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More people, more trees: A reversal of deforestation trends in Southern Ethiopia

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Abstract

Despite global commitments to forest restoration, evidence of the pathways through which restoration creates social and ecological benefits remains limited. The objective of this paper is to provide empirical evidence to generate insights on the relationship between forest cover change and key provisioning ecosystem services and reforestation pathways. In Southern Ethiopia, three zones along a gradient of decreasing land cover complexity and tree cover were examined. The land cover change was assessed using satellite remote sensing and complemented ground-based tree inventory. Perceptions of land cover and ecosystem services change and farmer responses were evaluated through three Participatory Rural Appraisals and eight Focus Group Discussions. Since the 1970s, a landscape shift from a forest-grassland to a cropland mosaic was associated with increased food production, improved food security, and higher incomes. However, this shift also coincided with reductions in livestock, construction materials, fuelwood and water availability, prompting reforestation efforts designed to recover some of these lost ecosystem services. In particular, some households established *Eucalyptus* woodlots and encouraged natural regeneration. Natural trees, *Eucalyptus* woodlots, *Ensete* plantations (a type of plantain), and grasslands were positively associated with homestead proximity; thus, homestead establishment resulting from population increase in this predominately agricultural landscape appeared to foster a viable forest restoration pathway—that is, 'more people, more trees'. This is a reforestation pathway not previously described in the literature. A return to a more diverse agricultural landscape mosaic provided more secure and diversified income sources along with better provisioning of construction materials, fuelwood, and higher livestock numbers.

KEYWORDS
agrarian change, forest transition pathways, landscape restoration, reforestation, rural livelihoods

1 | INTRODUCTION

Despite slowing deforestation in some countries, the majority of tropical nations are still experiencing relatively high rates of forest loss (Keenan et al., 2015), a trend which is likely to continue in the foreseeable future (Gibbs et al., 2010; Sloan & Sayer, 2015). Because tropical forests represent some of the most biodiversity-rich areas on the planet (Myers et al., 2000), their loss is a major contributor to the

current biodiversity extinction crisis (Ceballos et al., 2015). Biodiversity loss impacts people's livelihoods in many ways. For example, in landscapes composed of agricultural-forest mosaics, forests and trees provide fuelwood, fodder for livestock, construction materials, and nutrients for crops (e.g., Baudron et al., 2017). Forest products are also an important source of income as well as food, particularly for the poor, and particularly during times of crises (Arnold et al., 2011; Beck & Nesmith, 2001; Wunder et al., 2014). Similarly, because on-farm trees may provide provisioning and other ecosystem services—that is, products and other benefits from the ecosystem to humans—critical for agricultural production, they are often integrated within mixed crop-livestock systems (Reed et al., 2017). Therefore, deforestation along with general loss of trees tends to have negative consequences for rural livelihoods.

Despite claims to the contrary (Boyd & Slaymaker, 2000; Gibbs et al., 2010), reforestation can occur in conjunction with a growing human population and also be associated with increased agricultural productivity (Tiffen et al., 1994). For example, farmer-managed natural regeneration dramatically increased tree density and household income in Niger (Haglund et al., 2011). In a heavily degraded and densely populated region of Northern Ethiopia, rural communities have restored tree cover and improved soil protection over the last 140 years, largely through the support of environmental recovery programs during the 1980s (Nyssen et al., 2009). In the Ethiopian Central Rift Valley region, farmers have also recovered tree cover, ground vegetation and related ecosystem services by implementing livestock exclosures (Baudron et al., 2015). In Southern Ethiopia, farmers actively manage their trees to promote ecosystem services and reduce disservices (Ango et al., 2014).

The forest transition literature describes several, sometimes interacting, reforestation pathways which lead to contrasting environmental and societal outcomes (Lambin & Meyfroidt, 2010; Meyfroidt et al., 2018). Understanding these transitions is key to guide interventions for improved sustainability of land systems while avoiding negative outcomes (Meyfroidt et al., 2018). Indeed, global forest and landscape restoration efforts are often assumed to lead to improved livelihoods and wellbeing, yet evidence on this remains limited. Our understanding of the direct and indirect pathways by which restoration creates social benefits is also limited (Erbaugh & Oldekop, 2018). Examining restoration activities undertaken and led by communities and farmers can provide a useful perspective and potentially, actual evidence of such benefits.

