VALUATING AND MODELLING THE SPATIAL DISTRIBUTION OF ECOSYSTEM SERVICES: TRADITIONAL USES VERSUS COMMERCIAL LOGGING

by

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Dedicated to

Manisa

Teesha

Tasbiha

My UTD family

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by

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Ecosystem services derived from tropical plants sustain indigenous societies and make significant contributions to global economies. Often, multiple ecosystem services are obtained from the same plant species which introduces a potential for conflict, particularly between indigenous peoples and commercial loggers. Currently, conventional forest management regimes favor the logging perspective, overlooking indigenous peoples' reliance on the forests. The problem is exacerbated by the lack of conceptual tools to value forests from indigenous peoples' perspective. This research began the process of addressing the problem through three objectives. First, indices were developed, based on plant attributes, to compare a plant species' value from indigenous peoples' versus commercial loggers' perspectives. Second, indigenous peoples' influence on the distribution of ecosystem services were examined using physical environment and demographic variables that are associated with their presence. Third, the relative differences in the spatial distributions of subsistence and commercial logging ecosystem services at the village-level were examined. The analyses produced three findings. First, while there was a larger number of plants whose commercial logging values were greater compared to their

subsistence values, at both the individual plant- and site-levels the mean subsistence values were higher than the mean logging values. Second, the influence of the human presence on the distributions of the subsistence and commercial logging services varied at both the landscape- and village-levels. Third, modeling the relative differences between the subsistence and commercial logging values at the village-level revealed that some areas favored the presence of subsistence services whilst others were more suitable for the presence of logging services. The valuation and spatial tools developed in this research can be used to assist indigenous peoples in addressing resource use and spatial optimization challenges, especially when commercial loggers and conservation initiatives, such as United Nations Reduced Emissions from Deforestation and Degradation (REDD+) program, have different perspectives on how forests should be used.

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LIST OF ACRONYMS

CLI	Commercial Logging Index
COP	Code of Practice
DBH	Diameter-at-breast-height
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographic information system
GFC	Guyana Forestry Commission
GLM	Generalized Linear Model
IIC	Iwokrama International Centre for Rainforest Conservation and Development
KMPA	Kanuku Mountains Protected Area
MEA	Millennium Ecosystem Assessment
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NTFP	Non-timber forest product
PES	Provisioning ecosystem service
REDD+	Reduced Emissions from Deforestation and Degradation
SDM	Species distribution modeling
SVI	Subsistence Value Index

INTRODUCTION

Ecosystem services are the direct and indirect contributions that ecosystems make to human well-being (e.g. Kumar, 2010; Millennium Ecosystem Assessment (MEA), 2005), and tropical forests are associated with a variety of ecosystem services that contribute to the social welfare and subsistence of local and global economies alike (MEA, 2005). In Amazonia, given the strong connections that indigenous peoples maintain with tropical forests (see Posey, 1992; Denevan, 1992), many plant species hold cultural and spiritual values (van Andel, 2000). Additionally, indigenous peoples derive food, drinks, medicines, fuelwood, construction materials, and weaponry from their forests (e.g. Cummings, 2013; Fischer et al., 1997; Forte, 1996; Shanley and Luz, 2003; van Andel, 2000). Therefore, it may not be surprising that such forests have been characterized as “supermarkets” for local communities (e.g. Fachrizal, 2015; Holten, 2016; Oumarou Ibrahim, 2016). Yet, the reliance of indigenous peoples on their forests has historically been overlooked in favor of commercial logging and other interests (e.g. Rist et al., 2012; Sabogal et al., 2013).

Conventional forest regimes are driven by the logging perspective that often dominates indigenous interests (e.g. Rist et al., 2012; Sabogal et al., 2013; Shanley et al., 2012; Shackleton & Shackleton, 2004), which is especially concerning in regard to plant species from which multiple ecosystem services are derived. The advent of conservation initiatives such as United Nations Reduced Emissions from Deforestation and Degradation (REDD+) program, whose priorities or mechanisms may overshadow local interests, means that indigenous peoples are facing more and more threats to their traditional way of life (Cummings, 2013).

Indigenous peoples comprise 5% of the global population and occupy about a quarter of the world's surface area (World Bank, 2018a). Yet, they account for 15 % of the global poor (World Bank, 2018a), and have been identified as amongst the most socioeconomically and culturally marginalized groups of people around the world (Saifullah et al., 2018). Although indigenous peoples are upholders of vital, ancestral knowledge systems, economic development and commercialization are threatening their cultural survival (World Bank, 2018a). Further, about 60 million people, particularly indigenous communities, are completely dependent on forests (World Bank, 2018b). Yet the lack of conceptual and spatial tools that can help them valuate their forest resources makes them vulnerable to external exploitation.

This dissertation began to explore ways to address the aforementioned issues by examining the case study of the Rupununi rainforests, home of some of Guyana's most prominent indigenous nations, and an area of interest for commercial loggers (as well as REDD+). This dissertation looked at plant species used by both groups of users in order to develop methods of valuating the plants from each perspective, and then examined the spatial distribution of the values that can help address spatial optimization challenges in forest use. This dissertation had three primary guiding questions:

Question 1:

"How is the value of plants from the indigenous peoples' perspective different from the value of the plants from the commercial loggers' perspective?"

This question drew on how plant species from which multiple ecosystem services are derived may be viewed by indigenous peoples and commercial loggers. The value of a plant from indigenous peoples' and loggers' perspectives was developed in the form of indices, based on inherent plant attributes and the surrounding physical environment attributes of a species, respectively. These values were then compared to each other at the level of individual plants, as well as at the study site-level. The indices were developed to provide a more equitable comparison on the same metric scale of two contrasting values of a plant, in order to 'level the playing field' between indigenous people and loggers. Thus, the values could give a sense of which plants should be prioritized for indigenous use, and which could be left for alternate uses.

Question 2:

"How does the human presence influence the distribution of indigenous subsistence and commercial logging ecosystem services through physical environment and demographic variables across the landscape?"

This question drew on field observations and ethnographic accounts that made inferences of the human influence on the distribution of provisioning ecosystem services throughout the forests. The impact of physical environment and demographic factors on the distribution of the indices were examined to see if they showed signals of influence by indigenous peoples' presence on ecosystem service distributions. Identifying the human influence on ecosystem services can provide deeper insights into where and how the ecosystem services are spatially distributed relative to where indigenous peoples may be present, and whether there may exist a potential tension if the same landscape factors drive different types of ecosystem services.

Question 3:

“How can the presence of one ecosystem service be favored over the other by the physical environment and demographic conditions of a given location, and how are ecosystem services distributed relative to each other?”

This question examined how the presence of subsistence services may be favored over logging services (and vice versa) as influenced by the physical and demographic characteristics of a landscape. The relative differences between the two ecosystem services were computed using relative log risk ratios, and visualized in bipolar theme maps to identify areas that were favorable for the presence of subsistence services as well as those that were favorable for the presence of commercial logging services. Such maps can serve as the basis of spatial strategies that allocate forest lands between indigenous peoples and commercial loggers depending on where the utility values of their resource use are optimized.

Each question was explored in a semi-autonomous article-styled chapter. Each chapter contained its own background which provided more in-depth background of the problem under study, its own methodology, analysis, results, and a discussion of the findings as well potential for further research in the future.

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CHAPTER 1

COMPARING LOGGING AND SUBSISTENCE VALUES OF PLANTS ACROSS AN INDIGENOUS-PEOPLES' INFLUENCED LANDSCAPE*

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CHAPTER 1

COMPARING LOGGING AND SUBSISTENCE VALUES OF PLANTS ACROSS AN INDIGENOUS-PEOPLES' INFLUENCED LANDSCAPE

1.1 Abstract

The ecosystem services derived from tropical plants sustain local societies and make significant contributions to the global economy. Often many types of ecosystem services are derived from a single plant species, introducing the potential for tensions between forest users. Despite the potential for forest users having different approaches in using a plant, little has been done to understand how a plant species' sustainability may be impacted by opposing views on their utility. In this chapter, the inherent properties of plants were used to propose a conceptual approach for comparing the values of plant species from the perspectives of commercial loggers and indigenous peoples. Using the provisioning ecosystem services associated with a sample of plants from the Rupununi, Southern Guyana, commercial logging and subsistence use indices were developed to compare how plant species may be perceived by the two opposing views of tropical forest management. The analysis found that while for 51.7% of the plants the logging indices were greater than the subsistence indices, at both plant- and study site-levels the mean subsistence values were greater than mean commercial logging values. This study suggested that by adopting indices to document how different users approach plants, forest managers can begin to answer questions on where in space conservation and management efforts should be pursued. The methods proposed in this chapter can be used by indigenous communities to make spatial optimization decisions on their use of forest resources for conservation initiatives such as United Nations Reduced Emissions from Deforestation and Degradation (REDD+).

1.2 Introduction

Human societies obtain a variety of ecosystem services from tropical forests (Brandon, 2014; Millennium Ecosystem Assessment (MEA), 2005). In Amazonia, the livelihoods of indigenous communities are strongly linked to provisioning ecosystem services, including food, fuel, and medicines that are derived from the plants found in the surrounding forests (see Cummings, 2013; Cummings & Read, 2016; Forte, 1999; Klimas et al. 2007; Klimas et al. 2012; van Andel, 2000). Within indigenous peoples-influenced landscapes, stakeholders with opposing views of forest management may often derive multiple ecosystem services from the same plant species (e.g. Cummings, 2013). Such species, described as *multiple use* (see Cummings & Read, 2016; Sivasailam & Cummings, 2017), may in fact dominate tropical landscapes (see Cummings, 2013). The opposing views of tropical forest use where commercial interests and subsistence uses intersect in a single species, and the implications for managing such ecosystem services, have not been extensively explored in the literature.

For many tropical plant species it is not uncommon for indigenous and forest-dependent communities to derive a range of provisioning ecosystem services. For example in Guyana, *Pouteria guianensis* (Aubl.) which has been documented as a major timber species (Polak, 1992) is used in traditional housing construction (see Cummings 2013; Uphof, 1959). Also, van Andel (2000) has noted that the fruits are consumed by some groups of indigenous peoples (van Andel, 2000). Similarly, the interests of commercial loggers' and indigenous peoples' may clash in cases where a plant species provides medicines (Shanley & Luz, 2003; Rist et al., 2012) while being included on state-approved lists for commercial timber (Cummings, 2013). These realities, where more than one provisioning ecosystem services are associated with a single species, may lead to tensions in resource management, especially as indigenous peoples-influenced landscapes are being targeted for payment for ecosystem services initiatives. In landscapes where people derive multiple uses from individual plants species to support their traditional or economic activities, there is a need to develop tools that will allow managers to make decisions on prioritizing monetary and non-monetary values of forests.

Undoubtedly, the monetary value of tropical forests, driven by commercial logging, has set the agenda for how these landscapes are viewed. A few dominant themes have emerged in the literature based on what and how resource uses are derived and prioritized in tropical forests. Firstly, there is a strong perception that timber is the most valuable product derived from forests (Rist et al., 2012; Sabogal et al., 2013). Secondly, the value of timber can be determined by market pricing whereas non-timber forest products (NTFPs), because of the absence of quality, quantity, and pricing information of cultural uses, are still lagging (Shanley et al., 2012). Thirdly, in cases where efforts are made to appreciate the value of NTFPs, the socioeconomic and cultural significance of such products have often been underestimated (Cocks, 2006; Cocks & Dold, 2006). Fourthly, there is a lack of understanding of the role of NTFPs in supporting the livelihoods of indigenous peoples and other forest–dependent communities (Shackleton & Shackleton, 2004). Fifthly, because forest-reliant communities have been historically sidelined or marginalized politically (Dove, 1994), their views on forest management have been taken for granted. Therefore, despite the importance of NTFPs the dominant views of the commercial value of tropical forests dominate the discourse on prioritizing forest uses within these landscapes.

Recently, scholars have drawn on the ecosystem services concept that emerged in the 1970s (Braat & de Groot, 2012; Gomez-Baggethun et al., 2010) to gauge the value of ecosystems to society (e.g. Braat & de Groot, 2012). In decision-making, the ecosystem services concept is intended to support policies aimed at integrating economic, social, and ecological perspectives of how ecosystems are perceived and used by society (Seppelt et al., 2011). But while the popularity of the ecosystem services concept have increased over the years, its applicability in determining the valuation and marketization of goods and services obtained from tropical forests is still underdeveloped (see Raum, 2018). One approach to bridging this gap is to understand how the ecosystem services derived from forest resources are perceived and valued by different users, including indigenous peoples, and how such perceptions and values are driven by a plant's inherent attributes.

Although commercial logging and indigenous uses may intersect within a single plant species, once a species has been identified as viable for commercial logging (see Guyana Forestry Commission (GFC), 2013), the final decision as to whether that plant can be logged is primarily shaped by its location in space. In this regard, and acknowledging that the quality of wood and market value are critical for making logging decisions (e.g. Vastaranta et al., 2014; Jayawardhane et al., 2016), most contemporary legal logging approaches rely heavily on the surrounding physical environment attributes of a plant to determine where across space it may be harvested (e.g. GFC, 2013). Such logging approaches within the tropics are invariably guided by Codes of Practices (COPs) for Timber Harvesting (GFC, 2013; see also Dykstra, 1997) that have been derived from the Food and Agricultural Organization of the United Nations (FAO) forestry codes (FAO, 1996). COPs have been established with specific goals, including better resource utilization, minimizing environmental impacts, and improving the economic and social contributions of forest resources (Dykstra, 1997; FAO, 2015). To estimate potential environmental impacts, COPs essentially stipulate to loggers how physical environment parameters, such as slope and distance to roads, should be considered when making decisions on which plants to log. The conventional COP assumes that logging operations, which follow its guidelines to determine where in space a plant can be harvested, will also help retain the non-commercial values of forests (Dykstra, 1997). However to date, there has been little evidence to suggest that abiding by COP guidelines does indeed preserve the subsistence value of forests.

Given the preceding challenges, there is a need for understanding how opposing resource uses, and consequently the distributions of ecosystem services, may be influenced by a plant's location in space as well as its inherent attributes. This chapter's primary goal was to develop conceptual approaches, drawing on the provisioning ecosystem services derived from plants species, to determine how a plant's value varied from the perspective of a commercial logger versus that of indigenous use. Two indices, the Commercial Logging Index (CLI) and the Subsistence Value Index (SVI), that reflected a plant's value from the perspective of commercial loggers and of indigenous subsistence uses, respectively, were developed. The assumption was made that a logger's perspective of a plant's value was heavily determined by where in space that plant was located. On the contrary, indigenous peoples' perspective of the same plant species was measured by how they used the plant for food, medicine, fuel, and whether it provided food for the wildlife species that they hunt. The overarching hypothesis that guided this research was that the CLI and SVI values of the same plant species would differ significantly at the levels of individual plants and study sites. Specifically, this study addressed two primary objectives. First, the CLI and SVI values were developed to capture an individual plant species' value to loggers and indigenous peoples. Second, the distributions of the CLI and SVI values were compared at the level of individual plants and of study sites. The chapter concluded by discussing how these indices may help address spatial optimization challenges for indigenous peoples and their use of forests.

1.3 Materials and Methods

1.3.1 Study area

This study was completed with data collected from the Rupununi rainforests of Southern Guyana (Figure 1.1). The Rupununi is home to over 2,000 plant (Iwokrama International Centre for Rainforest Conservation and Development (IIC), 2014), and 9,000 wildlife species (Global Wildlife Conservation, 2014). The area's two main indigenous nations, the Wapishiana and the Makushi, share strong connections to their forests (see Cummings, 2013; David et al., 2006; Polak, 1992; Read et al., 2010; van Andel, 2000) and maintain traditional knowledge on forest uses (see Cummings 2013; Forte 1996). The study area included two protected areas: the Iwokrama Forest Reserve managed by the IIC, and the Kanuku Mountains Protected Area (KMPA). Commercial reduced-impact logging is currently ongoing in the Iwokrama forest (see www.iwokrama.org).

Commercial timber activities have occurred in Guyana for centuries (ter Steege et al., 2002), but because access to the Rupununi from coastal Guyana has been difficult for much of its history, the area only recently attracted interests for logging (Cummings, 2013). Since the Rupununi hosts a high concentration of timber species, it is expected to continue to attract logging interests which may lead to tensions with traditional practices. Beyond commercial logging, Guyana has committed to developing a low carbon development economy (see lcds.gov.gy) in response to the United Nations Reduced Emissions from Deforestation and Degradation program (REDD+). Given the opposing views of how forests should be managed, there is a need to provide the Rupununi's indigenous communities with tools to better appreciate the complex spatial optimization questions with regards to the use of forest resources.

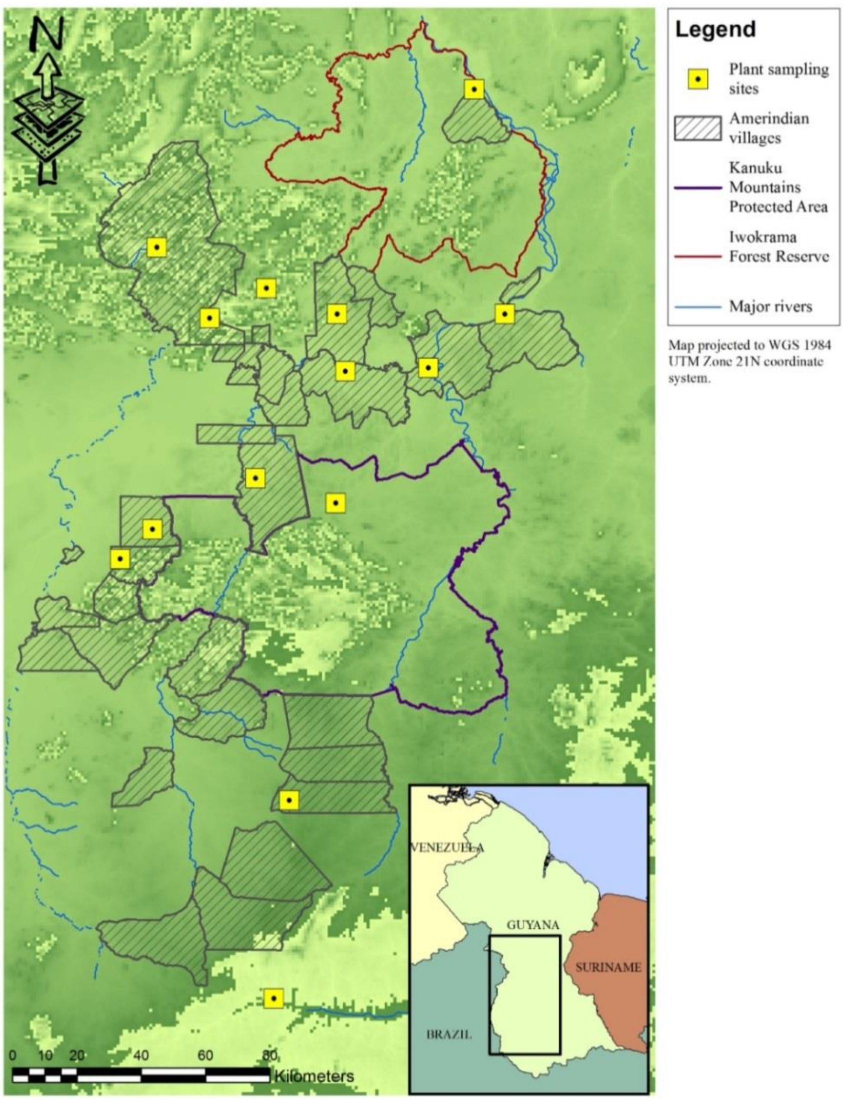

Figure 1.1. Location of the Rupununi landscape, Guyana.

