

Spatiotemporal Impacts of Drug Crop and Commodity Agriculture on Cultural Ecosystem Services: The Case of *Ischnosiphon* in Ticuna Communities of Loreto, Peru



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RESEARCH

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ABSTRACT

In recent decades, drug crop eradication and drug trafficking interdiction have pushed drug crop cultivation into new areas of the Amazonian rain forest. The presence of the drug industries in these regions—followed by alternative development programs that aim to substitute illicit drug crops with commodity crops like cacao—has transformed forest ecologies, risking loss to both biodiversity and cultural ecosystem services (CES) for surrounding communities. In the last ten years, forest loss linked to the increase in cultivation of commodity crops—both licit and illicit—has been monitored, generating extensive geospatial data. However, the spatiotemporal impacts on key plant species utilized by indigenous communities who have recently shifted to drug crop and commodity agricultural production remains poorly understood. In this paper, we use geospatial modeling to explore potential impacts of drug crop cultivation and alternative development programs on the CES of Ticuna indigenous communities of the Peruvian Amazon. We analyze the spatiotemporal impact of drug and commodity crop cultivation on three culturally significant species of the genus *Ischnosiphon*, known locally as *dexpe* or *huarumá*, by generating a model of potential distribution of the three species. The rate of increase of legal and illegal agricultural crops was also calculated and the spatiotemporal impact was measured and represented using spatial analysis techniques. Our analysis finds that, between 2010 and 2020, the increase in both illicit and licit commodity crop cultivation is correlated with changes in the distribution of *huarumá* species, which in turn affects the cultural ecosystem services of Ticuna communities.

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Over the past 50 years, the War on Drugs has produced wide-reaching social problems in the Western hemisphere, including the strengthening of paramilitary groups and gangs (Correra-Cabrera, 2017), a rise in mass incarceration (Alexander, 2020), and the formation of alliances between drug traffickers and licit industries (Paley, 2014). Scholars have shown that both drug trafficking and hemispheric antidrug policies and practices have resulted in a range of unanticipated environmental impacts, too (Brombacher et al., 2021; McSweeney et al., 2014; McSweeney et al., 2018). In drug crop producing countries, these damages include pollution of water sources due to chemical runoff from drug production operations (Bedoya, 1999), deforestation and degradation of lands due to monocropping and grazing (Davalos et al., 2021), and in the case of Colombia, harm to soil and human health due to aerial herbicide unleashed over large zones of coca crops (Ramirez, 2011). However, due to the clandestine nature of drug production and the challenges in conducting research in areas rife with conflict, the full extent of the environmental impacts of drug production, trafficking, and antidrug policies remains poorly understood.

One thing that is clear is that militaristic antidrug policies aimed at supply-side eradication and interdiction—such as Plan Colombia, which over its duration made Colombia one of the primary recipients of US aid money, behind only Israel and Egypt (Shifter, 2012)—have produced what scholars describe as a “balloon effect” (Rouse and Arce, 2006), whereby focused attention on sites of drug crop production have not eliminated drug supplies at their source but, rather, have relocated production efforts to new areas. In recent years, this effect has come to impact large swaths of the Amazonian rain forest, which extends into all the major coca-producing countries: Colombia, Peru, and Bolivia.

This study draws attention to some of the underexplored socio-ecological impacts of the balloon effect in an emergent hotspot of illicit coca production in the borderland province of Ramón Castilla in the Peruvian Amazon. As a result of aerial spraying campaigns in Colombia, illicit coca production has shifted significantly into neighboring Peru, particularly into the political department of Loreto—Peru’s largest but most sparsely populated department, covered largely by rain forest—and specifically, the province of Ramón Castilla. There, a federal decree has declared a state of emergency due to an increasing threat from illicit coca operations (López and Tuesta, 2015; Silverstein, 2021).

The rise of illicit coca production in Peruvian Amazonian communities, both indigenous and nonindigenous alike, has introduced significant changes into rural life—bringing in cash income and industrialized goods as well as access to markets and educational opportunities, while reducing subsistence agricultural production and altering related cultural lifeways in the process (Martín et al., 2022; Paredes and Pastor, 2023; Silverstein, 2021). Antidrug strategies have also followed, including eradication and interdiction efforts, as well as more holistic alternative development projects (Grillo et al., 2021). Such alternative development projects have aimed to help rural farmers transition from illicit crop production to licit forms of commodity agriculture that can reduce dependence on drug crops and generate new livelihoods (Grisaffi and Ledebur, 2016). While such programs are often touted as humane strategies for regions ravaged by decades of violent antidrug policy, less attention has been given to some of the unintended socio-ecological consequences, including notable changes in land use, subsistence agricultural production, and associated forms of cultural and economic practices.

In this article, we explore how shifts to commodity agriculture—generated by both the global demand for cocaine and the alternative development agricultural production programs created in response—may contribute to other, more subtle changes in the landscape. Specifically, we use techniques of spatiotemporal modeling to analyze biodiversity changes within a series of Ticuna indigenous communities in the Peruvian Amazon, where we have conducted anthropological and ecological research for the past decade, and where our ethnographic research has documented changes in social and economic lifeways due to growing involvement in illicit coca cultivation (Núñez et al., 2019; Martín et al., 2022). We build on these studies to further explore socio-ecological lifeways, by focusing on changes in the presence of *huarumá*—several botanical species that hold vital role for cultural ecosystem services (CES) within these communities for production of woven baskets and other cultural materials. Rather than claim that the observed patterns in the spatial distribution of *huarumá* are directly caused by illicit coca production solely, we argue that licit and illicit commodity crop production work together

in ways that alter the Amazonian landscape, including potential losses of biota that have long been foundational to indigenous lifeways in the region. Situating these findings within the context of our ongoing ethnographic and ethnobotanical research, our primary aim here is to generate an exploratory assessment that can spur future research on the socio-ecological impacts of the War on Drugs in the Amazon region.

COCA, DEFORESTATION, AND CULTURAL ECOSYSTEM SERVICES

The impact of the loss of plant species due to the main drivers of deforestation, such as illegal logging or the expansion of commercial agriculture, is felt in many domains of social and economic life. For instance, drivers of diversity loss negatively affect the distribution of plant species that benefit indigenous communities with food, medicinal plants, cultural goods, construction materials, or handicrafts. These sorts of plant species, along with other elements in the ecosystem including wildlife, are considered a domain of cultural ecosystem services (CES), defined as “the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences” (Milcu et al., 2013). CES and the traditional ecological knowledge of CES species are linked to community resilience (Gomez-Baggethun et al., 2012) and cultural reproduction. This, in turn, can help to sustain forest health through the work of small-scale and indigenous forest use practices, demonstrated to be beneficial to biodiversity (Berkes et al., 1994).

Ticuna communities’ strong links to forests and river environments is foundational to their everyday livelihoods as well as the reproduction of Ticuna culture, manifested through both material and immaterial cultural production and reproduction (Martín et al., 2022; Ministry of Culture, 2016). For instance, vegetable fibers of different species of the *Ischnosiphon* genus are employed for traditional fabric production, creating elements of material culture necessary to sustain ritual life, as well as the tools, such as the *tipiti*, which is used to process bitter manioc varieties cultivated locally, and thus expanding the range of manioc varieties suitable for consumption (Núñez et al., 2018).

The fibers extracted from three species of the genus *Ischnosiphon* (*I. puberulus*, *I. arouma*, *I. obliquus*), known locally as *huarumá* and in the Ticuna language as *dexpe*, are a key element of the cultural ecosystem services that local forests provide Ticuna communities. However, the expansion of commodity crop cultivation—both illicit and licit—across Peru’s lower Amazonian region has provoked changes in the socio-economic dynamics of the Ticuna communities. This, in turn, has affected the traditional processes of knowledge transmission about forest plant species, their uses, and their vital role in the regeneration of their culture (Martín et al., 2017).

The spread of commodity crops, such as coca (*Erythroxylum coca*), has led to increased deforestation and alteration of vegetation cover. For instance, between 2011 and 2020, deforestation across Peru grew more than 50% compared to the prior decade. Sources estimate that approximately 63% of this deforestation is driven by coca cultivation (García, 2024). Furthermore, according to monitoring by Peru’s National Drug Control Commission (DEVIDA), the largest area of new coca cultivation is in Loreto, also home to the largest amount of rain forest in the nation (DEVIDA, 2021). While coca cultivation began to increase gradually across Loreto between 2001 and 2006, the cultivated area increased five times, from 699 to 4,708 hectares, between 2008 and 2012. The largest area of coca cultivation in Loreto is the province of Ramón Castilla, where this study is set (García, 2013).

Coca crops and cocaine production have also resulted in the degradation of ecosystems (Duarte et al., 2021; Palacios et al., 2022; Reygadas et al., 2023; Tellman et al., 2020). Meanwhile, mitigating measures, such as payments to communities for reducing deforestation (Ravikumar et al., 2023) or the planting of licit commodity crops such as cacao (Schroth et al., 2016), have altered indigenous livelihoods while also creating unanticipated impacts on local ecosystems, including soils and their capacity for carbon sequestration (Martín et al., 2017). DEVIDA’s efforts to promote alternative development programs in Loreto have focused on reducing coca cultivation by introducing sustainable agricultural practices, but challenges remain due to the high profitability of coca compared to alternative crops. Cacao production as an alternative development strategy to supplement incomes lost to coca eradication programs is relatively new to the region and may not yet represent a significant change in crop cover. Nevertheless, state-sponsored cacao cultivation programs, which began in the region in 2016, have continued to grow. In 2018, there were 1,569 hectares of cacao under cultivation (DEVIDA, 2020), and after a pause due to the pandemic, several new cacao cultivation projects have been launched over the past year.

International conservation initiatives in Amazonia have collected vast quantities of geospatial information on the types of land use and cover, with the hope that such data can support socio-ecological sustainability of the region (Baeza et al., 2022). However, forests that have been monitored in the lower Amazon over the last ten years reveal an increase in the rating of forest loss from high to very high (GEOBOSQUES, 2021). Still, few investigations have sought to carry out multitemporal spatial analyses of how such broad-scale changes in Amazonian forests have affected the distribution of plant species that have cultural importance, much less to understand their impacts on cultural ecosystem services.

Programs such as MaxEnt offer one way to model or predict the potential distribution of threatened and culturally significant species (Skroblin et al., 2021). At the regional level, for instance, the distributions of rare plant species across the Amazon have been modeled and mapped (Ter Steege et al., 2003), as have distributions based on the presence of species and bioclimatic explanatory variables (Gomes et al., 2020; He et al., 2022; Saatchi et al., 2008) and endemic species of the Neotropics (Zárate, 2022). Similar efforts at mapping spatial and temporal changes in key plant species on a more localized level can identify ecological problems and help make decisions to improve biodiversity management and the well-being of the most vulnerable populations (Cursach et al., 2020), whose livelihoods and cultural sustainability are linked to the continued flourishing of plants that form components of CES.

