Settler	Loreto	1994	220	55
21	San Vicente de Parayacu	Kichwa	Archidona	1963	22	5
22	Santa Elena de Guacamayos	Settler	Archidona	1980	135	35
23	Santa Rosa	Settler	El Chaco	1960	350	100
24	Sardinas	Settler	El Chaco	1948	600	95
25	Serena	Kichwa	Tena	1910	280	35
26	Shandia	Kichwa	Tena	1953	320	40
27	Supayacu	Kichwa	Orellana	1998	55	11
28	Tambayacu	Kichwa	Archidona	1953	500	60
29	Union y Progreso	Settler	Loreto	1988	150	24
30	Verde Sumaco	Kichwa	Loreto	1941	290	40
31	Villano	Kichwa	Archidona	1972	370	48
32	Wamani	Kichwa	Wamaní	1970	700	136

geographical territories containing communities that rely on forest and forest-products. From May 2007 to April 2008, two annual surveys (12 months apart) and four quarterly surveys were carried out at the household-level to collect data on livelihood sources and household information. Data were also collected at the village-level through two annual surveys (mainly derived from focus group discussions). Over a one-year period, a survey team visited the selected villages five times, during these visits they administered questionnaires (PEN, 2007) to a sample of 186 households, and met with focus groups.

Households were selected randomly using a control sampling method (Kish, 1965). In 2007 there were around 300 villages inside the buffer and transition zone of the SBR. Thirty-two of these villages (21 Kichwa and 11 settlers) were randomly selected, representing 12% of all villages (Table 1). The use of this approach ensures good re-presentation of communities and improves the robustness of the results (Cavendish, 2003).

3.3. Classification of income sources

Different systems of income classification in rural areas can be found in the literature. We followed the classification of Barrett et al. (2001a, 2001b) who defined on- and off-farm income based on the spatial distribution of income activities. However, to capture “forest income” we used the FAO definition of a forest (FAO, 2000) and the field and income methodology as proposed by the PEN technical guidelines (PEN, 2007). Thus, in this paper, the composition of income is classified into on-farm and off-farm, and the on-farm income depends on the land-use strategies of each household. These land-use strategies are usually determined by farmers' knowledge, customs and culture, household characteristics such as number household size, availability of assets and farm size, and characteristics of the area, such as access to transportation and markets (Cavendish, 2003). On the other hand, off-farm income refers to all activities away from the farmer's own property (Barrett et al., 2001a, 2001b; Barrett and Reardon, 2000; Schwarze and Zeller, 2005), and depends on the availability of jobs and the ability of households to procure income. In this study, farm income is defined as the total income from any land use within the farm (livestock, crop production and forest environment) and off-farm income refers to revenues from salaried work outside the farm, including jobs, re-mittances, royalties and self-employment. Socio-economic character-istics at the household level are evaluated through descriptive statistics and differences among groups.

Income assessment was based on data collected from household surveys. We classified income reported in the quarterly questionnaires into nine categories: forest, environment, agricultural crops, livestock and animal products, aquaculture, fishing, wages, businesses and others sources. Total income is defined as the gross income value in all cate-gories minus production costs (except household labour).

The per capita income and extreme poverty level was computed using the adult equivalent unit (AEU).[3] To determine the proportion of the population that is counted as extremely poor, we used the head-count ratio poverty index, which is the ratio between the number of extremely poor households and the total number of households (Foster et al., 1984). Thus, we use the following expression to calculate: $P_o = N_p/N$; where P_o is the proportion of sample counted as extremely poor, N_p is the number of extremely poor households and N is the total household sample in each LS. A household is classified as extremely poor if it earns, on average, less than US$ 1.25 per day according with the Ecuadorian national poverty line reported for 2009. Thus, a household with a total income less than US$ 1.25 per day is an ex-tremely income poor (INEC, 2016).

3 This study uses an adult equivalent scale: children below 15 years and adults above 65 years are assigned a weight of 0.5 while all other households members are assigned a weight of 1 (Angelsen et al., 2014).

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3.4. Multivariate approach to determine and assess livelihood strategy choices

To determine livelihood strategies two multivariate techniques were used: Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering (AHC). To analyze the factors associated with households' LS choice, a multinomial logit model (MLM) was executed, and to assess the effect of ethnicity and assets on household income in each LS, a Tobit regression model was performed.

PCA was performed to reduce dimensionality, which helps to visualize and process high-dimensional datasets while still retaining as much of the variance in the dataset as possible. Thus, the percentages of the nine revenue sources for each household were used in the PCA to show the relative importance of each source to total household incomes and to reduce the dataset into non-correlated principal components (PCs). The PCA was performed using the R package FactoMineR (Husson and Pages, 2013).

To group the households into LS, an AHC was performed on results from the PCA. This method, compared to other clustering method (such as k-means algorithms), does not need the number of clusters to initiate the procedures because it builds clusters incrementally, thereby producing a dendrogram which is also useful and easy for visualizing groups. In the AHC approach each observation starts in its own cluster, and pairs of clusters are merged as one moves up the hierarchy. Thus, the five major components resulting from the PCA were used; these accounted for 70.15% of the cumulative variance of the original data, which was considered sufficient to develop the AHC.

Both descriptive and inferential statistics were used to analyze the clusters. The income sources among clusters in absolute terms and the percentage share of total income were computed, as well as the main asset characteristics among clusters. One-way ANOVA analysis of variance (F-test) was used to test for significant differences among the clusters for continuous variables, while a Chi-square test was used for significance differences in dummy and categorical variables.

We use the MLM to identify the determinants of households' decision to choose which livelihood strategy should follow. MLM regression shows the determinant variables for each category versus the base category (i.e., wage-based strategy). We prefer using this model since it is the most common model to carry out analysis of dependent variables with more than two unordered outcomes (Wooldridge, 2002). MLM can be specified in terms of the probability of an outcome occurring given the independent variables. We therefore used a model of the following form:

$$\frac{e^{\beta_{K-1}\cdot X_i}}{1+\sum_{k=1}^{K-1} e^{\beta_k\cdot X_i}}$$

where; K is the number of LS alternatives (in this case four), one of which is the main source of income of an individual i, X is a vector of independent variables and β is a vector of coefficients whose magnitude and direction are of fundamental interest for this study. The dependent variables are the four LS (cluster results). The model contained eight explanatory variables: ethnicity, age head household, education head, altitude, distance to city, household access to credit and household total land. (see Table 2 for more explanation of the variables).

Additionally, we employed a Tobit regression to analyze the effect of assets on household LS. This methodology is useful when a non-tri-vial number of observations of the sample have the value of 0 (Wooldridge, 2002), which is the case for the four dependent variables analyzed here. The dependent variables of interest are the incomes obtained from the forest, crop and livestock production, and paid work outside of the farm (referred to as wage labour). Predictors include the age, ethnicity, trust and education level of the head of the household, household size, total land available for use, land in forest, access to roads, distance to city and location in the SBR (see Table 2 for variable definitions). Thus, we used a model of the form:

Table 2
Definition of variables used in the MLM and Tobit regression model.

Variables	Nature	Description
Dependent variable (MLM)		
Household livelihood cluster	Categorical	Take values from one to four based on the results of the Agglomerative Hierarchical Clustering (Forest-based strategy, Crop-based strategy, Livestock-based strategy, Wage-based strategy)
Dependent variables (Tobit)		
Forest income	Continuous	Total income from forest
Crops incomes	Continuous	Total income from crops
Livestock income	Continuous	Total income from livestock
Wage income	Continuous	Total income from paid work outside of the farm
Independent variables		
Age head household	Continuous	Age of household head (years)
Household size	Continuous	Number of household members
Ethnicity (Kichwa)	Dummy	Household head is Kichwa (0/1)
Education head	Continuous	Length of formal education of the household head (years)
High trust	Dummy	Trust in neighbors/people in the villages (0/1)
Access to credit	Dummy	Households access to any type of credit (0/1)
Inside buffer zone	Dummy	Household located inside the buffer zone – SBR (0/1)
Altitude (m)	Continuous	Meters above sea level were households are located
Remaining forest	Continuous	Percentage of remaining forest cover on farm
Distance city	Continuous	Time to reach cities from community (minutes)
Total land	Continuous	Household's total land in hectares
Road access	Dummy	Availability of roads to access village by car (0/1)

$$y_i^* = \beta x_i + \varepsilon_i \quad (2)$$

$y_i = 0$ if $y_i^* \leq 0$

$y_i = y_i^*$ if $y_i^* > 0$

where y_i is the total income from each category of household i, β is a vector of coefficients, x_i is a vector of the predictors described above, ε_i is the nuisance term. The observable output variable y will equal 0 if the unobservable variable $y^* \leq 0$ and will take the value of y^* provided $y^* > 0$.

The coefficients of the Tobit analysis indicate the extent to which a change of one unit in x can affect the latent variable y_i*. However, the results of a Tobit model cannot be directly inferred, hence we estimated the marginal effects at the unconditional value of y_i.

4. Results

4.1. Livelihood strategies and incomes

The PCA considered components with loading values above 0.5. Thus, two variables loaded highly on component 1: income from off-farm employment and other non-agricultural income. This component explains 17% of the variance (Appendix A). Component 2 explains 16% of the variance and contained two variables with high positive loadings: income from crops and other income sources. A single variable, revenues from sales of unprocessed wood, loaded highly on component 3, which explains 13% of the variance. Component 4 also contained a single variable (income from livestock); this component explains 12% of the variance. Component 5 explains 11% of the variance and comprises two variables: income from aquaculture and businesses. Consistent with the income analyses, seven factors (wage, crops, forest, livestock, business, aquaculture and other income) are the most influential for explaining LS; these five main components were used in the

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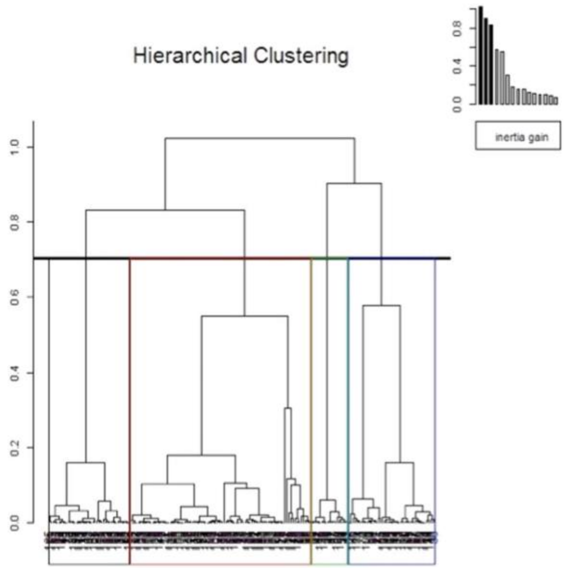

Fig. 2. Hierarchical Cluster graph.

cluster analysis.

The results of AHC, using the five main components (Appendix A), identified four household categories based on LS (Fig. 2 and Appendix B). Relative income for each activity in each category was used to name the four LS. For cluster 1, income from unprocessed timber resources constituted around 51% of total household income, followed by crop income (24%); other income accounted for 11% and livestock revenues for 0.1% of total income. This LS was therefore called "Forest-based". Cluster 2 consisted of households with three main sources of income: crops, other income and wages, representing 53%, 24% and 10% of total income respectively; for these households' timber sales constituted only 5% of total income. This group of households was identified as "Crop-based". For households in cluster 3, revenue from livestock comprised 62% of total income. Therefore, this group was labeled "Livestock-based". For this group, other income comprised 13% of total income, wages 10%, off-farm employment 11% and earnings from crops 7%; timber sales comprised just 0.3% of total income. Households in cluster 4 obtained substantial income in two categories, which together contributed about 75% of total revenue: 38% from off-farm wages and 37% from other non-agricultural income; hence, cluster 4 was named "Wage-based". This cluster also obtained 13% of total in-come from agricultural crops, but only 0.4% from wood revenues (Table 3).

Throughout the study area, forests (sales of unprocessed wood) contribute to, on average, about US$ 300 (14%) of total revenues. For LS Forest households, forest revenues represent on average, US$ 1217 (51%) in absolute and relative terms. Dependence on forest income differs significantly across LS; the three other LS have lower average values: US$ 86 (5%) for LS Crop-based, US$ 57 (4%) for LS Wage-based and US$ 92 (3%) for Livestock-based LS (Table 3). However, off-farm income emerges as one of the most important sources of income across all LSs; comprising between 21% (for Forest-based) to 78% (Wage-based) of total revenues (Appendix C).

4.2. Ethnicity, assets and remaining forest land

Forest-based LS and Wage-based LS showed similar ratios of ethnicities, where 64% and 65% of households are Kichwa, compared to 84% for Crop-based LS and just 9% for Livestock-based LS; remaining households are migrant settlers. These differences were statistically significant with $p < 0.001$. We analyzed five assets (human, social, natural, financial and physical) across LS. Social assets (trust in neighbors or people in the village, help received from other people in the village and level of satisfaction "well-being") did not differ significantly across the four LS. Financial assets (access to credit) were higher and marginally significant for Forest-based LS (Table 4). Looking at human capital, mean household size for Forest-based LS and Crop-based LS was 7.4 and 7.1 members respectively, which was significantly higher ($p < 0.01$) than the mean household size for Livestock-based LS (5.7) and Wage-based LS (5.6). The mean age of the head of household, ranges from 43 to 49 years, with no significant difference between the four LS. Likewise, the education level of the head of household did not differ significantly between groups; this value was lowest (5.8 years education) for households engaged in the Crop-based LS, and highest (6.8 years) for Wage-based households LS.

When considering natural capital and location, mean farm size was significantly larger for Livestock-based LS and Forest-based LS (40 and 36 ha respectively), than Crop-based LS and Wage-based LS, which both had a mean farm area of 24 ha ($p < 0.001$). Although the difference was not statistically significant, Wage-based LS and Forest-based LS comprised a greater proportion of the remaining forest land (65% and 64% respectively), compared to Livestock-based LS and Crop-based LS with 53% and 60% respectively (Appendix D). The percentage of cropland and pastures differed significantly across groups ($p < 0.001$). Livestock-based LS showed the lowest percentage of cropland (1.8%) and the highest percentage of pasture (37.6%), while the other LSs al-located, on average, 10% to 16% of land to these two uses. Vehicle access to villages also differed significantly between the LS ($p < 0.01$). All households engaged in Livestock-based LS could access villages by car, followed by 89% of households in Forest-based LS. Households with Crop-based LS showed the lowest road access (60%). Between 65% and 74% of the households are located in the buffer zone of the SBR (Table 4).

In terms of physical capital, cattle stock was the most important variable. Livestock-based LS households had the highest value (US$ 19,635), which was significantly greater than within the other groups ($p < 0.001$): five times more than Forest-based LS (US$ 3443), seven times more than Wage-based LS (US$ 2748) and nine times more than Crop-based LS (US$ 2199). This same trend is reflected in the variable 'Goods'; 100% of households involved in Livestock-based LS owned a TV or refrigerator, compared to 75% for Forest-based LS, 72% for Wage-based LS and 56% for Crop-based LS.

Two indicators are used to describe the welfare level: the per-capita income (PCI) and the poverty rate FGT index, which was computed using the adult equivalent (AE adjusted income) (see methodology). Mean PCI was highest in the Livestock-based LS households (US$ 704 per AE), followed by US$ 480 per AE for Forest-based LS households; these values were significantly greater ($p < 0.001$) than Wage-based LS households (US$ 373 per AE) and LS Crops-based households (US$ 327 per AE). In general, the four LS represent households with extreme poverty levels. However, Livestock-based LS has the lowest extreme poverty rate (39%), which is significantly below that of Forest-based LS (69%), Wage-based LS (78) and Crops-based LS (93%), with no significant difference between these three groups.

4.3. Determinants of household's livelihood choices

Table 5 presents the results from the MLM regression explaining households' adoption of the identified livelihood strategies. Wage-based strategy is the base category for the MLM analysis, thus the coefficients indicate the relative influence of explanatory variables compared to the choice of wage-based strategy.

This study identifies four household LS in SBR. Thus, the MLM analysis showed that ethnicity (in this case migrant settlers) location (living in the upper area of SBR and located close to city) and physical

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Table 3
Income sources among clusters in absolute terms (US$) and percentage share of total income by livelihoods strategies.
Source: Authors computation from survey data PEN/RAVA - SBR, 2008.

Income Portfolio	Absolute and relative mean income source								Overall n = 186		ANOVA[+]
	Cluster 1 Forest-based n = 36		Cluster 2 Crops-based n = 81		Cluster 3 Livestock-based n = 23		Cluster 4 Wage-based n = 46				
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	
Forest	**1216.7**[a]	**50.9**	86.0[b]	05.3	92.8[b]	03.2	56.9[b]	04.2	298.5	13.5	***
	(1158)	(20)	(155)	(7.9)	(201)	(6.1)	(113)	(7.2)	(689)	(21)	
Crops	614.8[a]	24.0	**765.6**[a]	**52.8**	249.9[b]	07.2	155.7[b]	12.8	521.8	31.7	***
	(729)	(18)	(511)	(15)	(458)	(11)	(173)	(12)	(562)	(24)	
Livestock	97.0[a]	01.2	127.0[a]	04.5	**1844.7**[b]	**62.0**	190.5[a]	03.7	478.5	10.8	***
	(138)	(2.8)	(261)	(7.0)	(1260)	(17)	(459)	(8.0)	(922)	(21)	
Wage	110.8[a]	05.2	157.9[a]	09.6	370.7[b]	10.9	**551.0**[b]	**38.2**	272.3	16.0	***
	(162)	(7.0)	(230)	(10)	(475)	(10)	(524)	(24)	(391)	(19)	
Other	217.8[a]	11.9	380.2[a,b]	24.2	317.9[a,b]	13.6	**612.2**[b]	**37.3**	398.4	23.7	**
	(217)	(23)	(589)	(12)	(190)	(9.7)	(971)	(21)	(635)	(17)	
Business	166.7[a]	05.3	2.88[b]	0.2	47.8[a,b]	01.4	10.35[b]	01.1	41.9	01.5	**
	(528)	(15)	(21)	(1.3)	(157)	(4.4)	(34)	(3.7)	(245)	(7.7)	
Aquaculture	7.1	0.05	20.32	01.7	16.0	0.08	15.5	01.1	16.0	10.2	–
	(20)	(1.8)	(76)	(5.8)	(62)	(3.7)	(47)	(3.6)	(60)	(0.8)	
Fish	9.8	0.05	6.6	0.05	9.08	0.04	13.6	0.13	9.3	0.7	–
	(14)	(0.9)	(11)	(1.1)	(12)	(0.7)	(15)	(1.7)	(13)	(1.2)	
Environment	1.6	0.002	9.4	0.07	6.3	0.02	1.4	0.06	5.6	1.3	–
	(53)	(0.1)	(39)	(3.5)	(16)	(0.5)	(5)	(0.2)	(26)	(0.7)	
Total	2201[a,b]	100	1449[a]	100	2898[b]	100	1353[a]	100	1750.1	100	***
	(1618)		(1154)		(1736)		(1586)		(1524)		

ANOVA[+] was performed for the mean of total income in absolute terms (US$). Significance levels: *, **, *** are 90%, 95%, and 99%, respectively. Values in parenthesis are standard deviations of the mean. Letters in superscript denote significant differences among LS based on ANOVA test.
Main income sources are shown in bold.

Table 4
Mean of the main socio-cultural and economic characteristics of livelihood strategy groups.

Variables	Strategies				Overall n = 186	Significance[a]
	Forest-based n = 36	Crops-based n = 81	Livestock-based n = 23	Wage-based n = 46		
Ethnicity						
Kichwa (%)	64.0	84.0	0.9	65.0	66.0	***
Human assets						
Household size	7.4	7.1	5.7	5.6	6.6	–
Household size (AE)	5.7	5.5	4.6	4.3	5.1	–
Age of household head (years)	44.7	43.3	49.2	43.6	44.4	–
Education level of head (years)	6.5	5.8	5.9	6.8	6.2	–
Social assets						
Trust in neighbour (%)	53	68	61	70	65	–
Help received (%)	47	46	39	48	46	–
Natural assets and location						
Inside buffer zone (yes = 1)	67.0	68.0	74.0	65.0	68.0	–
Total land (ha)	35.7	24.1	39.6	24.4	28.3	***
Remaining forest land (%)	63.8	60.2	53.0	64.9	46.6	–
Total crops land (%)	10.7	15.8	1.8	11.0	21.6	***
Total pasture land (%)	14.8	9.5	37.6	13.1	16.6	***
Total fallow land (%)	2.5	3.3	3.5	2.4	10.1	–
Altitude (m)	741	643	1508	872	826	***
Distance to city (minutes)	67.0	79.9	38.9	71.1	70.1	*
Road access to village (yes = 1)	89	0.6	100	76	78	**
Financial assets						
Access to credit (%)	72	52	39	50	54	*
Saving minus debts (US$)	−528	−185	−706	−244	−330	–
Physical assets						
Total stock of livestock (US$)	3443	2199	19,635	2748	4731	***
Goods (yes = 1)	75	56	100	72	69	***
Mobile phone (yes = 1)	17	6	30	17	14	**
Canoe or boat engine (yes = 1)	6	10	0	2	6	–
Car or motorbike (yes = 1)	8	4	26	09	09	**
Income						
Per-capita Income (AE/US$)	480	327	704	373	415	***
Headcount index (extremely poor)	69	80	39	78	78	***

Source: Authors computation from survey data PEN/RAVA – SBR, 2008.
[a] ANOVA for continuous variables; and X^2 for dummy/categorical variables.

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Table 5
Multinomial Logit Model predicting the determinant of households' livelihood adoption. Wage-based strategy (control). (Marginal effects).
Source: Authors computation from survey data PEN/RAVA - SBR, 2008.