1.3.2 Data

1.3.2.1 Plant inventory data for developing indices

To develop the CLI and SVI values, plants were sampled from 14 sites distributed across the study area (see Figure 1.1). Sites were selected based on their location, characteristic vegetation types, topography, and proximity to Amerindian villages (Read et al., 2010). Across the study sites a total of ninety-two 4 km-long, 10 m-wide belts transects (Figure 1.2) were randomly located and established from a georeferenced starting point (see Cummings, 2013; Read et al., 2010). In each transect, plants were randomly sampled by a two-person team: a trained tree spotter who examined plant parts such as leaves, bark, and fruits to identify each plant species, and a recorder who documented the details of each plant. At the time of sampling, the inventory team recorded the following attributes of each plant: the diameter-at-breast-height (DBH), the local name, and location along a transect. Post-sampling the identity of the plant was verified through consultations with local people and the literature (e.g. Polak, 1992; van Andel, 2000).

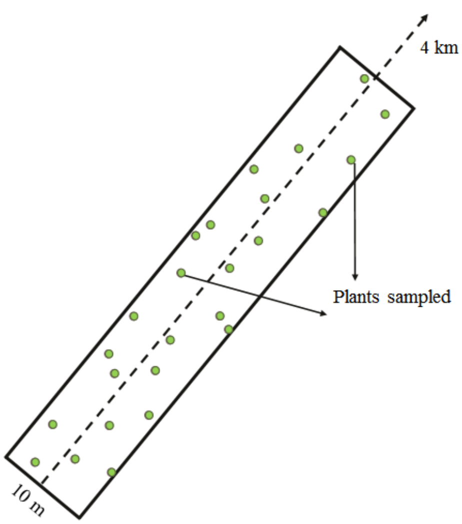

Figure 1.2. Illustration of a belt-transect in which plants were randomly sampled.

1.3.2.2 Identifying plant uses

To begin identifying the uses derived from a plant, its location relative to the surrounding physical environment attributes was defined and used to determine its eligibility to be commercially logged (COP, 2013), and its subsistence uses were determined from the literature (Forte, 1996; Polak, 1992; van Andel, 2000; van Roosmalen, 1985) and from traditional knowledge (TK; see Parrota & Trosper, 2012; Posey, 1992). For traditional uses the way local people drew on the inherent attributes (e.g. fruits, bark, and stems) of plants for provisioning ecosystem services, as well as whether parts of the plant were used by wildlife for food, was documented. After the uses derived from each species were identified, each plant was classified into three categories following Cummings (2013) as shown below:

1) Commercial Logging – a plant species is actively used for commercial timber.
2) Traditional Uses – indigenous peoples derive food (e.g. fruits, beverages), medicines, traditional weaponry, boat crafting, utensils, house construction, and fuel from this species (see Table A.1).
3) Wildlife Food – plant parts, such as fruits and seedlings, are consumed as food by wildlife species that are commonly hunted within the study area (see Table A.2).

1.3.3 Developing the indices

1.3.3.1 The Commercial Logging Index (CLI) approach

Under the CLI approach, a two-step process was followed to determine the value of a plant based on its inherent timber attributes and where it was located in space as per the COP guidelines. The GFC has two versions of the COP, one for large concessions and one for small concessions (GFC, 2014) which provides slightly different guidelines for loggers. In this study, the COP for small concessions was used as it was assumed that smaller scale loggers will be more likely to be present within the study area.

In the first step, it was determined whether a plant could be logged based on its inherent timber characteristics and stem diameter. Whether a plant was recognized as a commercial timber species was determined from the literature (e.g. GFC, 2013; IIC, 2006; Polak, 1992; van Andel, 2000) and local knowledge. The felling DBH for a species, which is the minimum stem diameter above which legal logging is permitted, was determined from two sources: the COP (GFC, 2013) and Iwokrama. In cases where a species was being logged by Iwokrama, the minimum DBH used in their operations superseded those of the COP (Table 1.1). Generally, Iwokrama commenced logging of a species at higher DBHs than those recommended by the COP.

Table 1.1. Plant characteristics that determine whether a plant could be harvested for commercial timber as determined by the Code of Practice and Iwokrama International Centre (GFC, 2013; IIC, 2006).

Is the plant a timber species?	*≥ Minimum felling DBH (Code of Practice, 2013 / Iwokrama, 2006)*	*Can the plant be harvested?*
Yes	Yes	**YES**
Yes	No	**NO**
No	Yes	**NO**
No	No	**NO**

In the second step, whether or not a plant could be logged was assessed based on where it was located in space relative to the guidelines of the COP. The COP defined “no-logging zones” as areas within 20 meters of creeks or lakes, 30 meters of rivers, or where the slope on which a plant was found exceeded 40%. To analyze the logging eligibility of each plant, the data collected by the sampling team were incorporated into ArcGIS for spatial analysis. The location of each plant relative to the “no-logging zones” was examined with distance-based and raster ArcMap tools. The distance between the plant and the nearest water body was computed using the river and creek shapefiles obtained from the Guyana Geospatial Information Management Unit (GIM, 2015). The relative slope on which each plant was located was derived from an ASTER digital elevation model (DEM) of the study site (Cogley, 2009). The distance and slope layers were then used to identify whether a plant could be logged as per the COP guidelines through a spatial query in ArcGIS. For example, if a plant was identified as being a commercial timber species and met the requisite stem diameter for logging, but was not located within space that made it suitable for harvesting, it was deemed to be in the “no-logging zones” and was assigned a CLI value of ‘0’. Where a plant was determined to have timber value and was outside the “no-logging zones”, its DBH would then be used in further analysis to measure its CLI value.

1.3.3.2 Computing the CLI

The CLI of a plant was computed as the ratio of its DBH to the largest DBH sampled in the dataset (Equation 1).

$$S_{i,CLI} = \frac{DBH_i}{max\,DBH} \tag{1}$$

where $S_{i,CLI}$ is the CLI of the *i*th plant, DBH_i is the stem diameter of the *i*th plant, and $max\,DBH$ is the highest stem diameter of a plant in the dataset.

To acknowledge the fact that species on the Iwokrama list were more likely to be logged, a weighted value was incorporated into their CLI values to give them greater importance than species not included on the list. The CLI values for species not included on the Iwokrama list were multiplied by a weight of 1, whereas those on the Iwokrama list were multiplied by 2. For example, two species *Mora excelsa* (Benth.) and *Swartzia benthamiana* (Miq.) both had stem diameters of 100 cm. Therefore, the CLI for both was 0.568. However *S. benthamiana* is not on the Iwokrama list whereas *M. excelsa* is, and therefore the CLI for *M. excelsa* was adjusted to 1.136 to acknowledge is current status as a logged species. Range normalization was then applied to the CLI to ensure that the value varied between 0 and 1 (Equation 2) (Tofallis, 2014; e.g. Dick et al., 2014).

$$normalizedS_{i,CLI} = \frac{DBH_i - min\ DBH}{max\ DBH - min\ DBH} \qquad (2)$$

where $normalized\ S_{i,CLI}$ is the standardized CLI of the *i*th plant, DBH_i is the stem diameter of the *i*th plant, *min DBH* is the lowest stem diameter, and *max DBH* is the highest stem diameter in the dataset.

1.3.3.3 The Subsistence Value Index (SVI) approach

In this study, the SVI of a plant species was developed as a sum of the traditional index and the wildlife food index of the species. As with the CLI, a two-step process was followed to measure the SVI.

In the first step, the traditional uses derived from the plants were explored using local knowledge and the literature (e.g. Cummings 2013; Forte, 1996; van Andel, 2000). The literature suggested that indigenous peoples derived seven major provisioning ecosystem services from the plants within their forests – food, medicines, house wares (e.g. utensils), accessories, raw materials for traditional tools, fuel wood, and local construction (Cummings and Read, 2016; see Table A.1). The uses obtained from each plant were determined and documented, for example, it was observed that the species *Manilkara bidentata* (A.DC; Chev.) is commonly used in house construction, and to make figurines and utensils.

In the second step, the wildlife food index of a plant species was developed based on the number of commonly hunted wildlife species that typically derived food from the plant. Local knowledge and the literature suggested that at least twenty-two wildlife species (Table A.2) that are typically hunted within the study area are dependent on the plants in the dataset for food. For example, it was found that four wildlife species – agouti (*Dasyprocta leporina*), red brocket deer (*Mazama americana),* grey brocket deer (*Mazama gouazoubira*), and tapir (*Tapirus terrestris*) – tend to consume the fruits of *Catostemma commune* (Sandwith) (Cummings, 2013).

1.3.3.4 Computing the SVI

The SVI of each plant species was computed as the aggregate value of the weighted traditional index and the wildlife food index of each plant. For calculating the SVI, this chapter modified the method developed by Maes et al. (2012) for studying the spatial relationships between biodiversity, ecosystem services, and the conservation status of protected habitats in Europe. Maes et al. (2012) standardized different ecosystem maps to compute the Total

Ecosystem Service Value (TESV) over a range of 0 to 1, and a similar approach was used here once the different traditional uses derived from each plant were identified. Prior to computing the SVI, each traditional use was assigned a weight based on the perception of its importance to indigenous peoples. Assigning weights was done for two reasons.

Firstly, it was assumed that indigenous peoples may value different traditional uses unequally based on personal preference, alternative sources, or abundance of the resources. For example, while people may have multiple sources for food (through extracting plants, hunting wildlife, or fishing), their sources for medicines may be much more restricted to certain plant species. For instance, the bark of *Clathrotropis macrocarpa* (Ducke) is used for curing scorpion and insect stings (Forte, 1996) which might otherwise be difficult to treat. Therefore, it was assumed that medicine extraction will be valued more highly than food extraction. To illustrate the conjecture that traditional uses might be valued differently, each use was assigned a weight based on its assumed order of importance from an indigenous person's perspective (Table 1.2). This study postulated that medicine would be prioritized over the other uses. Therefore, it was ranked as number one and assigned the highest weight value (w_u) of 7. The other uses were similarly ranked based on this assumption.

Secondly, the weights assigned in this study were directly linked to the dataset, because the way the plants were sampled would influence the distribution of species from which a certain traditional use is derived. Therefore, the ranked weight (w_u) of a traditional use was multiplied with the average density of plants (total number of plants per hectare) associated with that use (ρ_{N_u}). The product was then incorporated into the calculation of the traditional index of a plant (Table 1.2).

Table 1.2. The weight scheme for traditional uses based on the assumed order of importance of each use and the density of plants per hectare associated with that use.

Traditional uses	Rank (order of importance based on indigenous perception)	Weights (w_u)	Average density (ρ_{N_u})	Weight assigned to each use ($w_u \times \rho_{N_u}$)
Medicines	1	7	8.07	56.48
Food	2	6	2.52	15.12
Local construction	3	5	12.52	62.61
Tools	4	4	10.93	43.72
Household Items	5	3	2.2	6.59
Ornaments	6	2	3.33	6.65
Fuel	7	1	4.33	4.33

The traditional index of a plant species was computed by summing the products of the ranked weights and average density of plants associated with each use (Equation 3).

$$s_{i,traditional} = \sum(u_i \times w_u \times \rho_{N_u}) \qquad (3)$$

where $s_{i,traditional}$ is the traditional index of the *i*th plant, u_i is a constant value of 1 indicating a traditional use derived from the *i*th plant, w_u is the weight of the aforementioned use based on its assumed order of importance, and ρ_{N_u} is the density of the plants associated with the use per hectare.

As with the CLI, the traditional index was then standardized using maximum and minimum values (Equation 4) (e.g. Maes et al, 2012; Dick et al., 2014). For instance, *P. guianensis* is used in local construction e.g. fencing, and its fruits are eaten by local people (Forte, 1996; see Table A.3). Its traditional index was computed to be 77.73, which was then standardized to 0.459.

$$normalized\ s_{i,traditional} = \frac{s_i - min\ s_{traditional}}{max\ s_{traditional} - min\ s_{traditional}} \quad (4)$$

where $normalized\ s_{i,traditional}$ is the standardized traditional index of the *i*th plant, s_i is the traditional index of the *i*th plant before standardization, $min\ s_{traditional}$ is the minimum traditional index, and $max\ s_{traditional}$ is the maximum traditional index in the dataset.

Similarly, the wildlife food index $S_{i.}$ of the plant species was computed by dividing the number of commonly hunted wildlife species that depended on the plant for food by the total number of hunted wildlife species (22) dependent on all the plants in the dataset (Equation 5). As with the traditional index, the wildlife food index was then standardized (Equation 6). For example, *P. guianensis* provides food for seven wildlife species (Table A.3). Therefore, its wildlife index value was computed to be 7/22 or 0.318, which was then standardized to 0.636.

$$s_{i,wildlife} = \frac{N_{i,wildlife}}{N_{wildlife}} = \frac{N_i}{22} \quad (5)$$

where $s_{i,wildlife}$ is the wildlife food index of the *i*th plant, $N_{i,wildlife}$ is the number of wildlife species dependent on the *i*th plant, and $N_{wildlife}$ is the total number of hunted wildlife species (22) dependent on the plants in the dataset.

$$normalized\ S_{i,wildlife} = \frac{s_{i,wildlife} - min\ s_{wildlife}}{max\ s_{wildlife} - min\ s_{wildlife}} \quad (6)$$

where $normalized\ S_{i,wildlife}$ is the standardized wildlife food index of the *i*th plant, $s_{i,wildlife}$ is the wildlife food index of the *i*th plant before standardization, $min\, s_{wildlife}$ is the minimum wildlife food index, and $max\, s_{wildlife}$ is the maximum food wildlife index in the dataset.

The SVI was computed by aggregating the normalized traditional and wildlife food indices of a plant species (Equations 7), and then standardizing the index again to range between 0 and 1 (Equations 8).

$$S_{i,SVI} = normalized\ S_{i,traditional} + normalizedS_{i,wildlife} \tag{7}$$

where $S_{i,SVI}$ is the SVI of the *i*th plant, $normalized\ S_{i,traditional}$ is the standardized traditional index of the *i*th plant, and $normalizedS_{i,wildlife}$ is the standardized wildlife food index of the *i*th plant.

$$normalized\ S_{i,SVI} = \frac{S_{i,SVI} - min\, S_{SVI}}{max\, S_{SVI} - min\, S_{SVI}} \tag{8}$$

Where $normalized\ S_{i,SVI}$ is the standardized SVI of the *i*th plant, $S_{i,SVI}$ is the SVI of the *i*th plant before standardization, $min\, S_{SVI}$ is the minimum SVI, and $max\, S_{SVI}$ is the maximum SVI in the dataset.

1.3.3.5 Statistical Analyses

To deal with outliers within the logging and subsistence indices, the CLI and the SVI values were winsorized before standardization. Extreme values were identified through boxplots. These values were then changed by setting the bottom 5% to the value at the 5th percentile, and the top 5% to the value at the 95th percentile. The data values were then averaged to obtain the mean CLI and SVI values to facilitate a more accurate comparison.

Statistical tests comparing the CLI and SVI means at individual plant- and sampling site-levels were completed. The CLI and SVI values were examined to first determine whether they were normally distributed using histograms, the normal Q-Q plots, and the Shapiro-Wilk test. Since the data failed to conform to the assumptions of normality at both plant- and site- levels, logarithmic transformation was applied. However, the logarithmic transformation also failed to allow the data to meet the assumptions of normality. Therefore the non-parametric tests, Mann-Whitney U and Kruskal-Wallis, were used to examine whether there were statistical differences in the mean CLI and SVI values at plant- and site- levels. For the purpose of protecting individual sites across the Rupununi study area, only statistical differences in mean SVI and CLI found across the study sites were reported, rather than identifying which sites had higher values. All statistical analyses were completed in R for Windows version 1.0.153 using the ‘stats’ and ‘pgirmess’ packages (R-project.org, 2017).

1.4 Results

1.4.1 Overview

It was found that 8490 plants had inherent timber characteristics based on traditional knowledge and the literature. Yet, when the COP requirements (refer to Section 1.2.3.1) were applied to each plant, over 2% of the plants were found to be located in “no-logging zones” and were thus removed from further analysis. Of the 8286 individuals from 68 plant species that satisfied the COP conditions, 74.2% (34 species) were simultaneously used for logging, traditional uses, and wildlife food, indicating the plants’ potential for resource use conflicts.

Traditional uses were derived from about 91.5% of the plants (55 species) (Table 1.3). While the number of species from which two or more traditional uses were obtained was lower (22 species) than the number of species from which only one traditional use was obtained (33 species), the proportion of plants with two or more traditional uses (60.0%) was substantially higher than the proportion of plants with one traditional use (32.5%).

Table 1.3. Number of species and proportion of plants associated with traditional uses.

Number of traditional uses per species	Number of species	Proportion of plants (%)
0	13	8.5
1	33	32.5
2	12	29.2
3	9	23.6
4	1	6.2

The largest proportion of plants was used for local construction, raw materials and tools, and medicines (Table 1.4). While fewer species were used for construction (22 species) compared to those used for raw materials (23 species), the proportion of plants used for construction (54.4%) were more abundant relative to the proportion used for raw materials (47.5%). There was also an overlap of 10 species that were used for both local construction and raw materials. As for the other traditional uses, only 4 species were used for fuel, 8 species for food, 7 species in household items, and 6 species for ornaments. Yet, the species used for fuel accounted for 16.9% of the plants, while food accounted for 10.2%, household items for 8.7 %, and ornaments for 12.8 % (the percentages were not mutually exclusive).