The objectives of this paper are to explore empirical evidence that: (a) generates insights on the relationship between forest cover change and key provisioning ecosystem services; and (b) helps identify forest transition pathways leading to overall forest gain and its socio-ecological outcomes. For this, three agricultural landscapes spanning a gradient of tree cover and land cover complexity in Southern Ethiopia were examined. A suite of integrated methods—from participatory surveys to remote sensing to biodiversity inventories—designed to capture spatial and temporal dynamics of ecosystem services and human wellbeing was used (Sunderland et al., 2017).

## 2 | MATERIALS AND METHODS

2.1 | Study area

The study landscape is located between the Munesa State Forest and the town of Arsi-Negele—between 38°42.14′ and 38°49.92′ East and 7°15.05′ and 7°22.57′ North—in Oromia Region, Ethiopia (Figure 1). Munesa forest is considered a dry Afromontane forest, it is owned and regulated by the Ethiopian State and it can be accessed and used by the neighboring communities with certain limitations. Mixed crop-livestock farming is the main livelihood strategy with the main crops being maize, wheat, potato and Enset (Ensete ventricosum), an endemic perennial from the Musaceae (banana) family used to produce starchy food. Unharvested annual crop residues become a communal resource available for communal grazing after grain harvest.

Three zones, each with two villages, were identified along a gradient of decreasing tree cover and land cover complexity (i.e., increasing agricultural specialization; Figure 1). The zones were otherwise similar in social context (land tenure, farm area, ethnicity, local and religious institutions, transport services, population density) and environmental conditions (soil type, elevation, agroecological zone). The first zone borders the State forest of Munesa, which residents can access for grazing and collection of firewood, but live trees cannot be brought down; this zone has a high tree density and is referred to as 'complex' (in land uses and farming system composition) hereafter. The second zone is located 5.5 km away from Munesa Forest and its residents do not have access to the forest due to distance and local regulations. However, they have access to a large communal grazing area; this zone has a relatively high tree density and is referred to as 'intermediate'. The third zone is located about 11 km away from Munesa Forest and its residents do not have access to it or any other common land; it has a lower tree density and is referred to as 'simple'. The complex, intermediate and simple zones are located about 16, 11.5 and 6.5 km away from the main market of Arsi Negele Town, and their total area is 100.1, 164.9 and 110.5 ha, respectively. More information on the context and household and farm variables can be found in Baudron et al. (2017, 2019), Duriaux Chavarría et al., (2018) and Duriaux and Baudron (2016). Site selection occurred before the remote sensing analysis based on a coarse aerial assessment using Google Earth, consultation with Ethiopian scientists and field expeditions, to select a study set up as described by Sunderland et al. (2017).

