Smallholder agriculture results in stable forest cover in riverine Amazonia

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Abstract
Recent studies point to a rapid increase in small-scale deforestation in Amazonia. Where people live along the rivers of the basin, customary shifting cultivation creates a zone of secondary forest, orchards and crop fields around communities in what was once old-growth terra firme forest. Visible from satellite imagery as a narrow but extensive band of forest disturbance along rivers, this zone is often considered as having been deforested. In this paper we assess forest disturbance and the dynamics of secondary forests around 275 communities along a 725 km transect on the Napo and Amazon Rivers in the Peruvian Amazon. We used high-resolution satellite imagery to define the ‘working area’ around each community, based on the spatial distribution of forest/field patches and the visible boundary between old-growth and secondary forests. Land cover change was assessed between ca. 1989 and 2015 using CLASlite™ image classification. Statistical analyses using community and household-level data from the Peruvian Amazon Rural Livelihoods and Poverty project identified the predictors of the extent of forest disturbance and the dynamics of secondary forests around communities. Although shifting cultivation is the primary driver of old-growth forest loss, we find that secondary forest cover, which replaces old-growth forests, is stable through time, and that both the area and rate of expansion into old-growth forests are modest when compared to forest conversion in Peru for colonization and plantation development. Our findings challenge the notion that smallholder agriculture along rivers is an important threat to terra firme forests in Amazonia and point to the importance of protecting forests on community lands from loggers, colonists and other outsiders.

1. Introduction
The recent rise of small-scale deforestation in Amazonia, in Brazil and beyond, has raised concerns over the role of smallholder farmers in forest conversion [1]. Where roads are absent, people live along the rivers and practice customary shifting cultivation, creating a zone of secondary forest, orchards and crop fields around their communities in what was once old-growth terra firme forest. Visible from satellite imagery as a narrow but extensive band of disturbed forest along rivers of the Amazon basin, this zone is often considered to be deforested. Such secondary forests, however, are important to the livelihoods of local people and may represent a cost-effective opportunity for carbon sequestration in the humid tropics, one that national governments could embrace—rather than exclude—in climate mitigation policies [2–4].

Peru is an emerging ‘hotspot’ for deforestation with an estimated 2.4% of the 78.6 million ha of forest in the humid tropical biome being converted between 2000 and 2011; and 92% of the forest lost is due to clearing [1, 5]. The size of forest clearings is generally small, typically less than 1 ha, and blame for roughly 80% of such deforestation is laid by the government
on smallholder farmers who practice shifting cultivation [6]. Contesting the government’s presumptive claim, Ravikumar et al [6] argue that multiple actors with distinct motivations are likely responsible for deforestation but regional empirical studies are needed to clarify the role of smallholders. Although previous works have characterized land cover dynamics around selected riverine communities in Amazonia (e.g. [7–9]), none as yet empirically assess the drivers of forest disturbance and forest dynamics on a large scale beyond simulations of the role of river access in forest conversion [10, 11].

We report on a study conducted among 275 communities along two major rivers in northeastern Peru that combines remote sensing analysis with socio-economic field data to understand forest cover dynamics (following [6, 12, 13]). We first assess the factors that influence the depth, river frontal age and total area worked under shifting cultivation and of forest disturbance around riverine communities. Second, we identify the drivers of secondary forest fallow dynamics on the upland by drawing on household-level data that are aggregated to the community-level. And finally, we analyze forest cover change around communities between 1989 and 2015 to assess forest cover stability within the area where shifting cultivation is practiced. Our findings indicate low rates of felling of old-growth forest and stability of secondary forest cover around riverine communities, suggesting that smallholder agriculture is not a primary threat to terra firme forests in Amazonia.