Table 1.4. Typology of traditional uses derived from the plants. The proportions demonstrate that multiple uses may intersect in a single species and are not cumulative.

Typology of traditional uses	Number of species	Proportion of plants (%)
Local construction	22	54.4
Food	8	10.2
Fuel	4	16.9
Household items	7	8.7
Medicines	18	35.8
Ornamental	6	12.8
Raw materials & tools	23	47.5

About 82.7% of the plants (47 species) provide wildlife food (Table 1.5). Of all the plants, 20.2% (16 species) are consumed by only one wildlife species, while 37.1% (7 species) provide sustenance for two wildlife species. By comparison, even though the proportion of plants that provide food for three wildlife species (6.4%) were substantially lower, there was a greater diversity (12 species) compared to the plants providing food for two wildlife species (7 species). About 18.8% (12 species) of the plants provide food for four to eleven wildlife species and were less diverse and abundant than the 63.7% (35 species) that provided food for one to three species.

Table 1.5. Number of species and proportion of plants that provided food for wildlife (the percentages have been rounded to one decimal place).

Number of wildlife species supported by sampled plant	Number of species	Proportion of plants (%)
-	21	17.3
1	16	20.2
2	7	37.1
3	12	6.4
4	4	2.7
7	4	5.2
8	1	2.9
9	2	3.5
11	1	4.5

1.4.2 Comparison of the CLI and SVI values

When the logging and subsistence values of plants were compared, it was found that before winsorization, 85.1% of the plants had higher SVI than CLI values. However, after winsorization, 51.7% had greater CLI than SVI values, and 46.8% of plants had greater SVI than CLI values, with the remainder having equal values. The mean CLI of all the plants was 0.420 (standard deviation of 0.306) compared to the mean SVI of 0.437 (standard deviation of 0.297) (Figure 1.3). The Mann-Whitney U test showed that the mean SVI was significantly higher ($p < 0.05$) than the mean CLI at the level of individual plants.

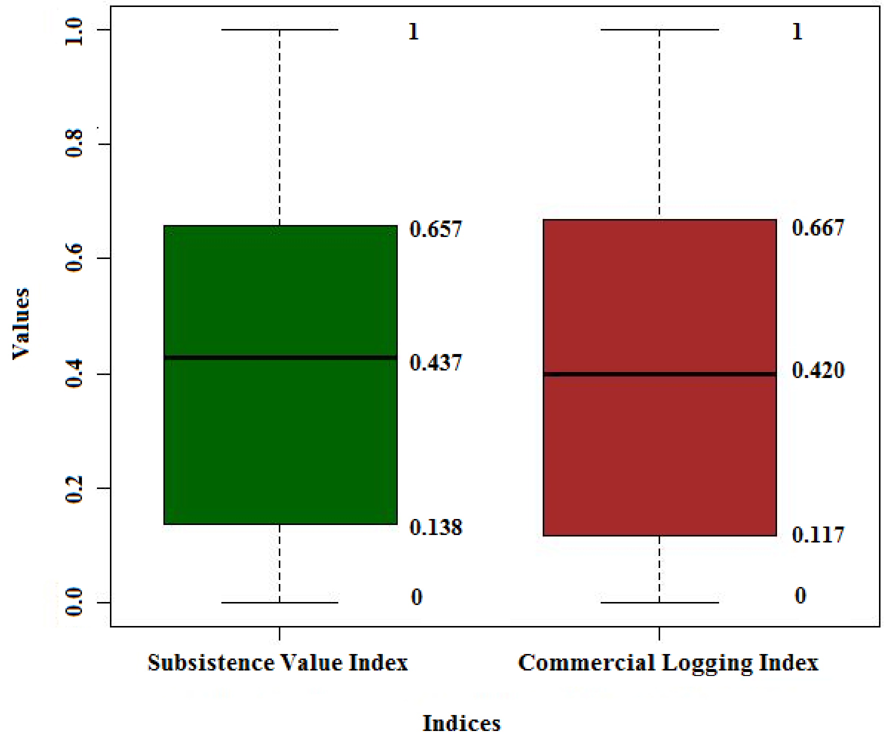

Figure 1.3. Boxplot showing distributions of the CLI and SVI values at plant-level.

At the study site-level, the mean CLI was 0.381 (standard deviation of 0.075) compared to the mean SVI of 0.449 (standard deviation of 0.062). Statistically, the mean SVI was found to be significantly higher ($p < 0.05$) than the mean CLI. Overall, this analysis found that although more plants had higher CLI than SVI values after winsorization, the mean SVI values were statistically higher than the CLI means ($p < 0.05$) at individual plant- and study site-levels.

1.5 Discussion and Conclusions

This chapter developed indices to compare and contrast how a tropical plant species may be valued from the perspectives of commercial loggers and indigenous peoples. Comparison of the CLI and SVI values can help capture the extent of the potential conflict that may converge within a plant species between logging and subsistence uses. The findings of this study suggest that a high proportion of plants within the study area are critical for subsistence activities and provide food for hunted wildlife while being targeted for commercial logging at the same time. Of the 8286 plants that could be logged as per the COP guidelines, traditional uses were derived from 91.5% (55 species) of the plants (Table 1.3), while 82.7% (47 species) were food sources for hunted wildlife (Table 1.5). Of all the plants, 74.2% (34 species) could be used for logging, traditional uses, and wildlife food simultaneously. When comparing the logging and subsistence indices of individual species, it was observed that harvesting particular plants might yield logging values for timber extractors that would be lower in comparison to the subsistence values lost by the indigenous peoples. For example, if a plant with a CLI value of 0.146 and a SVI value of 0.485 was harvested, the benefits of logging would be outweighed by the losses in subsistence services, thus suggesting that logging such a species may not be desirable for indigenous peoples. Overall, this analysis found that the subsistence values of plants captured through the SVI were statistically higher than the commercial logging values of plants captured through the CLI. This work, along with similar studies that examined plant-related indices (e.g. Tudela-Talavera et al., 2016; Turner, 1988) can help provide deeper insight into the indigenous perceptions of plants, and how such perspectives may be incompatible with the commercial views of tropical forest uses. This chapter also found three important points that may be applicable to broader forest management principles.

Firstly, while this analysis only used plants that could be legally logged based on the COP guidelines, it also indicated that there was a higher diversity of plants from which subsistence uses are derived (see Section 1.3.1). For example, while the plants that provided food for one to three wildlife species (35 plant species) dominated the samples (63.7%), the plants that provided food for four to eleven wildlife species were less diverse (12 species) and less abundant (18.8%) (Table 1.5). Such low species diversity and abundance that are important for ecological functions and are essential components of the forest ecosystems (e.g. Burivalova et al., 2014; Clark & Covey, 2012; Ramage et al., 2013) need to be considered in contemporary logging regimes. The current COP approach may deem these plants as potentially loggable, with limited reference to their importance to wildlife and by extension indigenous peoples' livelihoods. This chapter argued that being able to identify such species and addressing how they can be incorporated into forest management is possible through the use of indices similar to those developed in this research.

Secondly, applying the CLI and SVI in forest management can contribute towards developing a strategy for allocating plant uses between loggers and indigenous peoples according to how and where these indices are distributed. For example, an area of plants with higher CLI values can be allocated specifically for commercial extraction, and an area of plants with high SVI values can be set aside for the use of indigenous peoples. Previous studies have attempted to spatially reconcile timber harvesting with non-commercial or ecological objectives, including land-sharing and land-sparing strategies for biodiversity conservation (e.g. Edwards et al., 2014; Fischer et al., 2008; Green et al., 2005; Phalan et al., 2011). Dealing with such spatial optimization challenges, especially in landscapes where plant users are debating forest allocation for Reduced Emissions from Deforestation and Degradation (REDD+; http://www.un-redd.org/), can be facilitated by incorporating indices similar to the CLI and SVI into forest management and resource allocation strategies.

Thirdly, this work considered plant species from Guyana, South America, where traditional knowledge on forest uses remain strong (see Cummings, 2013). The timber species in Guyana's forests have attracted logging interests (see Environmental Management Consultants (EMC), 2012; Wenze, 2013), typically without considering the needs of indigenous populations within forests (Cummings, 2013). The SVI values that were developed incorporated only a limited number of indigenous peoples' groups and their use of resources, as it drew on the literature (Cummings, 2013; Forte, 1996; van Andel, 2000) and traditional knowledge primarily of the Makushi, Wapishiana, and coastal indigenous peoples. Exploring how other groups of indigenous peoples view the same plant species can provide deeper insights into uses and allow for a better appreciation for plant management across a small geographical scale. This chapter took steps in building a foundation by proposing conceptual approaches to develop indices that measured a plant species' value based on how it is used. In future work, monetary values can be incorporated into these indices which can aid both indigenous people and commercial loggers in making decisions on how to optimize their use of forest resources.

The aim of this research was to begin discussing a way to compare the values of plants based on two contrasting uses (logging and subsistence use) across an indigenous landscape. This problem was approached from a geospatial perspective using the attributes associated with plant species. This study developed indices, the CLI and SVI, to compare the logging and subsistence values of plants, respectively, across the same metric scale, and found that the subsistence values of plants were significantly higher than their logging value at the level of individual plants and of study sites. This work demonstrated that should contemporary logging approaches view plants from the perspective of indigenous peoples, a different view of forests may emerge. Adopting indices similar to the CLI and SVI can help provide conceptual tools for indigenous peoples and other forest-dependent communities to begin addressing the spatial optimization challenges they may face in terms of forest use.

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CHAPTER 2

AN EXPLORATORY ANALYSIS INTO HOW THE HUMAN PRESENCE INFLUENCES THE DISTRIBUTION OF FOREST ECOSYSTEM SERVICES

2.1 Abstract

Indigenous peoples have long shaped the distributions of ecosystems services derived from plant species to support their subsistence lifestyles. Yet, much knowledge on how they influence distributions of ecosystem services has been derived from ethnographic data. This study utilized a spatial analysis approach to examine whether signals of the human presence could be detected on the distribution of two types of provisioning ecosystem services, subsistence uses and commercial logging. Six variables were used as proxies for the human presence – village presence, distance to village, distance to road, distance to waterways, elevation, and slope – to examine their relationships with ecosystem service distributions. Data on the ecosystem services were obtained for the Rupununi, Guyana, and their distributions were regressed against each of the six variables. The analysis showed that at the landscape-level, five variables significantly influenced the distributions of subsistence services whereas four variables significantly influenced the distributions of logging service. However at the village-level, the effects of each variable on the distributions of both ecosystem services varied. It was also found that both types of ecosystem services were generally influenced by the same variables in similar locations. This spatial analysis provided support to earlier ethnographic work that suggested that the human presence does indeed influence the distributions of ecosystem services within landscapes.

2.2 Introduction

Humans have historically influenced the spatial distributions of plant species to meet their social and economic needs (Denevan, 1992). In particular, forested landscapes such as those in Amazonia, which have initially been perceived to be developed in the absence of humans (Denevan, 1992; Posey & Balick 2006; Smith, 1980; Williams, 1989), have been demonstrated to exist primarily due to the human presence and anthropogenic practices (e.g. Balée, 1989; Goudie, 1981; Marsh 1970; Posey & Balick 2006; Sauer 1958). Typically, indigenous populations have shaped forest structures through agricultural activities, plant management practices, and demographic changes (Cronon, 1983; Denevan, 1992). More recently, other forest users such as commercial loggers have modified forests by developing transportation networks (e.g. Kleinschroth & Healey 2017; Laurance et al., 2009; Nepstad et al., 2001). Thus, the human presence in forests have affected the distributions of plant species and, by extension, the provisioning ecosystem services derived from the species (e.g. Lamont et al., 1999; Miller et al., 2006; Posey, 1985).

For centuries, the various domestication strategies that indigenous peoples pursued, including forest clearance, expansion of forest fringes, forest felling, fire management, and swidden agriculture (Posey & Balick, 2006), have made forests more productive and compatible for human use (Harris, 1989). For example, Dufour (1990) observed that indigenous peoples in forests practiced swidden agriculture through fallows, forest-fields, and trailside plantings. In the process of domestication, indigenous communities managed to change forest ecology and the demographics of plant species (Harris, 1989). In fact, Sauer (1958) argued that much of the forests in Amazonia were anthropogenic in their form and composition due to indigenous peoples' agricultural activities. Further, Walschburger and Von Hilde-brand (1991) have suggested that the composition of mature forests could be traced directly back to the species found in swidden plots. Besides agricultural practices, scholars (e.g. Alcorn, 1989; Anderson & Posey, 1989; Groube, 1989; Posey & Balick, 2006) have noted that desirable plant species in the forests were actively managed by indigenous peoples. Denevan and Padoch (1987) observed that indigenous peoples protected and planted useful wild plant species to increase their densities in swidden fallows (Denevan, 1992), while the Kayapó communities of the Brazilian Amazon created resource islands and forest fields to keep plants of interest close to their homes (Posey, 1985). In Amazonia, plant species cultivated in homegardens became important sources of food, spices, medicines, and fiber (Lamont et al., 1999; Miller et al., 2006; WinklerPrins & de Souza, 2005). Similarly, in the Peruvian Amazon, indigenous families planted species in their homegardens which provided materials that were otherwise needed to be obtained from urban markets, saving significant travel time (Lamont et al., 1999).

Demographic shifts have also contributed to changes in the distributions of ecosystem services across forested landscapes (see Denevan, 1992). Although the relationship between indigenous peoples' population density and impacts on their landscapes were not always directly correlated (Whitmore et al., 1991), the decline in the numbers of indigenous peoples after the arrival of Europeans to the New World led to changes in species structures and compositions (Denevan, 1992; Williams, 1989). Unlike indigenous peoples who relied on plant species mainly for subsistence purposes such as food, medicines, and household materials (e.g. Dufour, 1990; Forte, 1996; Miller et al., 2006; Posey, 1985), colonists sought out trees for large amounts of fuel as well as lumber for constructing ships, buildings, and barrels (Cronon, 1983; Williams, 1989).

Additionally, because plants of timber value would be frequently scattered amongst species of lesser demand, indiscriminate logging by colonists have led to the damage of less desirable species when felling plants (Cronon, 1983). Such changes in the cultural uses of plants would ultimately affect forest species distributions.

Accessibility through landscapes also affected the distributions of ecosystem services. For example, difficulty in traveling to urban markets for subsistence materials, such as fruits, was a determining factor in indigenous peoples' decisions about the kinds of fruit tree species they cultivated in their homegardens (Lamont et al., 1999). From a commercial perspective, accessibility through tropical forests by road networks had increased the likelihood of logging (e.g. Kleinschroth & Healey, 2017; Laurance et al., 2009; Nepstad et al. 2001). Given the unique characteristics and ecological roles of forest species, plants became more vulnerable to environmental changes brought about by logging roads (Laurance et al., 2009). In fact, Kleinschroth and Healey (2017) found that construction of logging roads could lead to 0.6-8.0% loss in forest cover. Additionally, while most logging roads are usually abandoned to vegetation recovery, the original flora would be replaced by newer, more dominant species (Kleinschroth et al., 2016). Further, Edwards et al. (2014) noted that the increased accessibility to forests by roadways led to the conversion of more forested lands to plantations. Such commercial anthropogenic processes could effectively change forest species compositions and consequently ecosystem service distributions.

To date, much of the work describing human influences on forests (e.g. Denevan, 1992; Lamont et al, 1999; Miller et al., 2006; Posey 1985) have been derived from ethnographic methods, including historical accounts, participant observations, and field reports. For instance, scholars such as Cronon (1983) and Williams (1989) used eye-witness accounts and historical materials to describe indigenous and colonial impacts on forest species and on landscape ecology as a whole. Likewise, Day (1953) and Rostlund (1957) used historical descriptions of indigenous peoples' activities, such as fuelwood cutting, agricultural clearing, and hunting, to highlight how indigenous communities have modified forest structures. Additionally, Posey (1985) used ethno-ecological accounts to explain how the Kayapó peoples used their knowledge of ecological zones and forest resources to manage the distributions of important plant species close to their homes. Scholars also drew inferences about human impacts on ecosystem service distributions using the results of field surveys. For example, WinklerPrins and de Souza (2005) conducted a descriptive analysis of the importance of homegardens for urban households by interviewing new migrant families about their reliance on the types of plants they grew. Similarly, Lamont et al. (2009) used descriptive statistics to explore how the type and number of individual plant species grown in homegardens were connected to cultural and accessibility factors. In the Rupununi setting, Sivasailam and Cummings (2017) examined how plants that have multiple uses are distributed across the Rupununi landscape and found a strong connection between villages and where plants that provide important services are found. Other researchers, including Roosevelt (1991) and Sanders et al. (1979) used archaeological evidence to describe how the human presence and anthropogenic practices, such as mound building, historically shaped surrounding ecosystems including forests within landscapes. While these historical and descriptive reports were valuable, Dressler et al. (2015) suggested the need to move beyond ethnographic accounts in order to understand the roles of indigenous peoples in influencing modern-day policies on ecosystem services and land management. To date, a limited number of studies had been conducted that considered changes in spatial distributions of species in landscapes managed by people (Dalle et al. 2002). Dalle et al. (2002) assessed the spatial effects of human activities on species distributions and found that human-driven practices such as agriculture and logging changed the spatial structures of species (Dalle et al., 2002). Similar spatial analyses, which can complement ethnographic work, are needed to gain deeper insights into the influences on indigenous peoples' landscapes.

With the backdrop of past work in mind, this chapter hypothesized that an examination of spatial factors attributed to activities of indigenous communities would provide signals into how the human presence may influence the distributions of two types of provisioning ecosystem services. To address this hypothesis, two overarching objectives were explored. First, the impact of a suite of physical environment and demographic variables on the distributions of Subsistence Value Index (SVI), which measured the subsistence services that indigenous peoples derived from plants, versus the Commercial Logging Index (CLI), which measured the commercial logging services derived from plants, were assessed at the landscape- and at village-levels. Second, the distributions of the SVI and CLI values were mapped relative to the physical environment and demographic variables to determine which of these factors influenced the distribution of subsistence and commercial logging ecosystem services throughout the landscape, and what the influence of these factors may mean for indigenous communities seeking to prioritize access to ecosystem services within their forests.