2.2 | Land cover assessment

2.2.1 | Remote sensing

To explore historical changes in land cover, satellite imagery (LANDSAT MSS, TM and OLI) captured in January of 1972, 1986, 1999 and 2013 were used to classify dense forest (dense tree cover; native forest), medium dense vegetation (degraded open native forest), woodlots (monocrop forests for timber production), cropland
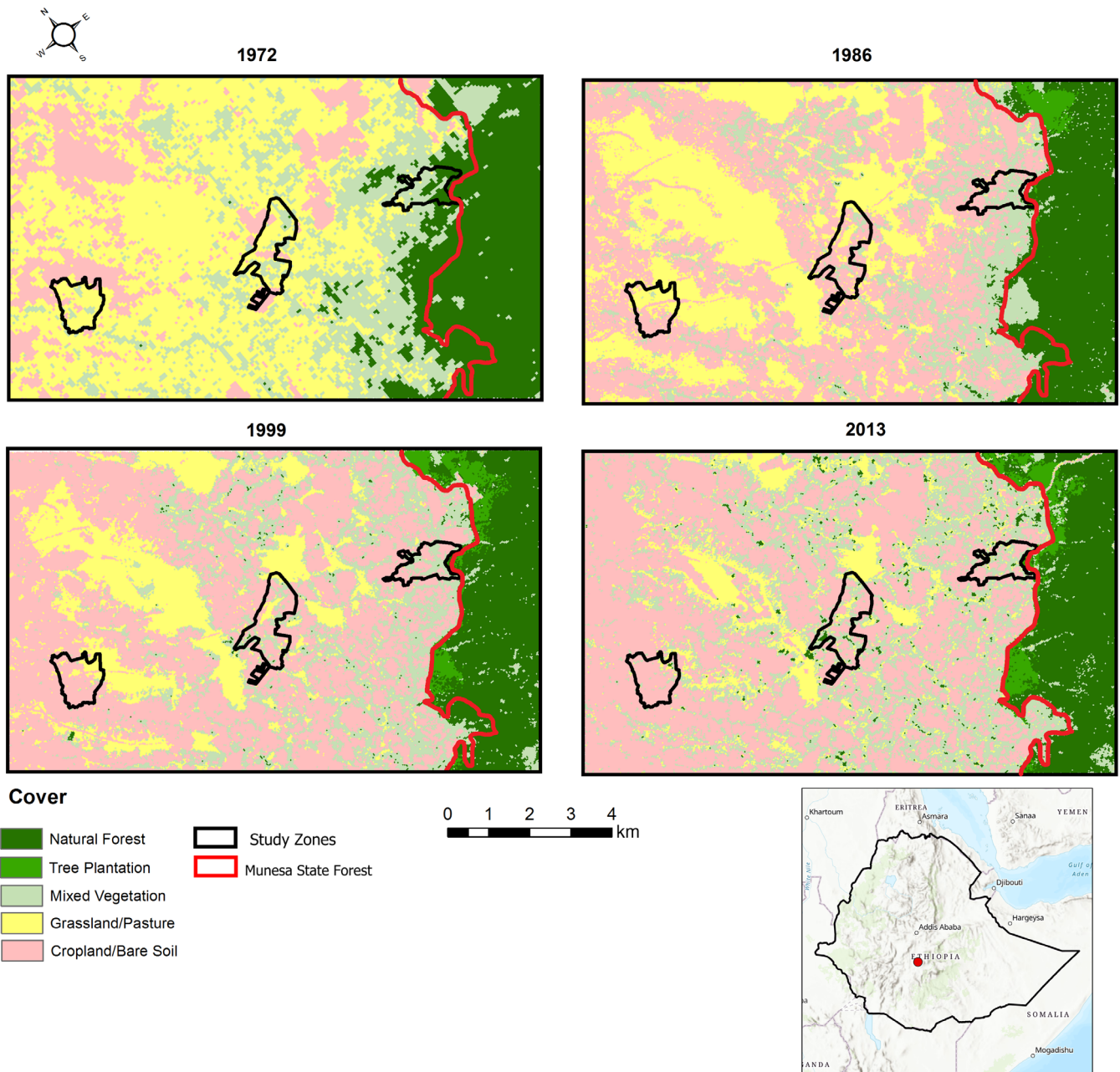
FIGURE 1   Land cover maps for 1972, 1986, 1999 and 2013 using imagery from LANDSAT 1 (1972) and LANDSAT 5 satellites. The borders of the studied zones are marked in black lines, the border of the Munesa State Forest is marked by the red line [Colour figure can be viewed at wileyonlinelibrary.com]

(annual crops), and grassland (pastures). Medium dense vegetation refers to pixels with high tree presence, but less than the dense forest class; for example, degraded native forest or non-forest land uses with high tree cover. To distinguish among these classes, a maximum likeli-hood supervised classification was performed. This included the steps of selecting training sites—representative georeferenced samples of each land use—estimating the spectral signature of each land use based on the training sites, and for each pixel, assigning the class with the highest probability. Training sites were verified using a mix of

Google Earth imagery, RAPIDEYE imagery, historical aerial imagery and ground verification. The minimum mapping unit (MMU) was set to the size of the spatial resolution of the imagery (60 m for 1972 and 30 m for subsequent dates). The specific years were selected based on the best available imagery (cloud free during the right dry season when annual crops are harvested).

To explore differences in landscape composition, the contempo-rary land cover was assessed at high spatial resolution using RAPIDEYE 3A imagery (5 m resolution) from January 2015. The

landscape was classified into cropland and bare soil, *Enset*, grassland, natural forest and tree cover and woodlots using a combination of object-based and maximum likelihood supervised classification as well as manual delineation of *Enset* homegardens and woodlots. Training sites were verified using a mix of high spatial resolution imagery from Google Earth and ground verification.

2.2.2 | Tree inventorying basal area

Between May and September 2015, tree basal area and tree numbers were assessed in the three zones. In each zone, 24 sampling points were randomly selected from a grid (of 150 m sized cells) across the zone (Baudron, Schultner, Duriaux, Gergel, & Sunderland, 2019). Within a 50 m radius of each point, all trees >10 cm of diameter at breast height (DBH; at 135 cm from ground level) were identified to species level and their DBH were recorded. For each circular plot, the relative basal area was determined using the cumulative basal area of all trees divided by the total ground surface within the circular plot, and then represented as m^2/ha. Tree density was calculated by dividing the total tree count by the total ground surface of the circular plot and then represented as trees ha^{-1}.