Currently, maps of spatial patterns are obtained from the application of spatial statistical indices that allow the analysis and representation of the spatial behavior of a geographic phenomenon (Miller, 2004; Palacios et al., 2022). Likewise, significant areas vulnerable to risk by anthropogenic activities are represented through spatial autocorrelation indices (Campos et al., 2021; Li et al., 2022; Shahfahad et al., 2022; Shirvani and Buchroithner 2020). However, in the current context and at the local level, it is unknown explicitly and spatially how the local cultural ecosystem services in lowland Amazonian Peru have been impacted by the increase in commodity crop cultivation. Our approach is novel in that it takes a more focused approach than prior studies, which have also evaluated the impacts of drug and commodity crop production on Amazonian biodiversity, by focusing on species with marked importance for both cultural production and reproduction.

The present investigation examines some potential impacts of the illicit coca economy on the diversity of plants with cultural significance to Ticuna indigenous communities, where in the last decade we have conducted both anthropological and ecological research. *Huarumá*, a plant used both for forms of cultural production and the reproduction of edible crop diversity, represents a key example of a CES plant vulnerable to changes generated by commodity-driven agriculture. Our results offer a preliminary assessment of potential correlations between commodity crop production—destined for both licit and illicit market channels—and changes in spatiotemporal distribution of plant species integral to CES of Ticuna community. This exploratory investigation highlights the likely impacts of commodity crop cultivation on the cultural ecosystem services, and on the three species of *huarumá*, specifically, in Ticuna indigenous communities of the lower Amazon, from 2010 to 2020.

METHODS

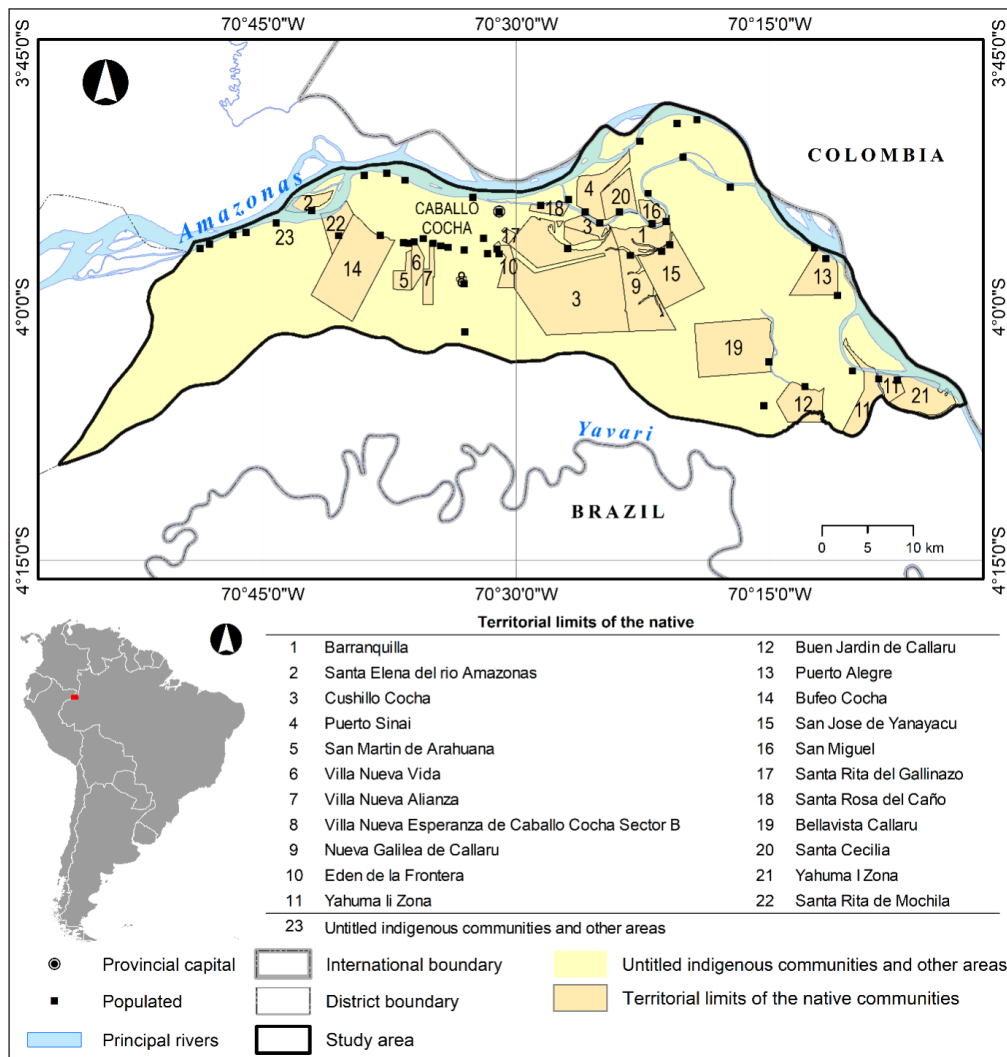
STUDY AREA

This study was conducted in the province of Mariscal Ramón Castilla, home to the majority of Ticuna indigenous communities within Peru's lowland Amazonian department of Loreto, which covers an area of 174,713.22 ha. The province is situated between the Amazon River to the north and east (where it marks the border with Colombia) and Yavari River to the south and west. Ramón Castilla is also an emergent epicenter of illicit coca cultivation and production of *pasta básica de cocaína*, or raw cocaine paste, prompting the recent installation of several federal antidrug operations as well as coca eradication efforts and alternative development projects that followed in their wake (DEVIDA, 2023).

The study site is made up of 22 indigenous communities, mostly from the Ticuna indigenous people. Ticuna communities are located across this triple border region encompassing both Brazil and Colombia, but communities across the border are shaped by different geopolitical

circumstances that in turn have shaped cultivation practices and biodiversity (López, 2014). The study site is home to a total of 53 settlement clusters, with a total population of 19,976 inhabitants. The main city, Caballococha, has 7,885 inhabitants and is the provincial capital. In general, the study area presents meandering plain and terra firme forests (Figure 1).

Figure 1 Map of the study area, with the territorial limits of the native communities (numbered polygons) and populated centers (black dots) indicated.



ETHNOGRAPHIC RESEARCH

This study builds on an ongoing collaboration between Peru's Institute for Amazonian Research (Instituto de Investigaciones de la Amazonía Peruana, henceforth IIAP) and Ticuna communities within the province of Ramón Castilla. Funding was provided by IIAP to study the use of everyday resources in Amazonian indigenous communities, under the project "Specialized studies for knowledge and integration of indigenous practices and technology linked to biodiversity." This broader research agenda included a study on several species of the genus *Ischnosiphon*—known in the area as *huarumá*, or *dexpe* in the Ticuna language—used to produce traditional utilitarian fabrics (Martín et al., 2017). Research on *huarumá* fibers is part of a broader program that seeks to study and reassess traditional knowledge and practices in indigenous communities in the province of Ramón Castilla. The research team was based in the city Iquitos, where IIAP headquarters are located, but dozens of trips were made to Ramón Castilla to conduct field research among the Ticuna communities. Ethnographic and ethnoecological research in these communities included household surveys on forest resource use, knowledge and usage of manioc varieties (Martín et al., 2017; Núñez et al., 2018), participatory workshops related to the recovery of traditional knowledge, and focus groups on the gendered impacts of coca and development projects (Núñez et al., 2019). Prior informed consent was obtained before beginning ethnographic and ethnoecological research, as indicated by Law No. 27811 in its Title II, Article 2. The permission to collect plant samples corresponds to Resolution 0068-2015-SERFOR-DGGSPFFS.

Locational data (in geographic coordinates) for the occurrence of three *huarumá* species (*Ischnosiphon arouma*, *Ischnosiphon puberulus*, and *Ischnosiphon obliquus*) were collected from the SpeciesLink network (<https://specieslink.net/search>). The selection criteria of these species were carried out in accordance with the established protocol described by Martín and colleagues (2017). To verify the presence of the three *huarumá* species, coordinates were collected for species occurrence in the Ticuna communities of Bufeo Cocha and Nueva Galilea de Callarú in 2021.

The base cartography and indigenous communities (in shapefile extension) used to generate the location maps and spatial analysis, were obtained through a request to the Sub-directorate of Territorial Planning and Spatial Data of the Regional Government of Loreto.

The ten land cover and land use maps for the 2010–2020 period (30 m pixel raster format) were compiled from the MapBiomias project's Google Earth Engine map service available at <http://amazonia.mapbiomas.org>. The 19 predictor bioclimatic variables (in raster format) used to generate the potential distribution model of *huarumá* were compiled from WorldClim <https://www.worldclim.org/data/bioclim.html>. These correspond to the averages obtained with global climate data from the period between 1970 and 2000 at a spatial resolution of 30 seconds of arc (Fick and Hijmans, 2017).

We relied on MaxEnt version 3.4.1 to model the potential distribution of the *huarumá* species (https://biodiversityinformatics.amnh.org/open_source/maxent), while ArcGIS version 9.1 served to integrate tabular data with geospatial data and elaborate location and thematic maps, and GeoDa 1.20 (<https://geodacenter.github.io/download.html>) allowed for the calculation of spatial statistics.

DISTRIBUTION OF HUARUMÁ

To identify the presence of *huarumá* in the study area, we carried out plant inventories and collected coordinate data using a GPS device in indigenous communities of Bufeo Cocha and Nueva Galilea de Callarú (Table 1). The collected plant species were processed using the method proposed by Judd et al. (1999) for herborization. For the identification of the species, the taxonomic publications of Andersson (1977), Gentry (1993), Suárez and Galeano (1996), and Vásquez (1997) were used, as well as the information available in Species Links (<https://specieslink.net/search>). Finally, the samples were deposited in the Herreense Herbarium of the Peruvian Amazon Research Institute (IIAP).

To determine the potential distribution of *huarumá* across the entire Amazon region, we used MaxEnt. MaxEnt was chosen for having better predictive power with different sample sizes (Phillips et al., 2006; Wisz et al., 2008); 835 records of the presence of the three *Ischnosiphon* species (Table 2), and 19 bioclimatic spatial variables were used in ASCII files with an extension of 30-pixel arc seconds (Table 3). The model was configured with 75% of records for training, 25% for validation, and 5,000 iterations (Cruz-Cárdenas et al., 2014). The logistic model generated in MaxEnt was classified into a map of potential distribution categories (0–20%, 20–40%, 40–60%, 60–80%, and >80%; see Lopes et al., 2021). For further analysis, the map of the potential distribution of *huarumá* across the Amazonia region was clipped to the study area.