Variables	Forest-based strategy	Crop-based strategy	Livestock-based strategy	Wage-based strategy
Ethnicity				
Kichwa (yes)	−0.464 (0.082)	0.150 (0.108)	−0.087** (0.048)	−0.017 (0.100)
Human assets				
Age head household	0.030 (0.022)	−0.000 (0.024)	−0.191 (0.207)	−0.027 (0.020)
Age squared	−0.000 (0.000)	−0.000 (0.000)	−0.000 (0.002)	0.000 (0.002)
Household size	0.170* (0.082)	0.009 (0.013)	0.111 (0.116)	−0.026* (0.013)
Education head (years)	−0.008 (0.011)	−0.016 (0.013)	−0.194 (0.120)	0.009 (0.012)
Location				
Altitude (m)	−0.000 (0.001)	−0.001* (0.001)	0.002*** (0.000)	0.000 (0.000)
Distance to city (minutes)	−0.005 (0.005)	0.002 (0.003)	−0.012** (0.005)	−0.000 (0.000)
Financial assets				
Access to credit	0.176** (0.068)	−0.103 (0.089)	−0.103 (0.732)	−0.069 (0.082)
Physical assets				
Total land (ha)	0.005*** (0.001)	−0.004* (0.002)	0.065*** (0.018)	−0.001 (0.002)
Chi^2 (27)	113.24***			
Numbers of observation	186			
Pseudo R^2	0.23			
Log likelihood	−182.180			

Significance levels: *, **, *** are 90%, 95%, and 99%, respectively. Values in parentheses are standard deviations of the coefficients.

assets (total land) have strong effects on households to adopt Livestock-based LS. Results also show that physical (total land), financial (access to credit) and human (households size) assets are influential factors in adoption Forest-based LS. While physical asset (total land) and location (upper area of SBR) are negatively associate with households engage into Crop-based LS (Table 5).

4.4. Effects of ethnicity and assets on household income

Table 6 presents the marginal effects of Tobit regressions. Belonging to the Kichwa ethnic group increases income from crops by US $ 223. In contrast, colonist households earn, on average, US $ 472 more from livestock than indigenous households. Similarly, colonist wage labourers earn, on average, US$ 182 more than their indigenous peers. Every new household member increases crop income by US $ 43. As expected, more educated people have higher wage earnings; each year of formal education increases wage income by US $ 17.

Residing within the buffer zone of the SBR reduces forest income by US$ 268. In terms of physical and natural capital, households with more land have higher forest income; every hectare of land increases (at 95% probability) forest income by only US$ 9. Conversely, total land negatively affected wage income; every hectare of land decreases (at 90% probability) income from wages by US$ 5. Surprisingly, the remaining forest cover was not significant in any of the four LS. Distance to the city also showed no significant effect on any of the LS. Vehicle access to the community had a significant positive effect of US$ 155 for households within Crops-based LS (Table 6).

5. Discussion

5.1. Determinants of livelihood strategies choices and level of incomes

The results presented above reflect that LS are not based on an individual source of income, but instead on portfolios of different income sources. Thus, of the nine income sources, five were decisive in shaping the four underlying LS (forest-based, crops-based, livestock-based, and wage-based). Similar to previous studies (Jiao et al., 2017; Walelign et al., 2016b; Walelign, 2016; Thanh et al., 2015; Nielsen et al., 2013), our research has determined the probability of a household choosing a particular LS using the MLM. Additionally, we also explain how ethnicity and household asset characteristics affect the level of income in each LS. Moreover, by using mean total income of each LS as the

Table 6

Tobit regression model to determine the effect of ethnicity and assets on the main source of household income for each livelihood strategy (marginal effects).
Source: Authors computation from survey data PEN/RAVA - SBR, 2008.

Variables	Forest-based strategy	Crop-based strategy	Livestock-based strategy	Wage-based strategy
Ethnicity				
Kichwa (yes)	−21.86	223.80**	−472.50***	−182.0***
Human assets				
Age head household	21.73	−10.42	6.275	−7.24
Age squared	−0.30	0.06	−0.06	0.10
Household size	17.37	42.80***	15.73	12.76*
Education head (years)	1.75	−1.43	−1.17	17.21**
Social assets				
High trust (yes)	−2.80	17.57	34.06	48.27
Natural assets and location				
Inside buffer zone (yes)	−268.40**	−4.28	−119.80	−44.32
Remaining forest (%)	−3.53	−5.22	−3.76	3.81
Distance city (minutes)	0.05	0.31	−0.94	0.07
Financial and physical assets				
Total land (ha)	8.77**	3.65	4.37	−5.38*
Road access (yes)	28.80	155.40*	−140.80	40.40
Uncensored observation	110	158	115	137
Chi^2	23.95**	32.92***	29.99***	25.49**

Significance levels: *, **, *** are 90%, 95%, and 99%, respectively.

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dependent variables, the Tobit model shows the effect of ethnicity and livelihood assets as explanatory variables on economic income for each LS.

The MLM analysis showed that ethnicity has strong influence on their choice of LS. Kichwa households were less likely to adopt the Livestock-based LS, in this case the most remunerative LS (Table 5). This confirms our first hypothesis that “ethnicity has strong influence on the households' adoption of LS”. Crop-based LS remains the largest contributor to household total income to Kichwa population (Table 6), confirming the statement that Kichwa populations are more dependent on agriculture (Vasco et al., 2015; Gray et al., 2008). In contrast, mi-grant settlers who are living close to cities adopted the highest remunerative LS. An explanation for this choice could be the better access to markets and information (Walelign et al., 2016a; Porro et al., 2015). Also, as observed by Jiao et al. (2017), households with higher physical asset holdings (in this case the total land) are more likely to engage in more remunerative LS. Financial assets, such as access to any type of credit, are associated with Forest-based LS, a new result in the Amazon and different from other studies where access to credit was related with livestock strategies (Zenteno et al., 2013; Bilsborrow et al., 2004) and off-farm activities (Walelign, 2016; Nielsen et al., 2013;). This could be because, in our case study, most of the credit was informal and usually provided by middlemen timber traders to finance most of the timber operations (Mejía et al., 2015).

Unlike prior research that has found that households in frontier areas are highly dependent on the extraction of natural resources (Porro et al., 2015; Walelign, 2016; Zenteno et al., 2013), our results indicate that off-farm income (including jobs, business and other income such as remittances or land rent) are important income sources. These off-farm activities comprise not < 21% of total income of all LS, and an average of around 40% considering the whole sample, confirming the trend towards income diversification in rural areas of the Ecuadorian Amazon (Gray et al., 2008; Izurieta et al., 2014; Mejía et al., 2015 and Vasco et al., 2015).

It has been reported that rural areas in tropical countries are in-habited by the poorest people (van der Ploeg, 2012). In our study site, the average annual household income in the sample is US$ 1750 re-presenting a PCI of just US$ 0.72 per day, far below the poverty line of 1.25 dollars per capita per day in 2008. However, rural poverty is not distributed homogeneously across LS (Ellis, 1999), which is confirmed in this study, because the four LS showed a marked difference in average incomes (see ANOVA Test, Table 3) and assets (Table 4). Households engaged in Livestock-based LS had the highest average income (US$ 2898), 60% higher than the average income for the rest of the sample; it is the only LS with a daily income (US$ 1.72 per capita) exceeding the poverty line. However, this group has the smallest pro-portion of land in the forest, though the difference was not statistically significant (Appendix D). One explanation for this finding is that grazing systems in the Ecuadorian Amazon Region (EAR) are associated with extensive operations (Lerner et al., 2014; MAGAP, 2014a) and therefore demand larger amounts of land. The higher economic earnings of Livestock-based LS could also be linked to the results of the multi-temporal analysis inside the entire SBR; this analysis showed that in 2007 pasture land covered 72,588 ha, or around 8% of SBR total area, but in 2013 had increased to 81,693 ha, which represents a 9105 ha increase in only five years (MAE-GIZ, 2013).

5.2. Effect of ethnicity on household income

The SBR population comprises around 70% Kichwa and 30% mi-grant settlers (Valarezo et al., 2002). The colonization process began in 1964 (Pichon, 1997; Bilsborrow et al., 2004), and since this time it is likely that these populations have exchanged customs on land use, which has allowed new LS to emerge, shaped mainly by ethnicity and access to natural, human and physical assets. Thus, the variable ethnicity showed strong effects on the level of household income in three of the four LS analyzed (Table 6). This supports our second hypothesis that “ethnicity will affect the level of household income in the determined LS”. The Tobit analysis showed migrant colonists' income from livestock is, on average, US$ 472 higher than that of indigenous households. A possible explanation is that migrant colonists have habitually specialized in cattle ranching, and so have more knowledge, experience and much larger herds (Murphy, 2001; Pichon, 1997). In contrast, be-longing to the Kichwa ethnic group increases annual income from crops by US$ 223. This probably reflects the fact that, in our study crop, in-come relates to production for consumption and sale, and most of indigenous people still practice subsistence agriculture (Vasco et al., 2015). Ethnicity also has a significant effect on off-farm income, with the Kichwa earning, on average, US$ 182 less than their colonist peers. A possible explanation is that settlers tend to live closer to the main towns while the Kichwa usually reside in remote areas. The characteristics of these new LS could be relevant when designing develop-ment and conservation policies. Nevertheless, further characteristics of the LS and ethnicity need to be studied. More research is also needed on improving off-farm activities focusing on people, ethnicity and their knowledge gaps, based on local contexts (Reardon, 2001; Vasco et al., 2015) and the LS they follow.

5.3. Policy implications for sustainable development and forest conservation

Households with livestock as their main LS obtain higher incomes, but also have the smallest mean area of forest remaining on their land (Appendix D), due to the extensive operation that requires the con-version of forests into grassland. This may be related to the tendency to convert primary forest to grassland over time in this study area (GIZ-MAE, 2013). It is important to analyze this scenario in greater detail because there is estimated to be around one million hectares of pasture throughout the EAR, which represents 38% of the total agricultural area in the EAR (MAGAP, 2014b). Additionally, since 2011, the Ecuadorian government in its Agenda for Productive Transformation in the Amazon (ATPA, using its Spanish acronym) has aimed to reduce the area of pastures by converting them into more sustainable production systems and through reforestation and natural restoration.

Off-farm income has become the most important source of income for the households in the study area, when following Wage-based LS (Appendix C). Furthermore, Wage-based LS is the second largest group of households in the SBR. This is probably due to pull factors, including higher demand for skilled and semi-skilled workers in oil companies and governmental offices (Murphy, 2001). It also highlights the urgent need to invest in education to improve not only the human capital, but also increase income levels of the rural population (Vasco et al., 2015). Moreover, in the Ecuadorian Amazon region, the government has focused most of its effort on facilities and road infrastructure, while donors focused mainly on technical assistance related to promoting sus-tainable agricultural systems or forest use, rather than increasing people's skills for off-farm activities. This situation is similar to many rural areas around the world (Reardon, 2001). Policies are needed to support off-farm activities that are responsible for no < 21–78% of the income among the LSs in the RBS. At the same time, improving education levels in the Amazon would help the rural inhabitants of this region to overcome entry barriers that off-farms activities involve.

When analyzing LS and their relationship with forest conservation, it is important to measure the degree of dependence of every LS on different sources of income, especially income sources impacting forest resources. Our results suggest that, by analyzing the data as a whole (without LS), forests are not the main income source. Its contribution to the average household income is around 14%. The first explanation for this finding is the reasoning behind the LS analyses, which suggests that not all households practice homogeneous livelihood schemes (Ellis, 1999). Nevertheless, forest income represents > 50% of the total in-come for those households involved in Forest-based LS, differing significantly from the other three LS (< 5%). At the same time, this

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Forest-based LS has a higher proportion of forest land (65%) compared to the other three LS. The second explanation relates to the fact that some villages are located inside the buffer zone of the SBR. The Tobit regression (Table 6) shows that residing in the buffer zone has a negative effect on forest income across all LS; even within Forest-based LS, forest income is lower for households inside the buffer zone. To conclude, the results show that all LS have a considerable proportion of forest (a mean value of at least 53%) remaining on farms (Appendix D).

However, extreme poverty is prevalent in both populations in the SBR, especially those households focused on Crop-based LS, which is the case in many tropical rural areas around the world (van der Ploeg, 2012). Consequently, in regions like SBR with high natural values, policies must promote socioeconomic development and environmentally friendly entrepreneurial activities such as ecotourism, community-based scientific tourism, bio-trade of non-timber forest products, etc. All these activities must consider the effects of ethnicity and household assets across LS. Consequently, analyzing the LS (Chambers et al., 1981) using the Sustainable Livelihood Framework (SLF) (Bebbington, 1999; Scoones, 1998) provides policy-makers with specific information to design sustainable development and forest conservation policies.

The fact that the proportion of remaining forest cover is not related to higher economic income, neither for Kichwa nor for settlers, might indicate that the forest dependency is relatively low. If soil conditions under forest would be suitable for agriculture or livestock production and if forest legislation would allow, these forests could be considered as vulnerable for conversion into non-forest land. On the other hand, this could also indicate a high potential for PES regimes to enhance forest conservation and sustainable income, especially for Crop-based LS, which is dominated by Kichwa people because they still have remnant forest areas and less income (Vasco et al., 2015). Livestock-based LS should be technically accompanied by silvopastoral advice in areas that are vulnerable to deforestation. Further research is required to study either forestry or conservation potential by means of forest inventories.

In terms of future research, based on our findings we recommend to: a) encourage the sustainable management of remaining forest land within all LS; b) analyze in detail the value chain of local timber markets and the options to assist legal timber harvests, as well as the different actors involved in the forest use, for households involved in Forest-based LS; and c) investigate the optimum household land-use portfolio in each LS (Knoke, 2008; Knoke et al., 2015; Knoke et al., 2009) and their interactions with the provision of ecosystem services (Knoke et al., 2016), to contribute to the debate about sustainable management and conservation of both forest and rural livelihoods.

6. Conclusion

The PCA and AHC are useful techniques for characterizing house-hold typologies and determining LS in rural areas. Moreover, the SLF offers a practical way to understand and gain insights into LS, poverty levels and sustainability. In this context, we analyzed multiple sources of income among households in the SBR and distinguished four LS based on: forest income, crop production, livestock production and wage labour. The findings suggest policy implications to extend the range of LS, especially to lower income groups.

Each LS has a different income portfolio characterized by a distinct composition of assets. Recognizing the different activities based on LS and understanding their implications for poverty reduction and forest conservation, could support efforts to reduce poverty and improve the conservation of natural resources in rural areas.

Our study shows that economic income in the study area is largely decoupled from forest management and conservation. Forest cover re-mains slightly higher in subsistence farm LS dominated by Kichwa, which are on average poorer than settlers. In general, forest cover is still relatively high. Thus, further expansion of the economically most interesting LS based on livestock production could promote deforestation and conversion into pastures. Alternatively, complementary land use strategies would have to be introduced, such as PES for conservation of forests or sustainable forest management of remnant forests, especially for land users living in buffer zones where economic income is lower than in areas outside. Policy-makers should also consider the contribution and composition of on- and off-farm income in each LS, as well as asset endowments that characterize particular LS, to ensure the effectiveness of development plans at local level, and to underpin the implementation of activities in accordance with sustainable development principles.

Acknowledgments

We thank the families of the 32 villages who shared valuable in-formation about their livelihoods with us during the multiple visits. We are also grateful to the park rangers of the "Sumaco Napo Galeras" National Park. We also thank the two networks PEN/CIFOR and RAVA, as well as the World Bank Institutional Development Fund (TF090577) and the Education for Nature Program of WWF for additional financial support. The authors also thank two anonymous referees for their useful comments and feedback.

Appendix A. Component matrix from PCA of the all percentage income source in the study area (n = 186). Factor loadings above 0.5 are in bold

Income portfolios	5 major components extracted				
	PC1	PC2	PC3	PC4	PC5
Wage	0.60	−0.23	−0.11	−0.65	−0.27
Other	0.57	0.56	0.22	0.14	0.12
Crops	−0.57	0.64	−0.38	0.02	−0.05
Forest	−0.55	−0.28	0.66	−0.14	−0.15
Livestock	0.19	−0.62	−0.30	0.67	−0.01
Fish	0.35	0.35	0.45	0.33	0.02
Business	−0.08	−0.29	0.17	−0.08	0.69
Aquaculture	0.03	0.06	−0.26	−0.25	0.62
Environmental	0.01	0.01	−0.37	0.01	−0.13
Eigenvalues	1.52	1.48	1.20	1.10	1.00
% of variance	16.89	16.52	13.33	12.26	11.13
Cumulative (%)	16.89	33.42	46.75	59.02	70.15

Source: Authors computation from survey data PEN/RAVA - SBR, 2008.

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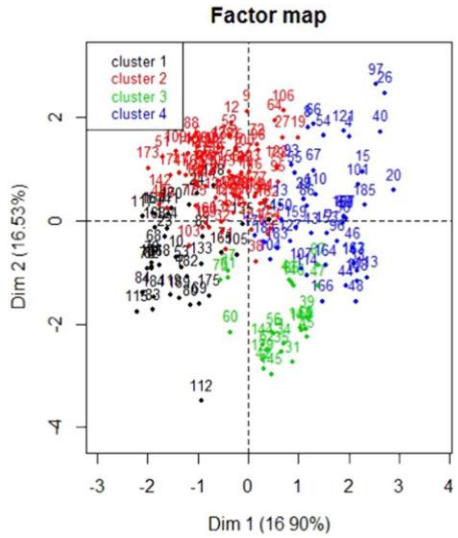
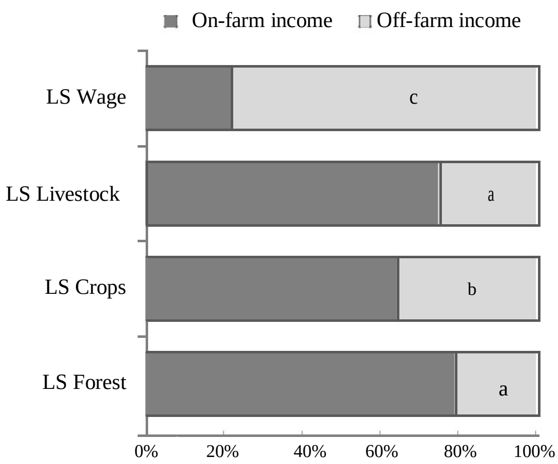
Appendix B. Cluster factor map



Appendix C. On-farm and off-farm income by livelihoods strategies. Letters denote significant differences among LS



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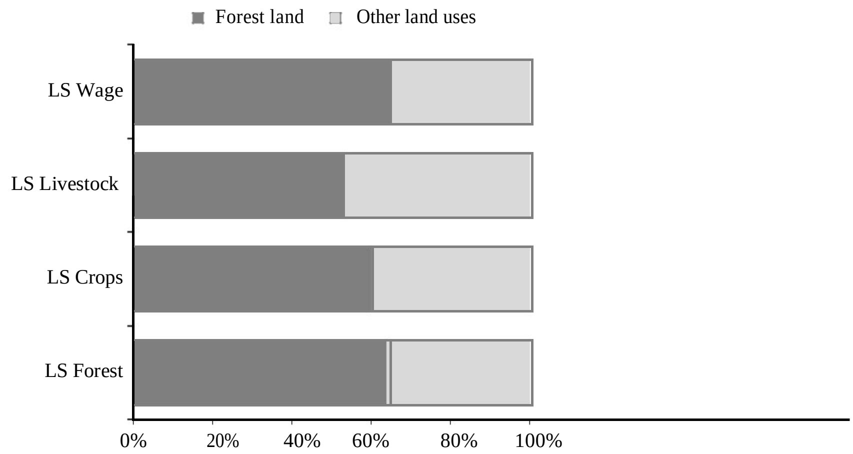
Appendix D. Percentage of remaining forest land among livelihoods strategies



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10.2. Publication 2

Cristian Vasco, Bolier Torres, Pablo Pacheco, Verena Griess. 2017. The socioeconomic determinants of legal and illegal smallholder logging Evidence from the Ecuadorian Amazon[8]. *Forest Policy and Economics Vol*. 78(2017): 133-140. https://doi.org/10.1016/j.forpol.2017.01.015

[8] The original source of this Elsevier article is the journal of Forest Policy and Economics, permission for publication in a Thesis/Dissertation is not required for authors.

Publication 2

Forest Policy and Economics 78 (2017) 133–140

Contents lists available at ScienceDirect

Forest Policy and Economics

journal homepage: www.elsevier.com/locate/forpol

The socioeconomic determinants of legal and illegal smallholder logging: Evidence from the Ecuadorian Amazon

Cristian Vasco [a,b], Bolier Torres [c], Pablo Pacheco [d], Verena Griess [b]

[a] Facultad de Ciencias Agrícolas, Universidad Central del Ecuador, Quito, Ecuador
[b] Department of Forest Resources Management, The University of British Columbia, Vancouver, Canada
[c] Universidad Estatal Amazónica, Km 2 ½ vía Tena, Puyo, Ecuador
[d] Center for International Forestry Research (CIFOR), Jalan CIFOR Situ Gede, Bogor Barat 16115, Indonesia

A R T I C L E I N F O

Article history:
Received 15 August 2016
Received in revised form 18 November 2016
Accepted 17 January 2017
Available online xxxx

Keywords:
Legal logging
Illegal logging
Colonists
Indigenous peoples
Amazon
Ecuador

A B S T R A C T

Using data from a household survey covering colonists and indigenous communities in the Ecuadorian Amazon, this paper analyzes the socioeconomic determinants of legal and illegal smallholder timber harvesting. The results of a multinomial probit model reveal that non-harvesting households are statistically likely to be poor, to receive nonfarm income, to have smaller areas in primary forest and to reside nearer population centers. Illegal logging is more likely to be carried out by poor households that do not have nonfarm income, have larger areas in forest and reside farther away from urban areas. Legal loggers, in contrast, are likely to come from wealthier households that have legal property rights to the land they possess or control but do not take part in nonfarm employment. Ethnicity has no effect on the likelihood of harvesting timber (either legally or illegally) and has only a marginally significant effect on non-harvesting households. The implications of these findings for policy are explored in the conclusions.

1. Introduction

Timber is one of the main sources of income for people living in or near tropical forests (Angelsen et al., 2014; Wunder et al., 2014). Nevertheless, smallholder logging often occurs at unsustainable levels leading to high rates of deforestation and environmental degradation (Geist and Lambin, 2002; Lambin et al., 2001). Timber overexploitation is closely linked to illegal logging which in turn is associated with a number of negative environmental, economic and social effects. Illegal logging often leads to high rates of deforestation, forest degradation and biodiversity loss, threatening not only the rich biodiversity and stability of tropical forests but also the welfare of those who depend on forest resources for their survival (Bowles et al., 1998; Curran et al., 2004). In terms of its economic impacts, illegal logging deprives governments of million dollars in tax revenues and discourages investments in the formal timber sector due to unfair competition from illegal operators (Contreras-Hermosilla, 2001; Hansen et al., 2012; Kaimowitz, 2003).