2. Study area

The study was undertaken in northeastern Peru along a 725 km river transect that begins near the city of Iquitos, on the Amazon River, extending downstream past the mouth of the Napo River, and then continuing upstream along the Napo to the last community in Peruvian territory (figure 1). The transect captures essentially all indigenous and traditional folk (ribereño) communities along both rivers (n = 275), of which 58% are situated in the Napo basin and 38% are indigenous settlements. Communities are generally small, with an average of 45 households (or 290 individuals), but range between four and 925 households. Although most communities were established in their current location some 40–50 years ago, the age of communities varies markedly, from being founded in 1522–2012. Between 1900 and 2012, an average of about two to three new settlements were established along the study transect each year, increasingly in the floodplain (figure S1 (available online at stacks.iop.org/ERL/17/014024/mmedia)). Most communities have access to land on both the upland (terra firme) and the floodplain. Satellite imagery reveals forest disturbance around settlements as a band of secondary forests and crop fields on the terra firme along the river (figure 2). Secondary forests are forests re-growing after initial clearing and cropping for shifting cultivation, representing the fallow phase in the swidden-fallow cycle.

Residents earn their living from agriculture, fishing, hunting, and forest extraction, and sell produce to pay for household needs, school supplies and the purchase of tools. Most households are income and asset poor, with the median income of households is 6600SUS yr⁻¹. The primary market is the city of Iquitos and to a much lesser degree, the district capitals of Indiana, Francisco de Orellana, Mazán, Santa Clotilde and Pantoja, which are reached by riverboat. The average distance to Iquitos from the study communities is 124 km (range: 17–597 km), and 63 km (range: 0–373 km) to district capitals.

Two forms of agriculture are practiced along the Napo-Amazon Rivers. On the fertile floodplain, farmers seasonally cultivate the levees as well as the silt bars and sandbars [14]. Households plant annual cash crops such as maize, rice, beans, and cowpea in the active channel during the flood recession period, and on higher levee tops, short cycle rotational crops such as plantains and perennial tree crops. On the upland, where soils are heavily weathered and less fertile, farmers practice shifting cultivation whereby a small plot of 0.5–1.0 ha is opened in the forest typically using machetes and axes; the vegetation is left to dry and then burned. Crops of varying maturation times are then planted including manioc, yams, pineapple, plantain, and perennial fruit trees [15]. When the field is no longer productive, the plot is left in fallow and secondary forest quickly regrows. After 8–12 years of fallow, the plot is cut and burned, and the cycle repeated [15]. Farmers manage multiple fields and falls scattered in the hinterland of the community. Land is held in usufruct and acquired by clearing of old-growth forest, and to a lesser degree through inheritance or gifting. There is no market for land but rights over falls are usually retained by those who cleared the land. Clearing is typically done by household members with the help of kinfolk [16, 17].

3. Methods

This study draws on data collected as part of the Peruvian Amazon Rural Livelihoods and Poverty (PARLAP) project that conducted a large-scale community and a household survey in the Departments of Loreto and Ucayali (https://parlap.geog.mcgill.ca/; SI Methods). Along the Napo-Amazon transect, the initial community survey reached 275 settlements (2012–2014) and the household survey was conducted in a randomly selected sub-sample of 86 communities (2014–2015) covering a total of 1542 randomly sampled households (mean: 17.9 households/community). Together, the two surveys provide data on
community and household characteristics, including on secondary forest fallow holdings by households within each community. Household data were aggregated to the community level and include the total area in forest fallow, the number of fallows, and mean age of fallows, mean age of fallows weighted by field size, and the age of the oldest fallow.