INCREASE IN THE AREA OF AGRICULTURAL LAND

For practical purposes of the spatial analysis, the analysis units were defined, dividing the study area into a gridded vector mesh of 30 arc seconds, coinciding with the pixels of the model resulting from the distribution of the *huarumá* (Bezeng et al., 2020). To calculate the crop increase rate in the period 2010–2020 (A_c) in each unit of analysis, the equation $A_c = (C_b - C_a)/C_b \times T_{ab}$ was used, where T_{ab} is the number of years in the period of analysis, C_a is the area cultivated in the initial year, and C_b is the area cultivated in the final year of the analysis period (Shirvani et al., 2017).

SPATIAL GROUPING OF THE DISTRIBUTION OF THE HUARUMÁ

To determine whether *huarumá* is spatially distributed in a grouped or random way, the global spatial autocorrelation of the potential distribution of the *huarumá* species was evaluated using the global Moran index. This index ranges from –1 to 1, in which 1 indicates positive spatial autocorrelation, –1 indicates negative spatial autocorrelation, and values close to zero indicate no spatial autocorrelation (Celemin, 2009; Mathur, 2015).

Furthermore, to analyze the spatial structure of the potential distribution of *huarumá* with a significance ($p < 0.05$), we applied the local Moran index of spatial association (LISA). This index generates maps of high-high (A-A) and low-low (B-B) cluster categories when a unit of analysis is surrounded by units with similar values and of high-low (A-B) and low-high (B-A) categories when a unit of analysis is surrounded by units with opposite values. The latter are also considered as areas with atypical values that do not conform to any spatial pattern (Anselin et al., 2009; Siabato and Guzmán-Manrique, 2019).

IMPACT ON THE POTENTIAL DISTRIBUTION OF *HUARUMÁ*

To evaluate and represent the relationship between the increase in commodity crop agricultural cultivation and the distribution of *huarumá*, we applied Moran's local bivariate spatial autocorrelation analysis (BILISA). This analysis measures the spatial correlation between the values of two variables in nearby locations (Siabato and Guzmán-Manrique, 2019). In the GeoDa program, an integrated queen-type third-order contiguity matrix was generated (Siabato and Guzmán-Manrique, 2019), with a significance level of $p < 0.05$ and with 999 permutations. This type of matrix was chosen due to the wide distribution of the three *huarumá* species and the broad expansion of agricultural lands (Celemin, 2009). The results in BILISA were represented in a map of combined categories (as in LISA) of high and low spatial correlation for the two variables analyzed (Ribeiro et al., 2021). For example, the category A-A indicates that the two variables have high values in adjacent locations, the category B-B indicates that the two variables have low values in adjacent locations. On the other hand, the category A-B indicates that a variable has high values in one location adjacent to another where the other variable has low values, and the B-A category indicates the opposite, that is, that one variable has low values in a location adjacent to another where the other variable has high values (Shahfahad et al., 2022).

RESULTS

COMMUNITY PERCEPTIONS OF CHANGING PATTERNS OF DISTRIBUTION

Over the course of our fieldwork in the province of Ramón Castilla, and particularly in the Ticuna communities of Bufe Cocha and Nueva Galilea, we were often privy to remarks about the presence of outsider coca cultivators deeper in the forest. These remarks were not always complaints or critiques—some community members that we met appeared grateful for an option to earn a wage during harvest times. These communities still practiced *minga* work parties—with able-bodied community members pooling their labor for large projects, such as clearing a field for planting or assembling a new roof on a home. Opportunities for cash wages more often involved travel—stints in nearby cities that took people away from their families and gardens. From our interviews and day-to-day conversations with community members, the presence of large-scale lots of illicit coca—maintained by outsiders with the capital to run these operations—was not necessarily unwelcome. That local populations receive benefits from illegal activities is part of a strategy to facilitate the entry and maintenance of illegal crops in indigenous territories (Huerta Bustamente, 2022) that has even prompted protests of local growers when the state takes eradication measures in the area (RCR, 2019).

Other community members, however, described anxieties about the encroachment of coca fields, and the resultant effects on the surrounding forests. Between 2017 and 2019, members of our research team conducted research with Ticuna women artisans who worked with forest materials to weave and sculpt household items while also selling some of their wares on an increasingly popular national crafts circuit.¹ During co-learning workshops, older experienced artisans demonstrated techniques of weaving, including the harvest and preparation of natural fibers, to younger women and our research team. During these workshops, women lamented the loss of forest space to coca cultivation. The weavers in the workshop, whom we later spoke with at greater length on the topic, noted a growing scarcity of *huarumá* in the surrounding forest. For women who were learning to expect a small cash income from the crafts circuit, where they could sell weavings and other wares, this situation represented a threat to their legal economic activity.

Workshop participants noted that agricultural activities, such as the expansion of farms and deforestation to open new crop areas, also contributed to the reduction of the presence of

¹ For a more thorough account of the incorporation of Ticuna artisans into Peruvian national crafts circuits, see Martin et al., 2022.

huarumá in the study area. Some of these changes were linked to alternative development programs seeking to create alternative livelihoods for communities vulnerable to entanglement in the coca economy. Cacao crops, while not yet occupying substantial acreage, are labor-intensive and take time away from other forms of subsistence agriculture and forest maintenance. While alternative crops have been widely promoted throughout the province of Mariscal Ramón Castilla, the communities where we worked often expressed skepticism about the efficacy of these programs, which rarely take into account local challenges (local diversity of soils and the presence of floodplains; local agricultural practices that do not rely on monocropping; lack of connectivity with coastal markets) that seem to set commodity agriculture projects up for failure. Social challenges were noted as well. One woman described her frustration, after dedicating months to the training program for cacao cultivation, only to be disqualified from the program after someone reported that her husband was still cultivating illicit coca deeper into the forest. Conversations and ethnographic observations highlighted the tensions between risky opportunities in coca, the challenges of opting into licit, state-sponsored income generation projects through other forms of commodity agriculture, and the desire to maintain traditional cultivation and forest maintenance practices. This, in turn, prompted our interest on the impacts of agricultural expansion on *huarumá* and led to further geospatial investigation.

DISTRIBUTION OF HUARUMÁ

The training value of the area under the curve (AUC) when modeling the potential distribution of *huarumá* across the Amazon region was 0.8364, indicating that the model worked effectively and produced an accurate evaluation. The internal jackknife test, which measures the contribution and importance of the variables to the model, showed that the precipitation of the driest month (BIO14, 25.8%), the precipitation of the coldest quarter (BIO19, 22.1%), the temperature seasonality (BIO4, 17.3%), and the minimum temperature of the coldest month (BIO6, 11.1%) contributed to a greater extent than other variables in the model. The total contribution value of the variables to the model was 76.3%. The potential distribution zones of *huarumá* were evaluated between 74% and 92%, located to the southwest and northeast respectively (Figure 2). Potential distribution was classified into high (60–80%) and very high (>80%) categories, the latter category being the one with the highest distribution both in Yaguas and Ticuna communities and in areas without community delimitation (Table 4).

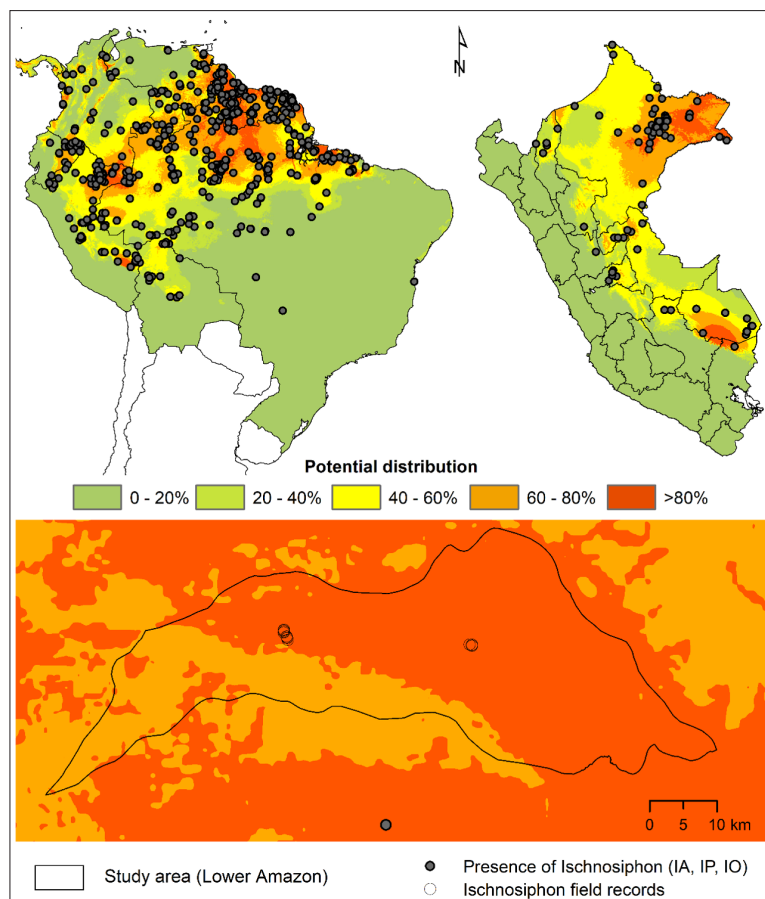


Figure 2 Potential distribution (%) of three species of the genus *Ischnosiphon*: *I. arouma* (IA), *I. puberulus* (IP), and *I. obliquus* (IO) in the lower Amazon.

SPATIAL CLUSTER ANALYSIS

The global Moran index of the potential distribution of the three *huarumá* species was 0.804 (significance $p < 0.05$ and random permutation of 999), indicating a positive spatial autocorrelation. A grouped distribution of values is observed in greater quantity in the first and third quadrants, which corresponds to a grouping A-A and B-B respectively (Figure 3).

