Food Security
https://doi.org/10.1007/s12571-025-01639-0

RESEARCH

# Food security and forest access in the Colombian and Peruvian Amazon

**Alexander Buritica**[1] · **Martha Vanegas**[1] · **Andres Espada**[1] · **Mary Ngaiwi**[1] · **Deborah Pierce**[1] · **Marcela Quintero**[1]

Received: 26 March 2025 / Accepted: 16 December 2025


**Abstract**

Food security depends on four dimensions: availability, stability, access, and utilization. In rural Amazonian contexts, forests influence these dimensions through food provision, ecosystem services, and livelihoods, with uneven contributions across seasons, which have been understudied. This study examines the relationship between forest proximity and food security in rural Indigenous and mestizo households across several communities in the Colombian and Peruvian Amazon. We define 'forest access' as the spatial proximity of households to forests, opposed to rights-based frameworks. Using household-level panel data collected across rainy and dry seasons, we develop a multidimensional food security index covering availability, access, utilization, and stability. To address potential endogeneity in forest access, we use an instrumental variable strategy based on travel time to forest areas. Our results show significant heterogeneity between countries and communities. In La Pedrera, Colombia, Indigenous households living near less-degraded forests show higher food security, supported by traditional practices and forest biodiversity. In contrast, in Ucayali, Peru, the benefits of forest proximity are more limited and vary between Indigenous (Shipibo-Conibo) and mestizo communities, with mestizo households relying more on markets. Forest access enhances food security, but its impact is uneven across seasons and ethnic groups, reflecting the complex interactions between ecological conditions, market integration, and cultural practices. These findings highlight the importance of forest quality, local culture, and seasonal dynamics in shaping food security. We argue for policies that integrate forest conservation with culturally informed strategies to enhance food and nutritional outcomes in Amazonian communities.

**Keywords** Food security · Forest access · Amazon · Ethnicity · Multidimensional analysis

## 1 Introduction

Forests play a critical role in the livelihoods and food security of rural households. Globally, an estimated 1.6 billion people depend directly on forests for their dietary diversity, nutrition, and health (FAO, 2010; Ickowitz et al., 2014; Arnold et al., 2011). In remote areas, far from urban centers and markets, this reliance is particularly pronounced (Sunderlin et al., 2007). Non-Timber Forest Products (NTFPs), such as edible plants, nuts, seeds, and wild meat, are central to the forest-food security relationship. They not only provide direct sources of food but also contribute to household income, poverty reduction, and well-being (Angelsen et al., 2014; Kuhnlein et al., 2013; Mukul et al., 2016; Rasmussen et al., 2017). Beyond food, NTFPs encompass medicine, fodder, fibers, gums, and resins, reflecting their multidimensional contribution to livelihoods and resilience (Shackleton & Pandey, 2014; Magry, 2025). A growing body of evidence suggests that proximity to forests can improve household food security. However, the relationship can be context-dependent. Studies have reported positive associations between tree cover and dietary diversity in countries such as Malawi and Indonesia (Ickowitz et al., 2016; Johnson et al., 2013). More recent analyses confirm that exposure to forested landscapes is linked to better dietary quality and nutritional outcomes, especially for children (Park et al., 2022). Reviews also highlight that forest contributions extend beyond monetary metrics, with multidimensional impacts on welfare and resilience (Miller

✉ Alexander Buritica
a.buritica@cgiar.org

[1] Alliance of Bioversity International and CIAT (Alliance Bioversity–CIAT), Km 17 Recta Cali–Palmira, Apartado Aéreo 6713, Cali, Colombia

& Hajjar, 2020; Sunderland & Vasquez, 2020). Complementary evidence shows that forests directly contribute to household income and poverty reduction (Ali, 2018), while secure tenure arrangements shape how communities access and benefit from forest resources (Larson et al., 2023). Evidence from the Amazon further underscores that wild foods serve both as regular dietary components and as fallback resources during scarcity, strengthening their role as buffers against food insecurity (Torres-Vitolas et al., 2019). Yet the forest-food security relationship operates within a complex socio-ecological framework characterized by important uncertainties. First, the relationship between forest access and food security is not always straightforward. Market integration, while often proposed as a pathway to improve food security through the commercialization of forest products, can also trigger dietary shifts from traditional wild foods to industrial substitutes with lower nutritional quality (van Vliet et al., 2017). Second, socio-economic disparities and geographic barriers constrain who benefits from forest and market systems, emphasizing the need for context-specific strategies (Belcher et al., 2015). Finally, forest quality and biodiversity,influencing both the quantity and variety of foods available, enhances resilience and supports the stability and utilization dimensions of food security (Balvanera et al., 2016). Methodologically, empirical analyses of the forest–food security nexus face challenges of endogeneity, as forest access and food security may influence each other. To address this, we use average travel time to the forest as an instrumental variable for household forest access. Travel time is plausibly exogenous because it reflects geographic and environmental constraints, such as terrain, rainfall, or river access, that are unlikely to be determined by household-level food security outcomes. Despite this expanding literature, three major methodological gaps remain unaddressed. First, most studies rely on cross-sectional or qualitative data, which limits generalizability and overlooks seasonal dynamics in food security outcomes (Cruz-Garcia et al., 2016). Second, few analyses employ causal identification strategies to account for endogeneity in forest access. Third, there is limited attention to ethnic and national heterogeneity, even though cultural and environmental differences are likely to shape how forest proximity influences food security. Although the data were collected in 2014–2015, they remain among the few household-level datasets in the Amazon that jointly track forest access, food consumption, and livelihood strategies across Indigenous and mestizo communities. Related work has examined overlapping dimensions; however, evidence on how forest proximity affects food security remains mixed (Ali, 2018; Larson et al., 2023). Recent studies in the Peruvian Amazon underscore the forests' central role in subsistence and income, particularly in remote settings (Begazo-Curie & Vranken, 2025). Against this backdrop, our study leverages this bi-seasonal, comparative dataset to revisit long-standing hypotheses with granular microdata spanning both Colombia and Peru.

Building on this motivation and the gaps outlined above, this study examines how forest access and tree cover influence household food security in the Amazon, accounting for seasonal variation, endogeneity, and cultural differences. We use panel data from rainy and dry seasons to capture temporal variability in food security outcomes. We employ a two-stage least squares (2SLS) approach using average travel time to the forest as an instrumental variable to obtain causal estimates that address potential endogeneity. By comparing Indigenous and non-Indigenous households in Colombia (La Pedrera) and Peru (two provinces in Ucayali), our analysis provides robust causal evidence that forest proximity contributes to food security, but in highly context-dependent ways.

The remainder of this article is organized as follows. Section II presents the materials and methods, including the study sites and the methodological approach. Section III reports the empirical results, covering food security, forest access, socioeconomic characteristics, and the combined analysis of forest access and food security. Section IV concludes with a discussion of the main findings and their implications.

## 2 Materials and methods

### 2.1 Site description

This research is part of the "Attaining Sustainable Services from Ecosystems through Trade-Off Scenarios" project.[1] The project investigated the linkages between forest-based ecosystem services, food security, and health in low-income rural Indigenous and mestizo communities. The research was carried out at the forest-agricultural interface across different socio-ecological contexts in the Amazon of Colombia and Peru.

The study focuses on two Amazonian sites: La Pedrera in the Colombian department of Amazonas, and several districts in two provinces in the Peruvian department of Ucayali. While both are located within the Amazon Basin, the two contexts differ significantly in terms of forest degradation, infrastructure access, and population and ethnic composition, factors that condition household interactions with forest landscapes.

### 2.2 Colombia study area

The research in Colombia was conducted in La Pedrera, a *corregimiento* (an official administrative subdivision of

[1] More information: https://www.espa.ac.uk/projects/ne-j002267-1

a municipality) located in the department of Amazonas (Fig. 1). The study area includes four legally recognized multi-ethnic Indigenous Reserves, comprising ten Indigenous communities and two *veredas* (rural settlements that are not formally recognized as part of a reserve, but are composed of Indigenous populations). The territory of an Indigenous reserve is a collective property of the Indigenous communities, holding collective land titles. The Indigenous communities autonomously organize and manage their territory using their own normative systems (decree 2164 of 1995). The dominant tribe in this region is the Tanimuka-Yucuna, who represent the majority of the local population. However, there are other tribes such as Macuna and Miraña. La Pedrera covers an estimated area of 394,994 hectares, of which approximately 90% is forested (Sánchez-Cuervo et al., 2012). The area has low deforestation rates and limited market access. Livelihoods are primarily based on fishing, gathering, hunting, and cropping in small plot through slash and burn agriculture (Ramirez-Gomez et al., 2015; Torres-Vitolas et al., 2019) The *corregimiento* is only accessible by river or air, contributing to its limited market access and shaping local subsistence strategies.

At the time of data collection, most households depended on subsistence agriculture in small plots (intercropped tubers, plantains) and on forest-derived wild foods, with very limited participation in market-oriented production. Although no standardized indicators of food insecurity were applied in the survey, qualitative accounts and previous research suggest that households experienced relatively stable food security, largely supported by access to forest resources and wild foods (Ickowitz et al., 2014; Sunderland et al., 2013). This strong reliance on local ecosystems underscores the centrality of forest access in maintaining household livelihoods and diets.

Since the surveys were carried out, demographic and environmental conditions in La Pedrera have shown modest changes. The population increased from approximately 3,267 inhabitants in 2005 to an estimated 4,700 by 2013, although density in the area remains low (Torres-Vitolas et al., 2019). Despite this demographic growth, deforestation rates have stayed minimal, indicating that the expansion of agricultural frontiers has been limited during the past decade (Sánchez-Cuervo & Aide, 2013). However, constraints in market connectivity and limited diversification of diets persist when compared to other Amazonian regions, suggesting that livelihoods remain highly dependent on subsistence activities and forest resources.