As a complement to the survey data, we undertook a remote sensing analysis of land cover and of land cover change along the Napo-Amazon transect (SI Methods). To assess current land cover around the study communities, we first defined community boundaries by partitioning land in the study area using the World imagery base map in ArcGIS v.10.7.1 into voronoi polygons for the 275 communities, defining community boundaries as being up to 5 km from the community center (figure 3; SI Methods). Within each community voronoi polygon, we

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**Figure 1.** Napo-Amazon basin transect indicating location of surveyed communities.
then manually delineated, based on visual analysis of World imagery basemap, the boundary between old-growth and non-old growth forest. All patches of agricultural fields and secondary forests around the community—falling within the non-old growth forest area—were digitized to assess patch parameters. In figure 3, the white lines indicate voronoi polygons and churn lines connecting patches with the community centroid within each voronoi polygon. All land being used by residents, as reflected by land cover (i.e. fields, fallows, grassy soccer pitch, paths, houses and bare soil), was defined as being worked and reflects the community ‘footprint’. The working area includes the area immediately surrounding the community (direct working area) as well as pockets of land beyond, on both the upland and floodplain (indirect working area) (figure 3, inset map). The total working area refers to the sum of the direct and indirect working areas. Forests within the working areas are secondary forests. Old-growth forests that may be used for hunting, timber and non-timber forest product extraction are not considered to be part of the community working area for our purposes.

To assess land cover change over time around communities, we used Landsat satellite imagery for the periods of ca. 1989 and 2015 (table S1). Land cover was classified using CLASlite™ v3.2 [18] into three categories: forest, non-forest and masked (cloud and water) classes. The overall accuracy of the classification was high at 89.5% and 94% for 1989 and 2015, respectively (table S2). As our purpose was to focus on terra firme forests, we masked areas of floodplain (Holocene) soils and near rivers, and calculated metrics for upland working areas of forest cover, forest cover change and forest patches. We also created variables for river front distance and depth inland. River front distance (or frontage) is the distance along the river’s edge within the direct working area (i.e. the contiguous area immediately around the community). Inland depth refers to the distance from the river’s edge to the further point inland of the direct working area. Correlations among inland depth, frontage, patches and working area were assessed using Pearson product-moment correlation.

Ordinary Least Squares (OLS) regression analyses identify the predictors of three sets of outcomes at the community level: characteristics of total working area (which includes lowland); forest cover change in upland working area; and upland secondary fallow. Our independent variables were drawn from the literature, theory and field experience (SI Methods). For the estimation of our dependent variables, we use community characteristics including community size (households), age (decades), ethnicity (indigenous and folk), distance to city (Iquitos), area of territory (proxied by voronoi polygon area) and share of a 5 km land buffer in floodplain (Holocene) soils. See table 1 for the descriptive statistics of the dependent and independent variables.
4. Results

4.1. Working area, patches and upland forest cover
The total working area per community on average is 234 ha or 8% of the community’s territory (table 2). About three quarters of the total working area lies immediately around communities (direct working area) with the remainder in non-contiguous areas (indirect working area). For a typical community, the working area of a community extends for about 3 km of river frontage and some 1.3 km inland, and both measures are correlated with one another, albeit weakly ($r = 0.12, p = 0.05$) (figure 4(a)). On the Napo River, the total river length being worked along 38% (226 km, left bank) and 46% (274 km, right bank) of river’s edge of Napo in Peru (598 km). Along the left bank of the Amazon, 93% of the 127 km reach in our study area is being worked. The total working area, summed for all 275 communities, is 64 309 ha ($643 \text{ km}^2$) or 5.23 ha/hhld.

A total of 20 301 patches—i.e., crop fields and secondary forest fallows—were identified in the working areas on the upland and floodplain surrounding communities. On average, a community had 74 patches at 1.3 km from center of the community (along the churn lines) (table 2). Seventy percent of the patches are found in the upland working area and the mean distance to patches on the upland ranges from 247 m to 4.5 km. Most patches (80%) lie within 2 km of the community. The number of patches is more strongly correlated with the size of the working area ($r = 0.83, p < 0.0001$) than is the distance to patches ($r = 0.32, p < 0.0001$) (figures 4(b) and (c)).