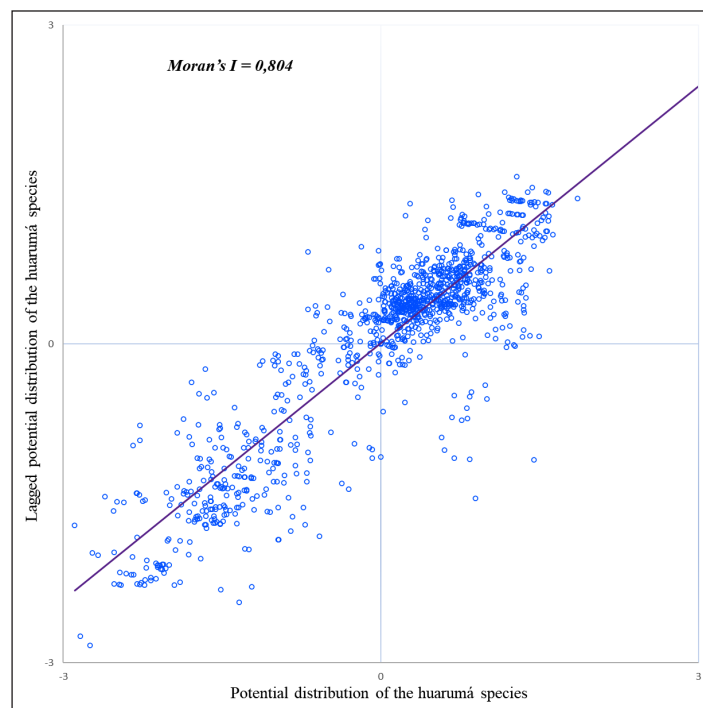


Figure 3 Moran scatterplot for the potential distribution of the three *huarumá* species (elaborated in GeoDa 1.20).

Likewise, the univariate local Moran's I is represented in a map of significant clusters (Figure 4), where the categories of clusters A-A are distributed to the east and north and the clusters B-B are distributed to the south and west of the study area. Other outlier grouping categories, A-B and B-A, can also be observed to a lesser extent. The communities with surface area of their territory greater than 50% where the very high potential of *huarumá* is grouped are San Miguel, Yahuma I Zone, Santa Rosa del Caño, Yahuma II Zone, Buen Jardín de Callarú, and Bellavista Callarú (Table 4).

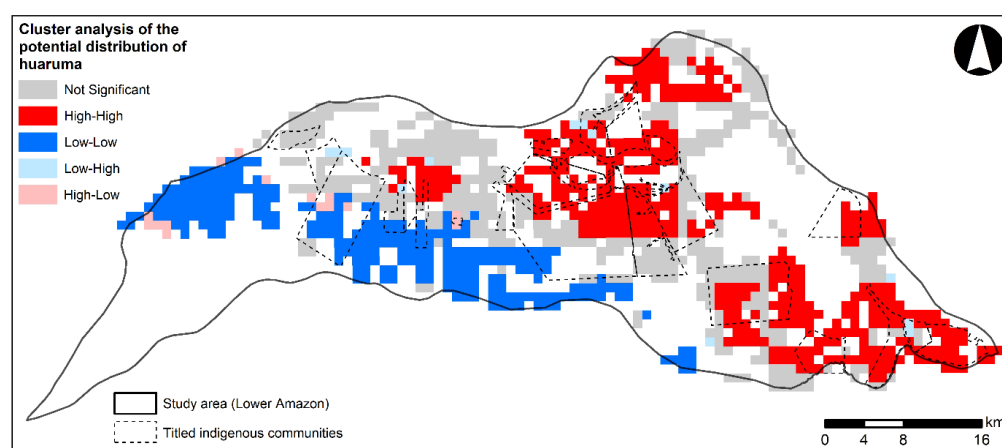


Figure 4 Map of grouping categories of the potential distribution of the *huarumá* in the lower Amazon.

INCREASE IN THE AREA OF AGRICULTURAL LAND

The distribution of the annual rate of increase in cultivated area during the period 2010–2020 is represented on two maps (Figure 5). Within these maps, we note both areas with increased cultivated area, as well as places without change where the forest has remained intact. The annual rate of increase in cultivated areas grew from 5 to 10%, largely concentrated in the south of the study area (Figure 5a). Furthermore, a very high categorization of the annual rate of increase in commodity crop cultivation is found in the south of the study area, and forms patches to the north and east in sectors close to the Amazon River (Figure 5b). In the territories of the San Martín de Arahuana, Santa Rita de Mochila, and Bufo Cocha communities, the annual rate of increase in cultivated areas was distributed from moderate to high in the period 2010–2020 (Figure 6).

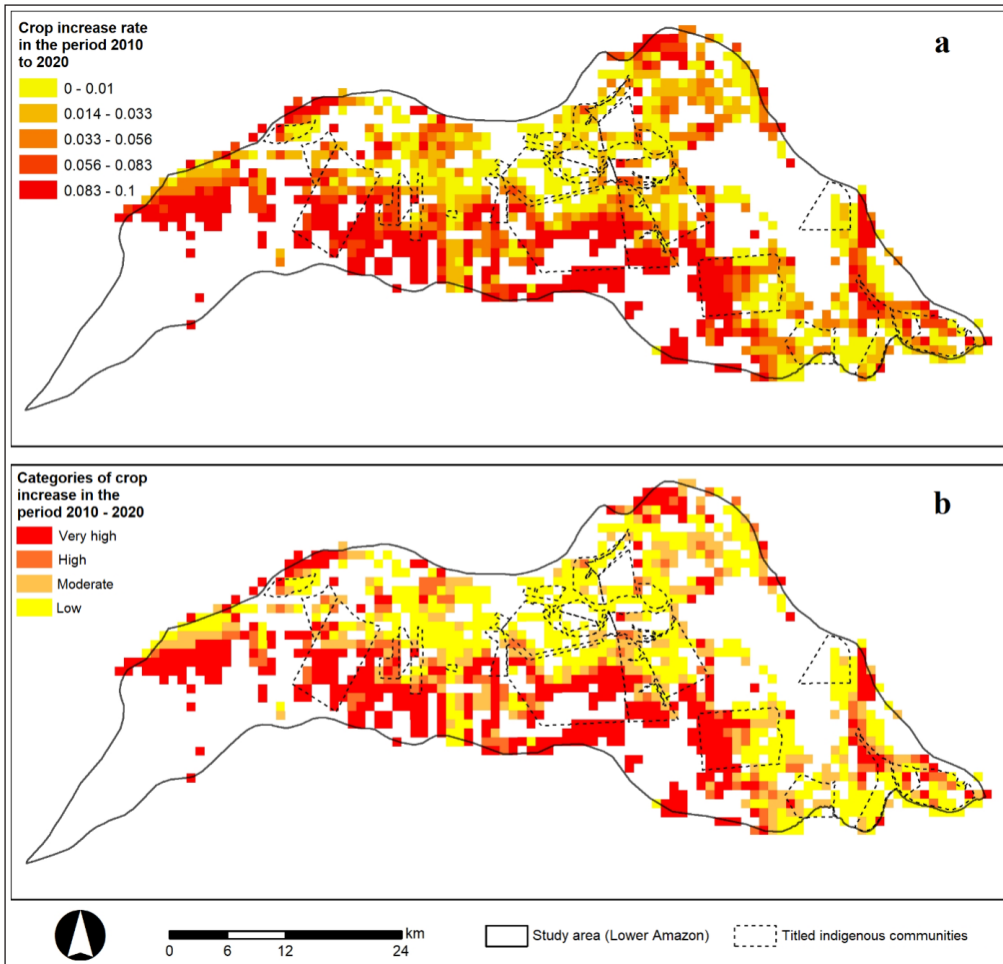


Figure 5 Spatial distribution of the annual rate (5a) and levels of increase (5b) of the areas of commodity agricultural cultivation.

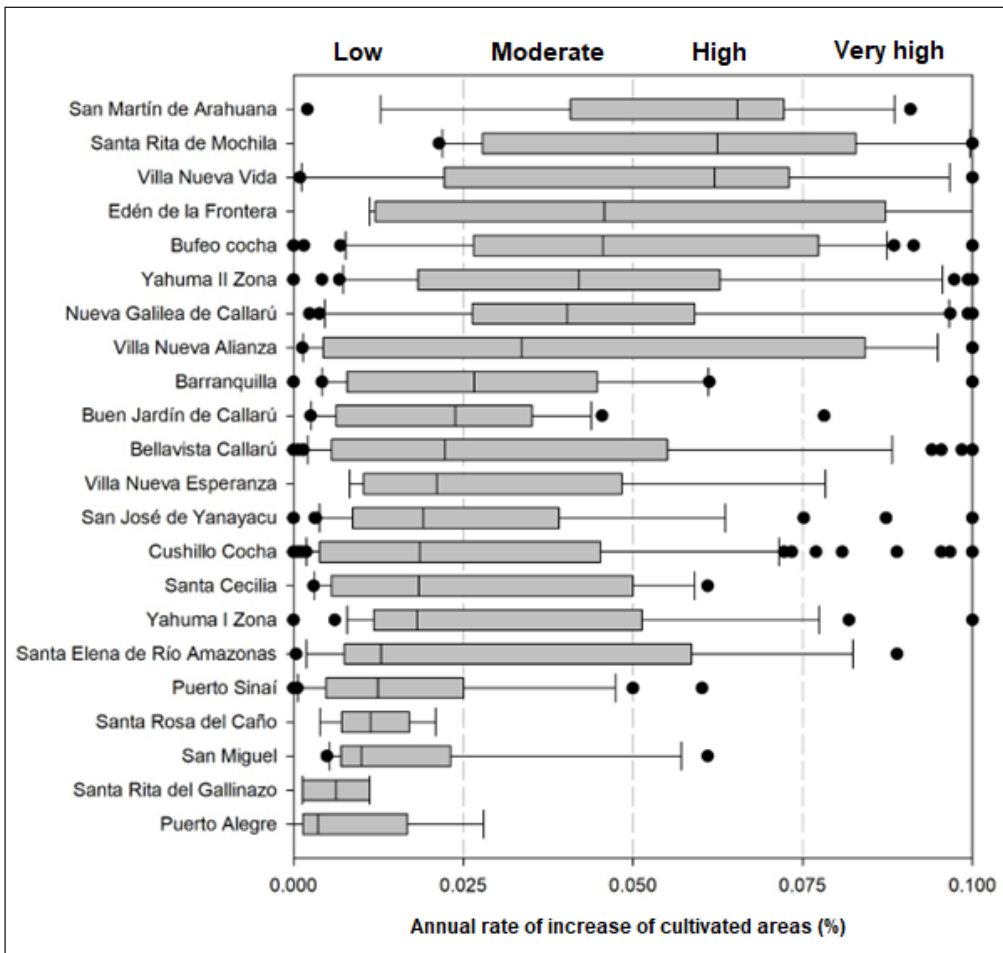


Figure 6 Distribution of the annual rate of increase of agricultural land by community (graph generated by Sigma Plot, version 14).