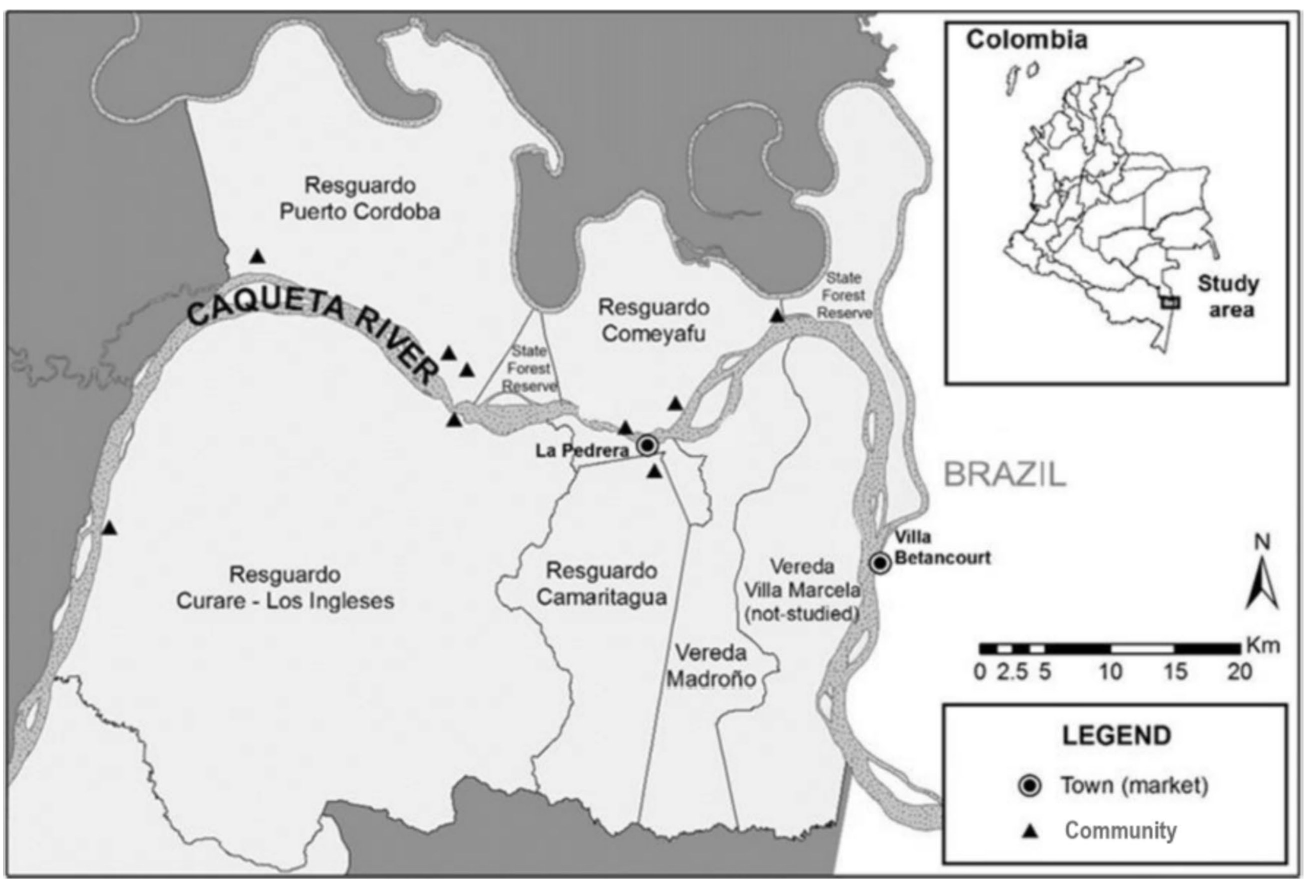


**Fig. 1** Study area in Colombia, Caquetá-La Pedrera

The study sample includes households from 11 of the 13 recognized communities in the district (Table 1). Household surveys were conducted during both the dry and rainy seasons, allowing for intra-annual comparison. In La Pedrera, the landscape is characterized by tropical rain forest and a biannual rainfall regime. These climatic conditions significantly influence local livelihood activities, particularly due to the seasonal flooding of agricultural lands and forest areas (Cruz-Garcia et al., 2019).

Table 1 summarizes the communities, their populations, and the number of household surveys conducted. While population figures correspond to individuals, the survey unit was the household. Based on an average household size of approximately five persons, the total number of households in the study area is estimated at around 220. Therefore, the 159 and 139 household surveys conducted in the dry and rainy seasons, respectively, represent about 60–70% of all households, ensuring high representativeness though not a complete census.

## 2.3 Peru study area

In Peru, the study was conducted in two provinces of the Ucayali department, Coronel Portillo and Padre Abad, located in the Amazon region. The area encompasses both Indigenous and mestizo communities, which differ in terms of geographic location, access to infrastructure, and patterns of interaction with forest resources. Nine communities were selected to reflect this diversity. The Shipibo-Conibo ethnic group inhabit the three Indigenous communities—Caco Macaya, Junín Pablo, and Puerto Belén. Six mestizo communities are situated at varying distances from major roads and rivers. These include two riverine mestizo communities (Cunchuri and Naranjal) and four non-riverine mestizo communities (La Union, Monte Olivos, Pueblo Libre and Yerbas Buenas) (Fig. 2 and Table 2). The mestizo communities are characterized by a mixed population of migrants, primarily from the Andean region and other parts of Peru. (Francesconi et al., 2018). Indigenous communities settle within titled reserves, which account for approximately 20% of Ucayali's land area (SICNA, 2012). Livelihoods in these communities are based on subsistence agriculture, fishing, logging, and occasional hunting. In contrast, the mestizo households typically engage in fishing, small-scale agriculture, and cattle ranching, depending on their proximity to rivers and forest edges (Francesconi et al., 2018).

At the time of data collection, both Indigenous and mestizo households relied heavily on small-scale farming, mainly cassava, rice, and plantain, complemented with fishing and forest products. In some areas of Ucayali, income derived from forests represented close to 40% of total household earnings, highlighting the importance of these resources in local livelihoods (Francesconi et al., 2018). Patterns of food security varied across ethnic groups: Indigenous households often displayed higher dietary diversity due to their stronger dependence on forest and river resources, whereas mestizo households were more reliant on purchased foods, which exposed them to fluctuations in prices and access (Ickowitz et al., 2014; Sunderland et al., 2013).

Over the past decade, the Ucayali region has experienced rapid deforestation and significant transformations in livelihood strategies. Between 2001 and 2015, the department lost approximately 382,300 hectares of forest (around 25,500 hectares per year), making it one of the most affected areas in the Peruvian Amazon (Bax et al., 2016). In specific communities such as Pueblo Libre and La Unión, forest loss exceeded 30% during this period (Francesconi et al., 2018). The construction of the Federico Basadre highway further accelerated forest clearing and settlement expansion, intensifying agricultural conversion (Bax et al., 2016). Shifts in food access have accompanied these changes: while Indigenous communities continue to rely on subsistence activities and forest resources, mestizo households increasingly depend on purchased foods, which has reduced dietary diversity and increased vulnerability to market fluctuations (Blundo-Canto et al., 2020). More recent analyses estimate that between 2001 and 2018, Peru lost approximately 2.2 million hectares of Amazonian forest, with Ucayali consistently among the departments with the highest rates of deforestation (MinAM, 2020; Hettler et al., 2018). Current evidence further indicates that oil palm and cacao expansion remain important drivers of deforestation in Ucayali, often associated with weak governance and illegal land conversion (Gutiérrez-Vélez et al., 2011; Selibas, 2024).

**Table 1** Communities and socioeconomic characteristics of the study area in La Pedrera, Colombia

| Indigenous reservations | Communities | Population | Household surveys dry season | Household surveys rainy season | Area (ha) |
|---|---|---|---|---|---|
| Puerto Cordoba | Puerto Cordoba, Loma Linda, Bocas del Miriti | 212 | 32 | 28 | 46,897 |
| Curare | Curare, Borikada | 263 | 30 | 28 | 237,643 |
| Comeyafu | Tanimuca, Yacuna, Angosturas, Bacuri | 520 | 79 | 71 | 19,023 |
| Camaritagua | Camaritagua | 64 | 10 | 6 | 8,456 |
| Veredad Madroño | Veredad MadroñoMadroño | 56 | 8 | 6 | 20,351 |
| Total | | 1,115 | 159 | 139 | 332,370 |

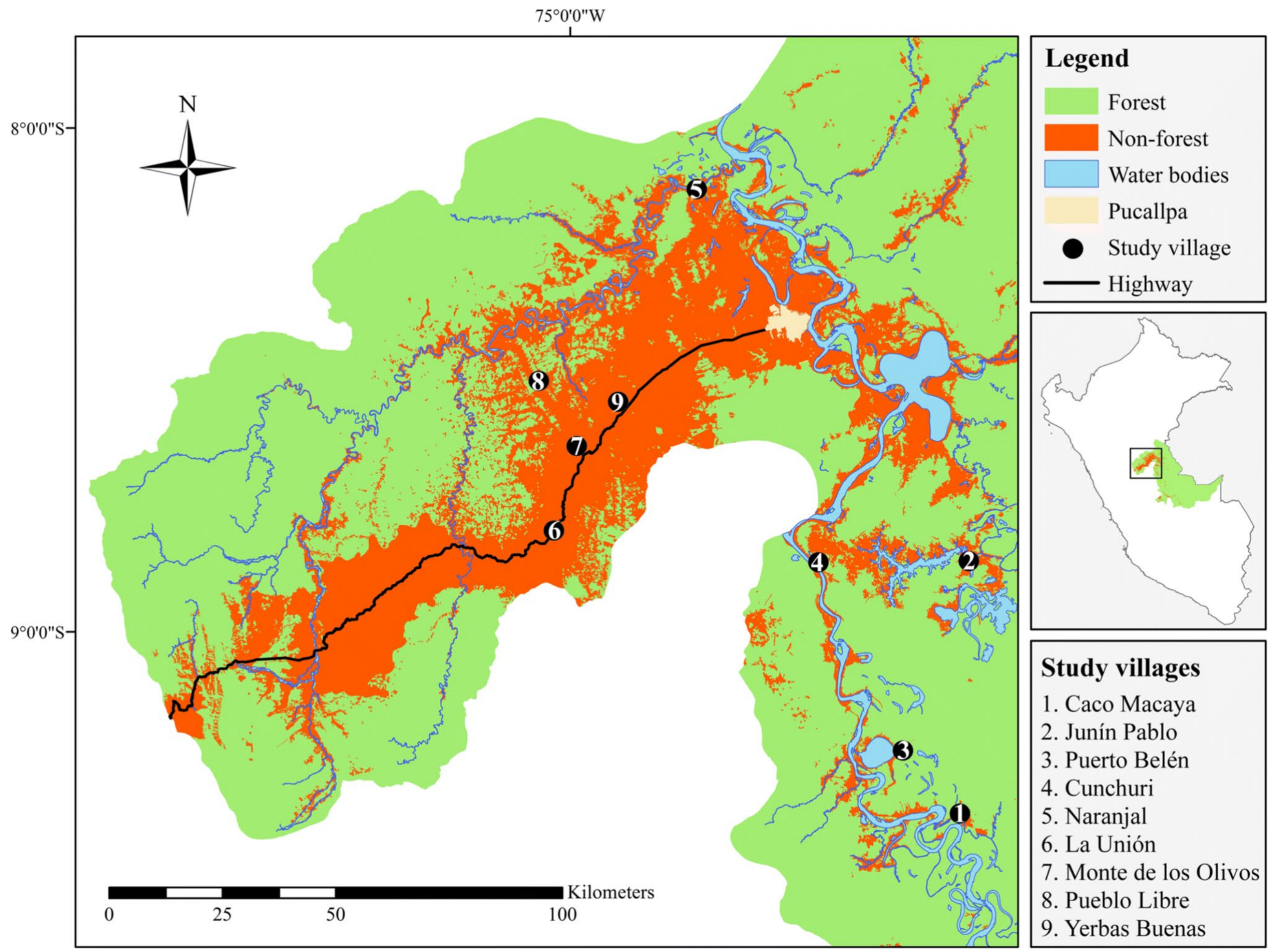


**Fig. 2** Study areas in Ucayali, Peru

**Table 2** Communities and socio-economic characteristics of the study area in Ucayali, Peru

| Ethnic group | Villages | Population | Household surveys dry season | Household surveys rainy season | Area (km2) |
|---|---|---|---|---|---|
| Indigenous | Caco Macaya | 1,031 | 32 | 32 | 20 |
| | Junin Pablo | 922 | 21 | 21 | 8 |
| | Puerto Belen | 893 | 29 | 33 | 11 |
| Mestizo | Chunchuri | 604 | 21 | 21 | 35 |
| | Naranjal | 289 | 8 | 7 | 10 |
| | La Union | 959 | 27 | 28 | 55 |
| | Monte de los Olivos | 313 | 21 | 21 | 25 |
| | Pueblo Libre | 354 | 9 | 11 | 25 |
| | Yerbas Buenas | 337 | 31 | 30 | 20 |
| Total | | 5,702 | 199 | 204 | 209 |

Table 2 describes the Indigenous and mestizo communities surveyed in Ucayali, their population sizes, and the number of household surveys conducted in both the dry and rainy seasons. In total, 199 households were surveyed in the dry season and 204 in the rainy season, representing a substantial share of the population across the nine selected communities. The three Indigenous villages together host 2,846 residents, while the six mestizo settlements account for 2,856 residents, for a combined population of 5,702. Survey coverage was relatively balanced across ethnic groups and seasons, ensuring comparability of results. Settlement sizes vary widely, from small riverine villages such as

Naranjal (<300 residents) to larger mestizo settlements like La Unión (~1,000), capturing Ucayali's social and environmental heterogeneity. The areas reported are expressed in square kilometers and sum to 209 $km^2$ across the nine communities, indicating substantial variation in community land bases and reflecting the mix of forest and agricultural landscapes that characterizes the region.