2.3 Materials and Methods

2.3.1 Study area

This research was completed using data collected from the Rupununi, Southern Guyana (Figure 2.1; see Cummings, 2013; Cummings & Read, 2016; Read et al., 2010; Shah & Cummings, 2018 for an overview of the area). The elevation of the area ranges from 30 m in the low-lying savannahs to about 1,100 m in the Kanuku and Pakaraima Mountains (Read et al., 2010). The Rupununi river, a tributary of Guyana's largest river, Essequibo, runs through the area and is scattered with oxbow lakes, ponds, and creeks (Cummings, 2013). Brazil's Roraima state is connected to Guyana by an unpaved road running across the Rupununi and to Georgetown (Cummings, 2013). Recent road improvements and developments (Cummings, 2013; Seales, 2010) have made the Rupununi more accessible from both Georgetown and Brazil.

For longer than recorded history, the area has been inhabited by the indigenous Wapishiana and the Makushi nations (Colchester, 1997) who still rely heavily on the forests for subsistence (see Cummings, 2013; David et al., 2006; Forte, 1996; Polak, 1992; Read et al., 2010; van Andel, 2000). The area's indigenous peoples employ swidden agricultural practices to obtain their staple cassava (*Manihot esculenta*; Crantz) and other crops (Cummings, 2013; Cummings et al., 2017). Local knowledge suggests that prior to the arrival of Christian missionaries in the early- to mid-1900's, many communities lived closer to the forests. The missionaries' arrival and the subsequent establishment of schools and installment of other social services led to the population moving to lower-lying lands and to the forest-savannahs interface. Villages were established throughout the Rupununi by indigenous communities once they have proven to the Guyanese government that they have been, for at least 25 years, living in the lands they were lobbying for (as per the Amerindian Act of 2006; https://moipa.gov.gy/). Today, there are 25 legally-titled indigenous communities within the study area (Cummings, 2013).

Commercial logging only recently became a part of the Rupununi landscape (Cummings, 2013), despite there being a high concentration of commercially valuable timber species within the area (Polak, 1992). With the development of roads to the area (Seales, 2010), improving access to the Rupununi over the years has led to an increasing number of logging interests being established (see Cummings, 2013; Wenze, 2013). Currently, the Iwokrama International Centre for Rainforest Conservation and Development (IIC) allows reduced-impact logging operations within its forests (see Putz, 2008).

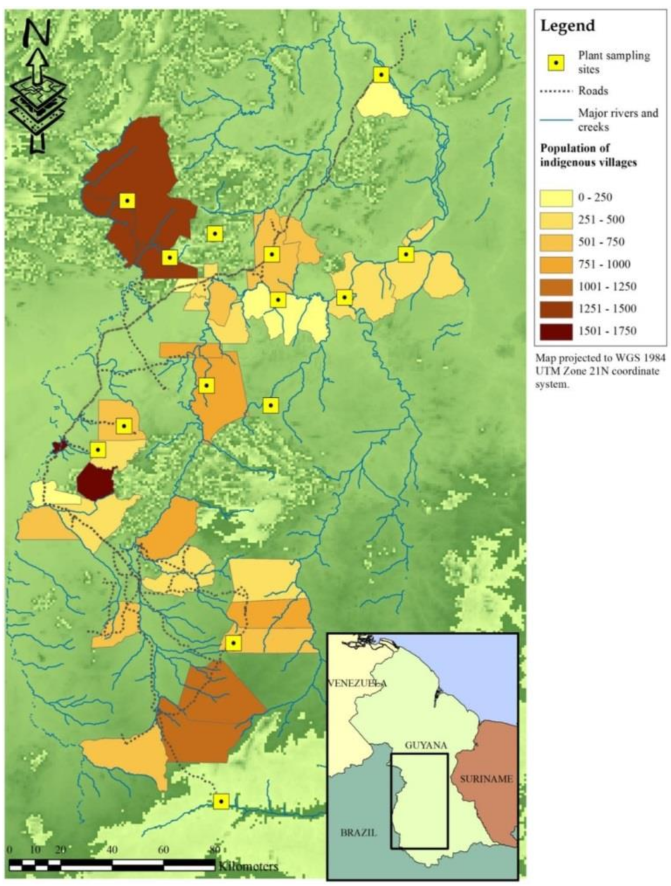


Figure 2.1. Physical environment and demographic characteristics of the Rupununi, Guyana.

2.3.2 Data

2.3.2.1 Subsistence and logging services data for model development

The SVI and CLI, developed by Shah and Cummings (2018), were used as indicators of the subsistence and commercial logging ecosystem services, respectively. The plant locations, which were used to develop the SVI and CLI, (see Shah & Cummings, 2018) depicted the presence of these ecosystem services within the landscape. Plants were sampled in ninety-two transects, sixteen in two control sites and the remainder in twelve indigenous villages (Figure 2.1). The control sites were uninhabited areas and their SVI and CLI values were utilized for comparison against the SVI and CLI values in indigenous villages (as defined by the Amerindian Act of 2006). To ensure that the outputs of this analysis were reflective of reality, the concepts of species distribution modeling (SDM) were drawn upon for model development, as well as to create "pseudo-absences" for SVI and CLI in areas where plants were not expected to grow, such as roads and waterways (see Barbet-Massin et al., 2012). The pseudo-absence data were used to identify where the ecosystem services may be present and where they may be absent, to enhance the comparisons between the spatial distributions of SVI and CLI.

2.3.2.2 Potential physical environment and demographic variables

Variables which reflected human presence or influence on ecosystem services distributions within the landscape, through accessibility, demographic factors, and anthropogenic activities, were considered for the spatial analysis. Based on the literature, a list of potential predictors was compiled to assess how each variable may influence the distributions of subsistence and commercial logging ecosystem services across the study area. The list included indigenous village locations (e.g. Posey, 1985), indigenous peoples' populations (e.g. Cronon, 1983; Denevan, 1992), distributions of plants relative to village locations (e.g. Miller et al., 2006; Posey, 1985), proximity of plants to roads (e.g. Kleinschroth & Healey, 2017; Laurance et al., 2009; Nepstad et al., 2001), proximity of plants to water networks (e.g. Lamont et al., 1999), vegetation cover (e.g. Mexia et al., 2018), soil types, (e.g. Jónsson et al., 2016), Normalized Difference Vegetation Index (NDVI, e.g. Krishnaswamy et al., 2009), and Normalized Difference Water Index (NDWI, e.g. Andrew et al., 2014). Further, other physical environment variables including elevation and slope were tested based on the fact that they had the potential to constrain accessibility to the two types of ecosystem services within the study area.

2.3.3 Analysis

2.3.3.1 Identifying relevant predictor variables

It was found that five physical environment variables – distance-to-village, distance-to-road, distance-to-water, elevation, and slope – and one demographic variable, village presence, may heavily influence the connections between people and ecosystem services (Table 2.1). These six variables also showed little to no collinearity amongst themselves, and were therefore used in subsequent analyses. The data for each of these variables were derived or extracted from a variety of spatially-referenced datasets, including satellite imagery, online databases (Table 2.1).

Table 2.1. The six physical environment and demographic variables used in this study to test SVI and CLI distribution, their sources and significance. Potential predictor variables that did not explain the SVI or CLI and were found to be collinear with the relevant variables are not listed.

Variable	**Data source**	**Indicator**
Presence within village boundary	Guyana Lands and Surveys Commission	Indicates peoples' proximity to SVI and CLI
Distance-to-village	Guyana Lands and Surveys Commission	Indicates peoples' proximity to SVI and CLI
Distance-to-road	DIVA-GIS (http://www.diva- gis.org)	Indicates access to SVI and CLI; many of the roads are walking trails
Distance-to-water	Guyana Geospatial Information Management Unit (GIM) (https://data.gim.gov.gy/)	Indicates access to SVI and CLI; many of the waterways are frequent routes of travel
Elevation	ASTER digital elevation model - DEM (Cogley, 2009)	Reflects the constraints people may have for accessing SVI and CLI; it is assumed that the ecosystem services are more difficult to access at higher elevations
Slope	ASTER digital elevation model - DEM (Cogley, 2009)	Reflects the constraints on accessing SVI and CLI; it is assumed that the ecosystem services are more difficult to access at steeper locations

The village presence variable was a demographic factor that assessed whether the relative proximity of human populations to subsistence and commercial logging ecosystem services, (indicated by the presence of SVI/CLI within or outside the boundary of a village) influenced the distributions of the two ecosystem services. Spatial data for the twelve villages of interest were obtained in the form of polygon shapefiles from the Guyana Lands and Surveys Commission (https://glsc.gov.gy/). The polygon layers clearly delineated village boundaries, which facilitated the process of identifying whether SVI/CLI values were present or absent within a given village through an overlay analysis. The shapefiles were then converted and processed as binary raster layers to represent the presence or absence of subsistence and commercial logging ecosystem services relative to a village boundary. If an ecosystem service was located within the boundary, it was assigned a village presence value of 1. If the service was located outside the boundary, it was assigned a village presence value of 0. The village polygon shapefiles were also used to develop the distance-to-village variable. This variable, also an indicator of people's proximity to the ecosystem services, measured the distance between each SVI/CLI and the nearest village center. Ideally, a cluster of homesteads or an area of high population density within a village could have been used to represent the village center. However, determining the distribution of each individual homestead was not possible due to lack of high-resolution satellite imagery of the villages. Furthermore, there was little to no data on how the local populace was distributed within each village. Given such challenges, a geographic method was used to estimate the center of each village. Most of the village polygon shapefiles were irregularly-shaped, and therefore the medial axis algorithm (e.g. De Smith et al., 2018) was applied to each village polygon to locate its center of gravity. The center of gravity then served as a proxy for homesteads and represented the village center. Subsequently, Euclidean distances between each SVI/CLI location and the coordinates of the nearest village center were computed in a geographic information system (GIS) to develop the distance-to-village variables. Similarly, the Euclidean distances between each SVI/CLI and the nearest road and water body shapefiles (indicators of peoples' accessibility to the ecosystem services) were computed to derive the distance-to-road and distance-to-water variables, respectively. Elevation and slope data were extracted from an ASTER digital elevation model (DEM) of the study area (Cogley, 2009; Cummings, 2013).

While other variables were also considered for the analysis, preliminary tests suggested that the variables would not contribute to model fit or have impact on the SVI and CLI. For example, the tests showed that vegetation class and soil cover were strongly correlated with elevation and were thus removed from consideration. The NDWI and NDVI, which were also strongly correlated to each other, did not explain SVI and CLI distributions and were also removed from further analysis. As a demographic factor, a population density variable, which can indicate the level of subsistence and commercial logging activities by people, was also considered. However, spatial data was unavailable for how indigenous populations were distributed within their village boundaries. Therefore, weighted kernel density estimation was used to develop a population density surface for each village based on where indigenous peoples carried out their subsistence activities relative to the center (as represented by the center of gravity derived from the medial axis algorithm applied to the village polygon shapefiles). The kernel weights were based on the population of each village that was obtained from the official website of Guyana's Ministry of Indigenous Peoples' Affairs (https://moipa.gov.gy/). For the estimation process, a bandwidth value was adopted based on the average distance an indigenous person travelled from the village center to access subsistence materials. Distance of travel would differ between different types of uses; an indigenous person would travel shorter distances to collect firewood but travel further for certain medicinal plants. Thus, based on literature (Forte, 1996) an average travel distance of 12 km was used as the bandwidth for the kernel density estimation procedure, while the village boundary was used to account for the edge effect. Subsequently, the procedure generated a population density surface of each village (Figure 2.2). However, multicollinearity tests found that there was a strong relationship between population density and the distance-to-village variable. Furthermore, unlike distance-to-village, population density was found to have weaker influence on the SVI and CLI values. Based on these findings, population density was subsequently removed from further analysis.

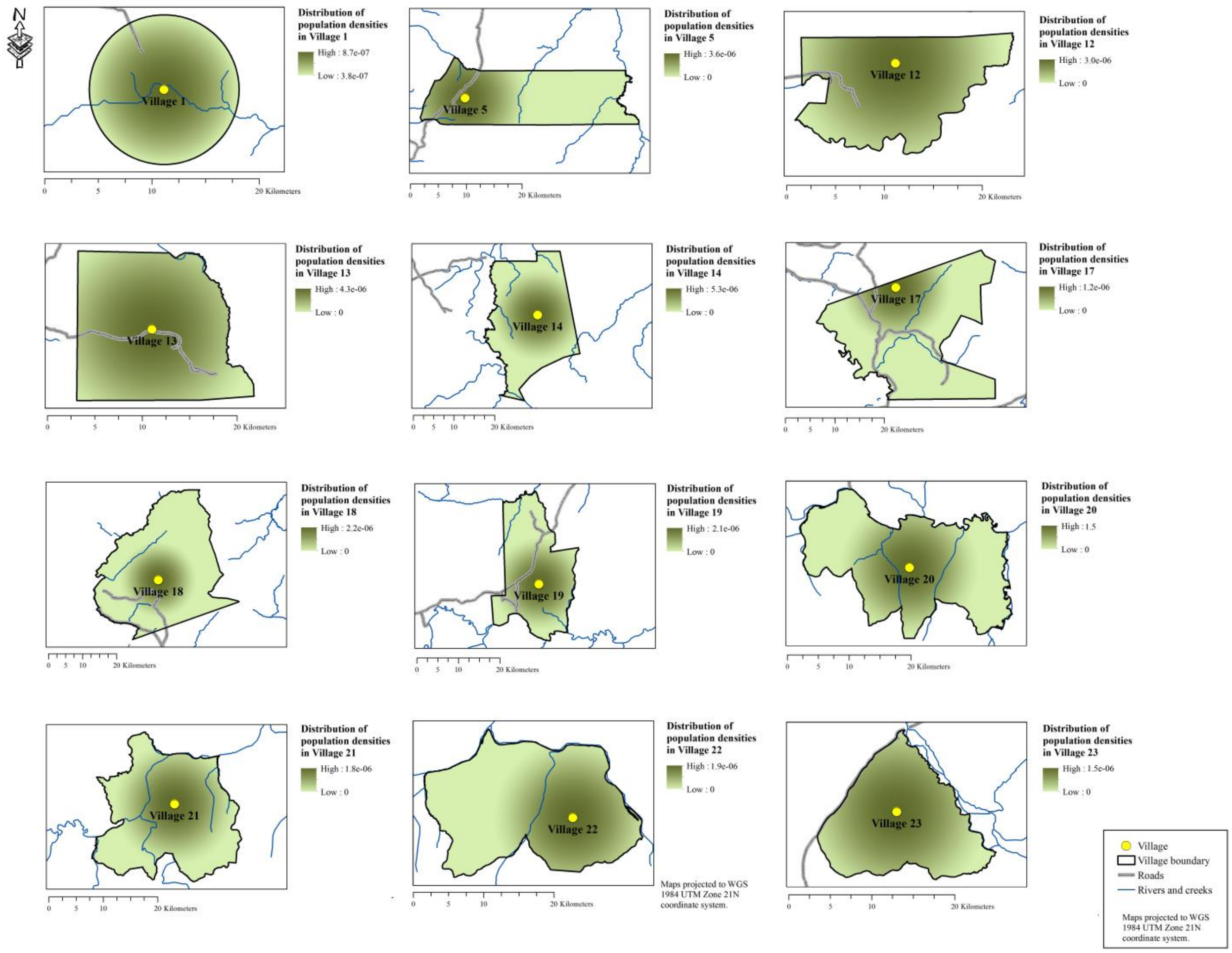


Figure 2.2. Population density surface of each village generated from weighted kernel density estimation based on indigenous peoples' subsistence activities.

2.3.3.2 Using generalized linear models to assess impacts of variables on SVI and CLI

In this analysis, binomial generalized linear models (GLMs) were used to assess the impacts of the six variables on the SVI and CLI distributions, as well as to generate the predicted probabilities of SVI and CLI presence within a given location. The GLMs (Equations 1 and 2) were developed at two spatial levels – at the landscape- and at the village-level. At the landscape-level, data for all the villages were incorporated into a single GLM to assess the influence of the six variables on the distributions of the subsistence and commercial logging ecosystem services across the Rupununi landscape. At the village-level, the impacts of the six variables on the SVI and CLI values were assessed for each of the two controls as well as the twelve villages to examine how the variables may influence the distributions of the two ecosystem services at a smaller, more localized scale. For each GLM, stepwise regressions were first performed to identify and remove the predictors that did not help the GLM explain the distributions of SVI and CLI or contribute to model fit. All regressions were performed in R for Windows version 1.1.453 using the 'stats', 'mgcv', 'dismo', and 'rsq' packages (R-project.org, 2017).

$$SVI_i = \beta_0 + \beta_1 presence + \beta_2 village + \beta_3 road + \beta_4 water + \beta_5 elevation + \beta_6 slope \quad (1)$$

where SVI_i represents a subsistence ecosystem service at the *i*th location, $presence$ is the binary variable that indicated the presence or absence of the service within the village's boundary, $village$ is the distance of the service to the nearest village center, $road$ is the distance of the service to the nearest road, $water$ is the distance of the service to the nearest river/creek, $elevation$ is the height of the area where the service is present or absent, and $slope$ is the steepness of the area where the service is present or absent.

$$CLI_i = \beta_0 + \beta_1 presence + \beta_2 village + \beta_3 road + \beta_4 water + \beta_5 elevation + \beta_6 slope \quad (2)$$

where CLI_i represents a commercial logging ecosystem service at the *i*th location, $presence$ is the binary variable that indicated the presence or absence of the service within the village's boundary, $village$ is the distance of the service to the nearest village center, $road$ is the distance of the service to the nearest road, $water$ is the distance of the service to the nearest river/creek, $elevation$ is the height of the area where the service is present or absent, and $slope$ is the steepness of the area where the service is present or absent.

The GLM estimates at the landscape-level were used in a GIS to visualize the potential SVI and CLI distributions, in the form of predicted probabilities, across the entire study area, similar to how species distribution models are generated (e.g. Guisan et al., 1999; Onikura et al., 2014). The maps of the two types of ecosystem services were then examined to compare how the SVI and CLI values were distributed across the landscape relative to the six physical environment and demographic factors, and the implications of the distributions of each of the ecosystem services were then assessed.

2.4 Results

2.4.1 Importance of the physical environment and demographic variables in determining the SVI

At the landscape-level, five predictor variables significantly influenced the SVI ($p < 0.05$), while at the level of individual villages at least three predictors showed significant impact ($p < 0.05$) on the SVI. It was also found that at the village-level, the relationships between the physical environment variables and SVI distributions were not always consistent. In comparison, in the control sites where the village presence and distance-to-village were absent, most the remaining physical environment variables were significant and consistently influenced the distributions of subsistence ecosystem services (Table 2.2).