Smallholder decisions on whether to comply with the law or not, depend not only on smallholder characteristics but also on access to timber markets and institutional factors, mainly regulations (Molnar et al., 2007). Many countries have implemented forestry regulations to organize and control timber exploitation aiming at reducing illegal logging activities and its pernicious effects, nevertheless, a substantial part of smallholder logging still occurs outside the law (Cano-Cardona et al., 2015; FAO, 2012; Pacheco et al., 2008). Understanding the nature and drivers of both illegal and legal logging is important for designing policies favoring the latter while achieving simultaneously environmental and livelihood benefits from tropical forests use.

Relatively scarce empirical research has examined smallholder decisions concerning timber harvest. Amacher et al. (2009) examined the determinants of timber sale – mostly illegal according to the authors – in the Brazilian Amazon. The authors determined that the likelihood of selling wood is higher for formally settled wealthy households that have received credit. Gray et al. (2015) examined the drivers of forest resource use among indigenous populations in the Ecuadorian Amazon. They found that households that have off-farm income, own large farms and reside farther away from urban centers are more likely to sell timber. In the Peruvian Amazon, Escobal and Aldana (2003) found that the probability of harvesting timber is strongly influenced by education, with the likelihood of harvesting timber increasing with schooling up to a level of incomplete secondary education and then decreasing at higher levels of formal instruction. Prior quantitative research, however, has not made a distinction between legal and illegal timber harvest.

With data from a household survey conducted in January–September 2012 in the Napo province, Northern Ecuadorian Amazon, this

* Corresponding author at: Gato Sobral y Gerónimo Leyton, Ciudadela Universitaria, 170521 Quito, Ecuador.
E-mail addresses: clvasco@uce.edu.ec (C. Vasco), bolier.torres@gmail.com (B. Torres), p.pacheco@cgiar.org (P. Pacheco), Verena.Griess@ubc.ca (V. Griess).

http://dx.doi.org/10.1016/j.forpol.2017.01.015
1389-9341/

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paper aims at answering the following research question: do legal and illegal loggers differ in terms of their socioeconomic characteristics? This study distinguishes itself from previous research in at least two ways: 1) it uses an unusual data set covering both indigenous and mi-grant-colonist populations, which allows us to assess the role of ethnicity on logging patterns, and 2) to the best of our knowledge, this is the first quantitative study treating legal and illegal logging as two different categories of analysis. Apart from this introduction, this paper is structured as follows: the next section presents the theoretical framework, followed by a description of the study area, the data source and the statistical methods. The subsequent section presents and discusses the results while the final section pulls together the main conclusions.

2. Theoretical framework

In this study, we take the livelihood model (Ellis, 2000b) as the theoretical framework of smallholder decisions concerning timber harvesting. In the livelihood framework, the rural household is the decision-making unit which makes livelihood decisions subject to different endowments of natural capital (land, water, forest resources), social capital (interpersonal networks, membership in groups and associations), human capital (education, skills, health), physical capital (irrigation canals, implements, roads), and financial capital or its substitutes (cash, savings and cattle). Access to these capitals and the way in which they are combined shape a household's livelihood strategies and the relationship it has with the environment (Bebbington, 1999; Scoones, 1998). For instance, households with high endowments of education but low endowments of natural capital (land and forest) are more likely to earn their livelihood from nonfarm work as a way of both coping with natural resource scarcity and maximizing the returns to education. On the other hand, households with low endowments of education and wealth, and high endowments natural capital (forest) are more likely to obtain their livelihood from timber and non-timber forest products as they lack the qualification and resources to diversify their income sources (Vasco and Bislborrow, 2016).

Livelihood decisions are also determined by a number of contextual factors including institutional factors (functioning of markets, land tenure schemes, common property regimes), cultural factors (gender roles, spiritual connection to land), economic factors (local and international demand for locally produced goods) and environmental changes (cli-mate change) (Sherbinin et al., 2008).

Amacher et al. (2009) focus on smallholder decisions concerning timber sale. According to the authors, smallholder logging decisions are shaped by a number of factors including household demographic characteristics, preference factors, opportunity cost of time and access to forest resources. In this context, logging is more likely to occur if the opportunity cost of labor time is high, the lost utility of non-timber labor is low or the marginal utility of income is high. A higher opportunity cost of labor time reduces the likelihood of selling timber since household utility can be met more easily through other means (i.e., ag-ricultural and nonfarm income).

Smallholders must also make the decision on whether exploiting timber in compliance with forest regulations or doing it outside the law. Forest regulations are a set of rules designed to protect forests from private actors who, in absence of such regulations, may overexploit and deplete forest resources (Agrawal, 2005). Literature presents two main views to explain smallholder participation in illegal forest operations.

The first is related to the high transaction costs of exploiting timber legally. Forest regulations typically define the resources that can be harvested, the processes for obtaining transportation permits as well as payment levels and tax criteria. However, obtaining an exploitation permit and selling timber involves the formulation of management plans and the payment of fees and taxes, the cost of which prevent many smallholders from entering the formal sector and, at the same time, push them to participate in illegal logging (Mejía et al., 2015). In this context, wealthier smallholders are in a better position to pay for the high transaction costs that obtaining a permit for forestry operations entails (Pacheco et al., 2008). In the second view, smallholders voluntarily choose to exploit timber outside the law based on an internal cost-benefit analysis where the trade-offs of selling timber illegally are found to be higher than the risk of being caught and criminalized (Amacher et al., 2009; Perry et al., 2007).

With this theoretical framework, we develop a multivariate regression model to establish the determinants of legal/illegal timber harvest decisions among smallholders in the Northern Ecuadorian Amazon. The implications of this broad theoretical framework regarding the specific effects of sets of household and community characteristics on small-holder logging decisions are presented in the section of results.

3. Methodology

3.1. The study area

The research was carried out in the Sumaco Biosphere Reserve buffer and transition zone in the Napo province, in the Central Ecuadorian Amazon (see Fig. 1), one of the world's biodiversity hotspots (Bass et al., 2010; Myers et al., 2000). Since the late 1960s - when roads were opened to exploit oil reserves - the Amazon region has received continuous migratory waves of poor peasants with little or no land who came from the Highlands and the Coast regions. Colonist communities do not belong to conglomerate territories (which is common for indigenous populations) so farm limits are symmetrical, mostly imposed by two laws of agrarian reform and colonization in 1964 and 1973 (Izurieta et al., 2014). Napo is also home of two indigenous groups, the Waorani and the Kichwa or “Napo Runa” (Izurieta et al., 2014).

The migrant-colonists number approximately 44,000 individuals and account for 43% of the province population (INEC, 2010). Tradition-ally, colonists engage in commercial agriculture including crops such as coffee, cocoa and maize, in addition to considerable cattle ranching (Barbieri et al., 2005). The high rates of population growth in colonist territories has resulted in an accelerated process of land fragmentation and stronger pressure on natural resources. Another effect of the high rates of population growth is the growing share of colonists engaging in nonfarm employment including self-employment (e.g., running a grocery store, cooking meals, selling handicrafts) and wage employment (e.g., public employee, soldier, driver, bricklayer, domestic servant) (Bilsborrow et al., 2004). Although most of the commercially valuable timber in colonist farms has already been harvested, earnings from timber sales account for 19–23% of colonist households' total in-come (Mejía et al., 2015; Torres et al., 2014; Vasco et al., 2015). This principally occurs in communities where timber still exists and roads have been recently opened.

The Kichwa of Napo or “Napo Runa” are the traditional inhabitants of the Northern Ecuadorian Amazon. They are the most numerous ethnic group in Napo with an approximate population of 53,000 individuals (52% of the province total population). While some descriptions account that the Kichwa obtain their livelihood principally from subsistence farming (cassava, plantain and maize), and the collection of forest products, hunting and fishing for self-consumption (Uzendoski, 2004), others report that, when in direct contact with the market economy, they also adopt colonist livelihood strategies including commercial agriculture, cattle ranching and timber logging (Gray et al., 2008). Although indigenous peoples normally control extensive areas of land under common property regimes, population growth and land fragmentation may also be an issue in Kichwa communities (Muzo et al., 2013). In terms of timber logging, prior research (Muzo et al., 2013; Vasco et al., 2015) determined that it accounts for about 10% of total income of Kichwa households already integrated into timber markets. Nevertheless, this share may grow in the future because, in distinction from colonists and other indigenous groups in the Amazon (e.g., the Shuar), the Kichwa still have valuable timber in their lands (Loaiza et al., 2015).

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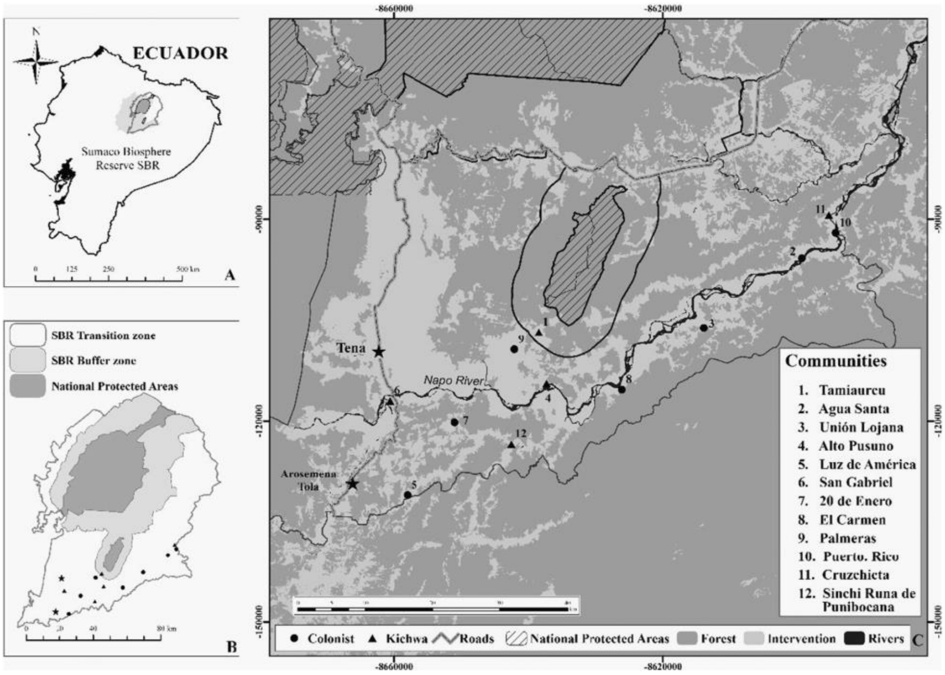

Fig. 1. A) Study area comprising the Napo province and the Sumaco Biosphere Reserve (SBR); B) Communities located within the buffer and transition zones of SBR; C) Mosaic of still forested and heavily intervened areas.

3.2. The data

The data came from a household survey conducted in January–September 2012 in the Napo province, more specifically in the Sumaco Bio-sphere Reserve buffer and transition zone (see Fig. 1). The interest in this area stems from two reasons: 1) an important share of the small-holders in this area engage in legal and illegal timber extraction (GIZ, 2013), and 2) one of the aims of the Sumaco Biosphere Reserve buffer and transition zone is improving the quality of life of the local population while promoting the conservation of natural resources through sustainable management practices, including legal timber logging (Valarezo et al., 2002).

A prototype questionnaire from the Poverty and Environment Net-work project (PEN-CIFOR, 2007) was adapted to gather information on household demographic characteristics (education, age-gender household composition, and ethnicity), land use, household assets, agricultural and non-agricultural income and social capital. Additional-ly, an independent section collected information on timber harvesting and legal and illegal operations, which makes this dataset useful for this study.

Households were selected using a two-stage sampling method (Goodman and Kish, 1950). First, twelve communities (Table 1) were selected following criteria of: 1) ethnicity, including a balanced sample of colonist and Kichwa households; 2) distance to the nearest accessible road; 3) distance to the nearest town of more than 10,000 inhabitants; and 5) population size and density including large communities (more than 40 households) and small communities (less than 40 households). Variability in these criteria insures a good representation of communities and improves the robustness of the study (Cavendish, 2003). In the second stage, households were randomly selected from a list including all the households in the community, which was provided by com-munity leaders. A total of 124 households (49 colonist and 75 Kichwa)

Table 1
List of communities in the sample.

Cantons	Parish	Communities	Predominant ethnic group	Number of surveyed households
Tena	Puerto Misahualli	Alto Pusuno	Kichwa	4
		Sinchi Runa Punibocana	Kichwa	16
		San Gabriel	Kichwa	4
	Ahuano	El Carmen	Colonist	8
		Palmera	Colonist	7
		Tamiahurco	Kichwa	26
	Chontapunta	Cruzchicta	Kichwa	18
		Puerto Rico	Colonist	8
		Agua Santa	Colonist	7
		Unión Lojana	Colonist	13
	Puerto Napo	20 de Enero	Colonist	7
Arosemena Tola	Arosemena Tola	Luz de América	Colonist	6
Total sample size				124

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were interviewed in 12 communities (7 colonist and 5 Kichwa).[1] While not strictly a statistically representative sample, the procedure above described insures good representation of the diverse livelihoods in the research area.

3.3. Multivariate analysis

As decisions concerning smallholder timber harvesting are made simultaneously rather than individually, we use a multinomial probit model to estimate the likelihood for a household either not to harvest timber, to harvest timber legally or to harvest timber illegally during the year preceding the collection of data. We prefer using this method-ology since – in distinction from other approaches (i.e., multinomial logit) – it is robust to identical irrelevant alternatives (IIA) (Wooldridge, 2002). We therefore used a model of the following form:

$$P_i^c = \Pr(TIMBER = c \mid X_i) = F(X_i \beta_i^c) \quad (1)$$

where P^c is the probability of household *i* to select one of the three categories *c* (not harvesting timber, harvesting timber legally and harvesting timber illegally the 12 months before the survey). *X* is a vector of household head, household and community characteristics to be de-scribed later on, and β_i is a vector of coefficients the size and direction of which are to be determined. Since the coefficients of a multinomial probit model are not directly interpretable, we rather estimate and re-port the marginal effects of the model.

Table 2 shows the descriptive statistics and the definitions of the variables used in the analysis. The dependent variables are three dichotomous variables taking the value of 1 if the smallholder either do not harvest timber, harvest timber legally or harvest timber illegally. The predictors presented below are expected to explain smallholder logging decisions.

Household head predictors include age and education level, which is controlled for by two binary variables taking the value of 1 if the head has completed primary and secondary education, respectively.[2] Age squared is also included in the specification in order to capture any possible nonlinearity between age and the dependent variables. The role of ethnicity on timber harvesting decisions is controlled for by a binary variable taking the value of 1 provided the head identifies himself/her-self as Kichwa, with colonist individuals as the comparison group (=0).

Among household-level characteristics, the household size account for the effect of labor availability on logging decisions. Better-off house-holds may be in a better position to overcome the “entry barriers” (bureaucratic processes and transaction costs) that formal logging entails than those who, on the other hand, lack the resources to engage in legal forestry operations (Pacheco et al., 2008). In order to control for this effect, we include a wealth index which is the first principal component of the possession of car, motorcycle, bicycle, TV, radio, cellphone, gas stove, spray pump and rifle. We prefer using this approach because, in distinction from simple count indices, which assign equal values to every asset, it provides higher weights to assets having more discriminatory power concerning household wealth (Filmer and Pritchett, 2001; Kuntashula et al., 2009). There is a possibility that reverse causality and thus simultaneity exist between wealth and logging. Nevertheless, it is not an issue here since the wealth index is a construct of assets accumulated over a relatively long period of time, which greatly reduces the risk of endogeneity.

As referred to earlier in the theoretical framework, smallholder logging decisions may be affected by the opportunity cost of devoting labor time to agriculture and non-agricultural activities (Amacher et al., 2009). We control for the opportunity cost of nonfarm work by including a dummy variable taking the value of 1 has the household received nonfarm income during the 12 months preceding the survey. The natural logarithm[3] of the household total agricultural area (crops and pastures) is included as a proxy of the amount of time (labor) a household devotes to agricultural activities. There is a possibility that reverse causality arises due to the fact that agricultural land in 2012 may be influenced by logging decisions of that same year. In order to avoid this effect, we rather use the area devoted to agriculture in 2006 as a predictor. Agricultural and non-agricultural work compete with logging for household labor and so are expected to have a negative effect on the likelihood of harvesting timber (Sunderlin et al., 2005).

Access to forest and secured land tenure are also reported to affect timber harvesting decisions (Amacher et al., 2009; Pacheco et al., 2008). In order to control for these effects, the natural logarithm of the area in primary forest in 2006 and a dummy taking the value of 1 provided the household has legal titling to the farm are added to the specification. Additionally, the natural logarithm of the total land area available for use, which is the total area a household possesses (in the case of colonists) or controls (in the case of indigenous peoples),[4] is included in the model.

The type of land tenure (i.e., community vs. private rights) may be an important determinant of logging decisions (Muzo et al., 2013). Nevertheless, we do not control for this here as this effect is captured by ethnicity, with colonists normally having private rights over land and its resources and indigenous smallholders typically holding common property rights over the land allocated to them, and so requiring permission from the community asamblea (assembly) to exploit timber.

Decisions of logging timber may be prompted by shocks threatening smallholders welfare (Amacher et al., 2009; Muzo et al., 2013). In order to control for this, a dummy variable taking the value of 1 if the house-hold has experienced a crisis the 12 months before the data were collected is added to the specification.

Finally, we proxy the level of market integration by including the travel time from each community to the nearest city with a population higher than 10,000 people -which in all the cases was Tena, the provincial capital. This strategy is consistent with prior research (Gray et al., 2008; Vasco et al., 2015) using the distance to larger towns as a proxy for market integration. We prefer using the travel time instead of the actual distance because - in the Ecuadorian Amazon context, where road density is low and transportation by foot and boat is common - it is a more accurate measure of distance to markets.

Preliminary models considered other controls including dummies for female headship, reception of the Governmental social transfer “Bono de Desarrollo Humano” and access to credit. Although prior re-search on tropical forests (Angelsen and Kaimowitz, 1999; Pichón and Bilsborrow, 1999) found that these covariates may shape natural re-source use, they were removed from the final model, given the relatively reduced sample size and their little contribution to improve the model fit.[5]

[1] While there are more colonist communities in the research area –possibly due to earlier settlement-, population in colonist communities tend to be lower due to factors such as lower fertility rates compared to those in indigenous communities and out-migration to urban areas and other provinces (Bilsborrow et al., 2004). In order to have adequate and balanced representation of colonists in the sample, more colonist communities were included in the sample. In any case, the proportion of indigenous and colonist households in our sample (61 and 39%, respectively), are reasonably consistent with the figures for the Napo province as a whole (57 and 43%, respectively) (INEC, 2010).

[2] No household head in the sample held a university degree.

[3] We use natural logarithms in order to reduce the effect of outliers.

[4] All colonist households in the sample have or claim private rights over their farms (see Table 2). Indigenous peoples, instead, have or claim collective rights over their territories. Bremner and Lu (2006) state that there are several forms of collective property in the Ecuadorian Amazon, going from a system in which community's land can be used by all members and is claimed through the cultivation of a plot, to semi-private schemes which involve that a plot of land is allocated to each household by the community assembly or “asamblea”. All indigenous communities in our sample belong to the second group.

[5] The Akaike and Bayesian information criteria (AIC and BIC, respectively) demonstrated that removing the above-mentioned variables resulted in better goodness of fit.

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Table 2
Descriptive statistics and definitions.

	Description	Overall (mean)	Colonist (mean)	Kichwa (mean)
Independent variables				
No harvest (0/1)	Household has not harvested timber the 12 months before the survey	0.29	0.28	0.31
Harvest illegally (0/1)	Household harvested timber without permit from the Ministry of Environment the 12 months before the survey	0.39	0.30	0.44
Harvest legally (0/1)	Household harvested timber with permit from the Ministry of Environment the 12 months before the survey	0.31	0.42	0.23
Dependent variables				
Age	Age of household head	46.86 (14.26)	52.97 (14.86)	42.86 (12.41)
Primary education (0/1)	Household head has completed primary education	0.79	0.73	0.82
Secondary education (0/1)	Household head has completed secondary education	0.08	0.06	0.09
Colonist (0/1)	Household head is colonist	0.39 (0.49)	–	–
Kichwa (0/1)	Household head is Kichwa	0.61	–	–
Household size	Number of persons in the household	5.64 (2.17)	5.54 (2.10)	6.36 (1.92)
Wealth	Wealth index constructed from household assets	0.000 (1.71)	0.886 (1.695)	-0.612 (1.459)
Nonfarm income (0/1)	Household has nonfarm income	0.16	0.16	0.17
Agricultural land	Area in crops and pasture in 2006 (ha)	4.20 (7.77)	6.07 (9.77)	2.94 (5.79)
Area in forest	Area in primary forest in 2006 (ha)	8.65 (13.03)	8.42 (12.14)	8.95 (13.64)
Total land area available for use	Households total land (ha)	21.11 (19.39)	26.21 (20.71)	18.05 (17.93)
Land title (0/1)	Household has formal title to land	0.69	0.86	0.59
Crisis (0/1)	Household had a crisis the year before the survey	0.45	0.38	0.51
Distance to market	Travel time from the community center to Tena (minutes)	28.88 (15.87)	29.17 (16.23)	28.70 (15.75)

Note: (0/1) identifies dummy variables. Standard deviations in parenthesis for continuous variables. While we take the logs of agricultural land, area in forest and total land available for use in the regression analysis, we use non-logged values here for ease of understanding.