## 3 Methods

The study applied a household survey design. The inclusion of both riverine and non-riverine communities, located at varying distances from forests, allows us to analyze how geographical conditions shape household-level access to natural resources and, in turn, influence food security outcomes. In La Pedrera, Colombia, where Indigenous groups represent the majority of the population, the sample included 289 households across 11 Indigenous communities and two rural settlements. In Ucayali, Peru, 303 households were selected from a mix of Indigenous and mestizo communities, distributed across locations with varying proximity to roads, rivers, and markets. Overall, the sampling strategy was designed to reflect heterogeneity in forest access and human–environment interactions (Cavendish, 2000; López-Feldman, 2020).

Data were collected during two rounds of fieldwork conducted in 2014 and 2015, covering both the rainy and dry seasons. Not all households could be re-interviewed in both survey rounds due to logistical constraints such as flooding, travel difficulties, or temporary household absences. As a result, small discrepancies exist between the rainy- and dry-season samples. Nonetheless, the overall coverage remained high, with more than 80% of the targeted households successfully surveyed in both seasons. Enumerators administered structured questionnaires through in-person interviews with male and female household members. The survey instrument included modules on demographic and socioeconomic indicators, food consumption, income sources, forest product use, time allocation, hunting and fishing practices, and agricultural production and sales. Each household was interviewed twice, once in each season, capturing seasonal variation in food security and livelihood strategies. To ensure comparability across survey rounds, modules on productive and extractive activities used a six-month recall period.

Our methodological framework was designed to investigate how household-level forest access influences food security outcomes across these two Amazonian contexts. To capture this relationship, we combine multidimensional measurement, spatial and behavioral indicators, and econometric techniques. First, we construct a multidimensional Food Security Index (FSI) aligned with international standards, incorporating seasonal and contextual variation at the household level. Second, we define forest access through both behavioral use and physical proximity, recognizing that ecological, geographic, and socio-cultural factors mediate access. Third, we implement an econometric identification strategy that addresses potential endogeneity using instrumental variables. By leveraging variation in seasonal forest access, ethnic composition, and local infrastructure, the model estimates causal effects while controlling for unobservable household characteristics and time-varying shocks.

### 3.1 Food security

To capture household-level food security in a multidimensional manner, we construct an index aligned with the four pillars identified by the FAO: availability, access, utilization, and stability. The index is based on primary data collected across rainy and dry seasons, allowing us to account for seasonal variability in household conditions.

Each dimension of food security is captured through specific, context-relevant indicators. Availability is measured through the economic valuation of all food consumed by the household during the reference period, regardless of whether it was purchased, grown, hunted, fished, gathered, or received in-kind. Expressed in USD, this valuation reflects the sufficiency of food available to the household, since it accounts for the total quantity and diversity of foods actually consumed, rather than only those acquired through markets. In contrast, the access dimension captures the number and type of food sources available to the household, including forests, markets, hunting, fishing, and subsistence agriculture, reflecting the household's capacity to obtain food through multiple and reliable channels. Utilization is assessed through indicators related to the quality of food preparation and diet, specifically the source of drinking and cooking water (e.g., public, private, river, or well) and the type of energy or fuel used (e.g., wood, gas, or electricity). These categorical variables are coded to reflect differences in safety and quality. Stability is evaluated based on the coping strategies households report during food shortages, such as reducing meal sizes, skipping meals, or relying on less preferred foods. These strategies are recorded as binary variables and aggregated into a measure of household-level food insecurity experience.

We apply Factor Analysis for Mixed Data (FAMD) to construct the index, which is particularly suited for datasets combining continuous and categorical variables. This method derives weights endogenously based on the variance explained by each component, avoiding arbitrary assignments. The resulting composite scores are standardized to a 0–100 scale, where higher values represent greater levels of household food security. Full methodological details, including the coding of variables are provided in Appendix 1.

## 3.2 Forest access

Previous research has documented the importance of forests for rural livelihoods. Ali et al. (2018), using data from the Himalayan region of Pakistan, show that forest products contribute significantly to household income and play an important role in poverty reduction. In contrast, Larson et al. (2023) focus on forest tenure and highlight that access to forests cannot be understood only in physical terms but also depends on the security of rights to use and manage forest resources. Together, these studies underscore that forest access influences livelihoods, but their approaches rely mostly on cross-sectional data and community-level definitions of proximity or rights. Such approaches overlook intra-community differences and forest characteristics such as biodiversity and tree cover.

In this study, we define household-level forest access using two indicators: (i) whether the household reported using the forest to collect natural resources (e.g., food, animals, medicinal plants, or construction materials), and (ii) the estimated time required to reach the forest on foot. Specifically, the first indicator is a binary variable coded 1 if the household reported using forest products at any moment during the six months prior to the survey, and 0 otherwise. Proximity is represented by the minimum time in minutes it takes to reach the forest, as self-reported by respondents for both rainy and dry seasons. This measure follows established practice in socio-environmental studies that use travel time as a proxy for forest accessibility (Porro et al., 2015; Zhang et al., 2019).

To situate these household measures within their local land-use context, we construct a village-level, descriptive covariate of proximate vegetation loss from Terra-i (Reymondin et al., 2012), which detects NDVI-based loss at 16-day intervals across Latin America. For each community, we compute the share of pixels flagged as loss within a 5 km buffer centered on the village centroid and aggregate to seasonal windows aligned with the survey rounds (annual totals are used in robustness checks).

## 3.3 Econometric strategy

To delve into the causal relationship between forest access and household-level food security, we adopt a robust estimation approach, employing ordinary least squares (OLS) specifications with household and seasonal fixed effects, as well as a fixed ethnicity effect ($\delta_e$) in the Peruvian case, where both Indigenous and mestizo households are observed. The model is formalized as follows:

$$FoodIndex_{(i,t)} = \beta * (ForestAcess_{(i,t)}) + \varphi * X_{i,t} + U_{i,t} + \upsilon_i + \omega_t + \delta_e \tag{1}$$

where $FoodIndex_{(i,t)}$ is the standardized food security index derived through Factor Analysis for Mixed Data (FAMD). This method integrates continuous and categorical variables corresponding to the four FAO pillars of food security (availability, access, utilization, and stability), producing composite scores standardized on a 0–100 scale. The FAMD approach ensures that weights are endogenously determined by the variance structure of the data, avoiding arbitrary assignment and making the indicator statistically robust for cross-household and cross-seasonal comparisons. $ForestAcess_{(i,t)}$ is a dummy variable that takes the value of 1 if the household i at time t makes use of the forest and takes the value of 0 otherwise; $X_{i,t}$ is a vector of household-level control variables that vary over time. $\upsilon_i$ and $\omega_t$ are the fixed effects at the household and time levels. The variable $\delta_e$ is a fixed ethnic effect, included only for the Peruvian case, where both Indigenous and mestizo households are observed. Finally, $U_{i,t}$ is the standard error term grouped at the household level that allows correlations between unobservable variables that could affect food security levels within the household $i$ over time $t$.

## 3.4 Addressing endogeneity

Equation (1) may suffer from endogeneity due to simultaneity or joint determination, as forest access and food security can influence each other. For instance, households with lower food security may face greater challenges in accessing remote forests, while easier access to forests may enhance food security through resources like wild foods, firewood, or additional income from forest products.

To address this issue, we employ an instrumental variables (IV) approach, where the minimum average distance to the forest in minutes ($TimeToForest_{(i,t)}$) serves as the instrument for $ForestAcess_{(i,t)}$. The IV methodology satisfies two critical conditions: i) relevance and ii) exogeneity. The first condition requires that the instrument must be strongly correlated with the endogenous variable (forest access). The exogeneity condition, in turn, requires that the instrument influences food security only through its effect on forest access and not via any other direct channel. A potential concern is that households living farther from forests may also be closer to markets, and market proximity could itself improve food security through income opportunities and food availability. To address this concern, we explicitly control for market access and other relevant covariates in our empirical specification, ensuring that the exclusion restriction is not violated.

The relevance of $TimeToForest_{(i,t)}$ as an instrument is supported by two key factors. First, geographical accessibility has consistently influenced access to and utilization of resources or services. Studies by Eckel et al. (2011), Pedrosa and Do (2011), and Popradit et al. (2015) highlight that the proximity to a resource provider significantly impacts whether individuals or households can utilize those resources. In the context of forests, households closer to forests are more likely to access and benefit from them, whether for food, income generation, or other livelihood activities. Second, temporal and climatic heterogeneity introduces variability in accessibility. Seasonal variations, such as rainy versus dry seasons, significantly impact travel times and physical access to forests. The $TimeToForest_{(i,t)}$ variable captures these temporal dynamics, allowing the analysis to account for heterogeneity in forest access due to changing climatic conditions. By incorporating this variable, the model reflects how seasonal changes influence the practical utilization of forest resources at the household level.

The exogeneity of the instrument is supported under the assumption that, conditional on the control variables, the minimum average distance to the forest is uncorrelated with the error term in Eq. (1). In addition to controlling for market access, we argue that travel time is plausibly exogenous because it reflects geographic and environmental constraints, such as terrain, rainfall, or river access, that are unlikely to be shaped by household-level food security outcomes. While the instrument is theoretically exogenous from an economic perspective, econometric robustness requires addressing potential confounders, which we do by including a rich set of controls.

Our two-stage model formalizes this approach. In the first stage, $ForestAcess_{(i,t)}$ is regressed on $TimeToForest_{(i,t)}$ along with control variables, capturing the relationship between forest distance and access. In the second stage, the predicted values of $ForestAcess_{(i,t)}$ from the first stage are used to estimate their effect on food security. Specifically, the equations are given by:

$$FoodIndex_{(i,t)} = \beta * (\widehat{ForestAcess}_{(i,t)}) + \varphi * X_{i,t} + U_{i,t} + v_i + \omega_t + \delta_e \quad (2)$$

$$\widehat{ForestAcess}_{(i,t)} = \phi * (TimeToForest_{(i,t)}) + \varphi * X_{i,t} + U_{i,t} + v_i + \omega_t + \delta_e \quad (3)$$

In short, the coefficient β of Eq. (2) captures the causal effect of forest access to the food security index among households that access the forest according to their distance in minutes. We explicitly address potential confounding effects from market access and leverage the exogenous variation in travel time. This two-stage approach ensures the robustness of our findings by addressing endogeneity concerns and isolating the impact of forest access on household food security.