IMPACT ON THE POTENTIAL DISTRIBUTION OF *HUARUMÁ*

Moran's BILISA analysis determined a value of -0.406 , indicating a significant spatial autocorrelation between the potential distribution of *huarumá* and the annual rate of increase of agricultural cultivation during the period 2010–2020. Likewise, grouping categories A-B and B-A can be observed to a greater extent (Figure 7). Here, category A-B indicates that, in a period of ten years, units with very high values ($>80\%$) of *huarumá* potential have been affected by neighboring units with low annual rate values ($<2.5\%$). In the case of category B-A units with high values ($60\text{--}80\%$) of *huarumá* potential, these areas have been affected by neighboring units with very high annual rate values high ($7.5\text{--}10\%$) increase in commodity crop cultivation. Likewise, we observed that when quantifying the affected area (Table 4), in the community of Bellavista Callarú, 46.14% of its area with a very high ($>80\%$) potential for *huarumá* had been affected by a very high annual rate ($7.5\text{--}10\%$) increase in commodity cultivation. In Bufe Cocha, 40.19% of its surface with high ($60\text{--}80\%$) potential for *huarumá* had been affected by a very high annual rate ($7.5\text{--}10\%$) of increase in commodity cultivation. The communities with very high ($>80\%$) potential for *huarumá* that have been affected by a low annual rate ($<2.5\%$) of increased commodity cultivation were San Miguel (83.98%), Villa Nueva Esperanza de Caballo Cocha Sector B (86.06%), Santa Rosa del Caño (67.42%), and San José de Yanayacu (64.51%). These communities have been affected to some extent by the increase in commodity cultivation, but not to the extent of others.

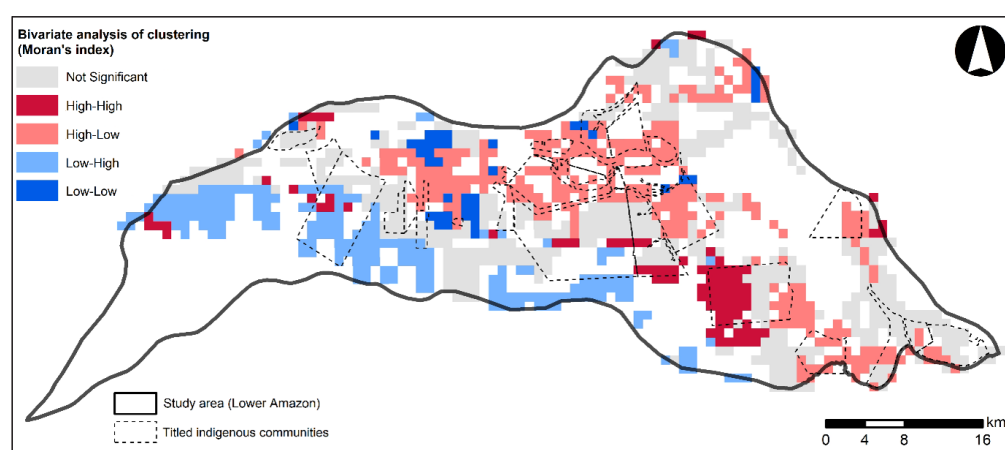


Figure 7 Groupings of the impact of the increase in commodity cultivation on the potential distribution of the *huarumá*.

DISCUSSION

In this paper we have explored connections between recent transformations toward illicit and licit commodity crop agriculture and concomitant changes in the distribution of a species of historic importance to local CES. Current data from drug crop monitoring systems have demonstrated the continued encroachment of illicit coca plantations into Amazonian lands (García Díaz, 2024), and our ethnographic research has demonstrated additional changes of cultivation practices toward licit commodity crops as part of state-sanctioned alternative development programs or broader shifts toward commodity agriculture. Here, we have explored potential impacts of these shifts not only on agricultural lifeways but on the distribution of species linked to forms of cultural production and preservation.

POTENTIAL DISTRIBUTION OF *HUARUMÁ* ACROSS THE AMAZON REGION

The model results indicate a potentially high ($60\text{--}80\%$) and very high ($>80\%$) distribution of the three *huarumá* species. Factors related to extreme environmental conditions (Leguía et al., 2010) prevail in the model, such as the precipitation of the driest month and the coldest quarter. This coincides with the results of Ter Steege et al. (2003), and the seasonality of the temperature and the minimum temperature of the coldest month. The use of the MaxEnt tool in this research shows consistent results, such as those obtained by Zárate (2022) when modeling the distribution of species of the genus *Iryanthera*, another species of ecological and economic importance in the Peruvian Amazon and in the region more broadly (Zárate et al., 2019).

Distribution models are important for supporting biodiversity management yet remain underexplored within the study area. Our findings suggest potential impacts of agricultural expansion on several

species that are key elements in the cultural ecosystem services for local Ticuna communities. More research is needed to understand the broader impacts of commodity agriculture as well as the impacts on CES of other communities—both indigenous and nonindigenous. Furthermore, more research is needed to fill in gaps in knowledge regarding the distribution of species that are essential for the reproduction of culture among rural and indigenous Amazonian communities.

Our results present a first approximation of the previously unknown distribution of the plant species used by the inhabitants of the Ticuna communities. However, since it was only modeled with bioclimatic variables that have ecological importance (He et al., 2022), future research might consider combining them with other explanatory variables, such as soil distribution (Figueiredo et al., 2018). This could lead to a better representation of the distribution of the *huarumá* species, as they have a wide distribution across the Amazon region. A more thorough understanding of the distribution of *huarumá* species is important for tracking impacts to CES in the wake of changing agricultural practices. Furthermore, with national recognition of *huarumá* weavings as part of Peru's national cultural patrimony (El Peruano, 2017), Ticuna artisans have been empowered to market goods woven with *huarumá* at prestigious national crafts markets such as Ruraq Maki. Access to diverse species of *huarumá* has also become a pathway to income generation for Ticuna women, who count on the sales of woven mats and *tipitís* to complement their limited incomes.

PATTERNS OF SPATIAL GROUPING OF THE POTENTIAL DISTRIBUTION OF HUARUMÁ

The Moran index indicates that groupings of the A-A category have a very high potential distribution (>80%). These groupings are distributed in a large part across the titled territories of the native communities found in the north and southeast of the study area. The A-A grouping shows that very high values (>80%) of potential of the three *huarumá* species are close to each other, suggesting the existence of certain factors in the environment that favor growth and distribution in those specific areas. Likewise, our results indicate a grouping category that conforms to the B-B spatial pattern, indicating a grouping of units with high potential values (60–80%) of the three *huarumá* species. This pattern is in three titled communities and in a sector on the banks of the Amazon River to the west of the study area where communities without titled lands are located. These results also show the potential risk of areas impacted by anthropogenic activities, corresponding to the results of Li et al. (2022). Likewise, they show—beyond the potential distribution of the *huarumá* species—the areas that are best suited for active management and use of the resource.

In this way, spatial autocorrelation allows for more detailed visualization of the potential distribution of *huarumá* (Miller, 2004; Palacios et al., 2022). It also can yield more significant results when modeling other indicators (such as NDVI) of vegetation presence, as noted by by Liu et al. (2021). However, more research is needed to better understand the use of spatial autocorrelation. For instance, future studies should expand the study to other neighboring areas to observe the behavior of the spatial autocorrelation indices due to the sensitivity of geographic phenomena to the proximity of changes (Palacios et al., 2021) and because the communities of the lower basin of the Amazon River and the triple-border region are considered vulnerable areas for coca cultivation and drug trafficking, an activity that is rapidly spreading across the territory (Pitman et al., 2011; UNODC, 2018; Herrera et al., 2021; Martín et al., 2022; Palacios et al., 2022; Silverstein, 2021).

INCREASE IN CULTIVATED AREA

Our results indicate an increase in the annual rate of agricultural clearing from 5 to 10% during the period 2010–2020, categorized into high (5–7.5%) and very high (7.5–10%) annual rate levels. These categories apply both in the territories of the titled communities and outside them, mainly to the south of the study area. Furthermore, communal territories affected in their entirety by the expansion of commodity crops are observed, due to their smaller surface area. In addition, in communities with larger territories, such as Bufeño Cocha, Cushillo Cocha, Nueva Galilea de Callarú, and Bellavista Callarú, the annual rate of increase in cultivated land is of varied distribution (Figure 6).

These results confirm the loss of the forest due to the increase in agricultural cultivation, including production of both coca and cacao, in the study area. This confirms findings indicated in a recent UNODC report (2023), which demonstrated an increase in the cultivated area of

coca in areas where it had previously been eradicated, shifting its distribution to more dispersed places. These shifting illicit cultivation practices directly affect the territoriality, governance, and cultural values of the indigenous communities in the study area by constraining their access to the forest and the resources necessary for cultural ecosystem services and cultural (re)production (Martín et al., 2022).

Geospatial understandings of these dynamics in Peru's lowland Amazonian region are limited. Palacios et al. (2022) indicate that the forests in the areas surrounding the study area have been suffering and will suffer a decrease in their forests, mainly due to the impacts caused by illicit commodity crops like coca. Furthermore, illicit crops have strong temporal and spatial dynamics and are a factor in forest fragmentation through the replacement of forests with small, transitory cultivation areas, the installation of coca-to-cocaine processing laboratories, and the construction of airstrips (Erasso and Vélez, 2020). Over time, illicit crops move into primary forests, promoting further destruction of the region's forested landscapes. However, some of these areas are later abandoned and allowed to regenerate.

IMPACT OF COMMODITY AGRICULTURAL CULTIVATION ON *HUARUMÁ* SPECIES

The impacts of agricultural clearing for the cultivation of crops such as coca and cacao are observed in the potential distribution of *huarumá* over a period of ten years. In this study, we identified places with a high and very high potential distribution of *huarumá*, such as Bellavista de Callarú, which has been affected by agricultural cultivation in 46% of its communal territory. Attention must also be paid to the low-high category, which indicates how territories with high (60–80%) potential for *huarumá* have been affected by a very high rate of increase in agricultural cultivation, considering that the category “low” in the potential variable of *huarumá* represents values between 0.5 and 0.75 of potential distribution of *huarumá* according to the model in MaxEnt. Using a spatiotemporal approach, our results reveal how the expansion of agricultural lands, driven in part by illicit coca, has been reducing the surface of the forests and affecting the potential distribution of the *huarumá* species. This reinforces analyses by other scholars who argue that illicit coca production contributes to deforestation and negatively affects forest cover (Quiroga Angel et al., 2022) while also raising the question of the some of the potential unintended consequences of alternative development programs that encourage transitions from illicit coca to licit commodity crops. Furthermore, the use of local bivariate spatial autocorrelation in this study highlights the utility of visualizing diverse variables that impact forest cover, as noted by Shirvani and Buchroithner (2020). Nonetheless, future research is needed to address how coca production impacts and potentially compromises traditional cultural uses of forested landscapes and the diverse species that are central to cultural ecosystem services, as well as research into how alternative development programs can more mindfully envision alternatives to illicit crop cultivation that do not perpetuate damage to CES and biodiversity.