Of the 275 communities, 200 had working area on the upland, encompassing a total area of 39 695 ha (199 ha/community). This area represents the maximum possible extent of total of old-growth forest loss on the terra firme. The area worked on the upland is related to the age of community, expanding...
Table 1. Descriptive statistics for community and household samples.

| Variable Description | Mean | Std. dev. | Min. | Max. | Obs |
|-----------------------|------|-----------|------|------|-----|
| Dependent variables    |      |           |      |      |     |
| Communities with upland Total working area | 279.5 | 20.7 | 10.0 | 1050.7 | 200 |
| Depth of working area | 966.8 | 428.7 | 195 | 1050.7 | 200 |
| Fronting of working area | 1498.2 | 1458.3 | 195 | 1050.7 | 200 |
| Number of patches | 3295.7 | 683.4 | 60.1 | 3560.0 | 195 |
| Communities with >20ha of upland Total upland working area | 254.7 | 20.0 | 15.9 | 1031.5 | 155 |
| Upland working area in forest | 65.9 | 15.3 | 0.3 | 103.8 | 155 |
| Communities where household survey conducted Total upland working area in forest | 30.1 | 25.2 | 0.3 | 103.8 | 155 |
| Number of upland fallows | 335.1 | 262.0 | 10.0 | 950.0 | 155 |
| Number of upland fallows (years) | 89.9 | 4.9 | 4.0 | 26.5 | 155 |
| Mean size of upland fallows (ha) | 1.0 | 0.8 | 0.1 | 4.5 | 155 |
| Mean age of upland fallows (years) | 8.9 | 3.9 | 9.0 | 26.5 | 155 |
| Mean age of upland fallows (weighted) | 8.5 | 3.9 | 9.0 | 26.5 | 155 |
| Age of oldest fallow | 24.1 | 12.1 | 4.0 | 80.0 | 155 |
| Independent variables |      |           |      |      |     |
| Community size | 48.6 | 8.1 | 4.0 | 927.0 | 200 |
| Community age | 162.5 | 138.6 | 3.4 | 397.3 | 200 |
| Ethnicity of community | 0.45 | 0.50 | 0.0 | 1.0 | 200 |
| Distance to city | 3272.7 | 2086.5 | 64.4 | 7851.9 | 200 |
| Area of community territory | 44.1 | 4.4 | 18.6 | 100.0 | 200 |
| Floodplain soils | 0.71 | 0.46 | 0.0 | 1.0 | 200 |
from establishment for the first two decades into old-growth forest, and then leveling off at between 200 and 250 ha (figure 5). In 2015, about two-thirds of the upland working area was forested (secondary forest fallows) and 28% was classified as non-forest (bare soil, crops) (with 5% missing data due to cloud cover) (table 2). Although our methodology does not permit us to develop a transition matrix to show the rate over time at which old-growth forest was converted to secondary forests or to crop land (because land cover is classified only as forest/non-forest), our results indicate that two-thirds of the total area of original old-growth forest around communities was in secondary forests in 2015.

Between 1989 and 2015, the share of forest in the upland working area was stable, ranging between 54% and 64% of the area, and importantly, the percentage of forest cover in 2015 was on average greater than in 1989 ($t = -2.33, p < 0.05, df: 196$) (figure 6). Over the same 27 year period, forest loss was effectively offset by forest recovery for a 4% net gain of forest area (table 2). Communities with larger upland working areas and more patches had greater net gains in forest share ($r = 0.20, p < 0.001; r = 0.17, p < 0.05$, respectively). These results suggest that despite the conversion of old-growth forest, forest cover around communities has been maintained through dynamic renewal associated with shifting cultivation whereby plots are cycled through phases of crops and secondary forest.

### 4.2. Regression analyses of working area

The results of our OLS regression analyses of key features of the working area around study communities are presented in table 3. For the total working area (which includes floodplain), we assess potential community-level predictors of area, inland depth, river frontage and number of patches. For the upland working area, we assess predictors of the size of the area in hectares and the proportion of the working area in forest cover (secondary forest) in 2015.