## 4 Results

### 4.1 Food security

Estimating the food security index allows us to evaluate the impact of seasonal variations on household food security. In La Pedrera, Colombia, Indigenous households rely heavily on surrounding natural resources for their livelihoods. As such, we expect overall food security to decline in the rainy season primarily because flooding limits overland mobility and reduces hunting and foraging opportunities; at the same time, high water can reconfigure fishing opportunities rather than uniformly restricting them.[2] Table 3 shows a statistically significant reduction of seven percentage points in the food security index during the rainy season compared to the dry season, highlighting the tangible effects of climatic seasonality on food security in La Pedrera, Colombia.

In Ucayali, Peru, the overall food security index is lower during the rainy season, but the 1.1 percentage point decrease is not statistically significant. In La Pedrera, Colombia, by contrast, the decline is larger and statistically significant. Taken together, these patterns are consistent

**Table 3** Estimation of food security index (La Pedrera, Colombia, and Ucayali, Peru)

| | La Pedrera, Colombia | | | Ucayali, Perú | | |
|---|---|---|---|---|---|---|
| Food security dimension | Rainy season | Dry Season | t-test ($p$-value)[*] | Rainy Season | Dry Season | t-test ($p$-value)[*] |
| Availability | 2,469.00 | 4,801.00 | 0.00*** | 1,385.00 | 226 | 0.01** |
| Stability | 1.34 | 2.56 | 0.37 | 2.26 | 2.53 | 0.22 |
| Access | 3.54 | 3.58 | 0.53 | 2.71 | 2.74 | 0.86 |
| Utilization | 5.46 | 1.60 | 0.09* | 29.60 | 29.60 | - |
| | 69.53 | 65.62 | 0.51 | 87.50 | 86.18 | 0.73 |
| Food Security Index[a] | 62.36 | 69.88 | 0*** | 11.55 | 12.62 | 0.13 |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$; [a]Food Security Index in Percentage (0–100); [b]Household percentage (%)

[2] In floodplain (várzea) systems, the "flood pulse" expands aquatic habitat and can facilitate near-home fishing from stilt-house settlements, while fish dispersion, currents, and travel risks may reduce catchability elsewhere; the direction of the fishing effect is therefore context- and gear-dependent (Castello et al., 2013).

**Table 4** Components of the food security index in Ucayali, Peru by community type (Shipibo-Conibo Indigenous and Mestizo) and season

| | Indigenous | | | | Mestizo | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Variables | Rainy Season [1] | Dry Season [2] | Annual [3] | t-test (1–2) (p-value)[*] | Rainy Season [4] | Dry Season [5] | Annual [6] | t-test (4–5) (p-value)[*] | t-test (3–6) (p-value)[*] |
| Economic valuation amount of food consumed in the household ($ US) | 1,218.00 | 1,711.00 | 1,464.00 | 0.15 | 1,585.00 | 3,903.00 | 2,113.00 | 0*** | 0.07* |
| Food scarcity intensity | 2.78 | 2.94 | 2.86 | 0.62 | 1.93 | 2.24 | 2.03 | 0.23 | 0.00*** |
| Number of food sources | 2.67 | 3.15 | 2.91 | 0.01** | 2.75 | 2.50 | 2.58 | 0.01** | 0.00*** |
| Source energy kitchen (gas)[b] | 0.00 | 1.49 | 2.38 | 0.32 | 57.63 | 51.28 | 54.47 | 0.33 | 0.00*** |
| Public water source[b] | 77.61 | 95.52 | 86.57 | 0.00*** | 95.76 | 80.34 | 87.06 | 0.00*** | 0.90 |
| Food security index[a] | 13.66 | 13.39 | 13.52 | 0.68 | 9.53 | 13.62 | 10.95 | 0.00*** | 0.00*** |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$; [a]Food Security Index in Percentage (0–100); [b]Household percentage (%)

with rainy-season constraints on overland activities (hunting/foraging) and with fishing being redistributed toward near-home or safer habitats in floodplain settlements, yielding a net rainy-season decline in La Pedrera and a smaller, non-significant change in Ucayali. In Ucayali, cultural and economic practices mediate these effects: Indigenous households exhibit greater resilience via diversified food sources and direct forest access, whereas mestizo households depend more on purchased foods and markets, increasing sensitivity to seasonal access and price shocks.

Table 4 reveals that Indigenous households exhibit higher food security indices than mestizo households in Ucayali, Peru, primarily due to their greater reliance on diverse food sources. Indigenous households also display more stability across seasons, with less pronounced fluctuations in food consumption and sources than their mestizo counterparts. Together, these findings indicate that food security in both Colombia and Peru is shaped by seasonal constraints, but household strategies differ. In Colombia, resilience is largely linked to subsistence activities tightly constrained by flooding and climatic variability. In Peru, resilience depends more on the interaction between subsistence and market-based strategies, with Indigenous households showing stronger buffers against seasonal fluctuations than mestizo households.

## 5 Forest access

In La Pedrera, Colombia, results show that over 85% of surveyed Indigenous households reported forest use, with an average access time of approximately 12 min. Travel times[3] increase significantly during the rainy season due to deteriorated road conditions, from 7.4 min in the dry season to 16.3 min in the rainy season. Households that reported no forest resource use were located much farther away, with average travel times of over 90 min in the rainy season (See Table 5). Importantly, "access time" is elicited by season and reflects the typical route and mode used in that season (canoe/boat or on foot). In La Pedrera, seasonal patterns are heterogeneous: riverine communities tend to pivot to canoes during high water, whereas terra firme settlements remain primarily on foot but face longer or disrupted overland routes.

In Ucayali, Peru, patterns differ by Indigenous and mestizo communities and by season. Among Indigenous households, 72% reported using forest resources, with an average access time of 37 min. In contrast, only 32% of mestizo households used forest products, and they reported an average access time of 27 min. Seasonal variations in travel times are smaller in Ucayali, Peru, but patterns differ across communities (Table 5). These contrasts reflect not

**Table 5** Access to the forest by season in La Pedrera, Colombia and Ucayali, Peru (Average time in minutes)

| | Forest access | Rainy season | Dry season | t-test (*p*-value)[*] |
|---|---|---|---|---|
| La Pedrera, Colombia (Indigenous) | Yes | 16.30 (29.40) | 7.40 (7.30) | 0.001** |
| | No | 94.40 (80.90) | 23.60 (11.80) | 0.033* |
| Ucayali, Perú (Indigenous) | Yes | 35.40 (41.60) | 39.30 (30.80) | 0,60 |
| | No | 147.00 (76.60) | 113.30 (45.50) | 0,11 |
| Ucayali,Perú (Mestizos) | Yes | 30.00 (70.70) | 23.00 (34.60) | 0,70 |
| | No | 174.40 (116.30) | 48.40 (41.30) | <0.001*** |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$.Values in parentheses are standard deviations. Access time is one-way from the dwelling to the nearest forest edge typically used, measured separately by season and including the predominant mode for that season (canoe/boat or on foot). In Ucayali, rainy-season access is predominantly canoe-based; in La Pedrera, mode varies with community geography (riverine vs. terra firme). Results are robust to conditioning on riverine status and to excluding households that report mode changes across seasons

[3] For households that do not access the forest, we calculate the minimum travel time in minutes as if they were accessing and utilizing the forest during that season.

only physical proximity but also socio-cultural and livelihood differences in how forests are valued and used.

Beyond household survey data, we also examined forest cover change around the study sites. In La Pedrera, Colombia, forest cover remains relatively intact, while sites in Ucayali, particularly surrounding mestizo areas, show more pronounced deforestation (Fig. 3). Between 2004 and 2013, average tree-cover loss around Indigenous communities in Ucayali was 11%, while around mestizo areas it was 19% (Fig. 3).

## 6 Socioeconomic characteristics

In this section, we examine households' socioeconomic characteristics and clarify the two dimensions of forest access considered in this study: (i) whether the household reports using forest resources, and (ii) one-way travel time (minutes) to the nearest forest edge.

La Pedrera, Colombia. Indigenous households that use the forest have a higher mean Food Security Index than those that do not (67.36 vs 53.57; $p<0.001$). They also have larger household size (6.22 vs 4.48; $p<0.001$) and greater total cultivated/managed farm area (1.47 ha vs 0.44 ha; $p<0.001$). The share of foods from hunting/collection is higher among forest-access households (0.31 vs 0.00; $p<0.001$), while the share from gifts/donations is lower (0.12 vs 0.38; $p<0.001$). Differences in the market access index and credit access are not statistically significant (Table 6).

Table 7 reports means by ethnicity and forest access, in Ucayali, Peru. Among mestizo households, the mean Food Security Index (FSI) is higher for households reporting forest access than for those without access, and the difference is statistically significant. Among Indigenous households, the difference is positive but not statistically significant. Using one-way travel time (minutes) to the nearest forest edge as a proximity measure, households with shorter travel time exhibit higher mean FSI; this association is statistically significant for mestizo households and not significant for Indigenous households. Forest-access households also report shorter travel times and a higher share of foods from hunting/gathering; corresponding means and $p$-values are presented in Table 7 for Indigenous households in Ucayali, the mean share of foods from hunting/gathering is higher among forest-access households (e.g., 24%) and the mean share from gifts/donations is lower (e.g., 12%) than among non-access households; the difference in FSI between access and non-access groups is not statistically significant.

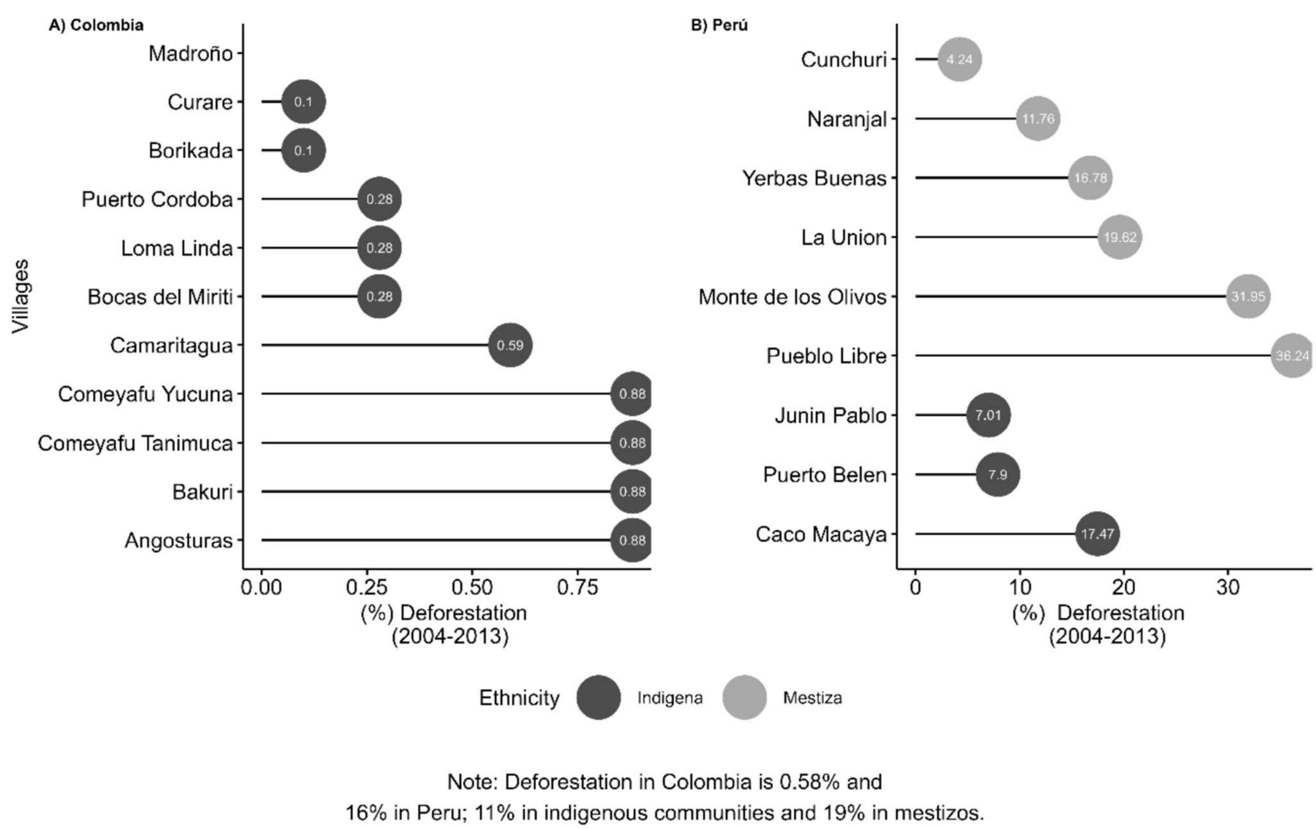


**Fig. 3** Deforestation by country and community type (Data source: Terra-i) (Data source: Terra-i (Reymondin et al., 2012). Terra-i is a near real-time monitoring system that detects habitat loss in Latin America using MODIS-NDVI and TRMM data. For more information, visit terra-i.org.)