CONCLUSIONS

The global market for illicit cocaine has wrought many consequences—social, economic, and environmental—for Amazonian communities. Sometimes, these consequences result from both the drug trade and antidrug strategies. Across the Ticuna communities of lowland Amazonian Peru, the recent rise in illicit coca production, and the eradication and alternative development efforts that have followed it, have created new social and economic realities (Martín et al., 2022; Núñez et al., 2019). In this paper, we have suggested ways in which it may also be shaping CES, by altering the diversity and availability of distinct species of *huarumá*, a plant crucial to cultural production and reproduction in Ticuna communities.

The results of the research allow us to visualize some potential direct impacts of commodity crops, such as coca and cacao, on plant species that are part of the cultural ecosystem services of the forest, which define the biocultural heritage of Ticuna communities. If environmental pressures generated from illicit crop production and export-based agricultural practices continue to increase, it will produce threats to the sustainability of both plant species and forms of material and immaterial local culture that finds its meaning in and with the surrounding forest. Global drug policies—including both eradication and interdiction efforts, as well as alternative development projects implemented in coca growing areas—should consider the impacts of these policies and practices on local forest uses and these socio-ecological systems more broadly.

SPECIES	TICUNA NAME	VEGETATION COVER	COMMUNITIES	LATITUDE	LONGITUDE
<i>Ischnosiphon arouma</i>	Dexpe	Terra firme forest	Bufo Cocha	-3.954638	-70.382719
<i>Ischnosiphon puberulus</i>	Müxü	Terra firme forest	Bufo Cocha	-3.954638	-70.382719
<i>Ischnosiphon obliquus</i>	Paxtü	Terra firme forest	Bufo Cocha	-3.956048	-70.382830
<i>Ischnosiphon puberulus</i>	Müxü	Terra firme forest	Bufo Cocha	-3.954379	-70.385880
<i>Ischnosiphon obliquus</i>	Paxtü	Terra firme forest	Bufo Cocha	-3.954379	-70.385880
<i>Ischnosiphon arouma</i>	Dexpe	Terra firme forest	Nueva Galilea de Callarú	-3.934774	-70.633477
<i>Ischnosiphon puberulus</i>	Müxü	Terra firme forest	Nueva Galilea de Callarú	-3.934774	-70.633477
<i>Ischnosiphon obliquus</i>	Paxtü	Terra firme forest	Nueva Galilea de Callarú	-3.934774	-70.633477
<i>Ischnosiphon arouma</i>	Dexpe	Flooded forest	Nueva Galilea de Callarú	-3.935813	-70.633659
<i>Ischnosiphon puberulus</i>	Müxü	Flooded forest	Nueva Galilea de Callarú	-3.935813	-70.633659
<i>Ischnosiphon obliquus</i>	Paxtü	Flooded forest	Nueva Galilea de Callarú	-3.935813	-70.633659
<i>Ischnosiphon arouma</i>	Dexpe	Flooded forest	Nueva Galilea de Callarú	-3.937423	-70.633401
<i>Ischnosiphon puberulus</i>	Müxü	Flooded forest	Nueva Galilea de Callarú	-3.937423	-70.633401
<i>Ischnosiphon obliquus</i>	Paxtü	Flooded forest	Nueva Galilea de Callarú	-3.937423	-70.633401
<i>Ischnosiphon puberulus</i>	Müxü	Flooded forest	Nueva Galilea de Callarú	-3.943788	-70.629830
<i>Ischnosiphon puberulus</i>	Müxü	Flooded forest	Nueva Galilea de Callarú	-3.944973	-70.629490
<i>Ischnosiphon puberulus</i>	Müxü	Terra firme forest	Nueva Galilea de Callarú	-3.945950	-70.629150
<i>Ischnosiphon arouma</i>	Dexpe	Terra firme forest	Nueva Galilea de Callarú	-3.948150	-70.628335

Table 1 Field record of *Ischnosiphon* species.

GENUS	SPECIES	OCCURRENCES	SOURCE
Ischnosiphon	<i>I. arouma</i>	281	https://specieslink.net/search/
Ischnosiphon	<i>I. puberulus</i>	276	https://specieslink.net/search/
Ischnosiphon	<i>I. obliquus</i>	278	https://specieslink.net/search/

Table 2 Species list and number of occurrences in the genus *Ischnosiphon*.

CODE	EXPLANATORY VARIABLES	SPATIAL RESOLUTION
BIO1	Annual Mean Temperature	30 seg
BIO2	Mean Diurnal Range (Mean of monthly (max temp – min temp))	30 seg
BIO3	Isothermality (BIO2/BIO7) (×100)	30 seg
BIO4	Temperature Seasonality (standard deviation ×100)	30 seg
BIO5	Max Temperature of Warmest Month	30 seg
BIO6	Min Temperature of Coldest Month	30 seg
BIO7	Temperature Annual Range (BIO5-BIO6)	30 seg
BIO8	Mean Temperature of Wettest Quarter	30 seg
BIO9	Mean Temperature of Driest Quarter	30 seg
BIO10	Mean Temperature of Warmest Quarter	30 seg
BIO11	Mean Temperature of Coldest Quarter	30 seg
BIO12	Annual Precipitation	30 seg
BIO13	Precipitation of Wettest Month	30 seg
BIO14	Precipitation of Driest Month	30 seg
BIO15	Precipitation Seasonality (Coefficient of Variation)	30 seg
BIO16	Precipitation of Wettest Quarter	30 seg
BIO17	Precipitation of Driest Quarter	30 seg
BIO18	Precipitation of Warmest Quarter	30 seg
BIO19	Precipitation of Coldest Quarter	30 seg

Table 3 Explanatory variables used to model the potential distribution of three *Ischnosiphon* species using WorldClim data (<https://www.worldclim.org/data/worldclim21.html>).

INDIGENOUS COMMUNITIES	POTENTIAL DISTRIBUTION AREA OF HUARUMÁ (%)		SPATIAL CLUSTERING OF POTENTIAL HUARUMÁ DISTRIBUTION (%)				IMPACT OF POTENTIAL HUARUMÁ DISTRIBUTION 2010–2020 (%)			
	HIGH	VERY HIGH	HIGH- HIGH	LOW- LOW	LOW- HIGH	HIGH- LOW	HIGH- HIGH	LOW- LOW	LOW- HIGH	HIGH- LOW
Barranquilla		46.37	38.88		3.04			3.89		40.72
Bellavista Callarú		90.93	49.5				46.14			12.34
Buen Jardín de Callarú		67.38	60.63							47.79
Bufo Cocha		66.01		33.98	0.56	6.61	6.61		40.19	
Cushillo Cocha	0.68	59.39	34.64	4.84			4.36		5.05	21.92
Edén de la Frontera		41.64	5.97				0.2		1.49	17.68
Nueva Galilea de Callarú		93.14	41.87				21.99			8.75
Puerto Alegre		35.5	35.5							35.5
Puerto Sinaí		79.46	43.21		9.13			9.13		42.96
San José de Yanayacu		77.6	42.4		0.43			2.66		61.85
San Martín de Arahuana		93.7		45.04	2.21					
San Miguel		83.98	83.98							83.98
Santa Cecilia		33.12	33.12							33.12
Santa Elena del Río Amazonas		80.8								2.6
Santa Rita de Mochila		57.24			14.52				4.57	
Santa Rita del Gallinazo		33.75								33.75
Santa Rosa del Caño		67.42	67.42							67.42
Villa Nueva Alianza		80.97	18.31	49.66				5.35	15.07	22.73
Villa Nueva Esperanza de Caballo Cocha Sector B		100		14.51		80.54		5.52		80.54
Villa Nueva Vida		48.12	3.72	6.03	4.71					20.95
Yahuma I Zona		78.05	75.2							16.3
Yahuma II Zona		87.59	61.42		7.1					25.4
No communities	2.08	45.23	13.53	13.16	0.42	0.55	2.54	2.36	10.19	11.09

Table 4 Summary of areas (%) by communities of the potential distribution of huaruma, clusters of huaruma potential, and impact on huaruma distribution.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

Juan José Palacios: conceptualization, data curation, formal analysis, software, writing—original draft; **Manuel Martín:** conceptualization, writing—review and editing, supervision; **Sydney Silverstein:** conceptualization, writing—translation, original draft, review and editing; **Ricardo Zárate:** conceptualization, formal analysis; **Nicholas Kawa:** conceptualization, writing—review and editing; **Margarita del Aguila Villacorta:** conceptualization, ethnographic research, writing—review and editing.