At the village-level, the village presence variable was a significant factor ($p < 0.05$) in influencing SVI distributions in seven sites. However, while it had a positive impact in five villages, indicating that that distributions of subsistence services were higher within the villages relative to areas outside their boundaries, the variable had the opposite effect in two others sites and at the landscape-level. The distance-to-village variable significantly ($p < 0.05$) influenced SVI distributions in eleven sites, eight of which demonstrated negative effects, as well as at the landscape-level. This indicated that generally subsistence services decreased with distance from village centers across the inhabited areas of the Rupununi. On the other hand, the distance-to-road variable showed positive impact ($p < 0.05$) in six villages and negative impacts in six more ($p < 0.05$). Conversely, the distance-to-water variable demonstrated positive influence on the SVI distributions in all the nine villages it was found to be significant ($p < 0.05$), demonstrating that subsistence services increased with distance from rivers and creeks. Similarly elevation, which had significant impact ($p < 0.05$) in eight villages, had positive influence on the SVI in seven of those villages. On the other hand, it was observed that slope explained distribution of SVI values ($p < 0.05$) in only one village (Table 2.2), indicating that it is not a significant determinant of subsistence services throughout the Rupununi landscape.

Table 2.2. GLM results of the effects of the physical environment and demographic variables on the SVI.

Regression models (~SVI)	Village	Presence within village boundary	Distance to village (m)	Distance to road (m)	Distance to water (m)	Elevation (m)	Slope (%)
GLM 1	Control 3	-	-	-	2.23e-04 (< 2e-16)*	6.98e-03 (< 2e-16)*	1.90e-02 (0.00393)*
GLM 2	Control 4	-	-	-3.63e-05 (1.56e-07)*	5.27e-04 (< 2e-16)*	5.80e-03 (4.16e-08)*	-
GLM 3	1	0.57 (0.017)*	-1.50e-04 (2.01e-04)*	6.78e-05 (9.60e-07)*	2.30e-04 (4.70e-09)*	0.089 (4.01e-13)*	-
GLM 4	5	-2.08 (< 2e-16)*	-0.0013 (< 2e-16)*	0.0011 (< 2e-16)*	-	-	-
GLM 5	12	-1.23 (2.83e-06)*	-2.90e-04 (1.24e-09)*	3.70e-04 (2.38e-14)*	2.50e-04 (5.17e-07)*	-	-
GLM 6	13	-	2.90e-04 (4.47e-09)*	3.10e-04 (5.94e-04)*	5.60e-04 (4.30e-15)*	-0.013 (2.00e-6)*	0.053 (0.0017)*
GLM 7	14	-	-3.00e-04 (< 2e-16)*	-3.20e-04 (< 2e-16)*	-	0.11 (< 2e-16)*	-
GLM 8	17	5.65 (2.34e-14)*	2.50e-04 (4.08e-06)*	4.80e-04 (2.05e-10)*	-	-	-
GLM 9	18	-	-5.96e-05 (1.81e-04)*	-9.93e-05 (5.66e-04)*	3.00e-04 (< 2e-16)*	0.0042 (8.6e-14)*	-
GLM 10	19	-	-3.30e-04 (< 2e-16)*	3.00e-04 (< 2e-16)*	3.10e-04 (< 2e-16)*	0.033 (< 2e-16)*	-
GLM 11	20	-	-8.40e-05 (0.0034)*	-1.30e-04 (1.18e-07)*	5.40e-04 (6.52e-14)*	0.066 (2.43e-12)*	-
GLM 12	21	1.18 (3.36e-14)*	7.20e-05 (1.39e-06)*	-3.33e-05 (5.84e-04)*	9.70e-04 (< 2e-16)*	-	-
GLM 13	22	0.51 (0.0010)*	-3.00e-04 (< 2e-16)*	-3.90e-04 (< 2e-16)*	1.50e-04 (4.27e-05)*	0.015 (0.0028)*	-
GLM 14	23	0.18 (0.0074)*	-	-3.50e-05 (9.78e-05)*	8.68e-05 (7.83e-09)*	0.050 (< 2e-16)*	-
GLM 15	ALL	-4.61e-01 (< 2e-16)*	-1.10e-04 (< 2e-16)*	1.97e-05 (< 2e-16)*	1.38e-04 (< 2e-16)*	-5.02e-04 (2.30e-10)*	-

(*) indicate statistical significance at $p < 0.05$
(-) indicates that the predictor variable does not explain the distribution of the SVI values
Note: GLM 15 was performed at the landscape-level, the rest of the GLMs were run at village-level.

2.4.2 *Importance of the physical environment and demographic variables in determining the CLI*

As for the CLI, four variables significantly ($p < 0.05$) influenced the distribution of the CLI at the landscape-level, while at the village-level at least three variables showed significant ($p < 0.05$) impact. As with the SVI, the relationship between some physical environment variables and CLI distributions were not consistent at the level of individual villages. On the other hand, in the control sites the CLI distributions consistently increased with greater distances from waterways as well as with rise in elevation (Table 2.3).

At the village-level, village presence was significant ($p < 0.05$) in nine sites with regard to its influence on the CLI distribution. However, its effect was positive in five sites and negative in four others, as well as at the landscape-level. On the other hand, while CLI distributions showed a positive pattern with distance from the nearest village center in only one site ($p < 0.05$), their distributions declined with distance from the centers in nine other villages as well as at the landscape-level ($p < 0.05$), indicating that logging services were generally spatially concentrated near indigenous villages across the Rupununi. On the other hand, the CLI distributions appeared to increase with both distances from road and from water ($p < 0.05$) in nine of the twelve villages, and across the Rupununi study area as a whole, highlighting the general influence of transportation networks on the distributions of logging services. Similarly, elevation was an important predictor ($p < 0.05$) in seven villages. In comparison, slope influenced CLI distribution in only one village ($p < 0.05$). This finding indicated that overall slope was not a major influence in the distributions of commercial logging services across the inhabited parts of the Rupununi (Table 2.3).

Table 2.3. GLM results of the effects of the physical environment and demographic variables on the CLI.

Regression models (~CLI)	Village	Presence within village boundary	Distance to village (m)	Distance to road (m)	Distance to water (m)	Elevation (m)	Slope (%)
GLM 1	Control 3	-	-	-	1.68e-04 (<2e-16)*	7.94e-03 (<2e-16)*	-
GLM 2	Control 4	-	-	-3.44e-05 (5.93e-07)*	6.47e-04 (<2e-16)*	6.17e-03 7(.26e-08)*	-
GLM 3	1	5.07e-01 (0.034)*	-1.68e-04 (2.39e-05)*	9.26e-05 (1.85e-11)*	2.14e-04 (4.50e-08)*	1.01e-01 (3.04e-16)*	-
GLM 4	5	-1.73 (2.97e-08)*	-9.20e-04 (2.67e-12)*	7.70e-04 (1.3e-10)*	-	0.0085 (0.34)	-
GLM 5	12	-1.71 (1.39e-13)*	-3.06e-04 (1.19e-12)*	3.00e-04 (4.04e-10)*	-	0.0043 (< 2e-16)*	-
GLM 6	13	-	1.75e-04 (6.30e-04)*	3.66e-04 (5.50e-04)*	6.78e-04 (5.80e-16)*	-6.64e-03 (9.40e-04)*	4.55e-02 (0.0021)*
GLM 7	14	-	-1.20e-04 (1.6e-04)*	-2.30e-04 (< 2e-16)*	1.90e-04 (5.24e-06)*	0.078 (< 2e-16)*	-
GLM 8	17	4.77 (1.30e-05)*	-	0.00029 (0.0030)*	0.00076 (1.98e-05)*	-	-
GLM 9	18	-	-7.49e-05 (3.87e-06)*	-9.88e-05 (9.10e-04)*	0.00028 (5.42e-15)*	0.0053 (< 2e-16)*	-
GLM 10	19	1.052 (1.46e-06)*	-0.00011 (1.90e-05)*	0.00020 (< 2e-16)*	0.00025 (< 2e-16)*	-	-
GLM 11	20	-7.87e-05 (0.012)*	-9.72e-05 (1.60e-04)*	0.00029 (9.10e-05)*	0.083 (< 2e-16)*	-	-
GLM 12	21	0.86 (4.25e-11)*	-	4.91e-05 (3.30e-04)*	0.00068 (< 2e-16)*	-0.021 (0.016)*	-
GLM 13	22	0.97 (1.27e-09)*	-0.00043 (< 2e-16)*	-0.00053 (< 2e-16)*	-	0.038 (< 2e-16)*	-
GLM 14	23	-2.34e-05 (0.025)*	-3.44e-05 (7.30e-04)*	5.29e-05 (0.011)*	0.043 (< 2e-16)*	-	-
GLM 15	ALL	-2.38e-01 (3.08e-11)*	-1.04e-04 (< 2e-16)*	2.50e-05 (< 2e-16)*	1.40e-04 (< 2e-16)*	-	-

(*) indicates statistical significance at $p < 0.05$

(-) indicates that the predictor variable does not explain the distribution of the SVI values

Note: GLM 15was performed at the landscape-level, the rest of the GLMs were run at village-level.

2.4.3 Comparisons of how the physical environment and demographic variables determine SVI and CLI within a given area

So far, the findings of this analysis demonstrated that in many instances the same variables significantly determined both SVI and CLI distributions ($p < 0.05$) within the same villages as well as at the level of the landscape (Tables 2.4a and 2.4b). For example, the distance-to-road variable determined SVI and CLI in all the locations, while slope influenced the distributions of both SVI and CLI in the Village 13 (Tables 2.4a and 2.4b). Overall, these findings demonstrated that some physical environment and demographic variables not only determined the distributions of both subsistence and logging services, they also influenced both ecosystem services within similar geographic spaces.

Table 2.4a. Comparisons of the impact of the each variable on the SVI and CLI distributions at the landscape-level.

	All villages (landscape-level)	
	SVI	CLI
Presence within village boundary	-4.61e-01 (< 2e-16)*	-2.38e-01 (3.08e-11)*
Distance to village (m)	-1.10e-04 (< 2e-16)*	-1.04e-04 (< 2e-16)*
Distance to road (m)	1.97e-05 (< 2e-16)*	2.50e-05 (< 2e-16)*
Distance to water (m)	1.38e-04 (< 2e-16)*	1.40e-04 (< 2e-16)*
Elevation (m)	-5.02e-04 (2.30e-10)*	-
Slope (%)	-	-

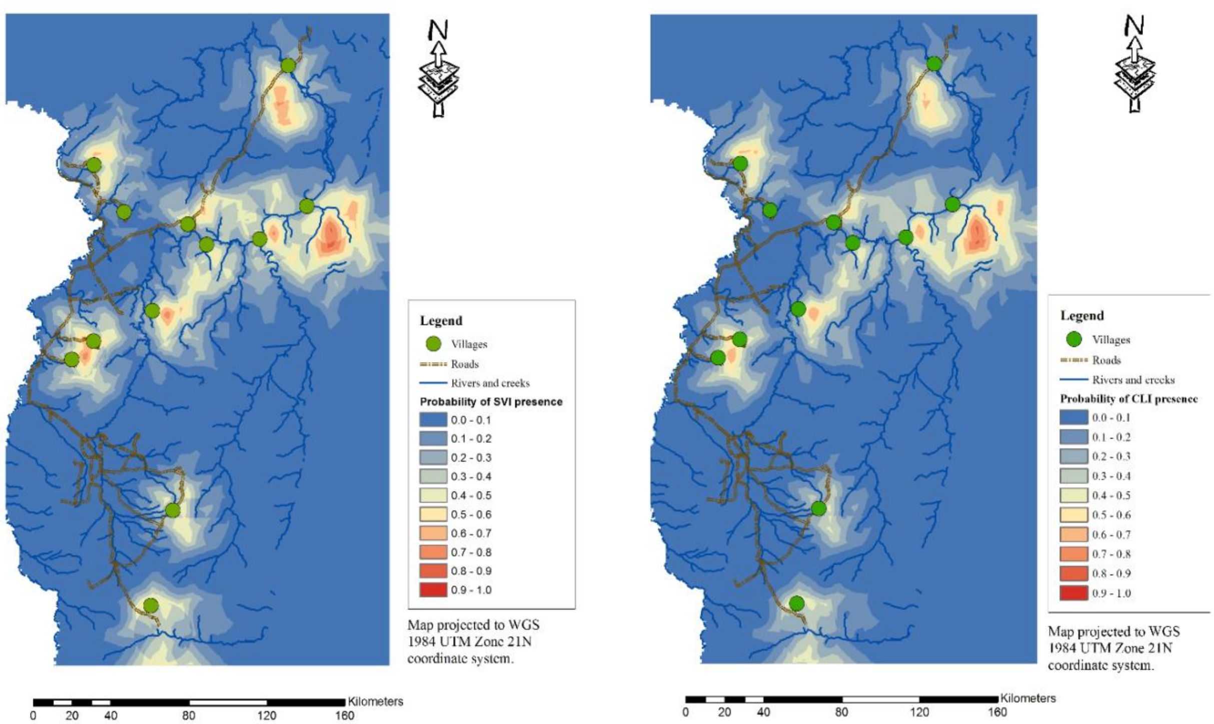
Table 2.4b. Comparisons of the impact of the each variable on the SVI and CLI distributions in each village.

	Village 1		Village 5		Village 12		Village 13		Village 14		Village 17	
	SVI	CLI	SVI	CLI	SVI	CLI	SVI	CLI	SVI	CLI	SVI	CLI
Presence within indigenous boundary	0.57 (0.017)*	5.07e-01 (0.034)*	-2.08 (< 2e-16)*	-1.73 (2.97e-08)*	-1.23 (2.83e-06)*	-1.71 (1.39e-13)*	-	-	-	-	5.65 (2.34e-14)*	4.77 (1.30e-05)*
Distance to village (m)	-1.50e-04 (2.01e-04)*	-1.68e-04 (2.39e-05)*	-0.0013 (< 2e-16)*	-9.20e-04 (2.67e-12)*	-2.90e-04 (1.24e-09)*	-3.10e-04 (1.19e-12)*	2.90e-04 (4.47e-09)*	1.75e-04 (6.30e-04)*	-3.00e-04 (< 2e-16)*	-1.20e-04 (1.6e-04)*	2.50e-04 (4.08e-06)*	-
Distance to road (m)	6.78e-05 (9.60e-07)*	9.26e-05 (1.85e-11)*	0.0011 (< 2e-16)*	7.70e-04 (1.3e-10)*	3.70e-04 (2.38e-14)*	3.00e-04 (4.04e-10)*	3.10e-04 (5.94e-04)*	3.66e-04 (5.50e-04)*	-3.20e-04 (< 2e-16)*	-2.30e-04 (< 2e-16)*	4.80e-04 (2.05e-10)*	0.00029 (0.0030)*
Distance to water (m)	2.30e-04 (4.70e-09)*	2.14e-04 (4.50e-08)*	-	-	2.50e-04 (5.17e-07)*	-	5.60e-04 (4.30e-15)*	6.78e-04 (5.80e-16)*	-	1.90e-04 (5.24e-06)*	-	0.00076 (1.98e-05)*
Elevation (m)	0.089 (4.01e-13)*	1.01e-01 (3.04e-16)*	-	0.0085 (-0.34)	-	0.0043 (< 2e-16)*	-0.013 (2.00e-6)*	-6.64e-03 (9.40e-04)*	0.11 (< 2e-16)*	0.078 (< 2e-16)*	-	-
Slope (%)	-	-	-	-	-	-	0.053 (0.0017)*	4.55e-02 (0.0021)*	-	-	-	-

	Village 18		Village 19		Village 20		Village 21		Village 22		Village 23	
	SVI	CLI	SVI	CLI	SVI	CLI	SVI	CLI	SVI	CLI	SVI	CLI
Presence within indigenous boundary	-	-	-	1.052 (1.46e-06)*	-	-7.87e-05 (0.012)*	1.18 (3.36e-14)*	0.86 (4.25e-11)*	0.51 (0.0010)*	0.97 (1.27e-09)*	0.18 (0.0074)*	-2.34e-05 (0.025)*
Distance to village (m)	-5.96e-05 (1.81e-04)*	-7.49e-05 (3.87e-06)*	-3.30e-04 (< 2e-16)*	-0.00011 (1.90e-05)*	-8.40e-05 (0.0034)*	-9.72e-05 (1.60e-04)*	7.20e-05 (1.39e-06)*	-	-3.00e-04 (< 2e-16)*	-0.00043 (< 2e-16)*	-	-3.44e-05 (7.30e-04)*
Distance to road (m)	-9.93e-05 (5.66e-04)*	-9.88e-05 (9.10e-04)*	3.00e-04 (< 2e-16)*	0.0002 (< 2e-16)*	-1.30e-04 (1.18e-07)*	0.00029 (9.10e-05)*	-3.33e-05 (5.84e-04)*	4.91e-05 (3.30e-04)*	-3.90e-04 (< 2e-16)*	-0.00053 (< 2e-16)*	-3.50e-05 (9.78e-05)*	5.29e-05 (0.011)*
Distance to water (m)	3.00e-04 (< 2e-16)*	0.00028 (5.42e-15)*	3.10e-04 (< 2e-16)*	0.00025 (< 2e-16)*	5.40e-04 (6.52e-14)*	0.083 (< 2e-16)*	9.70e-04 (< 2e-16)*	0.00068 (< 2e-16)*	1.50e-04 (4.27e-05)*	-	8.68e-05 (7.83e-09)*	0.043 (< 2e-16)*
Elevation (m)	0.089 (4.01e-13)*	1.01e-01 (3.04e-16)*	0.033 (< 2e-16)*	-	0.066 (2.43e-12)*	-	-	0.021 (0.016)*	0.015 (0.0028)*	0.038 (< 2e-16)*	0.05 (< 2e-16)*	-

2.4.4 *Spatial distributions of SVI and CLI values throughout the landscape*

The analysis found that the maps generated from the GLM estimation of the SVI (Figure 2.3a) and the CLI (Figure 2.3b) values had similar patterns of distributions at the landscape-level. However, the predicted probabilities of SVI presence appeared to be higher in areas near indigenous villages in comparison to the predicted probabilities of CLI presence which were distributed further away from the villages. Nevertheless, in both cases the distribution of SVI and CLI appeared to be in highest concentrations away from roads, waterways, and the savannahs. These findings, along with the GLM estimates of the physical environment and demographic variables (Table 2.4a), reiterated the observation that the same spatial factors that drive the distribution of SVI may similarly drive the distribution of CLI.



Figures 2.3. (a) Predicted probabilities of SVI presence at the landscape-level, and (b) Predicted probabilities of CLI presence at the landscape-level.