**Table 6** Descriptive socioeconomic variables by forest access in La Pedrera, Colombia

| Variables | Forest access | No forest access | t-test ($p$-value)[*] |
|---|---|---|---|
| Food security | | | |
| Food security index (0–100) | 67.36 | 53.57 | 0.00*** |
| Share of total foods that come from the farm[c] | 0.39 | 0.32 | 0.21 |
| Share of total foods that come from hunting or collection[c] | 0.31 | 0.00 | 0.00*** |
| Share of total foods that come from gifts or donations[c] | 0.12 | 0.38 | 0.00*** |
| Household socioeconomic variables | | | |
| Households owning at least one canoe (dummy variable)[a] | 0.56 | 0.39 | 0.13 |
| Total farm area (ha)[b] | 1.47 | 0.44 | 0*** |
| Average household age | 23.78 | 29.81 | 0.16 |
| Household size (persons) | 6.22 | 4.48 | 0.00*** |
| Credit access (dummy)[a] | 0.29 | 0.26 | 0.79 |
| Market access index(0–100) | 13.29 | 18.4 | 0.35 |
| Number of subsidies | 1.04 | 0.87 | 0.37 |
| Average distance to the forest(minutes) | 11.70 | 72.83 | 0.00*** |
| N | | | |
| Observations | 233 | 33 | |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$. Values are means.[a] Proportion of households, [b] Total cultivated/managed agricultural area reported by the household (includes chacras, i.e., household agricultural plots); values in hectares, [c] Proportion of total foods (0–1). Multiply by 100 to express as percentages

## 7 Forest access and food security

Tables 8 and 9 show the results of Eq. (2) for each country and community type (Indigenous and mestizo) using two-stage least squares (OLS) and instrumental variables (IV). Column 1 in both tables shows the result of the OLS estimate, assuming that access to the forest is exogenous, while column 2 shows results from the regression with instrumental variables.

In Indigenous communities of La Pedrera, Colombia, access to the forest has a positive effect on household food security. The coefficient using the OLS model (column 1) is small and statistically significant ($p < 0.05$). In contrast, the instrumental variable methodology shows that the effect is more important and maintains the same significance level. The difference between the OLS and IV estimators confirms attenuation bias in the OLS model due to reverse causality. On average, households that access the forest present a food security index 11.56 percentage points higher than households that do not (Table 8). By subdimension (Table 3), differences are largest in availability and access; differences in utilization are smaller, and stability is not statistically significant (see Table 3).

In Ucayali, Peru, ethnicity-specific estimates are reported in Table 9. For Indigenous households, the OLS coefficient on forest access is 1.65 (SE=0.97; $p<0.10$) and the IV (2SLS) coefficient is 3.45 (SE=1.59; $p<0.05$), both

**Table 7** Descriptive socioeconomic variables by forest access in Ucayali, Peru

| | Indigenous | | | Mestizo | | |
|---|---|---|---|---|---|---|
| Variables | Forest access | No forest access | t-test ($p$-value)[*] | Forest access | No forest access | t-test ($p$-value)[*] |
| Food security | | | | | | |
| Food security index (0–100) | 13.84 | 12.73 | 0.19 | 14.70 | 9.21 | 0.00*** |
| Share of total foods that come from the farm[c] | 0.22 | 0.14 | 0.04** | 0.21 | 0.16 | 0.11 |
| Share of total foods that come from hunting or collection[c] | 0.24 | 0.00 | 0.00*** | 0.15 | 0.00 | 0.00*** |
| Share of total foods that come from gifts or donations[c] | 0.12 | 0.33 | 0.00*** | 0.11 | 0.09 | 0.52 |
| Household socioeconomic variables | | | | | | |
| Households owning at least one canoe (dummy variable)[a] | 0.42 | 0.34 | 0.43 | 0.20 | 0.034 | 0.00*** |
| Total farm area (ha)[b] | 1.87 | 1.29 | 0.03** | 8.66 | 11.70 | 0.20 |
| Average household age | 23.69 | 23.93 | 0.91 | 32.54 | 34.65 | 0.43 |
| Household size (persons) | 6.25 | 6.47 | 0.66 | 4.35 | 4.21 | 0.63 |
| Credit access (dummy)[a] | 0.07 | 0.08 | 0.91 | 0.32 | 0.23 | 0.28 |
| Market access index(0–100) | 4.21 | 4.63 | 0.6 | 25.39 | 57.46 | 0.00*** |
| Number of subsidies | 0.62 | 0.66 | 0.78 | 0.17 | 0.043 | 0.03** |
| Average distance to the forest(minutes) | 37.39 | 131.05 | 0.00*** | 27 | 107.07 | 0.00*** |
| N | | | | | | |
| Observations | 96 | 38 | | 54 | 116 | |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$; Values are means.; [a] Proportion of householdsHousehold percentage, [b] Total cultivated/managed agricultural area reported by the household (includes chacras, i.e., household agricultural plots); values in hectares, [c] Proportion of total foods (0–1). Multiply by 100 to express as percentages

**Table 8** Effect of access to forest on food security in La Pedrera, Colombia

| | Food security index | |
|---|---|---|
| Variables | OLS (1)[*] | IV (2)[*] |
| Forest Access) | 9.86** | 11.56* |
| | [4.73] | [6.03] |
| Observations | 256 | 256 |
| First-Stage (F-Statistic) | | 47.75 |
| Season F.E | Yes | Yes |
| Household F.E | Yes | Yes |
| Set of Controls | Yes | Yes |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$

**Table 9** Effect of access to forest on food security in Ucuyali, Peru

| | Food security index | | | |
|---|---|---|---|---|
| | Indigenous | | Mestizo | |
| Variables | OLS (1)[*] | IV (2)[*] | OLS (3) | IV (4) |
| Forest access | 1.65* | 3.45** | 0.89 | −9.78 |
| | [0.97] | [1.59] | [2.46] | [11.96] |
| Observations | 134 | 134 | 170 | 170 |
| First-Stage (F-Statistic) | | 31.42 | | 2.97 |
| Season F.E | Yes | Yes | Yes | Yes |
| Household F.E | Yes | Yes | Yes | Yes |
| Set of Controls | Yes | Yes | Yes | Yes |

[*]Note: * $p<0.05$. ** $p<0.01$. *** $p<0.001$

positive. For mestizo households, coefficients are 0.89 (SE=2.46; not significant) in OLS and –9.78 (SE=11.96; not significant) in IV. All specifications include season and household fixed effects and the standard set of controls; first-stage F-statistics are reported in Table 9 (Indigenous: 31.42; Mestizo: 2.97).

## 8 Discussion

This study provides empirical evidence on how forest access influences household-level food security in two Amazonian contexts: La Pedrera, Colombia, and Ucayali, Peru. Using a multidimensional framework that captures availability, stability, access, and utilization, we show that proximity to forests, forest quality, and sociocultural characteristics jointly shape food security outcomes. These findings contribute to academic debates and policy design, particularly regarding the achievement of Sustainable Development Goals (SDGs) such as Zero Hunger (SDG 2) and Life on Land (SDG 15).

A key contribution of this research lies in the use of travel time to the forest as an instrumental variable to estimate the causal effect of forest access on food security. Travel time captures both physical and economic constraints to forest use, households closer to forests face lower extraction costs and are more likely to benefit from forest provisioning services. Prior studies support this logic. Babigumira et al. (2014) and Wu et al. (2017) show that greater distances reduce forest resource use and the associated benefits derived from natural ecosystems. We also found that seasonal variability reinforces this relationship, with rainy conditions restricting mobility and increasing reliance on nearby natural resources, particularly forest products (Wunder et al., 2018). Conditioning on market access, credit, and household assets strengthens identification and supports the robustness of the estimates.

However, this relationship is moderated by forest quality. In the Indigenous communities of La Pedrera, Colombia, where forest ecosystems remain relatively biodiverse and less degraded, households with forest access report greater food availability and dietary diversity, especially during the rainy season when agricultural productivity and market access decline. These findings align with previous studies recognizing forests as essential safety nets in times of food scarcity (Ickowitz et al., 2022; Sunderland & O'Connor, 2020; Torres-Vitolas et al., 2019). Moreover, Torres-Vitolas et al. (2019) highlight the role of forest quality and traditional social institutions as important factors in preventing severe food insecurity among Indigenous communities of the Colombian Amazon.

In Ucayali, Peru, the relationship is more complex: Indigenous households benefit more consistently from forest access, while mestizo households derive fewer advantages. This heterogeneity points to differences in traditional ecological knowledge, land rights, and reliance on markets versus forest-based systems (Chukwuone et al., 2020; Clapp et al., 2022). The absence of a positive effect among mestizo households is directly related to their lower frequency of forest use and weaker dependence on forest products. As shown in Table 5, mestizo households rely more heavily on purchased foods and market access, which reduces the relative contribution of forests to their food security outcomes. Supporting this, Andrieu et al., (2019) found that some mestizo communities, when they did have access to forested land through ownership, often perceived it not as a source of food or ecosystem services, but as a potential land for future agricultural production activities.

Commodity cropping and land-use change in Ucayali further shape the forest–food nexus. Remote-sensing evidence shows that oil palm expansion concentrates along transport corridors and frequently replaces forests; although expansion regimes (industrial vs. smallholder) differ, both add conversion pressure near roads and settlements (Glinskis & Gutiérrez-Vélez, 2019; Vijay et al., 2018). For cacao, meta-analyses and regional assessments indicate that agroforestry systems can maintain tree cover and diversify incomes relative to monocultures, yet cacao expansion has also been documented as a driver of deforestation in parts of Peru, depending on siting and production systems (Niether et al., 2020; Rojas et al., 2021). These land-use dynamics help contextualize greater reliance on purchased foods and lower use of wild foods in some mestizo areas undergoing commercialization.