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REFERENCES

- Alexander, M.** (2020) *The new Jim Crow: mass incarceration in the age of colorblindness*. New York: The New Press.
- Andersson, L.** (1977) The genus *Ischnosiphon* (Marantaceae). *Opera Botanica*, 43, pp. 1–113.
- Anselin, L., Syabri, I., and Kho, Y.** (2009) 'GeoDa: an introduction to spatial data analysis.' In *Handbook of applied spatial analysis: software tools, methods and applications*. Berlin: Springer, pp. 73–89. DOI: https://doi.org/10.1007/978-3-642-03647-7_5
- Baeza, S., Vélez-Martin, E., De Abelleira, D., Bancho, S., Gallego, F., Schirmbeck, J., et al.** (2022) Two decades of land cover mapping in the Rio de la Plata grassland region: the MapBiomass Pampa initiative. *Remote Sensing Applications: Society and Environment*, 28, p. 100834. DOI: <https://doi.org/10.1016/j.rsase.2022.100834>
- Bedoya Garland, E.** (1999) *Coca expansion, labor scarcity, and deforestation in Upper Huallaga, Peru: population and deforestation in the humid tropics*. Lieja: International Union for the Scientific Study of Population (USSP).
- Berkes, F., Folke, C., and Gadgil, M.** (1994) 'Traditional ecological knowledge, biodiversity, resilience and sustainability.' In *Biodiversity conservation: problems and policies*. Papers from the Biodiversity Programme Beijer International Institute of Ecological Economics Royal Swedish Academy of Sciences. Dordrecht: Springer, pp. 269–287. DOI: https://doi.org/10.1007/978-94-011-1006-8_15
- Bezeng, B.S., Yessoufou, K., Taylor, P.J., and Tesfamichael, S.G.** (2020) 'Expected spatial patterns of alien woody plants in South Africa's protected areas under current scenario of climate change.' *Scientific Reports*, 10(1), pp. 1–12. DOI: <https://doi.org/10.1038/s41598-020-63830-x>
- Brombacher, D., Garzón, J.C., and Vélez, M.A.** (2021) 'Introduction special issue: environmental impacts of illicit economies.' *Journal of Illicit Economies and Development*, 3(1). DOI: <https://doi.org/10.31389/jied.107>
- Campos, J.A., da Silva, D.D., Moreira, M.C., and de Menezes Filho, F.C.M.** (2021) 'Environmental fragility and land use capacity as instruments of environmental planning, Caratinga River basin, Brazil.' *Environmental Earth Sciences*, 80(7), art. 264. DOI: <https://doi.org/10.1007/s12665-021-09553-2>
- Celemin, J.P.** (2009) 'Autocorrelación espacial e indicadores locales de asociación espacial: importancia, estructura y aplicación. *Revista Universitaria de Geografía*, 18(1), pp. 11–31.
- Correa-Cabrera, G.** (2017) *Los Zetas Inc.: criminal corporations, energy, and civil war in Mexico*. Austin: University of Texas Press.
- Cruz-Cárdenas, G., Villaseñor, J.L., López-Mata, L., Martínez-Meyer, E., and Ortiz, E.** (2014) 'Selección de predictores ambientales para el modelado de la distribución de especies en Maxent.' *Revista Chapingo. Serie ciencias forestales y del ambiente*, 20(2), pp. 187–201.
- Cursach, J., Far, A.J., and Ruiz, M.** (2020) 'Geospatial analysis to assess distribution patterns and predictive models for endangered plant species to support management decisions: a case study in the Balearic Islands.' *Biodiversity and Conservation*, 29, pp. 3393–3410. DOI: <https://doi.org/10.1007/s10531-020-02029-y>
- Davalos, L.M., Davalos, E., Holmes, J., Tucker, C., and Armenteras, D.** (2021) 'Forests, coca, and conflict: grass frontier dynamics and deforestation in the Amazon-Andes. *Journal of Illicit Economies and Development*, 3(1). DOI: <https://doi.org/10.31389/jied.87>
- DEVIDA** (2021) *Reporte No. 6: Monitoreo de la superficie cultivada con arbusto de hoja de coca en producción, en los territorios de pueblos indígenas u originarios 2020*. Sistema de Información de Lucha contra las Drogas y Observatorio Peruano de Drogas.
- DEVIDA** (2023) *Perú: Monitoreo de Cultivos de Coca 2022*. Lima: DEVIDA.
- DEVIDA** (Comisión Nacional para el Desarrollo y Vida sin Drogas) (2020) *Programa Presupuestal Desarrollo Alternativo, Integral, y Sostenible (PIRDAIS)*.

- Duarte, H.F.S., Schmidt, A., and Wahl, S.** (2021) 'Addressing coca-related deforestation in Colombia: a call for aligning drug and environmental policies for sustainable development.' *Journal of Illicit Economies and Development*, 3(1). DOI: <https://doi.org/10.31389/jied.79>
- El Peruano** (2017) *Declaran patrimonio cultural de la nación a los conocimientos, saberes y prácticas del pueblo ticuna asociados al tejido con fibras vegetales*. 8 August.
- Erasso, C., and Vélez, M.A.** (2020) '¿Los cultivos de coca causan deforestación en Colombia?' *Documento Temático-CESED*, 5, pp. 1–14.
- Fick, S.E., and Hijmans, R.J.** (2017) 'WorldClim 2: nuevas superficies climáticas con resolución espacial de 1 km para áreas terrestres globales.' *Revista Internacional de Climatología*, 37(12), pp. 4302–4315. DOI: <https://doi.org/10.1002/joc.5086>
- Figueiredo, F.O., Zuquim, G., Tuomisto, H., Moulatlet, G.M., Balslev, H., and Costa, F.R.** (2018) 'Beyond climate control on species range: the importance of soil data to predict distribution of Amazonian plant species.' *Journal of Biogeography*, 45(1), pp. 190–200. DOI: <https://doi.org/10.1111/jbi.13104>
- García Díaz, J.A.** (2013) *2013: La situación del narcotráfico en la región Loreto*. Lima, Perú: Pontificia Universidad Católica del Perú, Instituto de Estudios Internacionales (IDEI). Available at: <http://repositorio.pucp.edu.pe/index/handle/123456789/39951>.
- García Díaz, J.A.** (2024) *Una aproximación a la deforestación por cultivos de coca en el Perú (2011–2021)*. Lima, Perú: Pontificia Universidad Católica del Perú, Instituto de Estudios Internacionales (IDEI). Available at: <https://repositorio.pucp.edu.pe/index/handle/123456789/199340>.
- Gentry, A.** (1993) *A field guide to the families and genera of woody plants of Northwest South America (Colombia, Ecuador, Peru) with supplementary notes on herbaceous taxa*. Chicago: The University of Chicago Press.
- GEOBOSQUES.** (2021) 'Bosque y pérdida del bosque.' In *Geoservidor del Programa Nacional de Conservación de Bosques para la Mitigación del Cambio Climático*. Available at: <https://geobosques.minam.gob.pe/geobosque/view/perdida.php>.
- Gomes, V.H., Mayle, F.E., Gosling, W.D., Vieira, I.C., Salomão, R.P., and ter Steege, H.** (2020) 'Modelling the distribution of Amazonian tree species in response to long-term climate change during the Mid-Late Holocene.' *Journal of Biogeography*, 47(7), pp. 1530–1540. DOI: <https://doi.org/10.1111/jbi.13833>
- Gómez-Baggethun, E., Reyes-García, V., Olsson, P., and Montes, C.** (2012) 'Traditional ecological knowledge and community resilience to environmental extremes: a case study in Doñana, SW Spain.' *Global Environmental Change*, 22(3), pp. 640–650. DOI: <https://doi.org/10.1016/j.gloenvcha.2012.02.005>
- Grillo, L., Kendra, A., Pastor, A., and Manrique, H.** (2021) 'Addressing socio-environmental challenges and unintended consequences of Peruvian drug policy: an analysis in two former Cocalero Valleys.' *Journal of Illicit Economies and Development*, 3(1). DOI: <https://doi.org/10.31389/jied.92>
- Grisaffi, T., and Ledebur, K.** (2016) 'Citizenship or repression? coca, eradication and development in the Andes.' *Stability: International Journal of Security and Development*, 5(1), pp. 1–19. DOI: <https://doi.org/10.5334/sta.440>
- He, B., Wu, X., Liu, K., Yao, Y., Chen, W., and Zhao, W.** (2022) 'Trends in forest greening and its spatial correlation with bioclimatic and environmental factors in the greater Mekong subregion from 2001 to 2020.' *Remote Sensing*, 14(23), art. 5982. DOI: <https://doi.org/10.3390/rs14235982>
- Herrera, M., Martín, M., Jarrett, C., del Aguila, M., Reinoso, R., Suárez, M., et al.** (2021) 'Historia cultural y de poblamiento de la region del Bajo Putumayo-Yaguas-Cotuhé.' In C. Jarrett, M. Thompson, N. Pitman, C. Vriesendorp, D. Alvira, A. Lemos, F. Carrasco-Rueda, et al. (eds.), *Colombia, Perú: Bajo Putumayo-Yaguas-Cotuhé: Rapid Biological and Social Inventories Report 31*, pp. 178–191. Chicago: Field Museum. Available at: <https://repositorio.iiap.gob.pe/handle/20.500.12921/592>.
- Huerta Bustamante, P.** (2022) 'Narcobenefactores: el tributo del narco en los márgenes de la Amazonía peruana.' *La Republica*, 6 March. Available at: <https://data.larepublica.pe/narcobenefactores-el-tributo-del-narcotrafico-en-los-margenes-de-la-amazonia-peruana>.
- Judd, W.S., Campbell, C.S., Kellogg, E.A., Stevens, P.F., and Donoghue, M.J.** (1999) 'Plant systematics: a phylogenetic approach.' *Ecología Mediterránea*, 25(2), art. 215.
- Leguía, E., Soudre, M., and Rugnitz, M.** (2010) *Predicción y evaluación del impacto del cambio climático sobre los sistemas agroforestales en la amazonia peruana y andina ecuatoriana*. Pucallpa, Perú: IIAP, ICRAF.
- Li, L., Tang, H., Lei, J., and Song, X.** (2022) 'Spatial autocorrelation in land use type and ecosystem service value in Hainan Tropical Rain Forest National Park.' *Ecological Indicators*, 137, art. 108727.
- Liu, C., Li, W., Wang, W., Zhou, H., Liang, T., Hou, F., et al.** (2021) 'Quantitative spatial analysis of vegetation dynamics and potential driving factors in a typical alpine region on the northeastern Tibetan Plateau using the Google Earth Engine.' *Catena*, 206, art. 105500. DOI: <https://doi.org/10.1016/j.catena.2021.105500>
- Lopes, A., Demarchi, L.O., Franco, A.C., Ferreira, A.B., Ferreira, C.S., Wittmann, F., et al.** (2021) 'Predicting the potential distribution of aquatic herbaceous plants in oligotrophic Central Amazonian wetland ecosystems.' *Acta Botanica Brasílica*, 35, pp. 22–36. DOI: <https://doi.org/10.1590/0102-33062020abb0188>
- López, C.L.** (2014) *Tikunas Brasileiros, Colombianos e Peruanos: etnicidad y nacionalidad en la region de fronteras de Alto Amazonas/Solimões*. Belem: Museo Emilio Goeldi.