4. Results and discussion

4.1. Descriptive analysis

To begin with, the accuracy and reliability of self-reported data on illegal logging warrant some discussion. When the topic under investigation is either sensitive or illegal, the data may be affected by "social desirability bias" (Nuno and ST. John, 2015). In the Ecuadorian Amazon, exploiting timber outside the law is a controversial activity so that smallholders may purposely choose not to report or to under report il-legal forestry operations due to fear of retaliations. If that is the case, there is the possibility that self-reported figures of illegal logging are biased which would lead to inexact results and misleading interpretations. We use several strategies to address this potential source of bias. Prior research (Tourangeau and Yan, 2007) has stated that the charac-teristics of the survey taker may influence responses, with respondents being more likely to divulge/hide sensitive information depending on the characteristics of the person who delivers the survey. In this sense, our survey team was composed of indigenous and colonist undergraduate students who in most cases were native to the area. In distinction from other agents who may require such information (e.g., public employees, forest rangers), survey takers with such characteristics are normally not perceived as a threat by smallholders, who, on the contrary, were willing to cooperate with the survey team. In the questionnaire utilized, questions concerning legal/illegal logging were asked near the end of the survey. This strategy is expected to reduce the likelihood of false responses to sensitive questions (Brace, 2008). Additionally, we simultaneously checked the self-reported data against the data set of the Ministry of the Environment for legal timber operations, so that we were able to identify the group of smallholders who actually had permit to exploit timber. While there is still the possibility that some illegal loggers respond that they are not harvesting any timber at all, the characteristics of both the questionnaire and the survey takers are expected to greatly reduce the possibility of collecting biased data. Fur-thermore, prior research on sensitive topics in the Amazon (i.e., wildlife hunting) showed that self-reported values are relatively accurate and useful. For instance, in a very similar environment, Vasco and Sirén (2016) found the self-reported values of wild life harvesting and hunted biomass reports to be reasonably consistent.

Table 2 shows that there is little difference in the share of house-holds that do not harvest timber among colonist and Kichwa house-holds (28 and 31%, respectively). However, there are marked differences among logging households, with most colonists (42%) harvesting timber legally and most Kichwa (44%) logging without permit from the Ministry of the Environment.

Colonist heads are older than their Kichwa peers which is probably related to younger colonists migrating to urban areas in search of work and older household members staying and assuming household headship (Bilsborrow et al., 2004). Comparatively, more Kichwa heads completed primary and secondary school than their colonist peers. While this result stands in contradiction to national figures reporting that, overall the non-indigenous population has higher schooling levels than indigenous peoples (INEC, 2010), it is consistent with prior case studies showing that indigenous peoples in the Amazon have higher schooling levels than colonists (Vasco et al., 2015). On average, Kichwa households are larger than their colonist peers, which is likely related to higher fertility rates among indigenous peoples in the Amazon (Bremner et al., 2009). Although it is difficult to interpret the values of the wealth index, the negative sign for Kichwa households may reflect that, on average, they are poorer than their colonist counterparts in terms of the assets upon which the index was constructed (Kuntashula et al., 2009).

There is little variation in the share of participation in non-agricultural work among colonist (16%) and Kichwa (17%) households. This figure is modest if compared to the 38% reported by Vasco et al. (2015) for Pastaza, in the central Ecuadorian Amazon. This may reflect

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that income diversification opportunities in the study area are rather scarce.

The mean agricultural area of the Kichwa in 2006 (2.9 ha) is half as large as that of colonist households (6.0), which is consistent with the figures reported by Vasco et al. (2015) (3.12 and 6.5 ha for Kichwa and colonists, respectively). This difference is likely related to colonists more often engaging in commercial agriculture (cash cropping and cattle ranching) (Muzo et al., 2013) and so devoting more land to agricultural uses. There is little difference in the area in forest for colonists (8.4 ha) and Kichwa households (8.9 ha). Nevertheless, the total area available for use is considerably larger for colonist (26 ha) than for Kichwa smallholders (19 ha), so in relative terms, Kichwa households keep larger areas in forest.

In terms of land tenure, more colonists (86%) hold formal property rights over land than Kichwa smallholders (59%). Comparatively, more Kichwa households (51%) have experienced a crisis than their colonist peers (38%), with sickness of a household member being the most com-mon type of crisis for both ethnic groups. Finally, there is no difference in the mean travel time to Tena between colonist and Kichwa communities. This differs from other areas in the Amazon where indigenous peoples are settled farther away from urban areas (Vasco et al., 2015; Vasco and Sirén, 2016).

4.2. Regression analysis

Table 3 presents the marginal effects of a multinomial probit model where smallholders harvesting timber legally are taken as the comparison group. The significant predictors for each dependent variable are discussed below.

The results show that non-harvesting households are less likely to be headed by a Kichwa. It is worth noting, however, that this effect is weak (significant at only at 90% probability). Furthermore, the dummy ac-counting for Kichwa headship has no effect on the likelihood of extracting timber (either legally or illegally). Overall, indigenous house-holds are as likely to harvest timber as their colonist counterparts. This finding is consistent with prior research (Godoy, 2001; Gray et al., 2008; Rudel et al., 2002) stating that indigenous peoples also engage in profit-oriented activities, including timber logging (either legal or illegal) when in contact with colonists and the market economy. It is worth noting, however, that the volume of timber harvested by Kichwa small-holders (8.7 m^3/year on average) is considerably smaller than that extracted by colonists (36 m^3/year on average).

Table 3

Determinants of smallholder timber logging decisions (marginal effects).

	No harvest	Harvest illegally	Harvest legally
Age	0.000	−0.023	0.022
Age squared	−0.000	0.000	−0.000
Primary education (0/1)	0.088	−0.029	−0.059
Secondary education (0/1)	0.002	0.117	−0.120
Kichwa (0/1)	−0.272*	0.098	0.174
Household size	−0.013	0.022	−0.008
Wealth	−0.054***	−0.032**	0.087***
Nonfarm income (0/1)	0.156**	−0.216**	−0.373**
Agricultural land	0.093	−0.103*	0.010
Area in forest	−0.115***	0.099**	0.016
Total land area available for use	−0.002	0.003	−0.000
Land title (0/1)	−0.090	−0.088	0.179**
Crisis (0/1)	0.084	0.084	−0.168
Distance to market	−0.336***	0.201**	0.134
Number of observations	124	124	124
Wald test	39***		

Note: *, **, *** stand for statistical significance at 10, 5 and 1% levels, respectively. (0/1) identifies dummy variables.

Wealth has a significant effect on the likelihood of harvesting timber either legally or illegally. On one hand, wealthier households are less likely to exploit timber illegally, while on the other hand, they are more likely to obtain a permit from the Ministry of the Environment for their forestry operations. This finding is consistent with the theoretical insights presented in the theoretical framework section and indicates that wealthier smallholders have the financial capital to pay for the high costs that obtaining a forestry operation permit involves.

Having nonfarm income reduces the livelihood of harvesting timber either legally (by 37%) or illegally (by 21%), but increases the likelihood for a household not to harvest timber (by 15%). A possible explanation is that, in the Ecuadorian Amazon, nonfarm earnings tend to be higher than those obtained from agriculture (Vasco et al., 2015) so that it is possible that nonfarm earnings relax household needs to harvest timber to cover basic needs. A second possibility has to do with the opportunity cost of time since having a business (e.g., owning a grocery store, cooking meals for sale, selling handicrafts) or a full-time non-agricultur-al job (e.g., public employee, soldier, worker in an oil company) greatly reduces the time available for, in this case, harvesting timber (Angelsen and Kaimowitz, 1999; Ellis, 1999, 2000a).

In addition, the total agricultural area has no effect on the three de-pendent variables under study which may reflect that, in distinction from nonfarm work, agricultural work does not directly compete with timber harvesting for household labor. On the contrary, both activities appear to be compatible rather than exclusive. In this sense, several studies (Muzo et al., 2013; Vasco et al., 2015) depicted that smallholders harvest and sell timber as a byproduct of land clearing for agricultural purposes only if there are valuable species in the plot and the transport from the point of harvest to markets is feasible.

Households with less land in primary forest in 2006 are less likely to exploit timber in 2012. A 1% increase in the area in forest in 2006 leads to a reduction of 11% in the likelihood of not harvesting timber in 2012. In contrast, 1% increase in the area in forest in 2006 increases the likelihood of harvesting timber illegally by 10% in 2012. A possible interpretation of these results is that those who already exploited timber in the past do not have much timber left to harvest at present. In contrast, those who had larger areas in forest in the past are exploiting timber il-legally at present. The lack of significance in the case of legal harvest may reflect that it is determined by a forest management plan and forest regulations rather than by availability of timber, thus availability of timber may not play a significant role in shaping legal operations.

Having legal rights over the land increases the likelihood of exploiting timber legally by 18%. This finding supports the statement that securing property rights to smallholders in frontier environments will promote the use of more sustainable land use and forest management practices (Godoy et al., 1998; Pichón, 1997) and, at the same time, will reduce incentives for illegal forest resource use (Pacheco et al., 2008). Household crises do not play any role in driving timber har-vest decisions. This is consistent with prior research (Mejía et al., 2015; Muzo et al., 2013), which found that timber sales are not necessarily a mean to overcome financial crises but a way to cover essential needs (food, housing, education and health).

Finally, distance to markets also plays a role in shaping logging decisions. Non-harvesting smallholders tend to reside closer urban areas whereas illegal loggers live farther away Tena. A possible explanation for these findings is that timber was already logged in the surroundings of Tena while it is still available in more remote areas. In the case of illegal harvesting, it may also reflect that law enforcement is less intense in remote areas.

5. Conclusions and policy recommendations

This paper has examined the determinants of legal and illegal timber harvesting decisions among colonist and indigenous populations in the Ecuadorian Amazon. Summarizing the main findings, non-harvesting households are statistically likely to be poor, to have at least one

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member engaged in nonfarm employment, to have smaller areas in forest and to be located closer Tena. Moving on to illegal logging, this activity is principally carried out by poor households that do not receive nonfarm income, have larger areas in forest and are settled farther away Tena. In terms of who engage in legal forestry operations, these are wealthier households which do not participate in nonfarm employment and have legal property rights over the land they possess or control.

High transaction costs are probably the principal restriction preventing smallholders from obtaining a logging permit. These include registration fees, formulation of a forest management plan, payment of a forestry advisor, payment of a tax advisor and other administrative procedures. Poor households lack the resources to pay for these costs and are therefore pushed to harvest timber illegally. Although Ecuador has greatly simplified the requirements for obtaining a logging permit in comparison to other countries in the region (Mejía et al., 2015), our results reflect that additional efforts are needed to support poorer smallholders to overcome the "entry barriers" that legal logging involves. This is particularly important because the findings presented here show that illegal loggers are precisely those who have larger areas in forest and so are more likely to keep extracting timber in the future.

Smallholders holding legal titling over their plots are more likely to engage in legal forest operations. This supports the claims of those who advocate for the recognition of smallholders' property rights as a strategy to reduce tropical deforestation. While in the Ecuadorian Amazon most colonists have legal titles to land and extensive areas have been titled to indigenous peoples under common property regimes; the evidence presented here shows that, in some areas, an important share of smallholders (principally indigenous) still lack formal land titling. Practitioners should address this issue have they the intention of promoting legal logging in the Amazon.

Contrary to the common belief that indigenous peoples use more sustainable forest management practices than colonists, the results of this case study reveal that indigenous households are as likely to harvest timber (either legally or illegally) as their colonist peers. It is important to note, however, that colonists harvest four times as much timber as Kichwa smallholders. In any case, "indigenous stewardship" of forests should not be taken for granted as indigenous peoples in the Amazon are every time more integrated into the timber markets. This finding is especially important since indigenous peoples have, in relative terms, larger areas devoted to forest.

Nonfarm employment is negatively correlated with the likelihood of harvesting timber either legally or illegally. This suggests that promoting non-agricultural work may be a useful strategy to reduce deforesta-tion in the Amazon (Vasco et al., 2015). Nevertheless, the degree to which nonfarm employment can become an effective tool to reduce logging remains to be evaluated.

Keeping in mind the above points, practitioners for sustainable development, agencies and governmental organizations fostering legal logging should focus on: 1) reducing the costs and simplifying the process for obtaining a legal logging permit in order to support small-holders in overcoming the "entry barriers" of legal logging, and 2) improving land titling (especially among indigenous peoples) as a way to promote legal logging among smallholders.

Acknowledgements

This paper draws on data collected in the province of Napo, Ecuador, under a Letter of Agreement between the Universidad Estatal Amazónica (UEA), Ecuador, and The Center for International Forestry Research (CIFOR), Indonesia as a part of the EU-funded project "Policy and Regulatory Options to recognize and better integrate the domestic timber sector in tropical countries" (PRO-FORMAL), grant number EuropeAid/ENV/2010-242904/TPS. The first author's work was also supported by the National Secretariat for Science and Technology of the Republic of Ecuador (SENESCYT), grant number 051-CIBAE-2015. Filippo Del Gato, Aymé Muzo, Elena Mejía, Rolando López, Viviana Chico, Hugo Armijos, Félix Grefa and Lucy Andrade assisted with field work.

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10.3. Publication 3

Bolier Torres, Cristian Vasco, Sven Günter, and Thomas Knoke. 2018. Determinants of agricultural diversification in a hotspots area: evidence from colonist and indigenous communities in the Sumaco Biosphere Reserve, Ecuadorian Amazon. In: *Sustainability*. Vol. 10(5), 1432. https://doi.org/10.3390/su10051432

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sustainability MDPI

Article

Determinants of Agricultural Diversification in a Hotspot Area: Evidence from Colonist and Indigenous Communities in the Sumaco Biosphere Reserve, Ecuadorian Amazon

Bolier Torres [1,2,*], Cristian Vasco [3], Sven Günter [4] and Thomas Knoke [1]

1. Institute of Forest Management, Department of Ecology and Ecosystem Management, TUM School of Life Sciences Weihenstephan, Technische Universität München, 85354 Freising, Germany; knoke@tum.de
2. Facultad de Ciencias de la Vida, Universidad Estatal Amazónica, Km 2 $\frac{1}{2}$ vía Tena (Paso lateral), Pastaza 160101, Ecuador
3. Facultad de Ciencias Agrícolas, Universidad Central del Ecuador, Quito 170129, Ecuador; clvasco@uce.edu.ec
4. Thünen Institute of International Forestry and Forest Economics, 21031 Hamburg, Germany; sven.guenter@thuenen.de

* Correspondence: btorres@uea.edu.ec

Received: 23 February 2018; Accepted: 2 May 2018; Published: 4 May 2018

Abstract: With data from a household survey covering migrant settlers and indigenous (Kichwa) communities in the Sumaco Biosphere Reserve (SBR), this study analyses the drivers of agricultural diversification/specialisation, focusing on the role of ethnicity and the livelihood strategies (LS) they follow. Data were collected using the Poverty and Environment Network methodology of the Center for International Forestry Research (CIFOR-PEN). In order to establish the drivers of agricultural diversification, the number of crops and the Shannon index of crops areas were used as the dependent variables in ordinary least square (OLS) models, while a multinomial logit model (MLM) was used to assess a household's degree of diversification. The results of the OLS regression provides evidence supporting the notion that households, with Livestock-based and Wage-based livelihood strategies (LS) are less diversified and more specialized than households with Crop-based LS. Ethnicity has a positive and significant effect on agricultural diversification, with Kichwa farms more diversified than those of their migrant colonist counterparts. The results of the multinomial logit model (MLM) show that large Kichwa households, with Crop-based and Forest-based LS are more likely to adopt a highly diversified agricultural strategy. Based on these findings, we recommend a redirection of agricultural incentives, towards the adoption of diversified agricultural systems, as a strategy to promote more sustainable production systems in the Ecuadorian Amazon Region.

Keywords: crops-livestock; Shannon diversity index; indigenous; OLS; MLM

1. Introduction

Worldwide, almost half of the total usable land is now pastoral or intensive agriculture in use [1]. These systems produce about half of the world's food and are essential in addressing rural food insecurity and poverty in developing countries [2]. However, these systems are also considered to be the major cause of the continuous loss of tropical forests and degradation of tropical ecosystems [3] due to the expansion of the agricultural frontier [4–6]. Such land use changes have been responsible for around 12% of global CO_2 emissions over the last decade (2007–2016) [7]. Most of these estimations have been made using a large database with a global prediction subject to a high level of

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uncertainty. Whilst the problems are global, solutions must be treated at local, regional and global levels [1]. Hence, one of the principal challenges for researchers is increasing agricultural production without damaging the environment [4–6] and the facilitation of policy recommendation. In this sense, agricultural diversification is frequently identified as a potential strategy that contributes towards more sustainable and competitive commodities, increasing rural incomes, generating on-farm employment and alleviating poverty.

Hence, this paper uses the concept of Joshi and colleagues who consider agricultural diversification as "a shift of resources from one crop (or livestock) to a larger mix of crops and livestock, keeping in view the varying nature of risks and expected returns from each crop/livestock activity and adjusting it in such a way that it leads to optimum portfolio of income" [8] (p. 2457). In this context, several authors argue that diversification could improve risk management and alleviate poverty, economic crises, internal/external shocks [9–13], natural disturbances and climate change [6,14,15] while increasing food security and dietary diversity [14,16]. Despite the increase of industrialization in agriculture, millions of small-scale famers in rural areas still use diversified agricultural systems to produce sustained yields for their subsistence needs [14,17]. Previous local empirical studies have examined agricultural diversification and its relationship with household livelihoods in a wider context, for example, by examining poverty alleviation [10] and agricultural risk management [18,19]. Some authors also reported differences concerning the determinants of agricultural diversification. For instance, Tung [20] found that larger agricultural areas favour specialization rather than diversification, while McNamara and Weiss [21] state the opposite effect. Babatunde and Qaim [22] conclude that diversification increases with overall household income, whilst Jones et al. [16] suggest that wealthier households in Malawi accomplish a more diversified production without expanding the cultivated land area. On the other hand, a study conducted in a semi-arid agricultural system in Kenya outlines the influence of precipitation on crop diversity [15]. Furthermore, Bartolini and Brunori [23] observe that proximity to popular tourist areas and urban markets plays an important role in shaping on-farm diversity income. Such studies show that agricultural diversity is affected by a wide range of variables and show the need to conduct case studies in particular areas.

Several approaches are available to measure agricultural diversification. In many cases, the use of proportional abundance measures of diversity methods, for example, Simpson [16,20,24], Hirfendahl [22,25,26] and the Shannon equitability index of diversity [27–29] are appropriate. These methodologies are suitable for determining agricultural diversification or specialization and have usually been applied in economic literature. However, for the purpose of calculating the diversification of the crop area, we used the Shannon diversity index (H_{crop_area}). To classify the degree of diversification, we used the Shannon equitability index for crop area (E_{crop_area}). In the latter, a zero value indicates specialization and values greater than zero denote some degree of diversification [25]. In conjunction, we also used the simple richness index method that measures the total number of different crops a household grows, which is used in several studies [10,15,21,23]. In addition, to estimate the determinants of agricultural area diversification, a number of methodologies have been applied. We employed Ordinary Least Squares (OLS) since the outcomes have a small proportion of zero values as a fraction of the number of crops within the whole sample in our study area and a multiple regression using OLS is appropriate in these cases [16,25,30]. Moreover, to analyse the factors associated with the households' degree of diversification choice, a Multinomial Logit Model (MLM) was employed.

In Ecuador, one of the world's most mega-diverse countries [31,32], about 90% of the deforested area in the last two decades was converted somehow into agricultural areas, as a result of forests converted into crops and pastures [33]. The Ecuadorian Amazon Region (EAR) has experienced this same pattern of an expanding agricultural frontier. The EAR is a region that comprises about 48% of Ecuador's total surface area, with a population growth of 5.1% (up to the year 2010). The population is predominantly rural, with around 60 in extensive agricultural production systems [34]. It is estimated that throughout the EAR, there are around one million hectares of pastureland [35]. The Ecuadorian

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government in its Agenda for Productive Transformation in the Amazon (ATPA, for its Spanish acronym) has aimed at reducing the area of pastures by converting them into more sustainable production systems through reforestation and natural restoration. In these contexts, research on local production systems and traditional knowledge linked to sustainable agriculture is urgently needed in the EAR.

Conducting a study at a household level, in the transition and buffer zone of the Sumaco Biosphere Reserve in the EAR (Figure 1), we depart from the hypothesis that agricultural diversity is affected by ethnicity and the livelihood strategies (LS) that a household pursues with consequences on socioeconomic variables. Hence, this paper focuses on issues of agricultural diversification in a biological hotspot area inhabited by indigenous populations and migrant-settlers 50 years after colonization. The following questions are assessed: (i) How does diversification relate to livelihood strategies in terms of agricultural area and income sources? and (ii) What are the socioeconomic factors related to higher diversification?

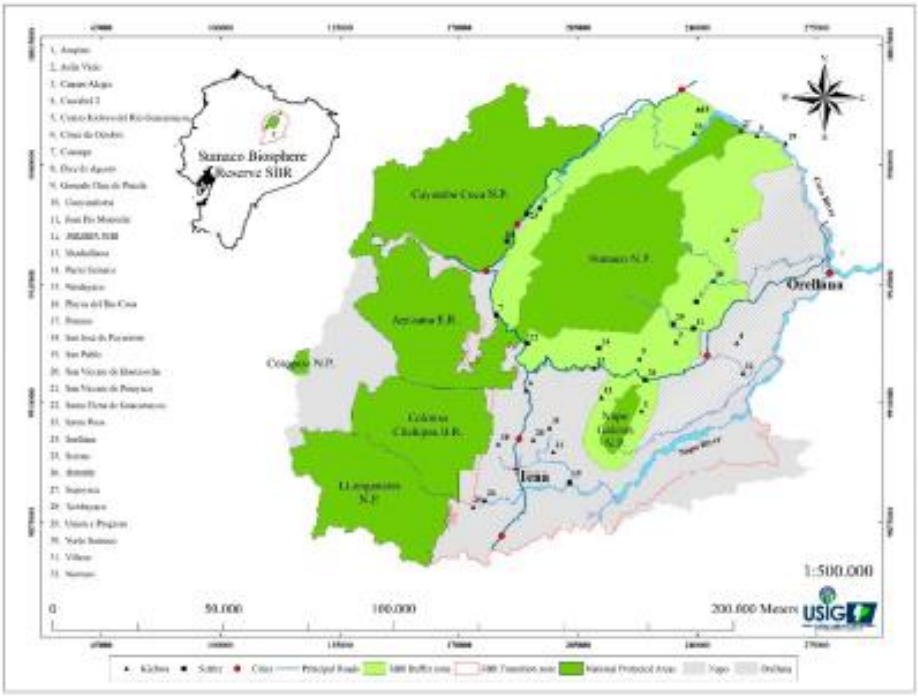

Figure 1. Map of the study area showing the thirty-two communities selected in the Sumaco Biosphere Reserve's (SBR's) buffer and transition zone in the provinces of Napo, Sucumbíos and Orellana.