Given our interest in the fate of upland old-growth forest, we limited the sample to communities with at least some upland working area ($n = 200$ communities) to predict the total working area. Our models explain between 27% and 39% of the observed variance across the dependent variables (table 3, four left columns). Community size and the share of land in floodplain (Holocene) soils are consistent and strong predictors of the working area. Larger communities tend to have larger working areas, including longer river frontage, greater inland depth, and more patches. The larger estimated coefficient for river frontage relative to depth suggests that as communities grow, they expand first along the river before pushing deeper inland. Communities closer to the city tend to have a larger working area, with less river frontage and greater depth. Those communities with a larger share of floodplain soils have smaller upland working areas, with less inland depth, and fewer patches. A community with no floodplain soils is predicted at the mean to have 435 ha in upland

### Table 2. Characteristics of working areas around communities along the Napo-Amazon transect (2015).

| Characteristics                       | Mean   | Std. dev. | Range   | Sum   | Obs. |
|--------------------------------------|--------|-----------|---------|-------|------|
| **Total working area (ha)**          | 234    | 199.4     | 10–1051 | 64309 | 275  |
| Upland                              | 199    | 203.7     | 0.03–1032 | 39695 | 200  |
| **Inland depth (m)**                 | 1278   | 879.6     | 60–4288 | —     | 269  |
| Napo River                          | 1365   | 814.6     | 60–4268 | —     | 157  |
| Amazon River                        | 1161   | 954.3     | 123–4288 | —     | 112  |
| **River frontage (m)**               | 3088   | 1649.0    | 145–10352 | —     | 269  |
| Napo River                          | 3482   | 1840.0    | 146–10352 | —     | 157  |
| Amazon River                        | 2535   | 1131.1    | 335–6237 | —     | 112  |
| **Patches**                          |        |           |         |       |      |
| Total working area                   |        |           |         |       |      |
| Number                               | 74     | 62.7      | 2–386   | 20301 | 275  |
| Distance (m)                         | 1274   | 516.9     | 193–2922| —     | 275  |
| Upland working area                  |        |           |         |       |      |
| Number                               | 52     | 56.9      | 0–259   | 10492 | 200  |
| Distance (m)                         | 1479   | 657.9     | 247–4542| —     | 182  |
| **Upland land cover (2015)**         |        |           |         |       |      |
| Forest (%)                           | 64     | 20.5      | 0–100   | —     | 196  |
| Non-forest (%)                       | 28     | 16.3      | 0–100   | —     | 196  |
| Missing (%)                          | 5      | 6.4       | 0–39    | —     | 196  |
| **Upland forest cover change 1985–2015** |     |           |         |       |      |
| Loss (%)                             | 15     | 12.3      | 0–86    | —     | 196  |
| Recovery (%)                         | 19     | 15.0      | 0–67    | —     | 196  |
| Net (%)                              | 4      | 23.6      | 85.7–65.7| —     | 196  |
| **Voronoi area (ha)**                | 3013   | 1954.5    | 397–7852| 828428| 275  |
working area, compared to 259 ha for a community with 50% in young soils, and 118 ha for a community with 90%. In addition to community size and share of floodplain soils, the river frontage of working areas is related to the current endowment of community land such that communities with more land tend to have longer river frontage and (although not statistically significant) less inland depth.

In the second set of regression models, we focus on communities with at least 20 ha of upland working area ($n = 155$) to assess the drivers of upland forest cover. This breakpoint is 10% of the mean

Figure 4. Correlation between (A) river frontage and working area depth; (B) working area and number of patches; and, (C) working area and distance to patches. Number of observations for (A) is 269 communities; 275 communities for (B) and (C).
Figure 5. Upland working area (ha) by community age, Napo-Amazon transect. Note: N = 190 communities, representing 95% of sample communities with upland. Communities established more than 80 years prior excluded.

Figure 6. Distribution of upland working area around communities in forest, 1989 and 2015.