A comparison of mean SVI and CLI values in each village along with their predicted probabilities showed comparable mean values in the ecosystem service data used to derive the models relative to the predicted surfaces (Tables 2.5 and 2.6). The predicted distributions of the SVI and CLI suggested that the physical environment and demographic conditions of the study area may be slightly more favorable for subsistence services with a mean SVI of 0.453 and mean predicted probability of 0.352, than for logging services with a mean CLI of 0.366 and mean predicted probability of 0.317 (Tables 2.5 and 2.6).

Table 2.5. Comparison of mean SVI values and their predicted probabilities in each village.

Village	Mean SVI Value from sample dataset	Mean Predicted Probability of SVI
1	0.48	0.34
5	0.56	0.39
12	0.40	0.39
13	0.37	0.38
14	0.56	0.39
17	0.44	0.10
18	0.43	0.47
19	0.37	0.37
20	0.48	0.32
21	0.51	0.36
22	0.42	0.29
23	0.42	0.42

Table 2.6. Comparison of mean CLI values and their predicted probabilities in each village.

Village	Mean CLI Value from sample dataset	Mean Predicted Probability of CLI
1	0.44	0.31
5	0.36	0.32
12	0.37	0.40
13	0.36	0.32
14	0.37	0.36
17	0.22	0.084
18	0.46	0.47
19	0.31	0.31
20	0.31	0.28
21	0.35	0.33
22	0.46	0.27
23	0.38	0.35

2.5 Discussion

To date, the influence of the human presence on ecosystem service distributions within a landscape have been described mostly through ethnographic accounts (e.g. Denevan, 1992; Marsh, 1970). Deviating from this previous literature, this study used a spatial approach to examine how physical environment and demographic factors attributed to the human presence influence ecosystem services distributions across a forested landscape. The findings of this analysis supported some of what has been published to date, with three notable observations being made that can help better understand how humans influence where ecosystem services, that are important to people's livelihoods, are found.

Firstly, this analysis showed significant signals of the impact of indigenous peoples' presence on where ecosystem services are distributed. It was observed that overall the presence of indigenous communities and distances to transportation networks (i.e. roads, rivers, and creeks) had significant impacts on both the SVI and the CLI distributions at the level of the landscape and of individual villages. These variables determined indigenous peoples' ability to move within a landscape to access ecosystem services, and the findings of this analysis were consistent with ethnographic accounts and descriptive studies of how accessibility through the physical environment of a landscape can affect ecosystem service distributions. For example, the distance-to-water variable was a major factor in driving the distributions of SVI in nine villages (Table 2.2), which arguably complements Lamont et al. (1999)'s observations that distance to markets through river travel affected the type and number of individual plant species grown in homegardens (Lamont et al., 1999). Similarly, CLI distributions was influenced by the distance-to-road variable in twelve villages (Table 2.3), supporting arguments that accessibility by road networks through the forests can affect the likelihood of what plants will be logged (e.g. Kleinschroth & Healey, 2017; Laurance et al., 2009; Nepstad et al., 2001).

Secondly, although most of the spatial factors attributed to human presence influenced both SVI and CLI distributions, one physical environment variable – slope – was generally less critical in influencing the distributions of both ecosystem services. More notably, slope was a significant driver of CLI in only one village. This particular finding was especially important because the current guidelines for logging in Guyana uses slope as an important factor for determining where in space commercial logging can occur (Guyana Forestry Commission (GFC), 2013; Shah & Cummings, 2018). Yet based on this analysis, there was generally no difference in how slope influenced SVI or CLI in a village, indicating that all plants within areas inhabited by indigenous communities were equally exposed to logging pressure. This has even greater implications for the protection of the indigenous use of plants because their accessibility for commercial logging services may not be hindered by slope (see GFC, 2013).

Thirdly, the potential for tensions between indigenous uses and commercial logging of plants was implied through two findings. First, the GLM estimates for the SVI and CLI (Table 2.4a and 2.4b) showed that often the same physical environment and demographic variables influenced both SVI and CLI distributions. Second, both SVI and CLI were most likely to be found within the same locations (Figures 2.3a and 2.3b). These two findings suggested that a potential for conflict in the sustainability of the two different types of ecosystem services might exist. Although the results of the analysis indicated that the landscape may favor SVI presence over CLI presence (Tables 2.5 and 2.6) which suggested that there is a deeper connection between the plant species and the traditional livelihoods of the indigenous peoples, the presence of commercial logging ecosystem services around the same areas might pose a threat to their relationship. Then how can forest users prioritize one ecosystem service over the other if both services are distributed within the same area? This spatial optimization challenge becomes even more urgent in the face of forest conservation programs such as the United Nation's Reduced Emissions from Deforestation and Degradation (REDD+) program (http://www.un-redd.org/) which may prioritize carbon credits over local interests (Friends of the Earth International, 2014; Overman et al., 2018a; World Rainforest Movement, 2015). Such difficulties posed by programs such as REDD+ can include penalties for forest damage or enable infringement of indigenous land rights due to lack of legal enforcement or political interventions (Overman et al., 2018b). These spatial challenges need to be addressed to help resolve the potential conflict between different types of ecosystem services that may exist within indigenous peoples' influenced landscapes.

This analysis also revealed some questions which will be explored in greater details in the future. In particular, how can the distance-to-village variable be improved to give a better insight into the relationship between homesteads and the distribution of ecosystem services? Since homestead data were unavailable, the medial axis algorithm had been applied to the village polygon shapefiles to derive the centers of gravity of each polygon which served as the village centers. Perhaps a better proxy for village centers may be obtained through the use of field surveys and interviews with local individuals and indigenous communities which might provide a better sense of where the "true" centers of their villages are. Another aspect of the analysis that would be addressed is the inconsistency in the impacts of the physical environment and demographic variables on the SVI and CLI at the village-level. Why were some variables significant at the landscape-level, but not at the level of individual villages? Why did a variable have positive influence on the SVI/CLI distribution in some villages, but a negative influence in others? Perhaps, these variable estimates may be improved in the future by the inclusion of updated and more comprehensive data such as unpaved or newly documented pathways and village age. In subsequent studies, it will also be useful to consider incorporating larger samples, as well as alternative sampling strategies into the spatial analysis. For instance, plant data can be collected and compared in areas that are known to have intensive subsistence activities versus areas where there is little subsistence activity.

This analysis has explored within a GIS the spatial connection between human presence and the distribution of ecosystem services within a landscape in response to earlier ethnographic work. The impacts of five physical environment (distance-to-village, distance-to-road, distance-to-water, elevation, and slope) and one demographic predictor variable (village presence) were tested on SVI and CLI distributions in binomial generalized linear regressions. The study found that for both types of ecosystem services, most of the variables were statistically significant at the landscape-level but showed varying impacts on the SVI and CLI distributions at the level of individual villages. The study also found that at the level of the landscape, SVI and CLI were generally influenced by the same variables and were found in similar locations. The chapter then discussed about how spatial analyses can provide evidence to support ethnographic accounts of human influences on ecosystem service distributions. Such spatial studies can also help address spatial optimization issues regarding the potential conflicts between different kinds of ecosystem services within indigenous peoples' influenced landscapes. If ethnographic studies go hand-in-hand with spatial analysis and statistical impact assessments of human influences on the landscape, the combination of field observations, geospatial methods, and statistical analyses can offer a more comprehensive set of information that can better inform decision–making in resource use and ecosystem services management.

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CHAPTER 3

SUBSISTENCE VS LOGGING: HOW IS THE PRESENCE OF ONE ECOSYSTEM SERVICE FAVORED OVER THE OTHER IN A LANDSCAPE?

3.1 Abstract

In tropical landscapes, indigenous peoples who are heavily dependent on their forests for their livelihoods are facing intense competition for plant use from commercial loggers. To gain insights into this conflict, this analysis examined how the presence of subsistence ecosystem services may be favored over commercial logging, and vice versa, by landscape conditions, and also visualized how the two ecosystem services may be distributed relative to each another. Data on the ecosystem services, physical environment, and demographic variables were obtained for twelve indigenous villages in the Rupununi, Southern Guyana. For each village, the relative log risk ratios of subsistence values to logging values were computed and regressed against six physical environment and demographic variables – village presence, distance to village, distance to road, distance to waterways, elevation, and slope – to examine how landscape conditions may favor the presence of one service over the other. The estimates were then used to map the relative differences in the spatial distributions of subsistence and commercial logging ecosystem services in each village. The analysis found that mean relative log risk ratios for the villages were generally positive, indicating an inclination towards the presence of subsistence services. However, the maps revealed that while some areas within a given village may indeed be more favorable for the presence of subsistence services, other areas within the same village may be inclined towards the presence of logging services. Additionally, the two ecosystem services were often present in similar levels around village centers, signaling areas of greatest conflicts. Spatial

analyses such as the one explored in this chapter can be used to help policy-makers develop land-use strategies to allocate forest lands between competing users by identifying areas that are best suited for indigenous peoples' subsistence activities and for commercial logging operations.

3.2 Introduction

In Amazonia, indigenous peoples have lived and relied on forest plant species to support their subsistence lifestyles for centuries (e.g. Colchester, 1997; Cummings, 2013; Fisher et al., 1997; Forte, 1996; Miller & Nair, 2006; Posey, 1985; Shackleton & Shackleton, 2004). However, in more recent times swidden landscapes have faced increasing competition from other forest users (Cummings et al., 2018; Rist et al., 2012; Shanley and Luz, 2003), in particular commercial loggers who are attracted to the high density of tropical timber species within these landscapes (e.g. Cummings, 2013; Shah & Cummings, 2018; Wenze, 2013). The lack of spatial tools that can help indigenous peoples assess how their own reliance on forest plant species may be compromised by conflicting uses (Shah & Cummings, 2018) makes it challenging for them to push back against competitors, despite the increasing recognition of the authority of local communities over their forests (e.g. Larson & Dahal, 2012).

Although there has been increase in the forest tenure rights of indigenous peoples (Larson & Dahal, 2012; White & Martin, 2002) and in the adoption of practices such as land-sharing and land-sparing strategies (Edwards et al., 2014; Scariot, 2013) and community forestry which gives local communities some degree of authority over the management of their forests, there has been more ecological than socioeconomic benefits (e.g. Brockington et al., 2006; Charnley & Poe, 2007; Sylvester et al., 2016). While community-based forestry schemes seek to benefit indigenous peoples by managing resources based on the local, traditional knowledge, the empowerment of indigenous communities are frequently hampered by government regulations (Sitoe & Guedes, 2015). Further, the jurisdictions of community-based conservation initiatives are not always clear, and land and resource management strategies are often not clearly defined. There is also a general ambiguity about those who benefit from such conservation policies (Hitchner, 2010). Additionally, although legally titled indigenous communities may allow other users to access the forests through formal or informal agreements (e.g. Colchester, 1997), the lack of their ability to value their forest resources means that such agreements with commercial loggers may subsequently result in unforeseen and often undesirable consequences for indigenous peoples. For example, in Corentyne, Guyana, the logging activities of the Barama timber company had diverted some Orealla members away from subsistence activities, which had negative impacts on families' socio-economic positions (Colchester, 1997). As such, addressing ways to support indigenous rights to their forest resources is becoming more urgent in the face of commercial logging and other extractive operations.

As more swidden landscapes undergo change, spatial allocation and optimization questions are arising especially in the face of the introduction of payment for ecosystem services initiatives such as the United Nation's Reduced Emissions from Deforestation and Degradation (REDD+) program (http://www.un-redd.org/). Many indigenous lands are already subject to threats from logging, mining and oil interests due to their impacts on the forests (Käyhkö et al., 2011), and such conservation schemes may become even more problematic for local communities especially in places where indigenous rights are either not recognized or tenuous (e.g. Adams & Hutton, 2007; Ghimire, 1994; Lam, 2011; McLean & Straede, 2003; van Dam, 2011). In fact, payment for ecosystem services programs have already been shown to have adverse impacts on the livelihoods of indigenous people. For example, the Chinantec community of southern Mexico have reported declines in agricultural yield due to the limitations set by new conservation policies (Ibarra et al., 2011), and the disruption of indigenous families' livelihood activities due to REDD+ regulations have led to a pushbacks against the initiative (Friends of the Earth International, 2014). Essentially, these landscapes are now facing challenges over balancing conflicting perspectives on the most optimal use of resources distributed throughout the forests (Roos et al., 2018).

In order to begin thinking of ways in which indigenous peoples can protect their uses of the forest, this chapter explored how comparing the relative distributions of subsistence and commercial logging ecosystem services can help identify and target forest areas in which plant use values are optimized for the indigenous peoples and commercial loggers. So far, the findings of Chapters 1 and 2 suggested that the potential conflicts of plant use were not limited to individual plant species as a result of plant attributes but could also exist at a larger spatial extent. Given the findings of the previous chapters, this chapter postulated that the landscape conditions of a given location would favor the presence of one type of ecosystem service over the other, and would influence the distributions of the two ecosystem services relative to each other. In order to address this hypothesis, two objectives were developed. First, the relative log risk ratios of the Subsistence Value Index (SVI) to Commercial Logging Index (CLI) were computed and regressed against six physical environment and demographic variables at the village-level, to assess how the presence of one ecosystem service may be favored over the other given the landscape conditions of a village. Second, the relative differences in the spatial distributions of the SVI and CLI values were mapped to identify areas where the presence of subsistence services may be more favorable versus where the presence of logging services may be preferred. To begin thinking of land-use policies that can mitigate the conflicting uses of forest resources, this chapter explored a potential resource use allocation strategy in which indigenous peoples and commercial loggers can spatially target their activities in particular areas of the forest where their plant use values are optimized.

3.3 Materials and Methods

3.3.1 Study area

The Rupununi study area (Figure 3.1) is home to two of Guyana's major indigenous nations, the Wapishiana and the Makushi, who share strong connections to their forests (Cummings, 2013; David et al., 2006). Some areas in the region have been inhabited by large numbers of indigenous populations for longer than recorded history (Colchester, 1997), although newer villages have been established in more recent years (Amerindian Act of 2006; see https://moipa.gov.gy/). The Rupununi has also attracted commercial logging interests due to the area's high densities of valuable timber species (Cummings, 2013; Polak, 1992; Shah & Cummings, 2018; Wenze, 2013).

Both subsistence and commercial logging ecosystem services have been accessed by streams, including the Rupununi river (Cummings, 2013), as well as unpaved paths and cattle trails (Cummings, 2013; Tourism and Hospitality Association of Guyana – THAG, 2017; also see Chapter 2), though recent road developments are increasing forest accessibility (Cummings, 2013; Seales, 2010). Accessibility is also constrained by the region's elevation which varies from the mountainous Kanuku and Pakaraima areas to the lower flatlands and savannahs.

Guyana has also committed to implementing a low carbon development economy (lcds.gov.gy) as part of its response to REDD+. One of the program's primary objectives is to enhance forest carbon stocks, which sometimes occurs at the expense of indigenous peoples' use of the forests (Friends of the Earth International, 2014; Overman et al., 2018a; World Rainforest Movement, 2015). While communities across the Rupununi area have been participating in REDD+ projects, there are concerns that some program incentives could increase land-grabbing by people with higher economic or political status, and threaten the land tenures and customary rights of the indigenous peoples to the forest (Overman et al., 2018b; Sunderlin et al., 2014).

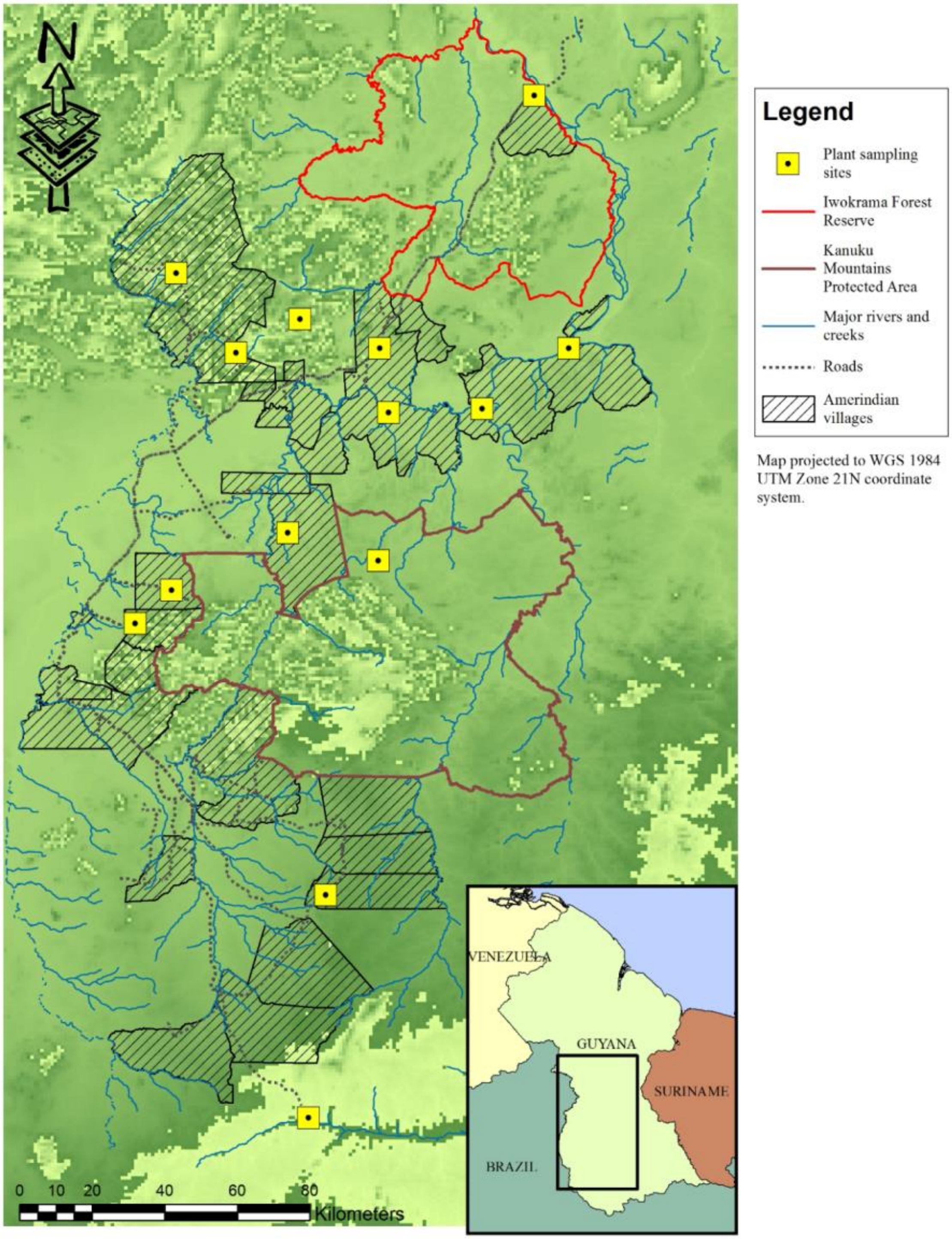

Figure 3.1. Areas of interest to indigenous peoples, commercial timber loggers, and REDD+ mechanisms across the Rupununi, Guyana

3.3.2 Data for computing the relative differences between SVI and CLI distributions

The data utilized for this analysis, including ecosystem services data and six physical environment and demographic variables – village presence, distance-to-village, distance-to-road, distance-to-water, elevation, and slope – were developed in Chapter 1 (also see Shah & Cummings, 2018) and Chapter 2. The plants for which the SVI and CLI were developed were sampled in 92 transects across fourteen sites including two uninhabited control sites (Shah & Cummings, 2018). This analysis used a subset of the SVI and CLI services data from 76 transects across twelve villages, the latter being defined as the lands legally granted to Amerindian communities who have lived there for at least 25 years (Amerindian Act of 2006; see https://moipa.gov.gy/). The six physical environment and demographic variables (see Chapter 2) dictated the landscape conditions of a each village.