Hence, this study aimed at (a) examining the agriculture diversification by LS using the Shannon diversity index of agriculture (Crops and livestock); and (b) evaluating the effect of LS and ethnicity on the degree of agriculture diversification using a range of high, medium and low diversification determined from the Shannon equitable index. Finally, as a basis for potential policy implications we discuss if agricultural diversification in rural livelihood strategies could lead to more sustainable production systems.

The paper is organized as follows: the next section briefly describes the material and methods, including the study area and the statistical methods used to analyse the effect of livelihood strategies, ethnicity and other socioeconomic factors affecting a household's agricultural diversification. Next, the results are described followed by the discussion, policy implications and main conclusions.

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2. Materials and Methods

2.1. Study Area and Agricultural Contexts

The northern and central part of the EAR, prior the petroleum era, was populated by indigenous people and very few colonists, with the forest landscape largely intact [36]. Since the discovery of crude oil in 1967, this region began to be occupied by agricultural settler families [37] who migrated from other rural areas of Ecuador [38,39], then roads were laid down for the oil exploitation and the Agrarian Reform Laws were enacted (1964 and 1972), which stimulated the colonization of Amazonian forest land [37,39]. These factors have promoted an intense process of land use change that generally follows similar productive and survival strategies, including the cultivation of subsistence and cash crops, pasture to raise cattle [40–42] and timber logging [39,41,43], as well as land fragmentation due to population growth [38,40]. However, during the last two decades, Ecuador has made efforts to encourage sustainable development. In 2008, Ecuador became the first country to grant legal rights to nature, with the aim of improving livelihoods and agricultural production systems in the EAR [42] and in 2011 with the government announced the ATPA, which promotes a sustainable productive transformation [35].

This study was conducted in the buffer and transition zones of the Sumaco Biosphere Reserve (SBR), where around one million hectares of tropical forest were established as a biosphere reserve by UNESCO's Man and Biosphere program (Biosphere reserve are "areas of terrestrial and coastal/marine ecosystems or a combination thereof, which are internationally recognized within the framework of UNESCO's Programme on Man and Biosphere (MAB)' (Statutory Framework of World Network of Biosphere Reserves") in 2000. This site was officially recognized by the Ecuadorian government in 2002. Its core area of conservation is the Sumaco Napo Galeras National Park (PNSNG), which is comprised of 205,751 ha [44]. The SBR is located in the central northern EAR. The SBR is spread between the provinces Napo, Orellana and Sucumbios and borders four important protected areas: Cayambe Coca National Park, Llanganates National Park, Antisana Ecological Reserve and Colonso-Chalupas Biological Reserve (Figure 1).

According to the Sevilla Strategy, each biosphere reserve serves three complementary functions: "a conservation function, to preserve genetic resources, species, ecosystem and landscapes; a development function, to foster sustainable economic and human development and a logistic support function, to support demonstration projects, environmental education and training and research and monitoring related to local, national and global issues of conservation and sustainable development" [45] (p. 4). Thus, the buffer and transition zones fulfils the development and logistic support functions respectively and this is where the communities within the SBR are located (Figure 1).

The SBR is part of an important ecosystem in the Amazonian foothills, located in an altitudinal gradient from tropical rain forest, 300 to 3732 m above sea level at the Sumaco volcano's summit. The area is part of the hotspot called the 'Uplands of Western Amazonia' [31,46]. Nevertheless, like many other areas of high biodiversity which are under threat from habitat destruction [32], the SBR also faces high rates of deforestation and land use change. From 2008 to 2013, the SBR lost 93,853 hectares of native forest [47]. This accounts for a 10.8% shift to other land uses over a period of 5 years, with a deforestation rate of 2.16% in the whole SBR. This change exemplifies a strong conversion from forests to land for pasture, crops and fallow [47].

Currently, the human population in the SBR is approximately 206,000 and the average annual growth rate is 3% [47]. Most of inhabitants are indigenous Kichwa and less than 40% are migrant settlers.

For most migrant settlers and some Kichwa populations in the SBR, the agricultural systems are made up mainly of cash crops, such as pasture for cattle (Figure 2), cocoa (*Theobroma cacao* L.), coffee (*Coffea canephora* Pierre ex A. Froehner), maize (*Zea mays* L.) and naranjilla (*Solanum quitoense* Lam.), in addition to staple crops, such as yucca (*Manihot esculenta* Crantz), plantain (*Musa paradisiaca* L.) and peach palm (*Bactris gasipaes* Kunth) [48–51]. These trends are fairly similar to those found in the northern Ecuadorian Amazon Region [37,39,41] and by Vasco et al. [52] and Lerner et al. [53] in the central and southern Ecuadorian Amazon Region, respectively.

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Figure 2. Traditional silvopasture system, Arosemena Tola, Ecuadorian Amazon Region.

For most of the Kichwa population, the "Chakra" system is the most common traditional agroforestry system [48,51,54,55]. It is characterized by its high level of biodiversity and high number of timber-yielding and fruit trees [48,51,56,57]. The chakra in the SBR is also considered a polyculture [48,56], where the principal crops are cocoa (*Theobroma cacao* L.), coffee (*Coffea canephora* Pierre ex A. Froehner) and nowadays guayusa (*Ylex Guayusa* Loes) [58,59]. These crops grow alongside plants used for medicine, spiritual rituals, making crafts and other consumption purposes [48], as well as together with forest trees (see Vera et al. [56]) and fruit trees for consumption and multipurpose materials (Figure 3). According to Torres and colleagues [51] there are nearly 12,500 ha of cacao cultivated in the chakra system in the buffer and transition areas of the SBR, with the size of chakra plots ranging from 0.5 to 4 ha [51].

Figure 3. Traditional agroforestry system (Chakra) based on cocoa plants, Archidona canton, Ecuadorian Amazon Region.

2.2. Data Collection

This study used the Poverty and Environment Network (PEN) methodology developed by CIFOR [60]. This approach consisted of four quarterly questionnaires at a household level, two annual household surveys (separated by twelve months) and, two community-level annual surveys. The questionnaires were administered to a sample of 186 households. Households were selected in two steps. Firstly, 32 communities were randomly selected (21 Kichwa and 11 settler), accounting for 12% of the total number of communities (300) inside the buffer and transition zone of the SBR (Table 1; Figure 1). The use of this approach ensures a fair representation of the communities and improves the robustness of the results [61]. The proportion of Kichwa and migrant settlers' communities in our sample is consistent with that reported for the SBR as a whole (70% Kichwa and 30% migrant settlers [62]. Next, five to seven households were randomly selected in each community.

Table 1. Main characteristics of the communities selected for the household survey within the Sumaco Biosphere Reserve, 2008.

Community	Elevation m.a.s.l.	Ethnic Group	Population	Major Agricultural Activities
Arapino	538	Kichwa	120	Agriculture, agroforestry
Avila Viejo	596	Kichwa	400	Agriculture, agroforestry
Campo Alegre	420	Settler	490	Agriculture, cattle
Cascabel 2	343	Kichwa	300	Agriculture, timber
Centro K. Rio Guacamayos	628	Kichwa	300	Agriculture, agroforestry
Cinco de Octubre	325	Kichwa	60	Agriculture, agroforestry
Cosanga	2004	Settler	700	Cattle, fish ecotourism
Diez de Agosto	377	Kichwa	80	Agriculture, agroforestry
Gonzalo Diaz de Pineda	1625	Settler	350	Cattle, monoculture
Guayusaloma	1997	Kichwa	108	Agroforestry, cattle
Juan Pio Montufar	497	Settler	700	Agriculture, timber
Makana Cocha	325	Kichwa	130	Agriculture, timber
Mushullacta	936	Kichwa	600	Agriculture, agroforestry
Pacto Sumaco	1519	Settler	600	Agroforestry, cattle
Pandayacu	472	Kichwa	550	Agriculture, agroforestry
Playas del Rio Coca	566	Kichwa	124	Agriculture, agroforestry
Pununo	414	Settler	250	Timber, Agriculture
San José de Payamino	304	Kichwa	325	Agriculture, agroforestry
San Pablo	349	Kichwa	500	Agriculture, agroforestry
San Vicente de Huaticocha	621	Settler	220	Cattle, agriculture
San Vicente de Parayacu	825	Kichwa	22	Agriculture, agroforestry
Santa Elena de Guacamayos	1646	Settler	135	Cattle, agriculture, fish
Santa Rosa	1493	Settler	350	Cattle, agriculture
Sardinas	1706	Settler	600	Cattle, agriculture
Serena	544	Kichwa	280	Agriculture, agroforestry
Shandia	514	Kichwa	320	Agriculture, agroforestry
Supayacu	395	Kichwa	55	Agriculture, agroforestry
Tambayacu	699	Kichwa	500	Agriculture, agroforestry
Union y Progreso	761	Settler	150	Agriculture, cattle
Verde Sumaco	324	Kichwa	290	Agriculture, agroforestry
Villano	821	Kichwa	370	Agriculture, agroforestry
Wamani	1174	Kichwa	700	Agroforestry, cattle

Source: Analysis from survey data PEN/RAVA—SBR, (project grant TF090877), 2008.

This paper is part of a collaborative research project conducted in the Amazon region seeking to understand the heterogeneity of livelihood patterns and the level of dependency on environmental resources in Amazonian contexts characterized by local or traditional populations engaged in agricultural activities. The project was implemented in 2008–2010 by a team of researchers linked to the Network for the Study of Livelihoods and Environment in the Amazon (RAVA). RAVA's tangible objective was to generate a solid shared regional database to define which Amazonian communities rely on natural resources and on agriculture for their livelihoods. This project is also part of the PEN.

2.3. *Identification of Livelihood Strategies*

We adopted the livelihood strategy clusters identified by Torres et al. [42]. These authors used two multivariate techniques: (a) first a Principal Component Analysis (PCA) to reduce dimensionality using the proportion of nine income sources. The nine income variables used in the PCA were the relative earnings from: environmental resources, fishing in rivers, aquaculture (fish ponds), business activities, wages from employment, forestry uses, agricultural production, livestock production and other activities; (b) followed by an Agglomerative Hierarchical Clustering (AHC), where the first five major

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components resulting from the PCA were used and accounted for 70.15% of the cumulative variance of the original income data, which was considered sufficient to develop the HCA. Thus, Torres et al. [42] determined four LS, namely Forest-based, Crop-based, Livestock-based and Wage-based. In the same study, the percentage of crop land and pasture land, as well as the total income, differed significantly across the four household LS with $p < 0.001$. These differences are analysed in this paper, including a break-down of each crop. In addition, we analysed the effect of the four LS and ethnicity on agricultural diversification.

Additionally, two important household characteristics of LS should be considered from a previous study: (a) firstly, that the proportion of the remaining forest land was in average 64% for those households engaged in Forest-based LS, 60% for those in Crop-based LS, 53% for households in Livestock-based LS and 65% for households in Wage-based LS; (b) secondly, that off-farm income (including jobs, business and other income such as remittances or land rent) are important income sources in the SBR. These off-farm activities comprise not less than 21% of the total income of all LS and an average of around 78% for those households engaged in Wage-based LS [42].

2.4. Computing Agricultural Diversification

To measure agricultural diversification amongst the LS, we first used the number of crop areas (NCA), which involves the numbers of household crops and pasture areas. Secondly, we measured the level of agricultural crop area diversification, computing the Shannon diversity index (H_{crop_area}). This methodology is commonly used to assess species diversity [63]. The complete formula of the H applied in this paper is described as follows:

$$H_{crop\_area} = -\sum_{i=1}^{S}[(cropshare_i) \times ln(cropshare_i)], \quad (1)$$

where, S is the number of farm crop area sources and $cropshare_i$ is the share of crop area from activity i in total household crop area. The Shannon index H_{crop_area} takes into account both the number of crops sources and their evenness. Based on this H index, the Shannon equitability index, E, is calculated as:

$$E_{crop\_area} = \left(-\frac{H_{crop\_area}}{\sum_{i=1}^{S}\left(\frac{1}{S} * ln\left(\frac{1}{S}\right)\right)} \right) \times 100, \quad (2)$$

where the denominator is the maximal possible H and E ranges from 0 to 100, reflecting the share of the actual crop area diversification in relation to the maximum possible diversity of crop area.

2.5. Modelling Agricultural Diversification and Their Determinants

We used a linear regression model to examine the determinants of agricultural diversification. Ordinary least square regression shows the determinant variable for each category versus the base category (in our case, crop-based strategy). We therefore used a model with the following form:

$$Y_i = \beta X_i + \varepsilon_i \quad (3)$$

where Y is the number of crop area source (NCS) and H_{crop_area}, X is a vector of individual and household characteristics described in Table 2, β is a vector of coefficients, the direction and magnitude of which are of interest in this study and ε stands for the disturbance term.

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Table 2. Descriptive statistics of dependent variables used in the regression models.

Variables	Nature	Description	Mean (Standard Deviation)
Dependent variable (OLS)			
Hcrop_area	Continuous	Shannon diversity index of crop area	0.75 (0.5)
NCS	Continuous	Number of crop sources (Richness)	2.9 (1.6)
Dependent variable (MLM)			
Household degree of crop area diversification	Categorical	Values taken from one to three based on the results of the Shannon equitable diversification status of Ecrop_area: high diversification, medium diversification and low diversification	
Independent variables			
Forest-based LS	Dummy	Numbers of households in forest-based LS (0/1)	36
Crop-based LS	Dummy	Numbers of households in crop-based LS (0/1)	81
Livestock-based LS	Dummy	Numbers of households in livestock-based LS (0/1)	23
Wage-based LS	Dummy	Numbers of households in wage-based LS (0/1)	46
Age head household	Continuous	Age of household head (years)	44.4 (12.1)
Household size	Continuous	Number of household members	6.6 (3.4)
Ethnicity (Kichwa)	Dummy	Household head is Kichwa (0/1)	66
Education head	Continuous	Length of formal education of household head (years)	6.2 (3.5)
Access to credit	Dummy	Households access to any type of credit (0/1)	54
Subsistence income	Continuous	Percentage of subsistence income	24.2
Remaining forest land	Continuous	Percentage of remaining forest cover on farm	46.6
Total land	Continuous	Household's total land (ha)	28.3 (20.5)
Inside buffer zone	Continuous	Percentage of households inside the buffer zone/SBR	68
Distance city	Continuous	Time it takes to reach cities from communities (minutes)	70.1 (62.8)
Road access	Dummy	Availability of road to access village by car (0/1)	78

Notes: OLS Ordinary least square. MLM multinomial logit model. LS Livelihood strategies. (0/1) identifies dummy variables.

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Additionally, we used a multinomial logit model to identify the determinants of the degree of agricultural diversification. The MLM shows the determinant variables for each category versus the base category (in this case, crop-based strategy). We chose this methodology because it is appropriate for determining the influence of a selected set of explanatory variables on a dependent variable with more than two unordered outcomes [64]. In this case, the model's dependent variable is the result of the diversification degree from the Shannon equitable indices (E_{crop_area}), with the three determined agricultural diversification levels: high diversification, medium diversification and low diversification, which accounted for fifteen independent variables (Table 2). Thus, the model was specified as the probability of occurrence of a particular degree of diversification given the independent variables. We therefore used a model of the following form:

$$\Pr(Y_i = K - 1) = \frac{e^{\beta_{K-1} \cdot X_i}}{1 + \sum_{k-1}^{K-1} e^{\beta_k \cdot X_i}}, \quad (4)$$

where K is the number of diversity degrees (in this case three), one of which is the main level of diversification of an individual i, X is a vector of independent variables and β is a vector of coefficients the magnitude and direction of which are of fundamental interest for this study. The dependent variables are the three diversification levels. The model contained fourteen explanatory variables: forest-based LS, livestock-based LS, wage-based LS, ethnicity, age of household head, education of household head, household size, access to credit, forest land, total land, allocation, distance to city and road access (see Table 2 for a more detailed description). The average total income was not included in the model to avoid endogeneity since the four LS were developed from income percentages.

3. Results

The following section uses cross-sectional study results to examine households' agricultural area and income distributions among four livelihoods strategies identified in the SBR. We also describe the result of the econometrics analyses, presenting relationships between variables and the determinants of agriculture diversification.

3.1. *Agricultural Area Distribution across Livelihood Strategies*

The mean household cultivated area across all LS was 7.64 ha. The main crops according to their proportion of area were: pasture (36%), traditional agroforestry system (locally known as Chakra) (36%), coffee (14%), cocoa (11%), maize (11%), naranjilla (3%), cassava (2%), rice (1%), plantain (1%) and other crops (2%). However, only pasture, chakra, coffee and maize were statistically significant with $p < 0.001$ among the four livelihood strategies (Table 3).

However, for households engaged in the Forest-based LS, the most important crops in terms of cultivated areas were: pastures (43%), chakra (19%), cocoa, coffee and corn (around 8%) and naranjilla (6%). For Crop-based LS households, the most representative crops were chakra (25%), coffee (23%), pastures (20%), maize (16%) and cocoa (12%). For Livestock-based LS, pastures constituted 87% of their area, followed by cocoa and coffee (with about 3%). For Wage-based households LS, pastures accounted for (34%), followed by chakra (18%), cocoa (15%) and maize (9%). The highest mean area under cultivation was Livestock-based households LS, with around 16 ha. The lowest average was in Wage-based LS, with around 5 ha (Table 3).

3.2. *Agricultural Income Distribution among Livelihood Strategies*

Table 4 presents the results from a one-year period for the nine most important agricultural income sources assessed in this study. A total of fourteen crop products were reported. Five of these crops were present in a few households with irrelevant quantities. This category was labelled as "other" and includes citrus fruits, peach palm, avocado and tree tomato. Regarding the overall sample, income from cocoa, coffee and livestock are the most important, accounting for about 15% of the total

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crop-livestock income. For those households engaged in Forest-based LS, naranjilla (24%), cocoa (20%) and coffee (15%) are the most important crops for income generation. Crop-based LS consisted of households with four main crops sources: coffee (23%), maize (16%), cocoa (15%) and yucca (13%). Households in Livestock-based LS obtained substantial income from two sources: livestock and coffee, representing (82%) and (14%) of total crop-livestock income respectively. Households in Wage-based LS attained income from three sources: cocoa (21%), livestock (12%) and yucca (14%). However, in absolute terms, households in Livestock-based LS obtained the highest agricultural income with an average of U.S.$2725. While the lowest agricultural income was obtained for those households in Wage-based LS with an average of U.S.$315 (Table 4).

3.3. Crop-Livestock Area and Income Relation among Livelihood Strategies

Figure 4 shows the relative proportion of crop-livestock area (a). The average share of pasture area was 38%, whilst for Livestock-based it was 86%, followed by Forest-based (45%), Wage-based (35%) and Crop-based (21%). The remaining proportion of land in Figure 4a concerns crop areas. To better understand the relationship between cultivated areas and income, we also computed the relative crop-livestock income for the whole sample and for each LS. Thus, the livestock income average in the whole sample accounted for 16% of total household crop-livestock income. Furthermore, for households engaged in livestock-based LS, the average livestock income was around 86% of the total agricultural income, followed by wage-based LS (15%), Crop-based LS (3%) and Forest-based LS (2%) (Figure 4b).

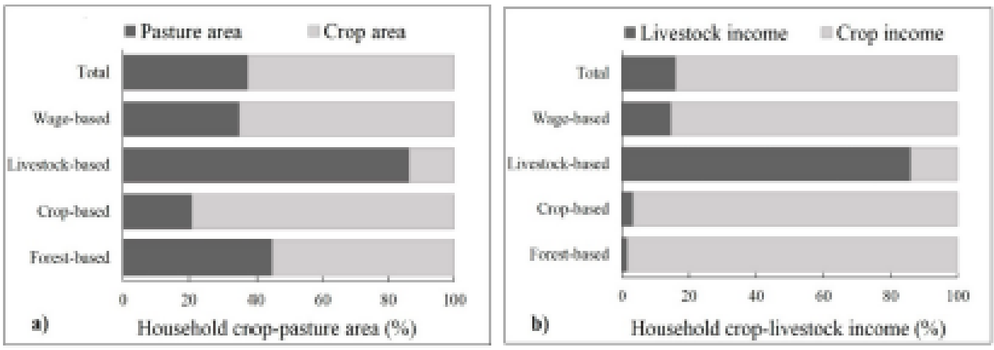

Figure 4. Average share of: (**a**) household crop and pasture area; (**b**) crop and livestock annual household incomes across the four livelihood strategies.

3.4. Agricultural Diversity Indices

We used three different measurements of agricultural diversity, using crop area sources. Thus, the majority of farmers were diversified in their cropping activities, with an average in the whole sample of 0.75 in the Shannon-Weaver H_{crop_area} index, 0.61 in the equity index and 2.9 in numbers from crop sources (Table 5). About 18% of the households were specialized producers growing a single crop only, the majority being in grasslands for cattle ranching and cocoa plantation, most of them involved in Livestock-based LS and Wage-based LS.

The H_{crop_area} differed significantly across the four LS ($p < 0.001$). Crop-based LS showed the highest average index (0.94), followed by Forest-based LS (0.83) and Wage-based LS (0.61). Meanwhile the lowest index (0.20) was in households involved in Livestock-based LS (Table 4). We also computed the numbers of crop sources (NCS) as another measure of diversification. The results reflect an average of 3.4 and 3.3 for number of crops per household in Crop-based LS and Forest-based LS, respectively, whilst the lowest average was obtained in households within the Livestock-based LS (1.8) (Table 5).

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Table 3. Average of area shares of different crops and pastures by livelihood strategies.