The upland working area and was selected based on field experience as being a sufficient minimum area (equivalent of the area of 20 fields and fallows). Our models explain 34% and 17% of the observed variance across the dependent variables (table 3, two right columns). The upland working area tends to be more extensive among larger communities, communities with less land in the floodplain, and among indigenous communities as well as those closer to the city. The percentage of forest cover in upland working areas, which comprises secondary forest fallows, is higher in communities closer to Iquitos, given community size and territory.

4.3. Regression analyses of forest fallow dynamics

To understand the dynamics of secondary forest falls within the upland working area, we conducted OLS regression analyses drawing on household data available from 57 communities (1052 households) with upland. Because our household-level data do not match the working area in the community territory (voronoi), we used community-level aggregate measures as a proxy. The average area in fallow, number of falls and fallow field size were 30 ha, 33 falls and 1 ha in area, respectively (table 4). The age of falls when averaged over households by community was 8.9 years (range: 4–26.5 years), and the
Table 3. Regression models of working areas around communities, Napo-Amazon transect.

| Variables                                | Total working area | Upland working area |
|------------------------------------------|--------------------|---------------------|
|                                          | Area (ha)          | Inland depth (m)    | River frontage (m) | Number of patches | Area (ha) | Forest cover (%) |
| Community size (log number of households) | 134.8***           | 410.3***            | 634.8***           | 45.31***          | 114.5***  | −3.781***         |
| Community age (number of decades)        | 2.435              | 9.72                | −6.91              | −0.876            | 2.216     | 0.135             |
| Ethnicity of community (1: indigenous; 0: folk) | 23.03              | 47.7                | 241.7              | −0.289            | 59.98*    | 3.206             |
| Distance to Iquitos (log km)             | −41.90*            | −169.2              | 169.1              | −7.212            | −74.44*** | −10.10***         |
| Area of community territory (log ha)     | 10.28              | −153.1              | 802.7***           | −10.86            | 8.209     | 3.662             |
| Floodplain soils (% of 5 km land buffer) | −3.529***          | −15.19***           | −3.35              | −0.831***         | −3.416*** | −0.0793           |
| Napo River                               | −38.85             | −87.6               | 139.6              | −5.032            | −40.32    | 4.642*            |
| Constant                                 | 93.42              | 2753***             | −6063***           | 89.83*            | 266.9*    | 96.47***          |

Observations 200 195 195 200 155 155
R-squared 0.39 0.29 0.27 0.39 0.34 0.17
Mean 279.5 1498 3296 82.23 254.7 65.87

Each column reports OLS estimates. ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors.

Table 4. Characteristic of secondary forest fallows among communities in household sample, Napo-Amazon transect.

| Mean         | Std. dev. | Min. | Max. | Obs. |
|--------------|-----------|------|------|------|
| Fallow area (ha) | 30.0      | 25.1 | 0.25 | 103.81 | 57  |
| Number of fallows | 33.0      | 26.1 | 1    | 95    | 57  |
| Fallow size (ha) | 1.0       | 0.8  | 0.135| 4.5   | 57  |
| Fallow age (years) | 8.9       | 3.9  | 4    | 26.5  | 56  |
| Fallow age (weighted)* | 8.5       | 9.0  | 0.88 | 64.4  | 56  |
| Age of oldest fallow (years) | 24.1      | 12.1 | 4    | 80    | 56  |

*Fallow age weighted by field size (ha).

The results of our regression analyses of secondary forest fallowing in the upland working area are presented in table 5. Given uneven sampling of households across communities for forest fallow data, we weighted observations in the regression analyses using the inverse of the household sampling rate in the community as weights. Our regression models explain 16%–43% of the observed variance in our dependent variables, and results point to the importance of community size, age, ethnicity, distance to the city and access to floodplain soils in explaining forest fallow area, fallow field size and fallow age. Households in larger communities tend to have more upland in forest fallow, more fallow fields, and younger fallows whereas older communities have fewer, larger and older fallow fields. In communities with more floodplain soils, which are apt for floodplain agriculture, households are more likely to have less upland in forest fallow and fewer fallow fields. In communities closer to the city, households are more likely to have more upland in forest fallow. Households in indigenous communities tend to have more upland fallows, and fallows are smaller in size and younger, although the total area in fallow is not statistically different from that in folk communities. As such, indigenous households appear to make more intensive use of fields in their swidden-fallow systems. These results for forest fallow area and fallow field size are largely consistent with those for upland working area discussed above.