3.3.3 Analysis

3.3.3.1 Using the relative log risk ratios to compute differences between SVI and CLI distributions

In order to begin looking at the relative differences in SVI and CLI distributions, relative log risk ratios were incorporated into the analysis. Relative risk ratios were used because the spatial distributions of the SVI and CLI values in each village were in the forms of predicted probabilities (ranging between 0 and 1) derived from binomial generalized linear models (GLMs; see Chapter 2). The relative risk ratio can measure the relative differences between the two values by dividing the probability of SVI presence by the probability of CLI presence. Applying the logarithmic transformation ensured that the output values generated from computing the ratios were not undefined and would also range between $-\infty$ to ∞ (instead of -1 to 1) which would facilitate accuracy. The relative log risk ratio values was first regressed against the six physical environment and demographic variables in stepwise regressions to identify and remove the predictors that did not help the models explain the relative differences in the predicted probabilities of SVI and CLI distributions with a given village (Equation 1). After the influential predictors for each model were identified, the distributions of the relative log risk ratio values for each village were re-computed.

$$log({}^{SVI_i}/_{CLI_i}) = \beta_0 + \beta_1 presence + \beta_2 village + \beta_3 road + \beta_4 water + \beta_5 elevation + \beta_6 slope \quad (1)$$

where $log({}^{SVI_i}/_{CLI_i})$ represented the relative log risk ratio of the predicted probability of presence of subsistence ecosystem services relative to the predicted probability of presence of commercial logging ecosystem services at the ith location, $presence$ is the binary variable that indicated the presence or absence of the services within the village's boundary, $village$ is the distance of the services to the nearest village center, $road$ is the distance of the services to the nearest road, $water$ is the distance of the services to the nearest river/creek, $elevation$ is the altitude of the area where the services are present or absent, and $slope$ is the steepness of the area where the services are present or absent.

3.3.3.2 Mapping the relative differences between SVI and CLI distributions in each village

The regression estimates were used in a geographic information system (GIS) to create raster maps showing SVI and CLI distributions relative to each other in each village. For each influential landscape variable, a raster layer was created with a cell size of 10m, based on the width of sampling transects (see Shah & Cummings, 2018). The village presence data was used to create a binary raster layer which identified whether SVI/CLI values were located within or outside of a village boundary. The distance-to-village, distance-to-road, and distance-to-water variables were processed as raster layers based on the Euclidean distances between each SVI/CLI and the variable. The elevation and slope raster layers were generated from the digital elevation model (DEM) of the landscape (Cogley, 2009). These layers were then incorporated into regressions in R, using packages 'raster', 'rgdal', 'dismo', 'maptools', and 'prettympr', and 'MASS' to generate raster maps of the relative differences in the SVI and CLI distributions in each village.

3.4 Results

3.4.1 Comparison of mean relative log risk ratio values between villages

Overall, it was found that the mean relative log risk ratio values in ten of the twelve villages were positive, suggesting that landscape conditions across the Rupununi may generally favor the presence of subsistence services over commercial logging services (Table 3.1 and Figure 3.2). The landscape conditions in Village 17 seemed especially favorable for the presence of subsistence services in light of its relatively high mean value of 0.667, while the negative mean values in Villages 12 and 18 suggested that the landscape conditions within these locations may be slightly more favorable for the presence of commercial logging services. Still, the mean relative log risk ratios in these two villages along with the mean values of Villages 1 and 13 were quite close to zero, indicating that the landscape conditions in these villages may not heavily prefer the presence of one ecosystem services over the other (Table 3.1 and Figure 3.2).

Table 3.1. Mean log risk ratio values of each village

Location	Mean log risk ratio values
Village 1	0.035
Village 5	0.234
Village 12	-0.063
Village 13	0.091
Village 14	0.537
Village 17	0.667
Village 18	-0.075
Village 19	0.353
Village 20	0.483
Village 21	0.432
Village 22	0.101
Village 23	0.324

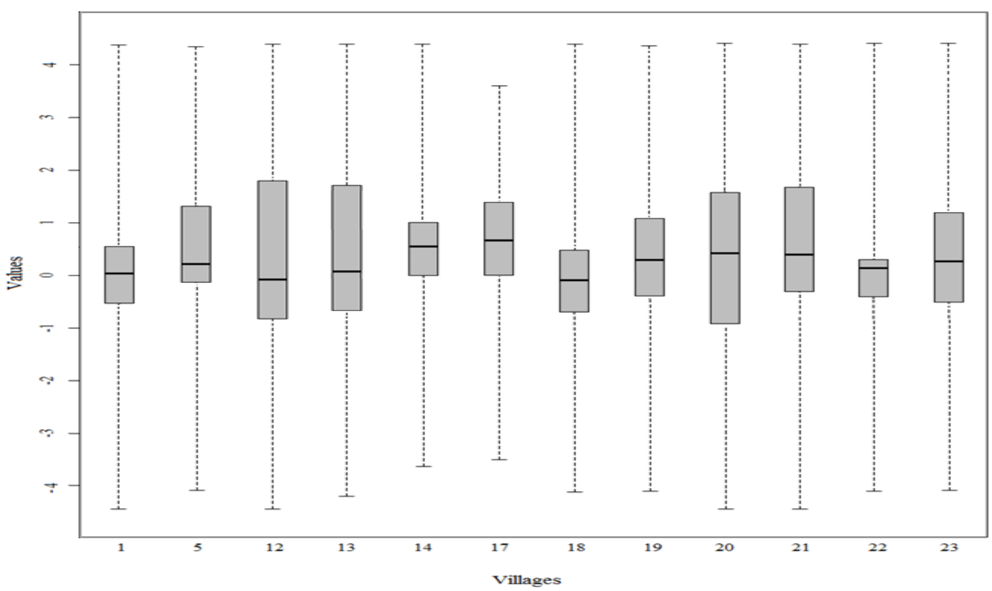

Figure 3.2. Boxplots to compare the mean log risk ratio values of the villages.

3.4.2 Influence of the landscape variables on the log risk ratio values

The impacts of the variables on the relative differences between the SVI and CLI distributions showed varying results from village to village. All the variables had significant impact ($p < 0.05$) on the relative log risk ratio in Village 19, but for the rest of the villages the number of variables that had significant impact ($p < 0.05$) differed (Table 3.2).

Of the individual variables, both distance-to-village and slope influenced ($p < 0.05$) the relative differences between SVI and CLI in four villages, and elevation was influential in five ($p < 0.05$). On the other hand, both distance-to-road and distance-to-water had significant impact on the relative differences between SVI and CLI ($p < 0.05$) in nine villages (Table 3.2), indicating that transportation networks such as roads and rivers might generally influence the type of ecosystem services found within an area.

Additionally, some of the variables showed inconsistent relationships with the relative log risk ratio values at the village-level. For example, the ratio grew more positive (presence of SVI more favorable compared to that of CLI) with increase in distance from road in six villages, but demonstrated opposite patterns in three others ($p < 0.05$). Similarly, the presence of SVI grew more favorable with distance from water in all villages but one ($p < 0.05$). On the other hand, elevation generally demonstrated a significant association ($p < 0.05$) with negative relative log risk ratio values; presence of CLI appeared to be more favorable at higher altitudes. Overall, it was found that the increase in distance-to-road and distance-to-water generally favored the presence of subsistence services, whereas increase in elevation appeared to favor the presence of commercial logging services (Table 3.2).

Table 3.2. Variables that affect the relative log risk ratio of SVI to CLI.

Risk ratio (SVI/CLI)	Village	Distance to village (m)	Distance to road (m)	Distance to water (m)	Elevation (m)	Slope (%)
MODEL 1	1	-	-	0.028 (0.031)*	-3.078 (0.051)*	0.057 (0.14)
MODEL 2	5	-	0.047 (0.0012)*	0.058 (9.52e-06)*	-	-
MODEL 3	12	-0.51 (2e-04)*	0.046 (0.038)*	-	-0.21 (0.017)*	-
MODEL 4	13	0.14 (0.071)	-	-	-	-
MODEL 5	14	-	-	0.12 (8.36e-15)*	-	0.40 (1.19e-05)*
MODEL 6	17	-	0.068 (0.020)*	0.074 (0.00099)*	-	-
MODEL 7	18	-	-0.019 (0.012)*	-0.020 (0.0058)*	-	-
MODEL 8	19	-0.27 (0.0016)*	0.045 (0.0021)*	0.031 (0.054)*	-0.47 (0.050)*	-0.18 (0.00027)*
MODEL 9	20	-	0.12 (0.033)*	0.16 (1.35e-07)*	-2.74 (3.39e-06)*	0.18 (0.059)*
MODEL 10	21	0.22 (0.0024)*	-0.65 (0.22)*	0.062 (0.0094)*	-	-
MODEL 11	22	-	-0.93 (< 2e-16)*	-	-0.41 (0.018)*	-
MODEL 12	23	-0.10 (0.027)*	0.050 (1.24e-07)*	0.060 (2.48e-11)*	-	0.19 (4.37e-08)*

3.4.3 Mapping the relative risk ratios in each village

While previous results suggested that the Rupununi landscape may generally favor the presence of subsistence services over commercial logging services, the maps indicated that the relative differences in the distributions of the two ecosystem services might be more comparable (Figure 3.3). The distributions of the ecosystem services in Villages 5, 12, 13, 17, and 18 suggested that areas within these villages may generally be more favorable for the presence of subsistence services, whereas Village 1 may overall be more suitable for the presence of commercial logging services (Figure 3.3).

It was also found that the presence of subsistence services may be favored over commercial logging services and vice versa in different areas of the same village. For example, in Village 19, the eastern part of the area appeared to be more suitable for the presence of subsistence services versus the northern parts, where logging services appeared to be preferable. Similarly, the western side of Village 22 appeared to be more conducive for the presence of subsistence services versus the eastern side which appeared to be more suitable for the presence of logging services (Figure 3.3).

On the other hand, the areas around the centers of four villages (20, 21, 22, and 23) generally exhibited paler shades (Figure 3.3), indicating that subsistence and commercial logging ecosystem services may exist in similar levels around these centers and that the presence of one service may not be significantly favored over the other.

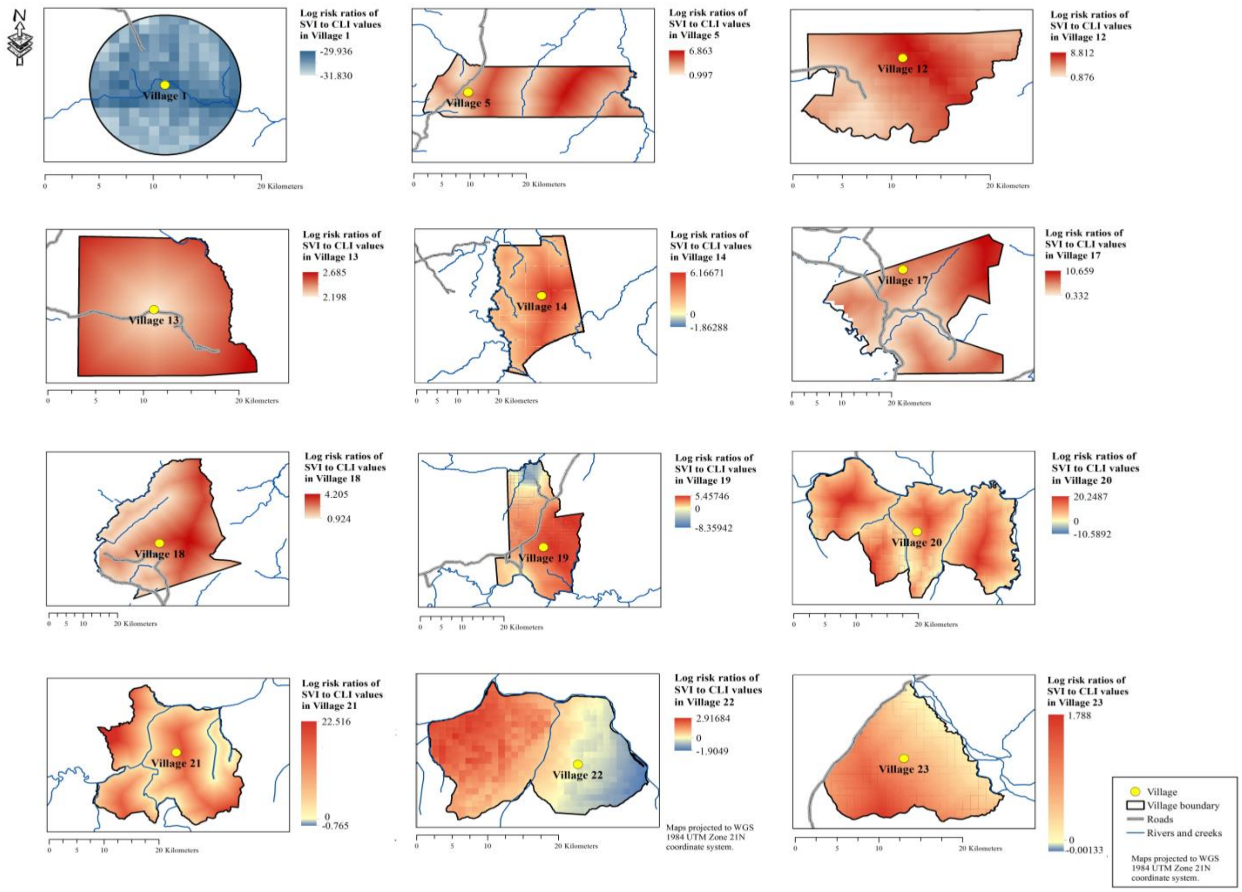

Figure 3.3. Differences in the spatial distribution of subsistence and logging ecosystem services relative to each other.

3.5 Discussion

The increasing competition that indigenous peoples are facing with regard to the use of their forest resources has led to the need for spatial tools that can help local communities address spatial optimization challenges in their forest use. To begin tackling this problem, this chapter has explored a potential resource use allocation strategy based on how subsistence and commercial logging ecosystem services may be spatially distributed relative to each other given the landscape conditions. The findings of this analysis highlighted four points which can help provide deeper insights into the issue.

Firstly, Roos et al. (2018) had noted that allocating forest land uses to generate optimal ecosystem service values can be challenging because of the different approaches to valuating ecosystem services. In this context, the SVI and CLI (Shah & Cummings, 2018) reflected the importance of the provisioning ecosystem services derived from forest species from the perspectives of two clashing groups: indigenous peoples and commercial loggers. Thus, applying these indicators in forest management to define and allocate forest land classes between indigenous peoples and commercial loggers can allow each group to optimize their use of plant species without significantly compromising the others' uses. Such allocation schemes can also clarify which group is benefitting from using plants in a given forest land and how (see Hitchner, 2010).

Secondly, the findings of this analysis suggested that slope generally did not influence the presence of any one ecosystem service over the other. On the other hand, not only was elevation influential in determining the relative differences between the two types of ecosystem services, but also appeared to favor the presence of commercial logging services over subsistence services. These findings have significant implications for Guyana's current logging guidelines. While slope is an important factor in Guyana's Code of Practice that determines where in space logging can take place (Guyana Forestry Commission (GFC), 2013; Shah & Cummings, 2018), the results of this analysis suggested that elevation, rather than slope, may be a more appropriate physical environment variable to consider when making decisions on where to log.

Thirdly, the results of this analysis demonstrated that in certain villages similar levels of subsistence and commercial logging services were concentrated around the centers. The proximity of the subsistence services to village centers reinforced Sivasailam & Cummings (2017)'s findings, and were also consistent with inferences from the literature (e.g. Denevan, 1992; Posey, 1985; Lamont et al., 2009; Miller et al. 2006) about the close proximity of useful plant species, and by extension ecosystem services, to homesteads. However, the presence of logging services in the same areas suggested that these centers may have potential for strong tensions between the two types of ecosystem services. Such results can provide insights into why swidden landscapes often attract commercial logging interests.

Fourthly, visualizing where landscape conditions favor the presence of subsistence ecosystem services can also be used to protect plant species important for indigenous peoples' subsistence livelihoods when they face potential drawbacks from the policies of payment for ecosystem services programs. For example, REDD+ provides incentives such as placing value on carbon stocks that can lead to increased land grabbing by elites (Overman et al., 2018b), and as a result, the indigenous peoples' customary rights to their use of the forest are threatened especially in the absence of legal land tenures (Overman et al., 2018b; e.g. Sunderlin et al. 2014). Based on the findings of this chapter, identifying forest lands around indigenous villages within which optimal values of subsistence services are derived can assist REDD+ policy-makers in better acknowledging the legal rights of the indigenous peoples to their subsistence resources (see Sivasailam & Cummings, 2017; Louman et al., 2011). Such spatial approaches can also help identify forest areas with high subsistence values that should be removed from considerations for REDD+ implementations.

The findings of this analysis also had implications for the spatial methods employed in this chapter which will pave way for future research. This analysis assessed landscape conditions in the form of physical environment and demographic variables that may influence the type of ecosystem service found in any given area. However, the relationship between the variables and their preferences for a particular ecosystem service varied across villages. It is important to understand why the spatial relationships between some of the landscape variables and the subsistence and commercial logging services were inconsistent, and whether these relationships may be attributed to other underlying factors such as village age, sample sizes, and location-specific factors such as the presence of logging concessions. Thus, gathering more comprehensive data and larger sample sizes will be made a point for future work. Another point to think about is the indices themselves. The SVI and CLI have been developed based on certain assumptions (see Chapter 1) but given the findings of this chapter, future research will revisit these assumptions to explore ways to modify the indices that may help them become better proxies for indigenous subsistence and commercial logging ecosystem services.