Beyond these local dynamics, evidence from other regions further illustrates how forest quality influences food security. Biodiverse forests tend to offer a greater variety of edible species and promote ecosystem stability, which are key to supporting the utilization and stability dimensions of food security (Dawson et al., 2019; Sunderland & Vasquez, 2020). Studies in Malawi and Indonesia, for instance, report positive associations between tree cover and dietary diversity (Ickowitz et al., 2016; Johnson et al., 2013). Still, much of the existing literature is based on localized or qualitative studies, often assuming static relationships between forest access and food security and overlooking seasonal variability and household heterogeneity (Cruz-Garcia et al., 2016; Zenteno et al., 2013).

In our study sites, these dynamics were evident. In La Pedrera, Colombia, lower deforestation rates have helped preserve forest biodiversity, thereby reinforcing the contribution of forests to local food systems. Cruz-Garcia et al. (2019) found that Indigenous communities in Colombia identified provisioning ecosystem services, such as fish, bush meat, and wild fruits, as the most important. The role of forests in food provision and utilization (e.g., firewood for cooking) are considered as key criteria for valuing ecosystem services in general. In contrast, higher deforestation in mestizo areas of Ucayali, Peru, limits forest functionality, reducing households' ability to secure food through forest resources (Blundo-Canto et al., 2020). These findings underline the importance of targeted conservation policies that protect both the extent and quality of forests to maintain their role in food provisioning (Gergel et al., 2020; Marselle et al., 2021; Raj et al., 2022).

Our results challenge the common assumption that market integration is a guaranteed pathway to improved food security. In Ucayali, Peru, mestizo households generally have better market access, and in some cases a higher average food security index, but this advantage is not consistent across all dimensions of food security or throughout the year. During the rainy season, when road and river transport are disrupted, market access becomes more difficult, and mestizo households experience greater fluctuations in food availability and stability. In contrast, Indigenous households with strong forest access maintain more stable food security by relying on forest-based resources such as fish, bushmeat, and wild fruits, which provide both nutritional diversity and a safety net during periods of limited mobility. These findings suggest that markets alone cannot replace the ecological and nutritional benefits provided by forests, particularly in remote or resource-dependent contexts. Policy interventions should therefore prioritize hybrid strategies—such as agroforestry systems, payments for ecosystem services (PES), and community-based forest management—that integrate market opportunities with sustainable forest use, aligning conservation goals with the livelihood needs of local communities (Kidane & Kejela, 2021).

Moreover, seasonal dynamics play a critical role. Our findings show that food insecurity intensifies during the rainy season due to poor road conditions and reduced mobility. In such periods, forests become vital sources of food and resilience. Yet this highlights an urgent need for infrastructural investments, particularly in transportation and storage, to reduce seasonal food insecurity (Mbuli et al., 2021; Nébié et al., 2021). Addressing spatial inequalities in forest and market access also demands place-based planning, with attention to geography, ethnicity, and institutional context (Parvez et al., 2022).

Finally, while the empirical findings of this study are context-specific to the Amazon and cannot be directly generalized to other regions, the conceptual and policy insights extend beyond this case. Forest-dependent communities in Africa and Southeast Asia face similar challenges in balancing environmental conservation with food and livelihood security. Thus, the lessons from this research are more applicable to shared dynamics and policy debates, such as REDD+, zero-deforestation laws, and the SDGs, rather than to direct quantitative comparisons across regions. Ultimately, sustainable forest management must integrate food security objectives, recognizing that forests are not only carbon sinks but also crucial assets in rural development. Achieving this vision requires cross-sectoral collaboration and the meaningful inclusion of Indigenous and local knowledge systems in policymaking and implementation.

That said, several limitations should be acknowledged. First, the analysis is restricted to two case-study sites, La Pedrera in Colombia and Ucayali in Peru, which constrains the generalizability of the findings to other Amazonian or tropical forest contexts. Second, while travel time to the forest is a useful proxy for forest access, it does not capture other important dimensions such as forest quality, tenure arrangements, or the formal and informal institutions that regulate forest use. Finally, the study focuses on household-level measures of food security. It does not account for intra-household differences in food allocation, which may vary by gender, age, or social role. Future research could address these limitations by expanding to additional sites, integrating fine-scale measures of forest governance and quality, and applying methodologies that capture intra-household dynamics.

## 9 Conclusions

This paper analyzes the relationship between forest access and food security among Colombian and Peruvian Amazon Indigenous and mestizo households located in La Pedrera and in two provinces of Ucayali. Using panel data collected at the household level across two seasons (rainy and dry), we empirically explore the influence of forests on a multidimensional food security index. This research is significant given the growing body of literature emphasizing the crucial role of forests in ensuring food security. We employ an instrumental variable approach to mitigate selection bias, enabling us to account for observable and unobservable heterogeneity. Our estimates provide causal evidence of the impact of forest access on food security.

The findings reveal a strong relationship between forest access and household food security. In La Pedrera, Colombia, where Indigenous households reside near forests with relatively low deforestation rates, forest access is associated with higher levels of food security across both seasons. In Ucayali, Peru, the effect is weaker, particularly among mestizo households, reflecting higher deforestation, greater dependence on markets, and lower reliance on forest resources. By contrast, Indigenous households in both sites benefit more significantly from forest access, underscoring the importance of cultural and socioeconomic factors in shaping food security dynamics.

Our analysis also challenges the conventional assumption that better market access automatically improves food security. While mestizo households in Ucayali often have greater market access, this advantage does not consistently translate into stable or higher food security, particularly during the rainy season when mobility is restricted. Indigenous households, by contrast, sustain more stable diets through their reliance on forest-derived foods.

In conclusion, this research highlights the critical role of forests in sustaining food security, particularly for marginalized and remote communities. Policy efforts should therefore prioritize conserving forest cover and biodiversity, strengthening institutional capacity to curb deforestation in Colombia and Peru, and integrating traditional ecological knowledge into conservation and food security strategies. Complementary approaches that combine sustainable forest use with market-based opportunities, such as agroforestry, payments for ecosystem services, and community-based forest management, can help safeguard food security while addressing the diverse needs of rural households.

## Appendix 1 Construction of food security index

To construct a food security index for Colombia and Peru, we applied Factor Analysis for Mixed Data (FAMD), a multivariate statistical method suited for datasets containing both categorical and continuous variables. The index was computed separately for the rainy and dry seasons. To facilitate comparability and interpretation, the resulting scores were rescaled to a standardized range from 0 to 100, using the following min–max normalization formula::

$$FoodSecurityIndex = \frac{(\mathrm{x} - x_{min})}{(x_{max} - x_{min})} x100 \tag{A.1}$$

For Colombia, we use the first component (Comp1) as the basis of the index. As shown in Table 10, Comp1 is positively associated with availability (valuation of food consumed) and access (number of food sources). Utilization categories show mixed signs, as expected with categorical blocks, reflecting contrasts between, for example, gas vs firewood or public vs non-public water sources once other dimensions are considered. Comp1 explains 26.23% of total variance, typical for multidimensional welfare constructs with mixed data.

Higher FSI values come from households positioned higher on Comp1, which, by construction, co-vary positively with greater availability and more food sources. Category rows with negative signs (e.g., "gas" in this table) indicate an inverse association within the joint pattern uncovered by FAMD and should be read as contrasts, not causal effects. All FSI values are then rescaled to 0–100.

In Peru, the first three components of the estimate capture the greatest data variance (Table 11). Although the first component exhibits a negative relationship with the availability dimension and a positive one with the stability dimension, the third dimension is utilized to create the food security index for rural households in Peru, as it predominantly captures the concept of availability (Fig. 4).

The food security index in Peru demonstrates a positive relationship with the economic valuation of total food consumption and the number of food sources, while exhibiting a negative relationship with the intensity of scarcity, the energy source, and water used for food preparation.

**Table 10** Estimation food security index-La Pedrera, Colombia

| Food security dimension | Variables | Comp1 | Comp2 | Comp3 | Comp4 | Comp5 |
|---|---|---|---|---|---|---|
| Availability | Economic valuation amount of food consumed in the household ($ US) | 0.713 | 0.185 | 0.001 | 0.154 | 0.658 |
| Stability | Food scarcity intensity | -0.126 | -0.783 | 0.303 | 0.512 | 0.133 |
| Access | Number of food sources | 0.634 | 0.230 | 0.405 | 0.321 | -0.526 |
| Utilization | Source energy kitchen (firewood) | 0.095 | -0.096 | 0.040 | -0.111 | -0.009 |
| | Source energy kitchen (gas) | -3.038 | 3.069 | -1.268 | 3.541 | 0.275 |
| | Do not use water source (public) | -0.642 | 0.469 | 1.091 | -0.210 | 0.281 |
| | Yes use water source (public) | 0.336 | -0.245 | -0.571 | 0.110 | -0.147 |
| FAMD | Eigenvalues | 1.311 | 1.079 | 0.960 | 0.870 | 0.780 |
| | Variance (%) | 26.230 | 21.590 | 19.170 | 17.340 | 15.670 |

**Table 11** Estimation food security Index-La Pedrera, Colombia

| Food security dimension | Variables | Comp1 | Comp2 | Comp3 | Comp4 | Comp5 |
|---|---|---|---|---|---|---|
| Availability | Economic valuation: amount of food consumed in the household ($ US) | -0.466 | 0.078 | 0.797 | 0.373 | 0.053 |
| Stability | Food scarcity intensity | 0.570 | 0.286 | -0.181 | 0.715 | 0.222 |
| Access | Number of food sources | 0.139 | 0.816 | 0.167 | -0.420 | 0.333 |
| Utilization | Source energy kitchen (firewood) | 0.613 | 0.085 | 0.256 | -0.062 | -0.285 |
| | Source energy kitchen (gas) | -1.289 | -0.178 | -0.537 | 0.131 | 0.599 |
| | Do not use water source (public) | 1.572 | -1.651 | 0.752 | -0.456 | 0.907 |
| | Yes use water source (public) | -0.251 | 0.263 | -0.120 | 0.073 | -0.145 |
| FAMD | Eigenvalues | 1.405 | 1.146 | 0.938 | 0.874 | 0.637 |
| | Variance (%) | 28.092 | 22.921 | 18.766 | 17.479 | 12.742 |