5. Discussion and conclusion

Our study of forest disturbance and secondary forest fallow dynamics found that the principal forest cover change along the Napo-Amazon basin transect in Peru is the conversion of old-growth into secondary forests through customary shifting cultivation. The working area around communities—which reflects old-growth forest conversion to secondary forests as...
well as crop fields, paths and other cleared land—along our 725 km transect covers approximately 400 km², in a narrow band 1–5 km deep along the almost entire reach of the Amazon River within our study area and about 40% of the Napo River in Peru. More extensive areas of old-growth forest conversion are found around larger communities which self-identify as indigenous communities, as well as in those with more upland and located closer to the city. The working area of communities extends further along the river’s edge than inland by a ratio of about 2.2:1, and communities—where the river is the highway—appear to develop first along the river, and then push further inland as river frontage becomes scarcer. The depth of inland incursion is driven not only by community size but access to floodplain soils: smaller communities with more floodplain soils tend to not intrude as deeply into old-growth forests.

Forest cover within the working area around communities is persistent over time despite being young in age. Households in larger communities have a larger area in fallow, more fallow fields, and younger fallows. Access to floodplain soils tends reduce the area and number of fields in forest fallow on the upland. Secondary forest fallows around indigenous communities are more numerous but smaller in size, suggesting that forest landscape there may be more granulated than around folk communities. The cycling of fields through phases of crop and fallow, across many households—each having multiple fields each at a different stage in the crop-fallow cycle—essentially gives rise to permanence of secondary forest cover in the working area around communities. As such, although the life of any one secondary forest fallow is ephemeral, at any given moment the stock of forest fallows at the community level remains relatively constant. Indeed, we found that the percentage of forest cover within the working area actually increased by a small amount rather than decreased between 1989 and 2015. These small patch-sized, young plots of secondary forest accumulate biomass quickly and so have potential for carbon sequestration [19] and merit being considered in carbon accounting for climate change mitigation (see [3, 20, 21]).

The area of old-growth forest loss since community inception (represented by the extent of the working area, which replaced old-growth forest) is modest both in terms of the number of communities supported and the low rate over time at which old-growth forest has been converted to fields and forest fallows. The community footprint is small—on the order of 200 ha per community or 6 ha per household—and is similar to that of riverine communities in the Brazilian Amazon. Jacovak et al [9] determined the total area of active shifting cultivation among 31 riverine communities along the middle-Amazonas River near Tefé to be 8259 ha, or 266 ha/community. The footprint among indigenous peoples of the Ecuadorian Amazon, some of which live along rivers, is similarly small and also stable over time [22]. Moreover, the area of old-growth forest conversion is slowly cumulative, reflecting decades (50–60 years, on average) and in some cases, such as the community of Orán (founded in 1522), even

Table 5. Regression models of secondary forest fallow dynamics around communities, Napo-Amazon transect.