Crop Area/LS	Absolute (Abs.) and Relative (Rel.) Mean Crops Sources: Forest-Based Strategy $n = 36$		Crop-Based Strategy $n = 81$		Livestock-Based Strategy $n = 23$		Wage-Based Strategy $n = 46$		Overall $n = 186$		Significance
	Abs. (ha)	Rel. (%)	Abs. (ha)	Rel. %	Abs. (ha)	Rel. %	Abs. (ha)	Rel. %	Abs. (ha)	Rel. %	
Maize	0.55^{a} (0.81)	8.7 (13.9)	0.70^{a} (0.85)	15.5 (20.8)	0.13^{b} (0.43)	1.2 (3.7)	0.26^{b} (0.50)	9.1 (20.0)	0.49 (0.76)	10.8 18.6)	***
Rice	0.06 (0.24)	1.5 (6.0)	0.06 (0.20)	1.9 (6.3)	- -	- -	0.02 (0.10)	0.5 (3.6)	0.04 (0.17)	1.3 (5.2)	-
Cassava	0.03 (0.12)	0.4 (1.2)	0.05 (0.15)	2.3 (11.5)	- -	- -	0.03 (0.15)	2.8 (14.9)	0.04 (0.13)	1.8 (10.6)	-
Plantain	0.09 (0.22)	1.2 (3.2)	0.05 (0.17)	1.1 (3.2)	0.03 (0.11)	0.2 (0.8)	0.038 (0.15)	0.9 (3.4)	0.05 (0.17)	0.9 (3.1)	-
Naranjilla	0.41^{a} (0.74)	6.3 (12.6)	0.22^{a} (0.55)	3.3 (8.6)	0.04^{b} (0.20)	0.1 (0.8)	$0.10^{a,b}$ (0.31)	2.1 (7.1)	0.21 (0.52)	3.2 (8.8)	**
Cocoa	0.59^{a} (0.89)	7.6 (12.3)	0.51^{a} (0.70)	12.0 (19.3)	0.10^{b} (0.25)	3.0 (10.5)	0.54^{a} (0.92)	14.8 (23.3)	0.49 (0.77)	10.7 (18.7)	*
Coffee	0.55^{a} (0.95)	8.6 (14.9)	0.78^{a} (0.91)	22.6 (44.3)	0.06^{c} (0.17)	2.7 (10.5)	0.29^{b} (0.72)	8.6 (19.3)	0.52 (0.85)	14.0 (32.1)	***
Crops in *Chakra*	1.68^{a} (2.28)	18.9 (22.6)	1.01^{a} (1.34)	24.8 (45.3)	0.29^{c} (1.05)	1.1 (2.9)	$0.77^{b,c}$ (1.06)	18.3 (22.7)	0.99 (1.52)	19.1 (34.1)	***
Pasture	5.41^{a} (7.30)	43.4 (38.3)	2.34^{a} (5.15)	20.5 (29.9)	14.8^{b} (11.1)	86.5 (28.5)	3.15^{a} (4.74)	33.7 (40.2)	4.68 (7.60)	36.4 (39.8)	***
Other	0.08 (0.22)	0.8 (2.1)	0.11 (0.37)	1.3 (4.8)	0.14 (0.30)	4.9 (20.7)	0.02 (0.10)	2.2 (14.7)	0.08 (0.29)	1.8 (10.7)	-
Total mean crop area	9.5^{b} (7.31)	100	5.88^{a} (5.78)	100	15.67^{c} (11.61)	100	5.26^{a} (5.02)	100	7.64 (7.63)	100	***
Total mean property size †	35.7^{b} (18.4)	100	24.1^{a} (18.1)	100	39.6^{c} (22.7)	100	24.4^{a} (22.0)	100	28.3 (20.55)	100	***

Significance was performed for the mean of crops areas in absolute terms (ha). Significance levels: *, **, *** are 90%, 95% and 99%, respectively. Values in parenthesis are standard deviations of the mean. Letters in superscript denote significant differences among LS based on ANOVA test. † Total mean plot size includes forest and fallow land and was added to examine the proportion of agriculture area in the discussion section. Source: Authors computation from survey data PEN/RAVA—SBR, (project grant TF090577), 2008.

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Table 4. Average of income sources among livelihood strategies (LS) in absolute terms (U.S.$) and percentage share of total crops and livestock income.

Crops/LS	Absolute (Abs.) and Relative (Rel.) Mean Crops Sources								Overall $n = 186$		Significance
	Forest-Based Strategy $n = 36$		Crop-Based Strategy $n = 81$		Livestock-Based Strategy $n = 23$		Wage-Based Strategy $n = 46$				
	Abs. (U.S.$)	Rel. %	Abs. (U.S.$)	Rel. %	Abs. (U.S.$)	Rel. %	Abs. (U.S.$)	Rel. %	Abs. (U.S.$)	Rel. %	
Maize	66.8 ^{a,b} (138.3)	11.4 (23.9)	132.9 ^{b} (224.9)	15.9 (20.6)	22.0 ^{a} (68.1)	0.7 (1.8)	30.5 ^{a} (79.0)	9.3 (18.8)	81.1 (172.7)	11.5 (20.0)	***
Rice	- -	- -	6.7 (27.0)	1.4 (5.7)	- -	- -	16.3 (110.5)	1.0 (6.9)	7.0 (57.6)	0.9 (5.1)	-
Cassava	42.9 (175.2)	5.8 (18.1)	85.3 (167.7)	13.2 (20.0)	198.0 (934.7)	3.3 (15.3)	53.3 (137.5)	13.5 (25.2)	83.1 (358.7)	10.6 (121.3)	-
Plantain	26.5 (46.5)	8.9 (20.3)	40.3 (54.6)	7.8 (13.1)	26.7 (102.3)	0.7 (1.8)	16.1 (34.8)	8.9 (21.4)	30.0 (57.8)	7.4 (16.5)	-
Naranjilla	323.5 ^{a} (936.8)	23.9 (35.5)	161.6 ^{a,b} (500.1)	9.8 (23.0)	9.3 ^{b} (32.9)	0.7 (2.8)	30.8 ^{b} (135.2)	5.0 (19.5)	141.8 (539.1)	10.2 (25.0)	*
Cocoa	112.5 ^{a} (214.1)	19.8 (33.5)	112.7 ^{a} (176.0)	14.7 (21.4)	29.2 ^{b} (62.7)	1.2 (3.1)	56.1 ^{b} (102.2)	21.2 (32.3)	88.4 (161.7)	15.7 (26.5)	*
Coffee	86.0 ^{a,b} (171.2)	15.2 (24.6)	166.1 ^{b} (259.0)	22.5 (27.6)	14.2 ^{a} (40.0)	14.0 (5.3)	25.4 ^{a} (71.7)	9.4 (19.9)	97.1 (200.1)	15.3 (24.5)	***
Livestock	16.0 ^{a} (68.7)	1.5 (6.4)	46.0 ^{a} (186.2)	3.13 (13.6)	2221.8 ^{b} (1475.3)	82.3 (27.4)	76.5 ^{a} (242.1)	12.0 (32.0)	316.8 (896.8)	14.8 (33.0)	***
Other	29.9 ^{a} (64.7)	5.1 (11.1)	132.3 ^{a,b} (450.1)	9.0 (18.6)	203.6 ^{b} (511.1)	5.5 (11.2)	9.7 ^{a} (51.3)	2.2 (9.9)	91.0 (353.3)	6.1 (14.8)	*
Total agricultural income	704.1 ^{a,b} (917.1)	100	884.3 ^{b} (807.9)	100	2725.0 ^{c} (1754.0)	100	314.8 ^{a} (365.5)	100	936.2 (1159.9)	100	***
Total Household income †	2021 ^{a,b} (1618)	100	1449 ^{a} (1154)	100	2898 ^{b} (1736)	100	1353 ^{a} (1586)	100	1750 (1524)	100	***

Significance was performed for the mean of crops-livestock income in absolute terms (U.S.D). Significance levels: *, *** are 90% and 99%, respectively. Values in parentheses are standard deviations of the mean. Letters in superscript denote significant differences amongst LS based on the ANOVA test. † Total household income included forest and off-farm income and was added up in order to examine the proportion of contribution of agriculture income in the discussion section. Source: Authors computation from survey data PEN/RAVA—SBR, (project grant TF090577), 2008.

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Table 5. Shannon index, richness by livelihood strategies.

Crops/LS	Absolute and Relative Mean Crops Sources				Overall $n = 186$	Significance
	Forest-Based Strategy $n = 36$	Crop-Based Strategy $n = 81$	Livestock-Based Strategy $n = 23$	Wage-Based Strategy $n = 46$		
H_{crop_area}	0.83 (0.49)	0.94 (0.50)	0.20 (0.29)	0.61 (0.51)	0.75 (0.54)	***
E_{crop_area} (%)	67.08 (32.15)	74.20 (33.30)	21.04 (27.27)	56.41 (41.64)	61.85 (38.36)	***
Number of crop area sources (NCS)	3.3 (1.6)	3.4 (1.5)	1.8 (1.0)	2.4 (1.3)	2.9 (1.5)	***

Notes: *** stand for significance at 99%. Standard deviations are in parentheses. H_{crop_area} Shannon diversity index of crop area. E_{crop_area} (%) Percentage of Shannon diversity index of crop area Source: Authors computation from survey data PEN/RAVA—SBR, (project grant TF090577), 2008. 3.5. Determinants of Agricultural Diversification.

The results of the multiple linear regressions for the determinants of household crop area diversification, as well as the number of crop sources are presented in Table 6. On average, households with Livestock-based LS have lower *NCS* and H_{crop_area} than their peers with Crop-based LS. A similar pattern is observed for households mostly engaged in Wage-based LS, which, ceteris paribus, exhibit lower levels of crop diversification. Households with Forest-based LS have only lower H_{crop_area} than those with Crop-based LS, Whilst the NCS and H_{crop_area} are higher for households located in communities next to a road.

Table 6. Ordinary least squares (OLS) regression predicting the determinant of crop area diversification.

Variables	*NCS*	H_{crop_area}
Livelihoods strategies		
Forest-based LS	−0.513 (0.292)	−0.195 * (0.093)
Livestock-based LS	−1.786 *** (0.329)	−0.642 *** (0.097)
Wage-based LS	−0.833 *** (0.244)	−0.263 *** (0.086)
Individual variables		
Kichwa (yes)	0.825 *** (0.287)	0.351 *** (0.096)
Age of household head	−0.001 (0.052)	−0.006 (0.018)
Age squared	−0.000 (0.000)	0.000 (0.000)
Education of head (years)	−0.022 (0.030)	−0.002 (0.010)
Household variables		
Household size	0.017 (0.030)	0.015 (0.010)
Access to credit (yes)	0.203 (0.201)	0.046 (0.065)
Forest land (ha)	−0.021 (0.012)	0.003 (0.004)
Total land (ha)	0.052 *** (0.011)	0.007 * (0.003)
Community variables		
Inside buffer zone (yes)	−0.202 (0.241)	−0.062 0.078)
Distance to city (minutes)	−0.001 (0.001)	0.000 (0.000)
Road access (yes)	0.765 *** (0.265)	0.196 ** (0.093)
Numbers of observation	186	186
F (14, 171)	12.44 ***	20.12 ***
Pseudo R^2	0.375	0.406

Notes: NCS Number of crop sources. *, **, *** stand for significance at 90%, 95% and 99%, respectively. Standard deviations are in parentheses. Source: Authors computation from survey data PEN/RAVA—SBR, (project grant TF090577), 2008.

3.5. Determinants of Degree of Diversification

To determine the level of agricultural diversification, we used the Shannon equitable index (E) in the crop area (see Equation (2) and Table 5) over the 186 households. Figure 5 shows three levels of agricultural area diversification determined in a range of: low diversification (<25%), medium diversification (<26–75%) and high diversification (>75%).

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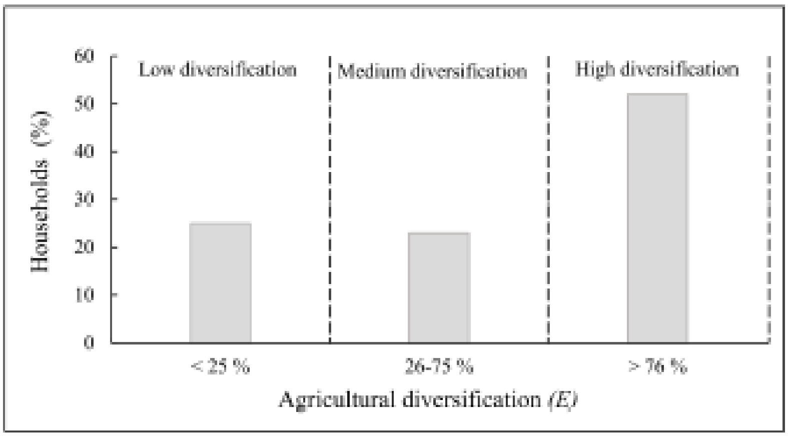

Figure 5. Percentage of households across diversification level, using Shannon equitable index.

In, Table 7 the MLM shows the households' adoption of the three degrees of agricultural diversification determined from *E* (Figure 5). Households in the Livestock-based LS ($p < 0.001$) and Wage-based LS ($p < 0.05$) are less likely to have highly diversified agricultural areas, compared to households with Crop-based LS, whilst households in Livestock-based LS have a strong tendency to adopt low diversified crop areas. Ethnicity (in this case Kichwa) has a significant effect ($p < 0.001$) on the adoption of highly diversified agricultural systems. The results also show that household size ($p < 0.01$) and forest land ($p < 0.001$) are likely related to the adoption of highly diversified crop areas. Total land ($p < 0.001$) and road access ($p < 0.001$) have a positive effect on medium diversification and the proportion of forest land ($p < 0.001$) negative effects medium diversification crop areas. On the other hand, low diversification is positively affected by Livestock-based LS and ethnicity (migrant settlers). Additionally, low diversified households are located at short distances from urban areas.

Table 7. Multinomial logit model predicting the determinants of the degree of agricultural area diversification. (Marginal effects).

Variables	Agricultural Area Diversification		
	High Diversification	**Medium Diversification**	**Low Diversification**
Livelihoods strategies			
Forest-based LS	−0.191 (0.128)	0.054 (0.116)	0.137 (0.149)
Livestock-based LS	−0.644 *** (0.057)	−0.107 (0.084)	0.752 *** (0.096)
Wage-based LS	−0.224 * (0.111)	0.044 (0.112)	0.179 (0.121)
Individual variables			
Kichwa (yes)	0.414 *** (0.112)	−0.058 (0.101)	−0.355 ** (0.138)
Age of household head	−0.043 (0.028)	0.028 (0.025)	0.014 (0.020)
Age squared	0.000 (0.000)	−0.000 (0.000)	−0.000 (0.000)
Education of head (years)	−0.002 (0.016)	0.007 (0.013)	−0.004 (0.013)
Household variables			
Household size	0.033 ** (0.016)	−0.001 (0.013)	−0.031 ** (0.014)
Access to credit (yes)	0.088 (0.104)	0.035 (0.081)	−0.124 (0.087)
Forest land (ha)	0.023 *** (0.008)	−0.018 *** (0.005)	−0.005 (0.006)
Total land (ha)	−0.010 (0.006)	0.017 *** (0.004)	−0.007 (0.005)
Community variables			
Inside buffer zone (yes)	−0.058 (0.121)	0.005 (0.095)	0.053 (0.092)
Distance to city (minutes)	−0.000 (0.000)	0.000 (0.000)	−0.000 (0.001)
Road access (yes)	0.057 (0.151)	0.280 *** (0.077)	−0.338 ** (0.160)
Numbers of observation	186		
Chi2 (28)	128.01 ***		
Pseudo R^2	0.33		
Log likelihood	−126.38		

Significance levels: *, **, *** are 90%, 95% and 99%, respectively. Values in parentheses are standard deviations of the coefficients. Source: Authors computation from survey data PEN/ RAVA—SBR, (project grant TF090577), 2008.

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4. Discussion

In this section, we discuss the main findings and offer some policy recommendations for practitioners to promote sustainable production in the Amazon.

4.1. Small-Scale Agriculture in the SBR

Throughout the study area (SBR), agriculture (crops and livestock) accounts for about 40% of the total annual household income, reflecting that household income still depends, to a large extent, on agricultural income, as in many other parts of the EAR [41,52,65]. Furthermore, the amount of land devoted to agricultural uses is still small (7.6 ha per household) in the SBR. These patterns of small-scale farming are consistent with previous research [52,66–68], which reported similar values for other areas in the EAR.

In this context of small-scale agriculture, our results identified two groups. The first group were relatively diversified in their cropping activities and are represented by households engaged in Crop-based and Forest-based LS (Table 5). These patterns of agricultural diversification align as a strategy that safeguards farmers with a variety of crops adapted to the Amazon's fragile and poor soils [69,70], frequently referred to as not suitable for agriculture [71]. The second group suggests a tendency towards more specialized producers for those households following Livestock-based LS and Wage-based LS, especially in communities with better access to cities and thus to markets, showing market-oriented forms of land use, consistent with previous research in the EAR [52,59,66,72,73]. This trend in the SBR is a commonplace for the cultivation of grasslands for cattle ranching as well as in maize and cocoa plantations.

4.2. Determinants of Agricultural Diversification

4.2.1. Socioeconomic Factors Affecting Agricultural Diversification

The OLS regressions provide evidence that ethnicity has a positive effect on both the diversification indices utilized (H_{crop_area} and NCS), with Kichwa households keeping more diversified farms than their migrant settlers counterparts (Table 6). A possible explanation is that the Kichwa population continues to maintain their traditional agroforestry practices based on subsistence agriculture [74]. They do so by using the "chakra," a traditional agroforestry system, characterized not only as a polyculture [48,56] but also for its high floristic diversity [51,54,75]. Land size is an important factor influencing the H_{crop_area} and NCS in the SBR. This is consistent with previous research, which reported a strong correlation between this variable and crop diversification [76,77]. Overall, this reflects that larger farms are more diversified in terms of number of crops and crop areas. Road accessibility positively influences number of crops and crop area diversification. This indicates that roads facilitate the transport of products to markets [78]. This implication is consistent with the theory of von Thünen & Hall [79] but it also could reinforce the link between forest clearing and the expansion of agriculture near roads [80,81]. This is found to be the case independently of which LS they are involved in. Moreover, given the absence of data surrounding the factors enabling high agricultural diversification at local levels in the EAR and the currently crucial importance for practitioners, we provide more evidence on households using high diversification. Thus, amongst household variables, household size is likely related to the adoption of highly diversified agricultural systems. One possible explanation is that agricultural diversification may be influenced by the availability of household labour. This explanation is similar to that of Culas [82] but differing from Asante and others [25], who found lower agricultural diversification for households with more family labour and higher numbers of dependents. Our results in the SBR suggest a profile of highly diversified farmers: households belonging the Kichwa ethnic group, with large families, remnants of forest land from which they obtain their livelihood, mainly from crops and the forest, are more likely to adopt highly diversified agricultural systems. This may be related to the fact that agroforestry, in general, has played an important role in indigenous tropical

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areas [83]. In particular, the Kichwa population in the SBR still rely on their culturally traditional chakra system [48] and their aforementioned subsistence agriculture [52].

4.2.2. Tendency to Agricultural Specialization

The results from OLS regression also provide evidence stating that households with Livestock-based LS and Wage-based LS are negatively associated with agricultural diversification in comparison with households in Crop-based LS. In the first case, it is possible that households engaged in Livestock-based LS have large areas devoted to pastures [42], which diminishes agricultural diversification on their farms. As for households earning their livelihood principally from wage work, our results may reflect that these kinds of households lack the labour required to keep a diversified farm due to the fact that some of their members are engaged in off-farm employment [42]. Reinforcing these findings, the results of the MLM show that smaller migrant settler households, which are not accessible by road and are engaged in Livestock-based LS, are more likely to adopt low agricultural diversification, with high trends towards specialization in monoculture activities. These activities greatly risk for pest and disease outbreaks [83].

4.3. Policy Implication for More Sustainable Production Systems

The methodological message for policy intervention, suggests that there is a potential for grouping households into LS in order to improve the analysis of household agricultural diversification in rural areas. As a matter of fact, we examined the agricultural diversification using the four LS identified by Torres et al. [42]: Forest-based, Crop-based, Livestock-based and Wage-based LS. Our findings indicate that households who utilize Livestock-based LS not only have the largest landholdings but also the least diversified. This notion demonstrates the heterogeneous livelihood schemes experienced by households living in the same area [84,85]. Additionally, the relative proportion of crop-livestock area versus crop-livestock income, highlights the fact that, only for those households engaged in Livestock-based LS, the relationship of pasture areas and livestock income is economically efficient. However, this relationship could be less resilient to agricultural risk and climate change. That is not the case for the rest of the households involved in the remaining LS. In fact, the average area in pasture for those households in the Forest-based LS was 43%, whilst their proportion of income via livestock was only 1.5%. This condition is common for those households in the remaining LS (see Figure 4a,b).

Based on these results, we summarize that livestock systems in the EAR reduce the degree of agricultural diversification due to the extensive use of pasture for cattle ranching [39,53,73] and recommend the following: (a) The livelihood strategy approach should be used to identify and facilitate the acceptance of farmers to convert less efficient or abandoned pastures areas into more sustainable production systems. For example, households engaged in Forest-based LS, Crop-based LS and Wage-based LS have a significant proportion of land in pastures areas, which does not reflect a significant contribution to their income (see Figure 4a,b). These households could be the potential target group to promote land conversion and the production of sustainable commodities to face agriculture risk [18,19]; (b) Degraded grazing areas of households within Livestock-based LS should be improved by planting new timber-yielding trees in pastures or allowing natural trees to regrow as found by Lerner and colleagues [53] in the southern EAR, especially under difficult conditions. In conjunction with the establishment of "live fences" and implementation of the best management practices to transition Livestock-based LS into a more sustainable low-emission management systems, with potential enrolments in REDD+ programs [53] and a reduced-emission agricultural policy [86]; (c) The fact that crops contribute to more than 40% of income and are still largely part of the traditional "chakra" system, we recommend considering this aspect in the redirection of agricultural incentives in the EAR to reward the sustainable traditional agricultural system [55]. This is because chakra provides a plethora of ecosystem services [87] and is, characterized by having a high number of timber-yielding and fruit trees [48,51,56,57,75], edible and medicinal plants [51,54], leaf litter restoration and a minimization process of water erosion compared to monocultures and pastures [70]. Thus,

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the chakra system is an example of the use of sustainable production to combat biodiversity loss and climate change for small-scale farmers [48,49,51]. This is especially true for the Crop-based LS and Forest-based LS, which have between 80% and 56% in crop areas, respectively. In the current context of ATPA, the chakra system is an essential element for a sustainable transition [48,88]. Finally, these insights are useful for practitioners and decision makers, who seek to address the challenge of sustainably by increasing food security and incomes without damaging the environment [5,6,89]. They are also vital in order to support the Ecuadorian government, specifically regarding the strengthening of the ATPA, whose aim to convert around 300,000 ha of pasture areas into more sustainable production systems [34,35].