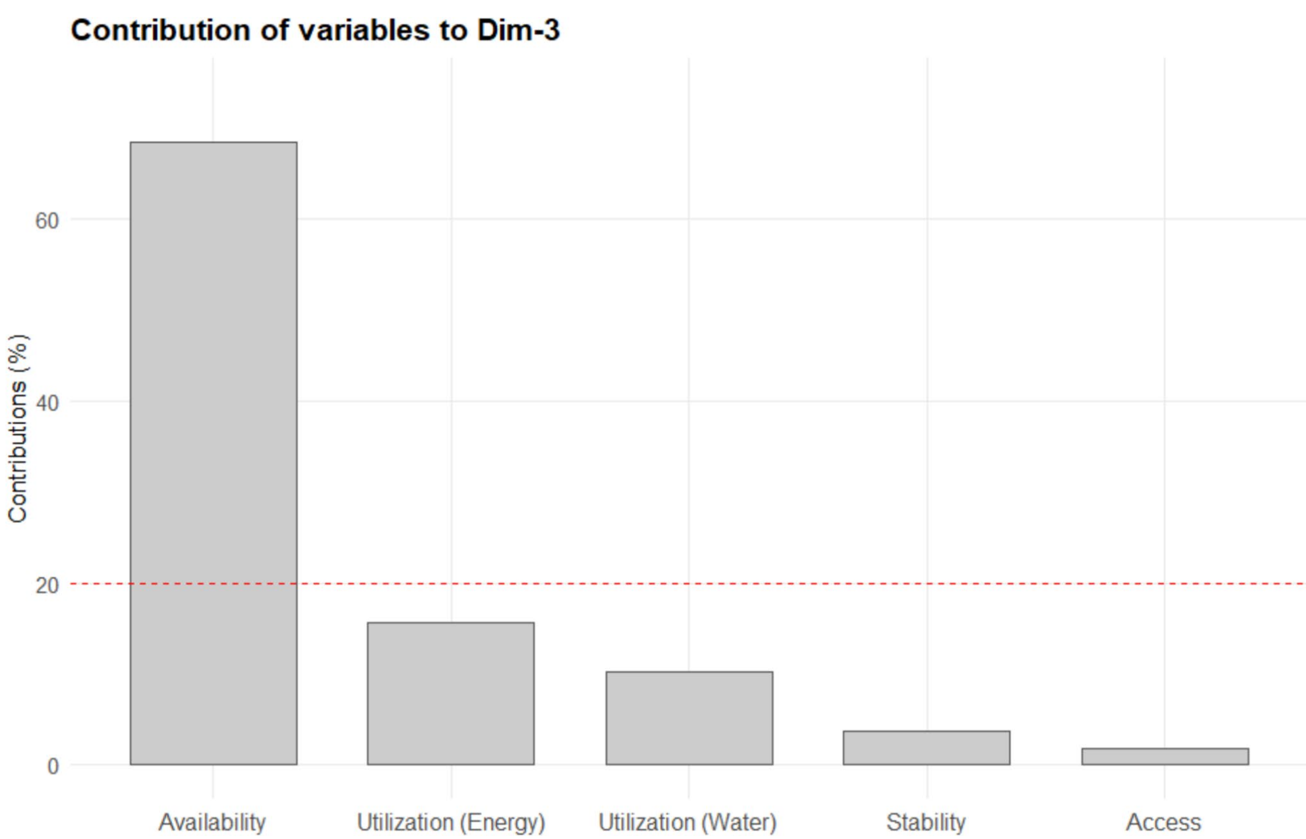


**Fig. 4** Contribution of each food security dimension in the first component of the FMAD-Uyacali, Peru Index

**Acknowledgements** We are deeply grateful to the Indigenous and mestizo households, community leaders, and local stakeholders who generously shared their time, knowledge, and patience during fieldwork. An earlier version of this work was presented at the World Bank Land Conference (Washington, DC, 13–17 May 2024); we appreciate the constructive feedback from conference participants and session discussants, which helped refine the analysis. We also thank the Science Writing Team of the Alliance of Bioversity International and CIAT for editorial feedback on the final draft.

**Author contributions** AB led the writing of this manuscript and performed data curation, formal analysis, validation, and visualization. MV assisted in methodology design, project administration, writing, reviewing, and editing. MQ contributed to conceptualization, funding acquisition, and project administration, as well as reviewing the manuscript. AE participated in the investigation and methodology design. DP and MN contributed to writing, reviewing, and editing.

**Funding** This work took place under the project "Attaining Sustainable Services from Ecosystems using Trade-off Scenarios" (ASSETS; http://espa-assets.org/; NE-J002267-1). The United Kingdom's Ecosystem Services for Poverty Alleviation (ESPA; www.espa.ac.uk) initiative funded the research. ESPA receives its funding from the UK's Department for International Development (DFID), the Economic and Social Research Council (ESRC), and the Natural Environment Research Council (NERC). The funding institutions had no role in the study design, data collection, analysis, interpretation, or decision to publish this manuscript.

**Data Availability** The data supporting the findings of this study are publicly available from the UK Data Service ReShare repository and can be accessed at: https://reshare.ukdataservice.ac.uk/855394/.

## Declarations

**Conflict of interest** The authors declare no competing interests.

## References

Ali, A. (2018). Forest-based livelihoods, income, and poverty: Empirical evidence from the Himalayan region of rural Pakistan. *Journal of Rural Studies, 57*, 44–54.

Andrieu, N., Blundo-Canto, G., & Cruz-García, G. S. (2019). Trade-offs between food security and forest exploitation by mestizo households in Ucayali, Peruvian Amazon. *Agricultural Systems, 173*, 64–77.

Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N. J., Bauch, S., & Wunder, S. (2014). Environmental income and rural livelihoods: A global-comparative analysis. *World Development, 64*, S12–S28.

Arnold, M., Powell, B., Shanley, P., & Sunderland, T. C. (2011). Forests, biodiversity and food security. *International Forestry Review, 13*(3), 259–264.

Babigumira, R., Angelsen, A., Buis, M., Bauch, S., Sunderland, T., & Wunder, S. (2014). Forest clearing by smallholders in the tropics: Forest clearance impacts on poverty and environmental sustainability. *World Development, 64*, S62–S72. https://doi.org/10.1016/j.worlddev.2014.03.001

Balvanera, P., Quijas, S., Martín-López, B., Barrios, E., Dee, L., Isbell, F., ... & de Groot, R. (2016). The links between biodiversity and ecosystem services. In Routledge handbook of ecosystem services (pp. 45–61). Routledge.

Bax, V., Francesconi, W., & Quintero, M. (2016). Spatial modeling of deforestation processes in the Central Peruvian Amazon. *Journal for Nature Conservation, 29*, 79–88.

Begazo-Curie, K., & Vranken, L. (2025). Forests' contribution to rural livelihoods and food security: Insights from a study case in the Peruvian Amazon. *Food Security*. https://doi.org/10.1007/s12571-025-01521-z

Belcher, B., Achdiawan, R., & Dewi, S. (2015). Forest-based livelihoods strategies conditioned by market remoteness and forest proximity in Jharkhand, India. *World Development, 66*, 269–279.

Blundo-Canto, G., Cruz-Garcia, G. S., Talsma, E. F., Francesconi, W., Labarta, R., Sanchez-Choy, J., & Quintero, M. (2020). Changes in food access by mestizo communities associated with deforestation and agrobiodiversity loss in Ucayali, Peruvian Amazon. *Food Security, 12*(3), 637–658.

Cavendish, W. (2000). Empirical regularities in the poverty-environment relationship of rural households: Evidence from Zimbabwe. *World Development, 28*(11), 1979–2003. https://doi.org/10.1016/S0305-750X(00)00071-4

Chukwuone, N. A., Adeosun, K. P., & Chukwuone, C. A. (2020). Socioeconomic factors affecting households' use of indigenous forest management practices in managing non-wood forest products: Evidence from forest communities in Nigeria derived savannah. *Heliyon*. https://doi.org/10.1016/j.heliyon.2020.e05281

Clapp, J., Moseley, W. G., Burlingame, B., & Termine, P. (2022). The case for a six-dimensional food security framework. *Food Policy, 106*, 102164.

Cruz-Garcia, G. S., Sachet, E., Vanegas, M., & Piispanen, K. (2016). Are the major imperatives of food security missing in ecosystem services research? *Ecosystem Services, 19*, 19–31.

Cruz-Garcia, G. S., Cubillos, M. V., Torres-Vitolas, C., Harvey, C. A., Shackleton, C. M., Schreckenberg, K., & Sachet, E. (2019). He says, she says: Ecosystem services and gender among indigenous communities in the Colombian Amazon. *Ecosystem Services, 37*, 100921.

Dawson, I. K., Park, S. E., Attwood, S. J., Jamnadass, R., Powell, W., Sunderland, T., & Carsan, S. (2019). Contributions of biodiversity to the sustainable intensification of food production. *Global Food Security, 21*, 23–37.

Eckel, S., Löffler, G., Maurer, A., & Schmidt, V. (2011). Measuring the effects of geographical distance on stock market correlation. *Journal of Empirical Finance, 18*(2), 237–247.

FAO. (2010). Food and Agriculture Organization of the United Nations. Forestry Department (Rome). Global forest resources assessment 2010: Main report. Food and Agriculture Organization of the United Nations.

Francesconi, W., Bax, V., Blundo-Canto, G., Willcock, S., Cuadros, S., Vanegas, M., Quintero, M., & Torres-Vitolas, C. (2018). Hunters and hunting across indigenous and colonist communities at the forest-agriculture interface: An ethnozoological study from the Peruvian Amazon. *Journal of Ethnobiology and Ethnomedicin, 14*, 54. https://doi.org/10.1186/s13002-018-0247-2

Gergel, S. E., Powell, B., Baudron, F., Wood, S. L., Rhemtulla, J. M., Kennedy, G., Rasmussen, L. V., Ickowitz, A., Fagan, M. E., & Smithwick, E. A. (2020). Conceptual links between landscape diversity and diet diversity: A roadmap for transdisciplinary research. *Bioscience, 70*(7), 563–575.

Glinskis, E. A., & Gutiérrez-Vélez, V. H. (2019). Quantifying and understanding land cover changes by large and small oil palm expansion regimes in the Peruvian Amazon. *Land Use Policy, 80*, 95–106.

Gutiérrez-Vélez, V. H., DeFries, R., Pinedo-Vásquez, M., Uriarte, M., Padoch, C., Baethgen, W., & Lim, Y. (2011). High-yield