- López, N., and Tuesta, D. (2015) 'Economías ilícitas y orden social: la frontera de Perú, Brasil y Colombia.' *Revista CIDOB d'Afers Internacionals*, pp. 79–104.
- Mathur, M. (2015) 'Spatial autocorrelation analysis in plant population: an overview.' *Journal of Applied and Natural Science*, 7(1), pp. 501–513. DOI: <https://doi.org/10.31018/jans.v7i1.639>
- Martín Brañas, M., Núñez Pérez, C., and Zárate Gómez, R. (2017) *El huarumá ticuna: biología y uso tradicional de tres especies del género Ischnosiphon*. Iquitos: IIAP Editorial.
- Martín Brañas, M., Silverstein, S.M., del Aguila Villacorta, M., Zárate Gómez, R., Núñez Pérez, C., Cándido Yumbato, A., et al. (2022) 'Ticuna ceramics amidst the expansion of illicit coca: rendering new relations.' *Tipiti: Journal of the Society for the Anthropology of Lowland South America*, 18(2), pp. 220–240.
- McSweeney, Kendra, et al. (2014) Drug policy as conservation policy: narco-deforestation. *Science* 343(6170), pp. 489–490. DOI: <https://doi.org/10.1126/science.1244082>
- McSweeney, K., Wrathall, D.J., Nielsen, E.A., and Pearson, Z. (2018) 'Grounding traffic: the cocaine commodity chain and land grabbing in eastern Honduras.' *Geoforum*, 95, pp. 122–132. DOI: <https://doi.org/10.1016/j.geoforum.2018.07.008>
- Milcu, A.I., Hanspach, J., Abson, D., and Fischer, J. (2013) 'Cultural ecosystem services: a literature review and prospects for future research.' *Ecology and Society*, 18(3), art. 44. DOI: <https://doi.org/10.5751/ES-05790-180344>
- Miller, H.J. (2004) Tobler's first law and spatial analysis. *Annals of the Association of American Geographers*, 94(2), pp. 284–289. DOI: <https://doi.org/10.1111/j.1467-8306.2004.09402005.x>
- Ministry of Culture (2016) *Woxrexcüchiga: El Ritual de la Pubertad Femenina en el Pueblo Ticuna*. Lima: Peruvian Ministry of Culture.
- Núñez, C., Martín, M., Del Aguila, M., and Zárate, R. (2018) *Tüxe: Conocimientos tradicionales vinculados a la yuca (Manihot esculenta) en el pueblo Ticuna*. Iquitos: IIAP.
- Núñez, C., Martín, M., Silverstein, S., and Rodríguez, R. (2019) *Suicidios en los tiempos de coca: género, violencia y cambios sociales en comunidades ticuna de la Amazonía peruana*. Available at: <http://repositorio.grade.org.pe/handle/20.500.12820/556>.
- Palacios-Vega, J.J., Zárate-Gómez, R., and Martín-Brañas, M. (2022) 'Impacto futuro del cambio de cobertura y uso de la tierra en comunidades indígenas yagua de la Amazonía peruana.' *Folia Amazónica*, 31(2), pp. 167–187. DOI: <https://doi.org/10.24841/fa.v31i2.607>
- Palacios-Vega, J., Zárate-Gómez, R., Martín-Brañas, M., and Minaya-Vela, R. (2021) 'Pérdida de bosque en zonas para la conservación y recuperación de la Zonificación Ecológica y Económica (ZEE) de la provincia Alto Amazonas, Loreto, Perú. *Ciencia Amazónica (Iquitos)*, 9(1), pp. 1–16. DOI: <https://doi.org/10.22386/ca.v9i1.316>
- Paley, D. (2014) *Drug war capitalism*. Oakland, CA: AK Press.
- Paredes, M., and Pastor, A. (2023) 'Illicit crops in the frontier margins: Amazonian indigenous livelihoods and the expansion of coca in Peru. *The Journal of Peasant Studies*, pp. 1–22. DOI: <https://doi.org/10.1080/03066150.2023.2225413>
- Phillips, S.J., Anderson, R.P., and Schapire, R.E. (2006) 'Maximum entropy modeling of species geographic distributions.' *Ecological Modelling*, 190(3–4), pp. 231–259. DOI: <https://doi.org/10.1016/j.ecolmodel.2005.03.026>
- Pitman, N., Vriesendorp, C., Moskovits, D., von May, R., Alvira, D., Wachter, T., Stotz, D., and del Campo, Á. (eds.) (2011) *Perú: Yaguas-Cotuhé*. Field Museum: Environment, Culture, and Conservation. Available at: <http://fm2.fieldmuseum.org/rbi/pdfs/peru23>.
- Quiroga Angel, V., Pablo, S., and Wagner, H.H. (2022) 'The effect of illicit crops on forest cover in Colombia. *Journal of Land Use Science*, 17(1), pp. 47–59. DOI: <https://doi.org/10.1080/1747423X.2021.2020921>
- Ramírez, M.C. (2011) *Between the guerrillas and the state: the cocalero movement, citizenship, and identity in the Colombian Amazon*. Durham, NC: Duke University Press. DOI: <https://doi.org/10.1215/9780822394204>
- Ravikumar, A., Uriarte, E.C., Lizano, D., Farré, A.M.L., and Montero, M. (2023) 'How payments for ecosystem services can undermine Indigenous institutions: the case of Peru's Ampiyacu-Apayacu watershed. *Ecological Economics*, 205, p. 107723. DOI: <https://doi.org/10.1016/j.ecolecon.2022.107723>
- RCR (Red de Comunicación Regional) (2019) *Loreto: cocaleros de pebas Amenazan con Otro Baguazo*. RCR. 23 April. Available at: <https://www.rcrperu.com/loreto-cocaleros-de-pebas-amenazan-con-otro-baguazo>.
- Reygadas, Y., Spera, S.A., and Salisbury, D.S. (2023) 'Effects of deforestation and forest degradation on ecosystem service indicators across the Southwestern Amazon. *Ecological Indicators*, 147, art. 109996. DOI: <https://doi.org/10.1016/j.ecolind.2023.109996>
- Ribeiro, C.J., Dos Santos, A.D., Lima, S.V., da Silva, E.R., Ribeiro, B.V., Duque, A.M., et al. (2021) 'Space-time risk cluster of visceral leishmaniasis in Brazilian endemic region with high social vulnerability: an ecological time series study.' *PLoS Neglected Tropical Diseases*, 15(1), art. e0009006. DOI: <https://doi.org/10.1371/journal.pntd.0009006>

- Rouse, S.M., and Arce, M. (2006) 'The drug-laden balloon: US military assistance and coca production in the central Andes.' *Social Science Quarterly*, 87(3), pp. 540–557. DOI: <https://doi.org/10.1111/j.1540-6237.2006.00395.x>
- Saatchi, S., Buermann, W., Ter Steege, H., Mori, S., and Smith, T. B. (2008) 'Modeling distribution of Amazonian tree species and diversity using remote sensing measurements.' *Remote Sensing of Environment*, 112(5), pp. 2000–2017. DOI: <https://doi.org/10.1016/j.rse.2008.01.008>
- Schroth, G., Läderach, P., Martínez-Valle, A.I., Bunn, C., and Jassogne, L. (2016) 'Vulnerability to climate change of cocoa in West Africa: patterns, opportunities and limits to adaptation.' *Science of the Total Environment*, 556, pp. 231–241. DOI: <https://doi.org/10.1016/j.scitotenv.2016.03.024>
- Shahfahad, Talukdar, S., Naikoo, M.W., Rahman, A., Gagnon, A.S., Islam, A.R.M.T., and Mosavi, A. (2022) 'Comparative evaluation of operational land imager sensor on board Landsat 8 and Landsat 9 for land use land cover mapping over a heterogeneous landscape.' *Geocarto International*, pp. 1–21. DOI: <https://doi.org/10.1080/10106049.2022.2152496>
- Shifter, M. (2012) 'Plan Colombia: a retrospective.' *Americas Quarterly*, 6(3), p. 36.
- Shirvani, Z., Abdi, O., and Buchroithner, M.F. (2020) 'A new analysis approach for long-term variations of forest loss, fragmentation, and degradation resulting from road-network expansion using Landsat time-series and object-based image analysis.' *Land Degradation and Development*, 31(12), pp. 1462–1481. DOI: <https://doi.org/10.1002/ldr.3530>
- Shirvani, Z., Abdi, O., Buchroithner, M.F., and Pradhan, B. (2017) 'Analysing spatial and statistical dependencies of deforestation affected by residential growth: Gorganrood Basin, Northeast Iran.' *Land Degradation and Development*, 28(7), pp. 2176–2190. DOI: <https://doi.org/10.1002/ldr.2744>
- Siabato, W., and Guzmán-Manrique, J. (2019) 'La autocorrelación espacial y el desarrollo de la geografía cuantitativa.' *Cuadernos de Geografía: Revista Colombiana de Geografía*, 28(1), pp. 1–22. DOI: <https://doi.org/10.15446/rcdg.v28n1.76919>
- Silverstein, S.M. (2021) 'Narco-infrastructures and the persistence of illicit coca in Loreto.' *The Journal of Latin American and Caribbean Anthropology*, 26(3–4), pp. 427–450. DOI: <https://doi.org/10.1111/jlca.12582>
- Skroblin, A., Carboon, T., Bidu, G., Chapman, N., Miller, M., Taylor, K., et al. (2021) 'Including indigenous knowledge in species distribution modeling for increased ecological insights.' *Conservation Biology*, 35(2), pp. 587–597. DOI: <https://doi.org/10.1111/cobi.13373>
- Suárez, S., and Galeano, G. (1996) *Las marantáceas de la región de Araracuara* (Vol. 10). Tropenbos Colombia. 115 p.
- Tellman, B., Sesnie, S.E., Magliocca, N.R., Nielsen, E.A., Devine, J.A., McSweeney, K., et al. (2020) 'Illicit drivers of land use change: narcotrafficking and forest loss in Central America.' *Global Environmental Change*, 63, art. 102092. DOI: <https://doi.org/10.1016/j.gloenvcha.2020.102092>
- Ter Steege, H., Pitman, N., Sabatier, D., Castellanos, H., Van Der Hout, P., Daly, D.C., et al. (2003) 'A spatial model of tree α -diversity and tree density for the Amazon.' *Biodiversity and Conservation*, 12, pp. 2255–2277. DOI: <https://doi.org/10.1023/A:1024593414624>
- UNODC (2023) *Global report on cocaine – local dynamics, global challenges*. United Nations Publications.
- UNODC (United Nations Office on Drugs and Crime) (2018) *Perú monitoreo de cultivos de coca 2017*. Available at https://www.unodc.org/documents/crop-monitoring/Peru/Peru_Monitoreo_de_Cultivos_de_Coca_2017_web.pdf (Accessed: 3 August 2023).
- Vásquez, R. (1997) *Flórula de las Reservas Biológicas de Iquitos, Perú*. St. Louis-USA: Missouri Botanical Garden Press. 1046 p.
- Wisn, M.S., Hijmans, R.J., Li, J., Peterson, A.T., Graham, C.H., Guisan, A., and NCEAS Predicting Species Distributions Working Group (2008) 'Effects of sample size on the performance of species distribution models.' *Diversity and Distributions*, 14(5), pp. 763–773. DOI: <https://doi.org/10.1111/j.1472-4642.2008.00482.x>
- Zárate Gómez, R., Rodríguez, C.A.R., Vega, J.J.P., Paredes, M.R., Romero, M.A.P., and Villanueva, J.L.C. (2019) 'Guía para la identificación de las especies de cumala colorada (*Iryanthera* Warb., Myristicaceae) de la Amazonía peruana.' *Ciencia Amazónica (Iquitos)*, 7(1), pp. 1–19. DOI: <https://doi.org/10.22386/ca.v7i1.261>
- Zárate, R. (2022) *Patrones, modelos y similitud de la distribución espacial de Iryanthera spp (Myristicaceae) en el Neotrópico*. Unpublished PhD thesis. Iquitos: UNAP.

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