5. Conclusions

This study aimed at assessing the factors influencing agricultural diversification for farmers within the buffer and transition zone of the Sumaco Biosphere Reserve. The results reflect that policy makers should devise multiple approaches for the different livelihood strategies used by households in the Ecuadorian Amazon Region. Crop-based LS and Forest-based LS are the most diversified, whilst Livestock and Wage-based LS are the least diversified. In addition, the use of the traditional chakra system facilitates agricultural diversification, so that the promotion of the diversified chakra system should be encouraged, whilst improving the Livestock-based LS and Wage-based LS with a more diversified strategy in order to cope with possible climate change events. Certainly, agricultural diversification in the Ecuadoran Amazon Region may play an important role in the success of the provision of food security of, self-employment and of the production of sustainable commodities to increase rural incomes. All these efforts would be supported by the national and local governments, as well as development agencies. Finally, these suggestions would establish valid and efficient instruments in the facilitation of the agenda for a productive transformation in the Ecuadorian Amazon.

Author Contributions: The first two authors carried out the fieldwork research in this study. All authors analysed the data, compiled the literature, prepared the text, provided revisions and approved the final manuscript.

Acknowledgments: We would like to thank both the PEN/CIFOR and the RAVA networks, as well as the families of the 32 villages who shared valuable information about their livelihoods with us during multiple visits. We are also grateful to the park rangers of the Sumaco Napo Galeras National Park for their assistance during data collection. The authors are also indebted to the World Bank Institutional Development Fund (project grant TF090577) and the Education for Nature Program of WWF for additional financial support. The authors also thank the two anonymous referees for their useful comments and feedback.

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

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10.4. Publication 4

Bolier Torres, Oswaldo Jadán Maza, Patricia Aguirre, Leonith Hinojosa and Sven Günter. (2015). The Contribution of Traditional Agroforestry to Climate Change Adaptation in the Ecuadorian Amazon: The Chakra System[9]. In: Leal Filho Walter (Ed.), *Handbook of Climate Change Adaptation. Springer-Verlag Berlin Heidelberg*. 1973-1994 pp. 10.1007/978-3-642-38670-1_102

[9] This paper is accepted for publication in a Thesis/Dissertation with license number 4397180830724 of Springer Nature License, obtained on July 27, 2018.

Publication 4

The Contribution of Traditional Agroforestry to Climate Change Adaptation in the Ecuadorian Amazon: The Chakra System

Bolier Torres, Oswaldo Jadán Maza, Patricia Aguirre, Leonith Hinojosa, and Sven Günter

Contents

B. Torres (✉)
Universidad Estatal Amazónica, Puyo–Napo, Ecuador

Institute of Forest Management, Center of Life and Food Sciences Weihenstephan, Technische Universität München, Freising, Germany
e-mail: btorres@uea.edu.ec

O.J.E. Maza
Universidad Nacional de Loja, Loja, Ecuador
e-mail: oswaldo.jadan@unl.edu.ec

P. Aguirre
The postgraduate Institute, Technical University of the North, Ibarra, Ecuador
e-mail: pmaguirre@utn.edu.ec

L. Hinojosa
Earth & Life Institute, Université Catholique de Louvain, Louvain-la-Neuve, Belgium
e-mail: Leonith.hinojosa@uclouvain.be

S. Günter
Tropical Agricultural Research and Higher Education Center, Turrialba–Cartago, Costa Rica

Thünen–Institute of International Forestry and Forest Economics, Hamburg, Germany
e-mail: sven.guenter@ti.bund.de

W. Leal Filho (ed.), *Handbook of Climate Change Adaptation*,
DOI 10.1007/978-3-642-38670-1_102

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Abstract

This chapter presents the contribution of "chakra," a traditional agroforestry system, to climate change adaptation and biodiversity conservation in Ecuador's Amazonian communities. IPCC's methodology was used for the estimation of carbon sequestration in soil, biomass, and cacao plantations. Carbon levels in multiple systems of land use were measured through temporary plots. Chakra is efficient to adapt to climate change due to higher levels of carbon sequestration and tree diversity in comparison to other forms of land use. Chakra allows for sustainable use of forests by combining cultivation of the Ecuadorian finest aromatic cacao, controlled timber extraction, production of staple food, and conservation of medicinal plants. Chakra enables Amazonian communities to contribute to both food security and well-being and conservation of the region's high biodiversity. The chapter informs policy makers and communities about the importance of strengthening traditional agroforestry to achieve environmental and social sustainability. The Amazon region is a vulnerable ecosystem, where adaptation to climate change depends on the extent to which the options for land use are compatible with the conservation of biodiversity and the provision of the ecosystem services that sustain local communities' livelihoods. The chapter provides solid evidence that this might be possible through traditional agroforestry.

Keywords

Ecuadorian Amazon • Climate change • Traditional agroforestry • Sustainability • Cacao

Introduction

Traditional systems of agricultural production, particularly agroforestry, have been recognized worldwide as an integrated approach to sustainable land use. More recently, agroforestry systems are believed to have a high potential to contribute to climate change mitigation through carbon sequestration. This has brought a renewed interest in research both on the biophysical conditions under which efficient carbon sequestration can happen and the factors that can enable positive gains for farmers. Yet, the evidence found in this recent literature is not conclusive and generalizations tend to become unrealistic, often because several interrelated and site-specific factors influence the rate and extent to which agroforestry can sequester carbon (Noponen et al. 2013; Oelbermann et al. 2004).

Agroforestry, generally referred as the practice of growing of trees and crops in interacting combinations, is based on the premise that complex land-use systems

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result in greater efficiency of resource (nutrients, light, and water) capture and utilization and greater structural diversity that enables tighter nutrient cycles, therefore, more system stability and resilience at site level and connectivity between forests and other landscape features at landscape and watershed levels (Nair et al. 2008). The advantage of agroforestry as a mechanism for climate change mitigation is that, compared with other terrestrial options, agroforestry has other environmental benefits such as restoring and maintaining above-ground and below-ground biodiversity, corridors between protected forests, and reduction of pressure on natural forests and maintaining watershed hydrology. These ecological foundations of agroforestry systems have been associated with a potential for the provision of ecosystem services worldwide and contribution to food security and poverty alleviation in developing countries (c.f. Lal 2001; Pandey 2002).

In large-scale studies of regions where data is available and reliable, the potential of agroforestry to increase carbon sequestration is promising. For example, in European agriculture it has been estimated to reach near 35 % of all CO_2-equivalent emissions in the EU in 2007, which at prices of 2012 would have a value of 282 euro/ha (Aertsens et al. 2013). Freibauer et al. (2004) analyzed the potential for carbon sequestration and economic viability of agricultural soils in Europe (EU-15) and concluded that efficient carbon sequestration in agricultural soils demands a permanent management change and implementation concepts adjusted to local soil, climate, and management features. In tropical agroforestry systems, Albrecht and Kandji (2003) estimated the carbon sequestration potential in a range of 1.1–2.2 pc carbon in the terrestrial ecosystems over the next 50 years. However, there are shortcomings of these estimates associated with the uncertainties related to future shifts in global climate, land use, and land cover and the poor performance of trees and crops on substandard soils and dry environments, pests, and diseases. Also, research in the Appalachian agriculture (López-Bellido et al. 2010) shows that current practices do not allow for contribution to C sequestration; hence, improved agricultural practices are needed in order to increase soil organic carbon sequestration.

In developing countries, where reliable environmental and economic data are less available c.f. (Claessens et al. 2012), there is increasing expectation about the economic impact of agricultural carbon sequestration. In the Andean region, the fragile nature of agroecosystems and limited capacity of resource-poor farmers to adopt the large-scale use of fertilizers and pesticides suggest the need for agroecological intensification to restore soil functioning and ensure long-term sustainability (Fonte et al. 2012). However, Antle et al. (2007) used a model to simulate the effects of adopting agroforestry practices in the Peruvian Andes and showed that the economic potential is relatively low at carbon prices below $50 per MgC. The price would need to rise significantly (100 %) to make the adoption of agroforestry in terraces attractive; if that happens, carbon sequestration could raise per capita incomes by up to 15 % and reduce poverty by 9 %. In Central America, Somarriba et al. (2013) suggest that, among the agroforestry crops that have the greater potential to mitigate climate change, the cacao tree is credited for stocking significant amounts of carbon.

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Research on sub-Saharan Africa, where climate change is predicted to have considerable negative impacts, shows also that carbon sequestration in agricultural soil can make only modest contributions, in a range of 3–6 of fossil-fuel contributions, to mitigation of overall greenhouse gas emissions (Hutchinson et al. 2007). Palmer and Silber (2012) showed that, in order to make the potential of traditional land use effective for improving the farmers' income of Mozambique, systems that combine sequestration and cash crop production have higher net benefits, although they have less carbon-sequestration potential. In West African Sahel as in sub-Saharan Africa, carbon sequestration is a promising incentive for introducing agroforestry practices and contributing to sustainable land use (Takimoto et al. 2008; Thangata and Hildebrand 2012); therefore, countries that incentive this practice can benefit from REDD+ and other global environmental policies for climate change mitigation. Additionally, as it has been demonstrated in traditional societies like in many parts of rural China (Xu et al 2007), the economic impact of environmental policies that promote carbon sequestration through agroforestry can also have social implications in terms of participation, increased mobility, and less subsistence agriculture-based livelihoods.

This brief review suggests that research is not conclusive and more is needed, especially for the tropics, to more accurately capture the impact of region-specific interactions between climate, soil, and management of resources on carbon sequestration, which are lost in global-level assessments. In the recent global context of climate uncertainty, many productive ecosystems are endangered. Diversified farming systems are an example of complex systems which are able to adapt and resist the effects of climate change. These systems have a high structural complexity which enables them to act as a buffer against temperature fluctuations (Nicholls 2013) and, as Ríos et al. (2007) suggest, there is increasing interest in understanding how local population's traditional practices can generate a path for sustainable use of plant diversity and adaptation to climate change. The purpose of this chapter is to present the contribution of "chakra," a traditional agroforestry system developed in Ecuador's Amazonian communities, to climate change adaptation and biodiversity conservation. Given that the Amazon region is a vulnerable ecosystem, where adaptation to climate change depends on the extent to which the options for land use are compatible with the conservation of biodiversity and the provision of the ecosystem services that sustain local communities' livelihoods, we argue that the chakra system is efficient to adapt to climate change due to higher levels of carbon sequestration in comparison to other forms of land use. Chakra also allows for sustainable use of forests by combining cultivation of the Ecuadorian finest aromatic cacao, controlled timber extraction, production of staple food, and conservation of medicinal plants. The local governance system established around chakra enables Amazonian communities to improve their chances for food security, increasing income, and conservation of the region's high biodiversity. In the remaining sections, we develop this argument, preceded by a description of the methodology used in the study and a contextual description of the Ecuadorian Amazon.

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Chakra in the Context of the Ecuadorian Amazon

Characteristics of the Ecuadorian Amazon

Ecuador represents only 0.2 % of the earth's surface; it is positioned in the 6th place among the most mega-diverse countries in the world (Mittermeier 1988), hosting around 10 % of the world's plant species (CAAM 1995). In this epicenter of biodiversity, the Andean-Amazonian space is considered as a "leading hotspot" (Myers et al. 2000) with a great potential to provide the ecosystem services needed to sustain local livelihoods and global goods such as carbon forest.

However, one of the major problems facing this area is deforestation mainly due to the increase of the agricultural frontier (Pichón 1997; Bilsborrow 2004; Pan and Carr 2010). The forest clearing started in the early 1960s, when the emergent oil industry induced the formation of human settlements in the rainforest, and continued at a rapid pace during the land reform, from 1964 to 1973, when a process of agricultural colonization (Murphy et al. 1997; Sierra 2000; Mena et al. 2006) changed significantly the pattern of land use from forests to agricultural crops and livestock grasslands (Carr and Bilsborrow 2001; Torres et al. 2005; Pan and Carr 2010). Farmers from coastal and highland areas of Ecuador settled in the Amazon and introduced practices of monoculture (Pichón 1997), unsuitable for the fragile Amazonian soils. The expansion of agriculture and the introduction of livestock induced significant levels of immigration and the construction of road infrastructure, which severely impacted the Amazon ecosystems and landscape (Pichón 1997; Wunder 2000; Pan et al. 2005).

The challenges of biodiversity conservation and recovery of cultural patrimony associated with traditional land use led to design a strategy based on spatial planning, supported by the UNESCO. As part of this strategy, the "Man and Biosphere" program delimitated an area located in northeastern Ecuador to be the Sumaco Biosphere Reserve (SBR), covering 931,930 ha, i.e., 8 % of the Ecuadorian Amazon (MAE 2002). The core of this strategy is the conservation of the Sumaco Napo-Galeras National Park in an area of 205751.11 ha (MAE 2013; see, Fig. 1).

The native Kichwa population inhabiting the Ecuadorian Amazon is concentrated in Napo province, representing 60 % of Napo's total population (Irvine 2000; INEC 2010). However, since the 1980s, Napo has become one of the main attractive centers for migration (Arévalo 2009), particularly to the SBR, for its potential for economic activity. The new human settlements have located in the SBR transition and buffer areas.

Traditional Agroforestry in the Ecuadorian Amazon: The Chakra System

Cultivation of small plots within the rainforest is a traditional practice that, over the centuries, the Kichwa population from the Ecuadorian Amazon has developed in order to sustain their livelihoods. Such a pattern of land use, locally known as "chakra,"

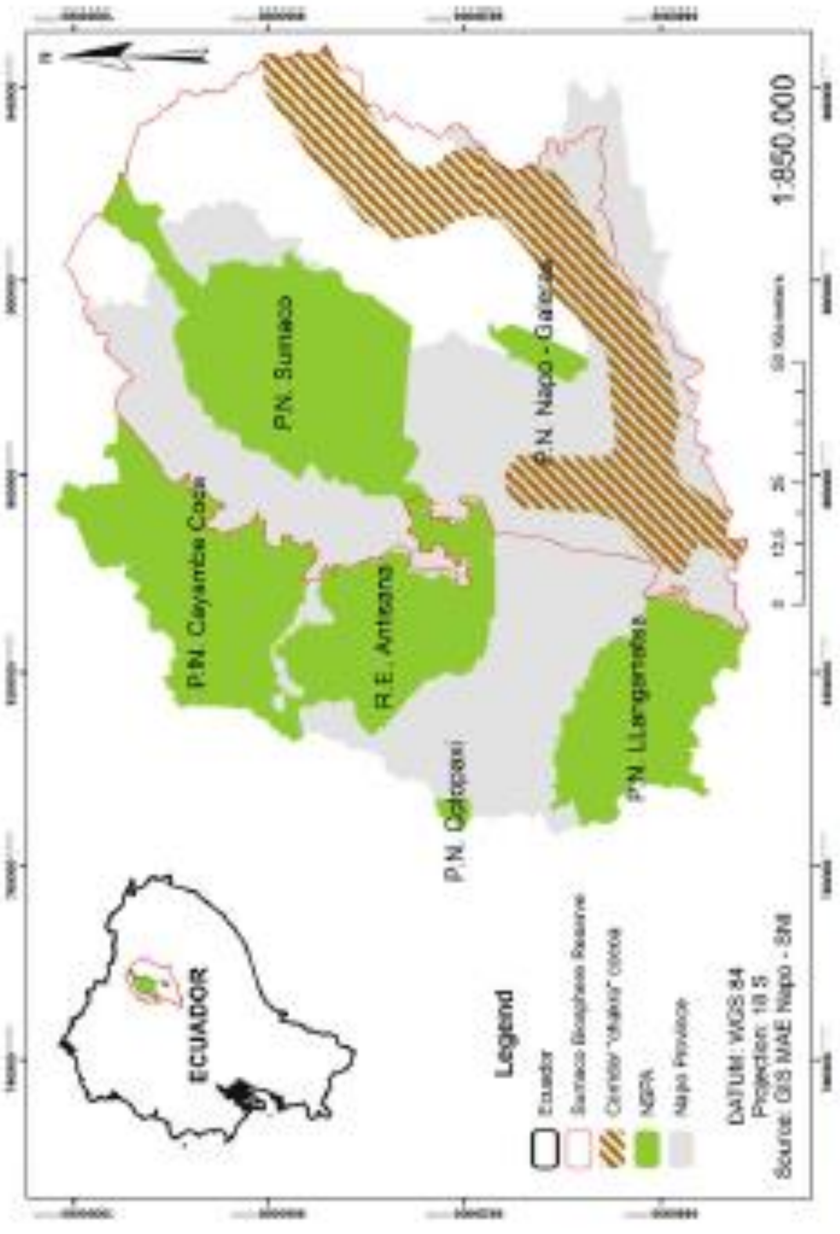

Fig. 1 Sumaco Biosphere Reserve and the chakra cacao corridor in Napo, Ecuador

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integrates cultivation of staple food and medicinal plants, including manioc (*Manihot esculenta* Crantz), banana (*Musa paradisiaca* L.), peach palm (*Bactris gasipaes* Kunth), and other edible and medicinal plants that enable food and health security (Irvine 2000; Lu et al. 2004; Whitten and Whitten 2008). Over time, other agricultural species with commercial value have been integrated into this traditional agroforestry system, which is the case of the fine-flavored cacao (*Theobroma cacao* L.) and robusta coffee (*Coffea canephora* Pierre ex A. Froehner). The size of cultivation plots of cacao within an Amazonian chakra is in a range of 0.5–4 ha (Gizb 2011); these plots are generally located in remaining areas of primary and secondary forests and fallow land. This forms a landscape that resembles a mosaic economically productive and ecologically friendly to the biodiversity of the area.

The SBR contains near 12,500 ha of cacao cultivated in the chakra system, which are managed by 9,200 farmers, approximately (Gizb 2011). Most of it is located in buffer and transition areas of the SBR and Yasuní, within the so-called cacao corridor (see, Fig. 1), and belongs to indigenous Kichwa communities which, since the 1970s, had to adapt to the process of agricultural colonization and relocated their settlements in areas surrounding the Sumaco and Yasuni reserves. While the state has guaranteed the property rights of these communities through land titles and facilitated their access to agricultural credit (Irvine 1989, 2000; Perreault 2003), the intensive migration to the area observed in the last 40 years (Bilsborrow et al. 2004) has also implied diversification of local population and new forms of land use oriented not only to subsistence but also to the market. From an economic perspective, the integration of subsistence and commercial agriculture specialized in the market niche of fine cacao has implied the improvement of households' income. Ecologically, it has produced the effect of redrawing the northern Amazon landscape, pictured now as a multifunctional rainforest with productive plots of cacao or coffee, patches of primary and secondary forest, and stubble and non-used areas, all of which are needed for the soils' resilience in their multiple strata.

The cultural meaning of the chakra system for local population is directly related to the conservation of the Amazon landscape. Cultural practices among the SBR and Yasuní reserve include: selective classification of crops and identification of fertile or unfertile time periods based on the moon's phases, a particular local calendar, the fluorescence of some trees, the birds' incubation period or flight style, and/or some insects' behavior (Avilés and Sarmiento 1997). As suggested by Irvine (2000) and GIZ (2013), these practices have enabled indigenous local population to achieve a certain harmony between food security, income generation, and the preservation of traditional medicine and spiritual values.

Recently, new challenges that climate change presents to local population in the SBR have motivated research both on the capacity of the chakra system to facilitate the adaptation of local population and the rainforest ecosystems to climatic conditions and their capacity to contribute to climate change mitigation. While the former goes beyond the scope of this chapter, the latter is developed in detail in the following chapters.

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Methodology

The research project "Diversification of land use and carbon assessment for biodiversity preservation," in its initial phase, studies changes in carbon storage, biodiversity preservation, and productivity in various land-use systems. The investigation was implemented in 2011 in the buffer and transition zone of the Sumaco Biosphere Reserve and aims at examining the potential for carbon storage by the chakra system, therefore assessing their potential for climate change mitigation. The project is located in the so-called cacao corridor in the province of Napo in the northeastern part of the Ecuadorian Amazon region. The research was performed as results of an international collaboration of universities including the Amazon State University (Universidad Estatal Amazónica) in Ecuador, the Tropical Agricultural Research and Higher Education Center (Centro Agronómico Tropical de Investigación y Enseñanza) in Costa Rica, and the Technical University of Munich in Germany.

The criteria used to select cultivation plots where traditional agroforestry practices are implemented (i.e., classification of plots under the chakra system) were percentage of shadow ≥10 %, net area of chakras ≥0.5 ha, and the farmers' willingness to support the system. Fifteen circular temporary plots of 1,600 m^2 under the chakra system were selected to measure the numbers and diversity of tree species and the amount of carbon captured in each plot and to assess the diversity of tree species and practices that produce food and medicinal plants. Similarly, 8 circular temporary plots under the monoculture system were also selected for the purpose of comparison. The cacao chakras included in the sample are, on average, 7 years old, have diversified shading systems in multiple strata and growth periods, and have the potential to store carbon efficiently each year. Table 1 summarizes the cultivation plots' characteristics.

In all temporary plots of 1,600 m^2, diameter at breast height (DBH) was measured (taken at 1.30 m) from all trees and palm with DBH ≥ 10 cm, and the total height was also measured. The floristic diversity of species was identified in situ, by using common and scientific names at the level of family, genus, and species. Species that were not recognized in situ were collected and identified in a national herbarium with the help of expert botanists.

Multiple systems of land use were selected in the lower area of the Sumaco Biosphere Reserve (Fig. 1), specifically in Tena and Archidona cantons within the Napo province. All sites are located below 700 m above sea level. The plots selected belong to farmers from the Kallari and Wiñak producer organizations, both members of the Cacao Dialog Table (MCFA in Spanish) in the SBR. Plots chosen for comparison in native forests were located in the Jatun Sacha Biological Station (EBJS).

Research on the contribution of the chakra system to climate change mitigation adopted the IPCC methodology for assessing the capacity of traditional agroforestry for carbon sequestration. This includes methods to estimate the amount of biomass and carbon in each one of the land-use systems.

According to the methodology used by Jadán et al. (2012), ground biomass was estimated using algometric equations formulated for primary rainforest species.