This chapter explored how landscape conditions may favor the presence of one type of ecosystem service over the other across an indigenous landscape. Relative log risk ratios were computed to measure the relative differences in the distributions of subsistence and commercial logging ecosystem services in each indigenous village, and the impacts of five physical environment (distance-to-village, distance-to-road, distance-to-water, elevation, and slope) and one demographic variable (village presence) on the relative log risk ratios were assessed. These ratios were then used to plot maps in a GIS to visualize the relative distributions of subsistence and commercial logging ecosystem services, and to identify where the presence of one service may be favored over the other given the landscape conditions of a village. It was found that while the landscape conditions were generally inclined towards the presence of subsistence services, some village areas also showed strong preferences for the presence of commercial logging services. Such comparative spatial analyses can serve as decision-making tools for indigenous communities who need to address resource use and spatial optimization questions about their forest use, especially in the presence of competing users such as commercial loggers and initiatives like REDD+ who have very different viewpoints on how forests should be used.

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CONCLUSION

In this dissertation, the values and spatial distributions of provisioning ecosystem services important for indigenous peoples and commercial loggers were examined to gain a deeper insight into the potential conflict of plant use associated with tropical forest species. The landscape of Rupununi, Southern Guyana, was an ideal case study given the strong connections that the area's indigenous nations maintained with their forests, and the commercial logging interests generated by the high densities of commercially viable species in the landscape. Further, the distributions of the indigenous subsistence and commercial logging ecosystem services derived from plant species within the forests were shaped largely by long-term human presence, sometimes through the same anthropogenic factors which might explain the existence of potential tensions between contrasting uses.

In Chapter 1, the Subsistence Value Index (SVI) and the Commercial Logging Index (CLI) of plant species were developed based on their inherent attributes and surrounding physical environment attributes to measure their values from the perspectives of indigenous peoples and loggers. While it was found that 51.7% of the plants had CLI values that were higher than their SVI values, the mean SVI was statistically higher than the mean CLI at both plant- and study site-levels. Additionally, 74.2% of the plants were used for multiple uses, suggesting an inherent potential for resource use conflict. The findings of the analysis highlighted how tropical plant species may be critical for subsistence livelihoods while being targeted for commercial logging at the same time, and indices similar to the SVI and CLI must be considered in forest management regimes to protect indigenous peoples' plant resources.

In Chapter 2, spatial factors, including physical environment and demographic variables attributed to indigenous peoples' presence, were analyzed to see if they provided signals of how human presence influenced ecosystem service distributions. It was found that most of the variables studied – village presence, distance-to-village, distance-to-road, distance-to-water, elevation, and slope – significantly influenced the distributions of SVI and CLI at the landscape-level but with varying effects at the village-level. The findings in the chapter reinforced ethnographic inferences of the human influence on landscapes, and emphasized the need for more spatial analyses of the human-environment interaction, as well as for understanding how human presence can contribute to tensions between the distributions of different types of provisioning ecosystem services.

In Chapter 3, to explore a potential resource use allocation strategy between indigenous peoples and commercial loggers with regard to their forest use, the relative distributions of subsistence and commercial logging ecosystem services as influenced by landscape conditions were explored. Relative log risk ratios of SVI to CLI values were computed to assess how landscape conditions – village presence, distance-to-village, distance-to-road, distance-to-water, elevation, and slope – favored the presence of subsistence and commercial logging ecosystem services relative to each other. It was found that although most of the villages showed an inclination towards the presence of subsistence ecosystem services, some village areas showed strong preferences for the presence of commercial logging ecosystem services. Also, in some villages both ecosystem services existed in similar levels around the centers, signaling areas of greatest conflicts. Such maps could be used to guide land-use policies in developing resource use allocation strategies for competing uses, as well as to assist indigenous communities in addressing spatial optimization questions in the advent of programs such as the United Nations Reduced Emissions from Deforestation and Degradation (REDD+).

With these research points in mind, the dissertation hoped to offer insights into indigenous people's perspective of their forests, the spatial optimization challenges they may face in the presence of other forest users such as commercial loggers and environmental conservation projects, and possible reconciliation strategies that may enable different users to optimize their use of forest resources. This research has been conducted with two specific targets in mind.

Firstly, this dissertation hopes to start an important conversation on forest management approaches especially in indigenous peoples' landscapes in the tropics. The reliance of indigenous peoples on their forests is often ignored by conventional forest managements in favor of commercial logging and too often, forest-dependent communities are marginalized and their perspectives overshadowed by logging market forces (Cocks & Dold, 2006; Dove, 1994; Rist et al., 2012; Sabogal et al., 2013; Shackleton & Shackleton, 2004; Shanley et al., 2012). Until now, commercial timber (e.g. Sabogal et al., 2013) and ecological values of plants have been acknowledged (e.g. Götmark, 2013; Pechanec et al., 2017), but the subsistence values of forests within indigenous landscapes are yet to be recognized. By introducing methods for incorporating the perspectives of indigenous peoples into plant management, this dissertation hopes to herald the need for understanding the values of forests from the perspective of indigenous peoples, as opposed to the typical economic-based viewpoints.

Secondly, this dissertation also hopes to contribute to resource management designs to help allocate forest resources equitably between competing users based on how forest services are perceived and valued. Often, tropical plant species are important sources of livelihoods for indigenous forest-dwelling communities, and the increasing recognition of the timber value of such species poses a very real threat to their way of lives. While indigenous peoples themselves have recognized that their livelihoods can be improved by controlled logging of their forests, they still need to make informed spatial optimization decisions on forest use to protect their traditional ways of life. Keeping these points in mind, plant use allocation schemes such as the one explored in this research can not only help avoid curbing economic activities drastically, but can also guide indigenous peoples to make resource use optimization decisions that ensure a minimum level of disruption to their traditional and cultural ways of life.

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APPENDIX

SUPPLEMENTARY TABLES

Table A.1. Main types of traditional uses derived from the plants in the dataset.

Traditional uses
Construction
Food
Fuel
Household Items
Medicines
Ornamental
Raw materials & tools

Table A.2. Wildlife species that derive food from the plants in the dataset.

Wildlife species	**Common name**
Agouti paca	Labba
Amazona spp.	Parrot
Ara spp.	Macaw
Cerdocyon thous	Savanna fox
Chelonoidis carbonaria	Red footed tortoise
Cotinga spp.	Cotinga
Crax alector	Powi or black curassow
Dasyprocta leporine	Agouti
Didelphimorphia spp.	Opossums
Mazama americana	Red brocket deer
Mazama gouazoubira	Grey brocket deer
Myoprocta acouchy	Acouchi
Ortalis motmot	Hanaqua or Variable Chachalaca
Ortalis spp.	Chachalaca
Pecari tajacu	Collared peccary
Penelope jacquacu	Marudi
Penelope marail	Marail guan
Potos flavus	Kinkajous
Ramphastos spp.	Toucan
Tapirus terrestris	Tapir
Tayassu pecari	White-lipped peccary
-	Common birds

Table A.3. List of species of plants and subsistence uses associated with them. All the species can be logged as per the COP guidelines.

Family/Species	Common name	Traditional uses	Eaten by
Abarema jupunba (Willd.) Britton & Killip	Huruasa	household items	-
Aniba hypoglauca Sandw.	Yellow Silverballi	-	cotinga, guan, toucan
Bagassa guianensis Aubl.	Cowwood	Food	acouchis, agouti, labba, peccary, red brocket deer, tapir, tortoise
Brosimum spp. (Aubl.) Huber	Leopardwood	household items; ornamental; raw materials & tools	birds
Calophyllum spp. Camb.	Cassava mama	construction; raw materials & tools	-
Carapa guianensis Aubl., *C. procera* DC	Crabwood	medicines	agouti, labba, peccary, rodents
Caryocar nuciferum L.	Sawari Nut	Food	labba, red brocket deer, rodents, tapir
Catostemma commune Sandwith	Baromalli	construction; medicines; ornamental; raw materials & tools	grey brocket deer, tapir

Catostemma fragrans Benth.	Sand Baromalli	Food	grey brocket deer, tapir
Cedrela spp. Sprague & Stapf.	Water Cedar	construction; raw materials & tools	-
Centrolobium paraense Tul.	Paurine	construction	-
Chlorocardium rodiei (Schomb.) Rohwer, H.G.Richt. & van der Werff	Greenheart	medicines	labba, peccary
Clathrotropis brachypetala (Tul.) Kleinhoonte	Aromata - fine leaf	medicines	-
Clathrotropis macrocarpa Ducke	Aromata	medicines	-
Cordia alliodora (Ruiz & Pav.) Oken	Freijor	raw materials & tools	birds
Diplotropis purpurea (Rich.) Amshoff	Tatabu	raw materials & tools	-
Dipteryx odorata (Aubl.) Willd.	Tonka bean	ornamental	birds, rodents, toucan
Eperua spp. Aubl.	Wallaba	construction; medicines; raw materials & tools	-

Eschweilera alata A.C. Smith	Guava Skin Kakaralli	construction	-
Eschweilera decolorans Sandw.	Smooth Leaf Kakaralli	raw materials & tools	labba
Eschweilera sagotiana Miers	Common Black Kakaralli	construction; raw materials & tools	birds
Eschweilera subglandulosa (Steud. ex O.Berg) Miers	Black Kakaralli	-	macaw, parrot
Eschweilera wachenheimii (Benoist) Sandw.	Fine Leaf Kakaralli	construction; raw materials & tools	-
Goupia glabra Aubl.	Kabukalli	construction; medicines; raw materials & tools	birds
Humiria balsamifera (Aubl.) A. St.-Hil.	Tauroniro	food; household items	birds, macaw, peccary, fox, tortoise, marudi, powis
Hymenaea courbaril L.	Locust	food; household items; raw materials & tools	labba, peccary, rodents, tapir
Hymenaea oblongifolia Huber	Locust -fine leaf	medicines	labba, peccary, rodents, tapir
Inga alba (Sw.) Willd.	Maporakon	construction; medicines; raw materials & tools	birds, grey brocket deer, labba, parrot, peccary, tapir, marudi, powis

Iryanthera lancifolia Ducke	Kerikowa	-	cotinga, guan, toucan
Iryanthera spp. (Benth.) Warb.	Black Kerikowa	-	cotinga, guan, toucan
Laetia procera (Poepp.) Eichl.	Warakairo	-	birds
Lecythis cf. chartacea Berg	Monkey Pot - small	raw materials & tools	labba
Lecythis corrugata Poit.	Wina Kakaralli	construction	-
Lecythis zabucajo Aublet	Monkey Pot	raw materials & tools	labba
Licania alba (Bernouli) Cuatrec. *and L. majuscula* Harvey ex Gomont	Kautaballi	construction; fuel	agouti
Licaria cannella (Meisn.) Kosterm.	Brown Silverballi	construction; medicines; raw materials & tools	cotinga, guan, toucan
Manilkara bidentata (A.DC.) Chev.	Bulletwood	construction; household items; ornamental	agouti, cotinga, grey brocket deer, labba, macaw, parrot, peccary, red brocket deer, tapir, tortoise, toucan

Mora excelsa Benth.	Mora	construction; raw materials & tools	peccary, tapir
Mora gonggrijpii (Kleinhoonte) Sandwith	Morabukea	-	rodents
Ocotea canaliculata (Rich.) Mez	White Silverballi	-	cotinga, guan, toucan
Ocotea rubra Mez	Determa	-	cotinga, guan, toucan
Ocotea spp. (Meisn.) Mez.	Kereti Silvaballi	-	cotinga, guan, toucan
Ocotea spp. (Rich.) Mez; *Aniba spp.* Sandw.	Silverballi	raw materials & tools	cotinga, guan, toucan
Ormosia coutinhoi Ducke	Korokororo	medicines	birds
Ormosia spp. (Aubl.) Jackson	Barakaro	construction; medicines; ornamental	birds, peccary
Pachira spp. Aubl.	Kanahia	fuel	acouchis, agouti, rodents
Parinari campestris Aubl.	Burada	food; fuel; medicines	macaw, rodents

Peltogyne spp. (Vahl) Benth.	Purpleheart	construction	-
Platonia insignis Mart.	Kaslego	food	peccary
Pouteria cuspidata (A.DC.) Baehni	Kokoritiballi	construction	cotinga, labba, macaw, parrot, red brocket deer, tortoise, toucan
Pouteria guianensis Aubl.	Asepoko	construction; food	cotinga, labba, macaw, parrot, red brocket deer, tortoise, toucan
Pouteria speciose (Ducke) Baehni	Suya	-	agouti, cotinga, labba, macaw, parrot, peccary, tapir, tortoise, toucan
Protium decandrum (Aubl.) Marchand	Kurokai	medicines	cotinga, grey brocket deer, guan, kinkajous, opossums, tortoise, toucan, marudi, powis
Pterocarpus rohrii Vahl	Hill Corkwood	raw materials & tools	-
Pterocarpus spp.	Corkwood	raw materials & tools	-
Quassia simarouba L.f.	Simarupa	construction	-

Quassia spp.	Angelina Rock	raw materials & tools	-
Ryania speciosa Vahl	Bastard Kabukalli	household items	-
Swartzia benthamiana Miq.	Itikiboroballi	-	rodents
Swartzia leiocalycina Benth.	Wamara	fuel	rodents
Symphonia coccinea (Aubl.) Oken	Manniballi	medicines; raw materials & tools	-
Symphonia globulifera L.f.	Manni	medicines; raw materials & tools	-
Tabebuia insignis (Miq.) Sandwith	White Cedar	construction	-
Tabebuia serratifolia (Vahl) G. Nicholson	Ironwood	construction; medicines	-
Talisia spp. Sagot	Sand Mora	household items	-
Trattinnickia rhoifolia Willd.	Ulu	-	birds

Virola michelii Heckel	Hill Dalli	-	cotinga, guan, toucan
Virola surinamensis (Rol.) Warb.	Swamp Dalli	medicines; ornamental	birds, cotinga, toucan

BIOGRAPHICAL SKETCH

Muna Shah moved to the United States for college and attended the University of North Texas in Denton, TX, where she was first exposed to GIS. After graduating with her bachelor’s in Geography and Economics, she went on to pursue her master’s degree in Environmental and Natural Resource Economics at the University of Rhode Island. She worked as a Conservation Economist at the Nature Conservancy in New Jersey, then returned to Texas to pursue her doctorate in GIS at The University of Texas at Dallas. Muna has been a Teaching Assistant since Fall 2013. She has instructed GIS courses in Fall 2018, Spring 2019, and Summer 2019 semesters in the Geospatial Information Sciences Department at The University of Texas at Dallas.

CURRICULUM VITAE

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EDUCATION

University of Texas at Dallas, Richardson, TX
PhD – Geospatial Information Sciences — August 2019

University of Rhode Island, Kingston, RI
MS – Environmental & Natural Resource Economics — May 2012

University of North Texas, Denton, TX
BA – Economics & Geography — May 2010

TEACHING EXPERIENCE

Teaching Associate, — August 2018 – Present
University of Texas at Dallas, Department of Geospatial Information Science, Richardson, TX
- Designed syllabus and course objectives
- Engaged undergraduate students from diverse academic backgrounds with creative lectures on GIS, utilizing multimedia and popular culture
- Introduced ArcGIS to students and taught them how to use the software through lab assignments and projects

Teaching Assistant — August 2013 – August 2018
University of Texas at Dallas, Department of Geospatial Information Science, Richardson, TX
- Assisted supervising faculty members with teaching duties
- Assisted supervising faculty members in research and GIS projects

RESEARCH INTERESTS

- Spatial modelling and analysis
- Application of GIS in environmental conservation and social welfare issues

PEER-REVIEWED PUBLICATIONS

- Shah, M., & Cummings, A.R. (2018). Comparing logging and subsistence values of plants across an indigenous peoples' influenced landscape. *Ecological Indicators*, *95*(1), 165-175. https://dx.doi.org/10.1016/j.ecolind.2018.06.045
- Fu, G., Uchida, E., Shah, M., & Deng, X. (2018). Impact of the Grain for Green program on forest cover in China. *Journal Of Environmental Economics And Policy*, *8*(3), 231-249. https://doi.org/10.1080/21606544.2018.1552626
- Cummings, A., & Shah, M. (2017). Mangroves in the global climate and environmental mix. *Geography Compass*, *12*(1), e12353. http://dx.doi.org/10.1111/gec3.12353

CONFERENCE PRESENTATIONS

- Shah, M., and Cummings, A.R. (2018). "Examining the Impacts of Physical Environmental and Demographic Characteristics on the Distributions of Subsistence and Logging Services Relative to Indigenous Villages," Annual Meeting, October 3-6, 2018, Baton Rouge, LA, Southwest Division of the American Association of Geographers.
- Shah, M., and Cummings, A.R. (2018). "Modelling Ecosystem Services Distribution Within Indigenous Peoples-Influenced Landscapes," Annual Meeting, April 10-14, 2018, New Orleans, LA, American Association of Geographers.
- Shah, M., and Cummings, A.R. (2017). "How do plant attributes affect the spatial distribution of multiple uses across space? An ecosystem service approach," Annual Meeting, April 5-9, 2017, Boston, MA, American Association of Geographers.
- Fu, G., Shah, M., Uchida, E., Deng, X., Huang, J., Gibson, J., Rozelle, S., and Xu, J. (2013). "Impact of the Grain for Green program on forest cover in China," Annual Meeting, August 4-6, 2013, Washington, DC, Agricultural and Applied Economics Association.

TECHNICAL SKILLS

- Geospatial: ArcGIS 10.x and ArcGIS Pro 2.x (including Spatial Analyst and Model Builder), QGIS
- Programming: Python, VB.NET
- Statistical: R, RStudio, STATA, SAS
- Remote Sensing: ERDAS Imagine, ENVI

HONORS & AWARDS

- Fall 2018 Pioneer Graduate Fellowship
- Fall 2017 Pioneer Graduate Fellowship
- UTD PhD Research Grant 2016

PROFESSIONAL MEMBERSHIPS

- Member, Association of American Geographers (AAG) 2016 – present
- Vice President, Gamma Theta Upsilon (GTU) Honor Society 2017 –2018
- President, GIS Student Organization (GISSO) 2014 –2016