| Variables                                 | Area in fallow (ha) | No. of falls | Mean fallow size (ha) | Mean fallow age (years) | Mean fallow age (wgted years) | Age of oldest fallow (years) |
|-------------------------------------------|--------------------|-------------|-----------------------|-------------------------|-------------------------------|-----------------------------|
| Community size (log number of households) | 10.92**            | 15.48**     | 0.135                 | −1.489**                | 1.206                         | −1.128                      |
| Community age (number of decades)         | −0.394             | −0.888**    | 0.0223***             | 0.101***                | 0.0456                        | 0.324***                    |
| Ethnicity of community (1: indigenous; 0: folk) | 2.733             | 18.08*      | −0.414*               | −2.345**                | −4.221**                      | 1.624                       |
| Distance to Iquitos (log km)              | −11.51**           | −5.002      | −0.186                | 1.393                   | 1.904                         | 3.269                       |
| Area of community territory (log ha)      | −1.131             | −2.146      | −0.132                | 0.153                   | −4.045                        | −0.974                      |
| Floodplain soils (% of 5 km land buffer)  | −0.814***          | −0.742***   | 0.002                 | −0.002                  | 0.0006                        | −0.0695                     |
| Napo River                                | −6.234             | −2.441      | 0.423                 | 2.380**                 | 3.774                         | 6.246**                     |
| Constant                                  | 99.14**            | 51.95       | 2.158                 | 4.991                   | 25.7                          | 15.29                       |

Observations: 57, R-squared: 0.43, Mean of dependent variable: 29.97. Each column reports OLS estimates. **p < 0.01, *p < 0.05, *p < 0.1. Robust standard errors.
centuries of human settlement and land use. Without an appreciation of the time depth over which this band of forest disturbance developed, one can understand how policy makers might assume that this landscape of disturbed forest reflects a disconcerting loss of old-growth forests and label it as ‘deforestation’. Still, communities, new and old, do gradually clear old-growth forest as they are established and grow in size.

The rate of clearing of old-growth forest around communities is low both in absolute terms and relative to forest conversion for commercial plantations and colonization. We found that an average-sized riverine community of 43 households (290 people) converted some 10 ha of old-growth forest each year in the first two decades of existence but then converted little additional old-growth forest thereafter. Moreover, this cleared land will be quickly cycled back into secondary forest once the cropping phase, which typically lasts only two to five years, is completed. Even lower rates are evident from Jacovak et al’s study from central Amazon where, of the 652 ha cleared per year among 31 established communities, only 15% was cleared in old growth forest, the equivalent of 3.2 ha/community.

The reason that clearing rates of old-growth forest are so low is because farmers practicing customary shifting cultivation strongly prefer to clear secondary forest falls, not only in Peru [23] and Brazil [9] but elsewhere in the tropical world [24, 25]. Although fields from old-growth forest may have higher soil fertility, they require more labor to clear and are less accessible, and increasingly so as communities grow in size and expand their working area [9, 26]. Indeed, riverine farmers in Brazil generally prefer not to travel more than 2 km to work their fields, given that much of the production is bulky and heavy to transport [9]. In our study the mean distance to patches was 1.5 km and 80% of upland patches were found within 2 km of the community center.

The scale and rates of old-growth forest encroachment associated with riverine settlements are dwarfed by recent plantation developments and colonist settlements in eastern Peru (see [27, 28]). A single oil palm plantation in the nearby Maniti River basin resulted in the loss of more than 11 000 ha of forest, mostly old-growth, between 2007 and 2011 [5]. Similarly, the United Cacao plantation near Iquitos cleared 800 ha yr⁻¹ between 2013 and 2015 [29], and three Mennonite colonies near Tierra Blanca on the lower Ucayali River have each felled approximately 400 ha yr⁻¹ since 2017 for intensive cultivation [30]. A new road linking Chazuta on the Huallaga River to Dos de Mayo along the Ucayali River is already opening more forest in the region to rapid colonization (M Pinedo-Vasquez pers comm.). In contrast to colonization, which brings rapid and extensive forest conversion, our findings show that smallholder agriculture contributes to the persistence of forest cover along Amazonian rivers. Although young in age, secondary forest fallows created by smallholders provide useful timber and non-timber forest products and important ecosystem services [21, 31–33]. As such, smallholder agriculture as practiced along the rivers is neither an imminent or primary threat to the biodiverse and carbon-rich terra firme forests of Amazonia. Our findings point to the importance of efforts to monitor and protect forests on indigenous and folk community lands from colonists, loggers and other outsiders [34].

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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