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Table 1 Cultivation plots studied to assess the capacity of the chakra agroforestry system to conserve tree species diversity and carbon sequestration

Land-use system	Forest cover (%)	Years of agricultural use (average)	Sample (number of plots)	Surface (hectares)
Traditional agroforestry system (cacao chakra)	40.6	7	15	2.4
Cacao monoculture	4	5	8	1.3

Source: Torres et al. (2013)

Table 2 Algometric equations used to estimate the air biomass of trees in the shade areas of cacao plantations in the Sumaco Biosphere Reserve, Napo Province

Ecosystem or species	Equation	Range (dap, age)	R^2	Source
Tropical forests	$Ln(Bt) = -1.864 + 2.608 \times Ln(dap) + Ln(d)$	5–150	0.99	Chave et al. (2005)
Bactris gasipaes	$Bt = 0.74 \times h^2$		0.95	Szott et al. (1993)
Cacao	$Bt = 1.0408 \exp^{0.0736 \times (d_{30})}$		0.97	Ordóñez et al. (2011)
Low latizales (1–5 cm dap)	$Bt = 10^{(-1.27+2.2 \times Log(dap))}$	0.3–9.3	0.88	Andrade et al. (2008)
Musaceae	$Bt = (185.1209 + 881.9471 \times (Log(h)/h^2))/1000$			ANACAFE (2008)
Palmas in general	$Bt = 7.7 \times h + 4.5$		0.90	Frangi and Lugo (1984)
Roots	$Br = \exp(-1.0587 + 0.8836 \times Ln\ Bt)$		0.84	Penman et al. (2003)

Notes: R^2 ajustado; *Bt* total biomass area (kg arbol^{-1}), *Br* underground biomass, *dap* diameter of breast length (cm), *d* basic density of the wood, d_{30} diameter taken from the base at 30 cm, *h* total height (m), *exp* strength of the base e, *Ln* natural logarithm (base e).
Source: Based on Jadin et al. (2012)

These equations were also used to calculate low-latizal sapling biomass and necromass (Table 2). The underground biomass was calculated using the equation recommended by the IPCC (2003). The biomass of dead wood was calculated based on volumes obtained via the Smalian formula taken in different decomposition categories (Table 3).

The estimated biomass was converted into units of C by multiplying by the 0.5 factor of conversion, as indicated in IPCC (2003). The values obtained were expressed as MgCha^{-1} (mega grams of C per hectare).

The organic carbon in the soil was estimated using the percentage of organic C and the apparent density and deepness of the sample. The total amount of C that is stored was calculated, adding the C to each of the components of the ecosystem (biomass, necromass, and soils) in each one of the evaluated systems (Table 3).

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Table 3 Equations used to calculate the underground biomass of different components evaluated in the Sumaco Biosphere Reserve, Napo Province

Component	Equation	Variable meaning	Source
Necromass		S1 = initial section	
Volume of dead wood	V = (S1 + S2)/2 *L	S2 = final section	
		L = length timber log	Schlegel et al. (2001)
Biomass of dead wood	B = V × Db	B = biomass (Mg)	
		V = volume (m^3)	
		Db = wood basic density (Mg m^{-3}) in the several decomposition categories proposed by IPCC (2003).	
Soil organic carbon	SC = CC × AD × P	SC = soil carbon (Mg C ha^{-1})	Schlegel et al. (2001)
		CC = content of carbon percentage	
		AD = apparent density (Mg cm^{-3}).	
		P = soil thickness in the sample (cm)	
Total carbon stored	TCS = CTB + CN + OCS	TCS = total stored carbon (Mg C ha^{-1})	
		CTB = carbon stored in the biomass (above and under the soil)	
		CN = carbon stored in the necromass	
		OCS = organic carbon in the soil	

Source: From Jadán et al. (2012)

The air biomass in tropical forests was estimated based on the wood density (d) of tree species with a DAP (diameter of breast length) greater than 10 cm through the equation formulated by the Global Wood Density Database (Zanne et al. 2009), i.e., $\mathrm{Ln}\,(\mathrm{Bt}) = -1.864 + 2.608 \times \mathrm{Ln}\,(\mathrm{DAP}) \times \mathrm{Ln}\,(d)$.

Contribution of the Chakra Agroforestry System to Climate Change Mitigation

As reviewed in the Introduction, the benefits of agroforestry systems for carbon sequestration and climate change mitigation are nowadays widely recognized. Adequate management of these systems increases their potential for recovering part of the carbon released into the atmosphere due to deforestation in the world (Montagnini and Nair 2004). Therefore, agricultural production has the potential to be less a problem and more part of the solution to problems related to climate change and development (Hoffmann 2011).

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Table 4 Average ± standard error for C stored in the traditional chakra cacao agroforestry system and in cacao monoculture, compared with carbon stored in primary rainforests evaluated in the cantons of Tena and Archidona, Sumaco Biosphere Reserve, Napo Province, 2011

Storage components (Mg C ha-1)	Primary rainforest	Cacao chakra agroforestry system	Cacao monoculture
C air biomass	206.2	52.8	5.7
	±29 a	±8.1 b	±2.5 e
C root biomass	58	15.3	1.8
	±7 a	±2 b	±0.8 d
C total biomass	**264.2**	**68**	**7.6**
	±36 a	±10.3 b	±3.2 de
C necromass	4	4.1	2.8
	±0.8 ab	±0.4 a	±0.6 abc
C organic soil	65.9	69.2	74.9
	±9.2 ab	±4.9 a	±6.8 a
Total carbon	**334.2**	**141.4**	**85.2**
	±41.7 a	±11.9 b	±7.9 c

Source: From Jadán et al. 2012

The initial findings of the project, reported in Table 4, show that, in comparison with primary rainforest, traditional agroforestry systems based on cacao farming store 42 % of C (334 Mg C ha^{-1}) and 56 Mg C ha^{-1} more than cacao monocultures (see, also, Torres et al. 2013).

The carbon content in air and root biomass shows that the cacao chakra system contains 896 % more C than cacao monocultures (68.1 Mg C ha-1 and 7.6 Mg C ha^{-1}, respectively). This high percentage of carbon storage in the chakra system corresponds to the diversity of trees used for timber, most of which have a high commercial value, for example, chuncho [*Cedrelinga cateniformis* (Ducke) Ducke], cedro (*Cedrela odorata* L.), caoba (*Swietenia macrophylla* King), aguacatillo (*Persea* spp.), canelos (*Ocotea* spp.), guayacán [*Tabebuia chrysantha* (Jacq.) G. Nicholson], laurel [*Cordia alliodora* (Ruiz and Pav.) Oken], and pigüe [*Pollalesta discolor* (Kunth) Aristeg] (see Table 6). There is also a diversity of fruit trees, bushes, and palm trees that form part of the local population gastronomic culture.

These findings on stored carbon in air and root biomass in cacao chakras are similar to those obtained by Ordoñez et al. (2011) in locations near the area of our study within the SBR. They register (68.6 Mg C ha^{-1}) in chakra agroforestry systems with cacao trees that are 8 years old, on average (Table 5).

These results show that, given the amount of carbon stored both in air biomass and in root biomass in cacao, fruit, and timber trees, the potential of the traditional cacao chakra system to enter into the carbon market is important. Also, participation in the carbon market could help to maintain other components of the chakra system, which produce ecosystem services with no market value.

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Table 5 Average C stored in cacao plantations using the traditional chakra agroforestry system with 2-, 4-, 8-, and 12-year-old trees, evaluated in the cantons of Tena and Archidona, Sumaco Biosphere Reserve, Napo Province

Storage components (Mg C ha-1)	Cacao plantations using the chakra system (age in years)			
	2	4	8	12
C air biomass in the cacao	2.15	5.00	14.63	27.17
C root biomass in the cacao	0.67	1.42	3.67	6.53
C total biomass in the cacao	**2.83**	**6.43**	**18.30**	**34.71**
C biomass in fruit and timber-yielding trees[a]	50.34	50.34	50.34	50.34
C total biomass in the cacao plus fruit and timber-yielding trees	**53.7**	**56.77**	**68.64**	**85.05**

Source: From Ordoñez et al. (2011)
[a]Constant value, calculated in 12-year-old cacao plantations

Contribution to the Conservation of Plant Species Diversity and the Amazon Landscape

One of the main characteristics of the chakra system is the floral diversity and density of timber-yielding species, which mostly regenerate naturally.

With regard to the floristic diversity at family, genus, and species levels, we found an average of eight families, nine genus, and nine species in the chakra system. Meanwhile, in cocoa monoculture farms, only one family, one gender, and two species were found (in average). These demonstrate the contribution of the chakra with cocoa production system to the conservation of floristic diversity of fruit and timber trees. In addition, having a variety of species, commonly used for food, medicine, energy drink, craft, spiritual rituals, and multipurpose materials (Table 7), also shows its potential to adapt to climate change.

In relation to density, the chakra system with cacao was found to have on average 170 timber and fruit trees with a diameter greater than or equal to 10 cm at breast height (DBH). Figure 2 shows the number of trees identified in line with the DAP ranking.

A particular pattern of spatial distribution of timber tree species and fruit trees could not be identified due to the absence of systematic practices for planting timber or fruit trees. These trees grow in a process of natural regeneration from the dispersion of seeds caused by wind or from the diversity of the fauna present in the system. As a general observation, it can be mentioned that timber-yielding trees can be found in distances between 15 and 20 m apart (Figs. 3, 4, and 5).

However, it is important to highlight that, at the time when producers engage in crop management, timber species of commercial value are generally carefully managed. The management of tree diversity in the chakra system (Table 6) shows how the Amazonian Kichwa population maintains crucial information about plant resources from a solid popular knowledge of plant species and their uses. Thus, it can be said that chakras are a model of biodiversity conservation; at the same time, they provide ecosystem services for the livelihoods of local population.

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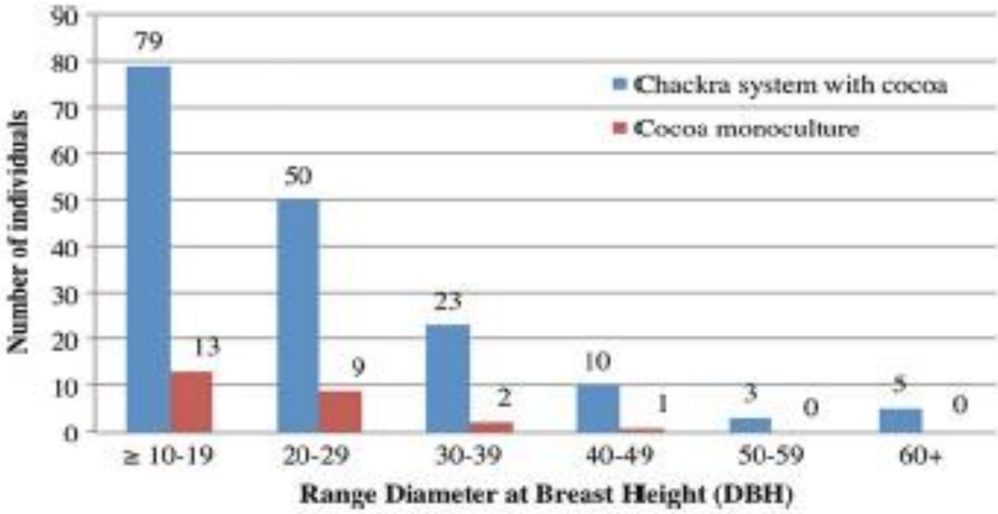

Fig. 2 Number of timber and fruit trees with DAP ≥10 cm

Fig. 3 Typical chakra system with cocoa plants in SBR, Napo, Ecuador (Photo: Bolier Torres_2013)

Contribution of Cacao Chakras to Food Security and Climate Change Adaptation

The effects of climate change on production systems are particular to each region. The number of extreme weather events, droughts, floods, and temperature rise affects agriculture, especially monocultures. Genetic diversity of production

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Fig. 4 Woman harvesting cocoa beans in the chakra system in SBR, Napo, Ecuador (Photo: Thomas Müller_2010)

Fig. 5 Local farmers in a training workshop for estimating carbon sequestration in chakra system with cocoa in SBR, Napo, Ecuador (Photo: GIZ_2012)

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Fig. 6 Parade members of the cacao round table – MCFA in the SBR, Napo, Ecuador (Photo: Mesa del Cacao RBS_2010)

Table 6 Main timber-yielding trees found in the traditional chakra system with cacao in the Sumaco Biosphere Reserve, Napo Province 2012

Species	Family	Local Name
Cordia alliodora (Ruiz and Pav.) Oken	Boraginaceae	Laurel
Cedrela odorata L.	Meliaceae	Cedro
Cedrelinga cateniformis (Ducke) Ducke	Mimosaceae	Seike, chuncho
Ceiba samauma (Mart.) K. Schum.	Bombacaceae	Ceibo
Myroxylon balsamum (L.) Harms	Fabaceae	Bálsamo
Cabralea canjerana (Vell.) Mart.	Meliaceae	Batea caspi
Capirona decorticans Spruce	Rubiaceae	Capirona
Minquartia guianensis Aubl.	Olacaceae	Guayacán
Tabebuia chrysantha (Jacq.) G. Nicholson	Bignoniaceae	Guayacán
Nectandra cissiflora Nees	Lauraceae	Canelo amarillo
Ocotea amazónica (Meisn.) Mez		
Swietenia macrophylla King	Meliaceae	Caoba
Clusia ducuoides Engl.	Clusiaceae	Pungara
Vochysia biloba Ducke	Vochysiaceae	Tamburo
Gustavia macarenensis Philipson	Lecythidaceae	Paso
Pollalesta discolor (Kunth) Aristeguieta	Asteraceae	Pigüe
Terminalia Amazonia (J.F.Gmel) Exell	Combretaceae	Roble Yumbingue
Otoba parvifolia (Markgr.) A.H. Gentry	Myristicaceae	Sangre de Gallina
Caryodendron orinocense H. Karst.	Euphorbiaceae	Maní de árbol

Source: This study 2013

systems with high diversity of plants and animals is a means to address climate change (Kotschi and von Lossau 2012).

In the Sumaco Biosphere Reserve, chakras are based on the cultivation of cacao, combined with fruit trees and food plants, which also have the function to store carbon during their growth process. This is the case of guabos (*Inga* spp.), grape

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tree (*Pourouma cecropiifolia* Mart.), hard chonta (*Bactris gasipaes* Kunth), white cacao (*Theobroma bicolor* Bonpl.), and introduced fruit trees such as achotillo (*Nephelium lappaceum*), cherimoya [*Rollinia mucosa* (Jacq.) Baill.], among others. Given that, at 2010, there were about 12,500 ha of cacao-based chakra farms in the SBR, managed by approximately 9,200 producers (Giza 2011), it can be said that the contribution of traditional agroforestry to climate change mitigation is important (see, also, section "Methodology").

Noteworthy, research supported by the German Development Cooperation (GIZ) on the contribution of traditional agroforestry to local economies suggests that the chakra system substantially supports rural livelihoods. Indeed, for producers from the Kallari Association in the SBR, it was found that 42 % of the household monetary income comes from the sale of cacao and 37 % corresponds to produce that contributes to food security, i.e., staple food produced and consumed in chakras (GIZb 2011).

Table 7 shows the main species of fruit trees, shrubs, and palms that are commonly found in a chakra. These species contribute both to carbon sequestration and storage and the preservation of local food culture. All species listed in the table correspond to the cacao-based chakras. Their botanical identification and most popular use were verified through two sources: de la Torre et al. (2008) and Ríos et al. (2007).

Edible plants found in chakras with cacao in the Sumaco Biosphere Reserve like banana (*Musa* spp.), cassava (*Manihot esculenta* Crantz), pineapple [*Ananas comosus* (L.) Merr.], corn (*Zea mays* L.), peanuts (*Arachis hypogaea* L.), lemongrass [*Cymbopogon citratus* (DC.) stapf], chili (*Capsicum annuum* L.), star peanut (*Plukenetia volubilis* L.), Chinese potato [*Colocasia esculenta* (L.) Schott], wild coriander (*Eryngium foetidum* L.), naranjilla (*Solanum quitoense* Lam.), and lemon (*Citrus* spp.) are among the 25 food species most consumed by 10 indigenous nationalities and one mestizo population, according to Ríos et al. (2007). This highlights that the chakra system, associated with a cash crop such as cacao, can be an option for carbon sequestration and climate change mitigation; it also contributes to food security. Chakras with cacao also can be integrated into wildlife corridors, connecting patches of primary or secondary forests while generating household income (Torres et al. 2013). Therefore, they potentially contribute to local populations' lifestyle in harmony with nature. However, more quantitative approaches are needed in order to develop concrete strategies for climate change adaptation.

Local Governance for Climate Change Management by Promoting Chakra System with Cacao

The Ecuadorian Constitution of 2008 includes two specific articles for climate change management: Article 413 ("The State shall promote energy efficiency, development and use of environmentally clean technologies, practices and policies as well as diversified renewable energy of low impact on and no risk for food

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Table 7 Main species of fruit trees, bushes, and palms that store carbon and are used for consumption in chakras with cacao in the Sumaco Biosphere Reserve

Scientific name	Family	Common name		Use					
		Kichwa	Spanish	Comestible	Medicinal	Spiritual	Craft	Drink	Material
Bixa orellana L.	Bixaceae	Puka manturu	Achiote	x	x		x		x
Theobroma bicolor Humb. and Bonpl.	Sterculiaceae	Patas yura	Cacao blanco	x	x				
Grias neuberthii J.F. Macbr	Lecythidaceae	Pitun	Pitón	x	x				x
Ilex guayusa Loes	Aquifoliaceae	Waysa	Guayusa		x	x		x	x
Sanango racemosum (Ruiz and Pav.) Barringer	Grossulariaceae	Chiri waysa	Panka grande		x	x			
Gustavia macarenensis Philipson *Gustavia longifolia* Poepp. ex O. Berg	Lecythidaceae	Pasu	Paso	x	x				x
Pouteria caimito Radlk.	Sapotaceae	Tarpu aviyu	Caimito	x	x				x
Micropholis melinoniana Pierre *Micropholis venulosa* Pierre	Sapotaceae	Aviyu	Caimitillo	x	x				x
Artocarpus altilis (Parkinson) Fosberg	Moraceae	Papanawa	Frutipan	x	x				x
Brugmansia arbórea (L.) Lagerh	Solanaceae	Wantuk	Floripondio		x	x			
Persea americana Mill.	Lauraceae	Palta yura	Aguacate	x	x				x
Bactris gasipaes Kunth	Arecaceae	Chunta	Chonta duro	x	x		x	x	
Mauritia flexuosa L.f.	Arecaceae	Muriti	Morete	x		x	x	x	
Iriartea deltoidea Ruiz and Pav.	Arecaceae	Pushiwa	Pambil	x	x		x		x
Inga edulis Mart.	Fabaceae	Pakay	Guaba de bejuco	x	x				x
Pourouma spp.	Urticaceae	Pikuanka	Uva del monte	x				x	x
Annona cherimola Mill.	Annonaceae	Chirimoya	Chirimoya	x	x			x	x
Psidium guajava L.	Myrtaceae	Guayaba	Guayaba	x	x			x	x

Source: This study 2013

sovereignty, ecological balance of ecosystems and the right to water") and Article 414 ("The State shall take appropriate and transverse measures to mitigate climate change by limiting emissions of greenhouse gases, deforestation and air pollution"). This mandate is implemented through the National Development Plan for Good Living (2009–2013), in which objective 4 includes a policy to "promote the adaptation to and mitigation of climate variability with focus on climate change."

In 2008, both legal instruments set up a framework for the First Forum of Cacao, established in the city of Tena. This started an innovative process of land management of cacao fields based on strengthening a space of coordination (the cacao round table – MCFA) in the SBR (GIZa 2011). Such a public space includes participatory governance principles for issues regarding mitigation of and adaptation to climate change.

The SBR MCFA promotes the production of cacao on the basis of the chakra system. At the time this chapter was finished (August 2013), the MCFA had 41 actors representing the social, public, private, and cooperative sectors. Remarkably, 16 of them are representatives of local producers. The MCFA works with a concerted strategy called "faces of cacao"; this includes (Chacón et al 2012) (a) the agro-productive face, (b) the ecological face, (c) culture and tourism, and (d) flavors and smells. In this strategy, the ecological face addresses issues of climate change in chakras with cacao.

The MCFA is a local governance mechanism that helps to coordinate actions to mitigate climate change through the cultivation of cacao. It has achieved to promote participatory processes that address and guide a local agenda, where stakeholders, from public and private sectors, put in practice their ideas and interests in local action plans. These are implemented on the basis of a single driving scheme where all actors have the same rights to evaluate and decide on the principle of horizontality.

This model of management allows for particular and transparent contribution from each member of the MCFA platform to collective action. Participation draws on the principles of inclusion and interacting planning becomes practical action on the principle of complementarity. All these consolidate, in practice, the implementation of climate-smart, socially, and ecologically sustainable production systems.

Revival of the Amazonian traditional chakra system, adapted to a commercial produce that adds value such as cacao, has facilitated the political understanding of sustainability both on productive and climate change grounds. As a land management system, the Amazonian chakra is an example that shows how adaptation of production systems based on traditional knowledge can contribute to mitigate and adapt to climate change; therefore, it is useful for the promotion of sustainable production patterns in other areas where traditional systems also exist.

Conclusion

This chapter reports findings on the capacity of a traditional agroforestry system, called chakra, to contribute to climate change mitigation and adaptation. The focus was particularly on the integrative characteristic of such a system to harmoniously

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pursue the achievement of multiple goals. The findings suggest that chakras can be taken as examples of sustainable production that must be preserved in order to tackle climate change effects in tropical zones. Chakras with cacao in the Ecuadorian Amazon region provide diversified ecosystem services that can only be recuperated through the recognition of local knowledge. Furthermore, it is within the chakra system where decisions concerning harmonized landscapes, territory, and locally constructed processes of adaptation to climate change are made every day.

The findings can guide policy makers and other stakeholders in their decisions on land-use policy and measures to tackle poverty and climate change. In this way, the intention is to contribute to making future policies more effective, thus better enabling local population to strengthen their organizational capacity for climate change adaptation. Yet, encouraging dialogue platforms to support local governance mechanisms, based on sustainable production systems, requires transdisciplinary research focused on issues of sustainable climate change adaptation, that is, combining climatic concerns with "good living" goals. Further, it requires a development strategy that has the sustainable conservation of the rainforest as a main pillar and integrates local population in the Amazon region territorial planning.

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