oil palm expansion spares land at the expense of forests in the Peruvian Amazon. *Environmental Research Letters, 6*(4), 044029.
Hettler, B., Thieme, A., & Finer, M. (2018). Deforestation Hotspots in the Peruvian Amazon, 2018.
Ickowitz, A., Powell, B., Salim, M. A., & Sunderland, T. C. (2014). Dietary quality and tree cover in Africa. *Global Environmental Change, 24*, 287–294.
Ickowitz, A., Rowland, D., Powell, B., Salim, M. A., & Sunderland, T. (2016). Forests, trees, and micronutrient-rich food consumption in Indonesia. *PLoS ONE, 11*(5), e0154139.
Ickowitz, A., McMullin, S., Rosenstock, T., Dawson, I., Rowland, D., Powell, B., Mausch, K., Djoudi, H., Sunderland, T., & Nurhasan, M. (2022). Transforming food systems with trees and forests. *The Lancet Planetary Health, 6*(7), e632–e639.
Johnson, K. B., Jacob, A., & Brown, M. E. (2013). Forest cover associated with improved child health and nutrition: Evidence from the Malawi Demographic and Health Survey and satellite data. *Global Health, Science and Practice, 1*(2), 237–248.
Kidane, L., & Kejela, A. (2021). Food security and environment conservation through sustainable use of wild and semi-wild edible plants: A case study in Berek Natural Forest, Oromia special zone, Ethiopia. *Agriculture & Food Security, 10*(1), 29. https://doi.org/10.1186/s40066-021-00308-7
Kuhnlein, H. V., Erasmus, B., Spigelski, D., & Burlingame, B. (2013). Indigenous peoples' food systems and well-being: interventions and policies for healthy communities (pp. xiv+-xxxii+).
Larson, A. M., Monterroso, I., Liswanti, N., & Tamara, A. (2023). What is forest tenure (in) security? Insights from participatory perspective analysis. *Forest Policy and Economics, 147*, 102880.
López-Feldman, A. (2020). Environmental economics in developing countries. *Springer*. https://doi.org/10.1007/978-3-030-45897-1
Magry, M. A. (2025). Socioeconomic dynamics of non-timber forest products: a gendered analysis of livelihoods in forest-fringe communities in central Highlands Biogeographic Zone of India. Forests, Trees and Livelihoods, pp. 1–23.
Marselle, M. R., Hartig, T., Cox, D. T., De Bell, S., Knapp, S., Lindley, S., Triguero-Mas, M., Böhning-Gaese, K., Braubach, M., & Cook, P. A. (2021). Pathways linking biodiversity to human health: A conceptual framework. *Environment International*, *150*, 106420. https://www.sciencedirect.com/science/article/pii/S0160412021000441
Mbuli, C. S., Fonjong, L. N., & Fletcher, A. J. (2021). Climate change and small farmers' vulnerability to food insecurity in Cameroon. *Sustainability, 13*(3), 1523.
Miller, D. C., & Hajjar, R. (2020). Forests as pathways to prosperity: Empirical insights and conceptual advances. *World Development, 125*, 104647.
Ministerio del Ambiente (MINAM). (2020). Cobertura y pérdida de bosques húmedos amazónicos al 2020: Reporte de deforestación bosques amazónicos 2020 [PDF]. Recuperado de: https://geobosques.minam.gob.pe/geobosque/descargas_geobosque/perdida/documentos/Reporte_de_deforestacion_bosques_amazonicos_2020.pdf?. Accessed 21 Feb 2024.
Mukul, S. A., Rashid, A. M., Uddin, M. B., & Khan, N. A. (2016). Role of non-timber forest products in sustaining forest-based livelihoods and rural households' resilience capacity in and around protected area: A Bangladesh study. *Journal of Environmental Planning and Management, 59*(4), 628–642.
Nébié, E. K. I., Ba, D., & Giannini, A. (2021). Food security and climate shocks in Senegal: Who and where are the most vulnerable households? *Global Food Security, 29*, 100513.
Niether, W., Jacobi, J., Blaser, W. J., Andres, C., & Armengot, L. (2020). Cocoa agroforestry systems versus monocultures: A multi-dimensional meta-analysis. *Environmental Research Letters, 15*(10), 104085. https://doi.org/10.1088/1748-9326/abb053
Park, S., Kim, E., Kim, G., Kim, S., Choi, Y., & Paek, D. (2022). What activities in forests are beneficial for human health? A systematic review. *International Journal of Environmental Research and Public Health, 19*(5), 2692.
Parvez, M., Islam, M. R., & Dey, N. C. (2022). Household food insecurity after the early monsoon flash flood of 2017 among wetland (Haor) communities of northeastern Bangladesh: A cross-sectional study. *Food and Energy Security, 11*(1), Article e326.
Pedrosa, J., & Do, Q. T. (2011). Geographic distance and credit market access in Niger. *African Development Review, 23*(3), 289–299.
Popradit, A., Srisatit, T., Kiratiprayoon, S., Yoshimura, J., Ishida, A., Shiyomi, M., & Phromma, I. (2015). Anthropogenic effects on a tropical forest according to the distance from human settlements. *Scientific Reports, 5*(1), 14689.
Porro, R., Lopez-Feldman, A., & Vela-Alvarado, J. W. (2015). Forest use and agriculture in Ucayali, Peru: Livelihood strategies, poverty and wealth in an Amazon frontier. *Forest Policy and Economics, 51*, 47–56.
Raj, A., Jhariya, M. K., Khan, N., Nema, S., Devi, A., & Ghanshyam. (2022). Effect of deforestation and forest fragmentation on ecosystem services. In P. Panwar, G. Shukla, J. A. Bhat, & S. Chakravarty (Eds.), Land Degradation Neutrality: Achieving SDG 15 by Forest Management (pp. 25–41). Springer Nature Singapore. https://doi.org/10.1007/978-981-19-5478-8_2
Ramirez-Gomez, S. O., Torres-Vitolas, C. A., Schreckenberg, K., Honzák, M., Cruz-Garcia, G. S., Willcock, S., & Poppy, G. M. (2015). Analysis of ecosystem services provision in the Colombian Amazon using participatory research and mapping techniques. *Ecosystem Services, 13*, 93–107.
Rasmussen, L. V., Watkins, C., & Agrawal, A. (2017). Forest contributions to livelihoods in changing agriculture-forest landscapes. *Forest Policy and Economics, 84*, 1–8.
Reymondin, L., Jarvis, A., Pérez-Uribe, A., Touval, J., Argote, K., Rebetez, J., Guevara, E., & Mulligan, M. (2012). Terra-i: A methodology for near real-time monitoring of habitat change at continental scales using MODIS-NDVI and TRMM. Remote Sensing of Environment.
Rojas, E., Zutta, B. R., Velazco, Y. K., Montoya-Zumaeta, J. G., & Salvà-Catarineu, M. (2021). Deforestation risk in the Peruvian Amazon basin. *Environmental Conservation, 48*(4), 310–319. https://doi.org/10.1017/s0376892921000291
Sánchez-Cuervo, A. M., & Aide, T. M. (2013). Consequences of the armed conflict, forced human displacement, and land abandonment on forest cover change in Colombia: A multi-scaled analysis. *Ecosystems, 16*(6), 1052–1070. https://doi.org/10.1007/s10021-013-9667-y
Sánchez-Cuervo, A. M., Aide, T. M., Clark, M. L., & Etter, A. (2012). Land cover change in Colombia: Surprising forest recovery trends between 2001 and 2010. *PLoS ONE, 7*(8), e43943. https://doi.org/10.1371/journal.pone.0043943
Selibas, D. (2024). Report shows Peru failed to stop Amazon deforestation for palm oil and cacao. Mongabay. Recuperado de https://news.mongabay.com/2024/02/report-shows-peru-failed-to-stop-amazon-deforestation-for-palm-oil-and-cacao. Accessed 21 Feb 2024.
Shackleton, C. M., & Pandey, A. K. (2014). Positioning non-timber forest products on the development agenda. *Forest Policy and Economics, 38*, 1–7.

SICNA. (2012). Sistema de Información Sobre Comunidades Nativas de La Amazonía Peruana.

Sunderland, T. C., & Vasquez, W. (2020). Forest conservation, rights, and diets: Untangling the issues. *Frontiers in Forests and Global Change, 3*, 29.

Sunderland, T., Powell, B., Ickowitz, A., Foli, S., Pinedo-Vasquez, M., Nasi, R., & Padoch, C. (2013). *Food security and nutrition*. Center for International Forestry Research (CIFOR).

Sunderland, T., & O'Connor, A. (2020). Forests and food security: A review. CABI Reviews, PAVSNNR202015019. https://doi.org/10.1079/PAVSNNR202015019

Sunderlin, W. D., Dewi, S., & Puntodewo, A. (2007). Poverty and forests: Multi-country analysis of spatial association. Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/002294.

Torres-Vitolas, C. A., Harvey, C. A., Cruz-Garcia, G. S., Vanegas-Cubillos, M., & Schreckenberg, K. (2019). The socio-ecological dynamics of food insecurity among subsistence-oriented indigenous communities in Amazonia: A qualitative examination of coping strategies among riverine communities along the Caquetá River, Colombia. *Human Ecology, 47*(3), 355–368.

Vijay, V., Reid, C. D., Finer, M., Jenkins, C. N., & Pimm, S. L. (2018). Deforestation risks posed by oil palm expansion in the Peruvian Amazon. *Environmental Research Letters, 13*(11), 114010. https://doi.org/10.1088/1748-9326/aae540

Van Vliet, N., Moreno Calderón, J. L., Gomez, J., Zhou, W., Fa, J. E., Golden, C., ... & Nasi, R. (2017). Bushmeat and human health: Assessing the evidence in tropical and sub-tropical forests.

Wu, Q., Li, D., & Wei, Y. (2017). Transportation and spatial distribution of poverty in China: A case study of rural poverty in Shaanxi province. *Journal of Transport Geography, 62*, 87–98. https://doi.org/10.1016/j.jtrangeo.2017.06.010

Wunder, S., Noack, F., & Angelsen, A. (2018). Climate, crops, and forests: A pan-tropical analysis of household income generation. *Environment and Development Economics, 23*(3), 279–297.

Zenteno, M., Zuidema, P. A., de Jong, W., & Boot, R. G. (2013). Livelihood strategies and forest dependence: New insights from Bolivian forest communities. *Forest Policy and Economics, 26*, 12–21.

Zhang, R., Chen, J., Park, H., Zhou, X., Yang, X., Fan, P., Shao, C., & Ouyang, Z. (2019). Spatial accessibility of urban forests in the Pearl River Delta (PRD), China. *Remote Sensing, 11*(6), 667.



**Alexander Buritica** is an economist with and Ph.D. in Economics with over eight years of experience in economic research, public policy, agriculture, technology adoption, and market access. He specializes in impact evaluation, economic modeling, and policy analysis, with a strong track record in publishing, project management, and international collaborations.Currently, he is a Postdoctoral Fellow at the Alliance of Bioversity International and CIAT, leading research in economic policy, sustainable agriculture, and impact evaluation for the (Colombia Agroalimentaria Sostenible) CAS program. His work focuses on developing economic analyses and methodological frameworks for monitoring and evaluation. Previously, he served as a Senior Research Associate at the same institution, contributing to national-level policy evaluations on food systems and economic coherence. His past roles also include being a Development Economics Specialist at Verité, where he led research on labor conditions and coffee market structures, and a Visiting Researcher at CIAT, managing baseline studies and economic evaluations of silvopastoral systems.

**Martha Vanegas** is MSc in Forest and Nature Conservation at Wageningen University (2012) and BSc in Ecology at Universidad de la Javeriana (2006). Martha is a Senior Research Associate at the Alliance Bioversity-CIAT. She is currently coordinating a project on promoting sustainable cacao and livestock value chains. Her field of expertise is among ethnographic research methods, notably participatory action research with marginalized communities. She is bilingual in Spanish and English and fluent in French.

**Andres Espada** is a political scientist with experience in rural development, territorial planning, and public policy. He has worked with various governmental and research institutions in Colombia to support evidence-based decision-making in the agricultural sector.

**Mary Ngaiwi** is an agricultural economist and gender expert at AGNES (African Group on Gender and Climate Change). She has contributed to multiple international programs focused on climate-smart agriculture, women's empowerment, and gender integration in policy and practice.

**Deborah Pierce** is an agricultural development specialist with a strong background in science-policy engagement. At the Alliance of Bioversity International and CIAT, she works on strategic initiatives to connect agricultural research with policy processes for sustainable food systems.

**Marcela Quintero** is an ecologist and internationally recognized expert in sustainable land management, ecosystem services, and landscape governance. She currently serves as Director of the Multifunctional Landscapes Research Area at the Alliance of Bioversity International and CIAT, where she leads interdisciplinary teams working on nature-positive solutions for agriculture, biodiversity conservation, and climate resilience.With over 20 years of experience, she has developed and managed global research-for-development initiatives focused on integrating ecological, social, and economic dimensions into land use planning and agricultural development. Her work emphasizes participatory processes and co-design approaches with local communities, policymakers, and international organizations to promote equitable and sustainable landscape transformations.Marcela holds a Ph.D. in Ecology from the University of Montpellier (France) and has published widely in peer-reviewed journals, technical reports, and global policy platforms. She is also an active contributor to global assessments and dialogues on food systems, water security, and ecosystem restoration.