2.3 | Participatory data collection

A participatory rural appraisal (PRA) was held in each zone with 50 to 60 community members of different households and of diverse age, gender and wealth, recruited with the help of the village leaders (Baudron et al., 2011). The PRA goal was to understand the current and historical context through the generation of a timeline of historical events, natural resources and land use maps, diagrams of access to major resources, Venn diagram of major institutions, value chains of main commodities and household typologies based on self-categorization (Duriaux & Baudron, 2016).

Two Focus Group Discussions (FGDs) were held in each zone with groups of 12 to 14 elders. In the first set of FGDs, trend lines were drawn and discussed by participants describing changes over the last 40 years (Geilfus, 2008). During the second set of FGDs, historical diagrams of land-use change (Geilfus, 2008) for five points in time during the last 40 years were created (see Figure 4).

Another FGD was held with 33 elders from the three zones to identify the main land use and land cover (LULC) change events, discuss their impact on the most important wellbeing elements as considered by the group and identify differences between the zones. Results from this FGD were similar across all zones and therefore are presented as one compiled table. Finally, a last FGD was held with adults of different ages from the three zones to present key results to the community and receive feedback which was used to improve the results. PRA and FGDs were held between October 2014 and December 2015; equal proportions of male and female participants were invited to the events, having similar proportions in attendance.

2.4 | Qualitative data analysis

Land use classification and spatial analysis were undertaken using ENVI 5.0 and ArcGIS 10.3. Change statistics were calculated by comparing the values of the dataset in one period with another (1972–1986, 1986–1999, 1999–2013). Current land use area within a radius of 50, 100 and 250 m of each household was calculated from the 2015 RAPIDEYE classification and based on household positions ($N = 266$; see Baudron et al., 2017) recorded with a handheld GPS Garmin Etrek 10.

For each zone over three periods, annual net forest change was calculated as the change in tree cover area as a percentage of the total surveyed area, using the formula $X = ((A_2 - A_1)/A * 100)/(t_2 - t_1)$, *Where*: A represents the total surveyed area, while A_1 and A_2 and t_1 and t_2 represent the tree cover areas and the year for the first and second period, respectively (Puyravaud, 2003). For tree basal area data, the Kruskal-Wallis test was used to compare the medians among zones, while *Chi*-squared contingency tables were used to compare proportions of tree cover. Both were conducted using R software.

3 | RESULTS

3.1 | Land use land cover change analysis between 1972 and 2013

Cropland expanded continuously from 1972 until 2013 with the largest and most rapid expansion occurring between 1972 and 1986 (Figure 1; Figure 2). Cropland expansion occurred at the expense of dense (natural) forest and medium dense vegetation until 1999, and later, mainly at the expense of grassland areas. Medium dense vegetation refers to forested areas—mainly used for grazing and cropping—with a lower tree density than natural forest. Medium dense
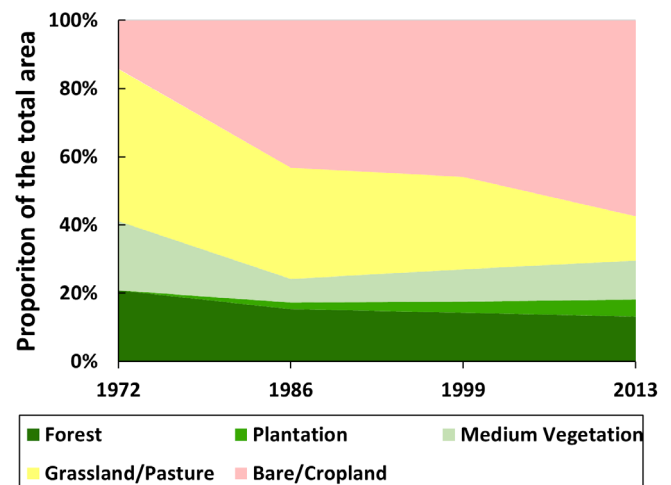
FIGURE 2 Proportion of area occupied by different land covers for 1972, 1986, 1999 and 2013 using imagery from LANDSAT 1 (1972) and LANDSAT 5 satellites [Colour figure can be viewed at wileyonlinelibrary.com]
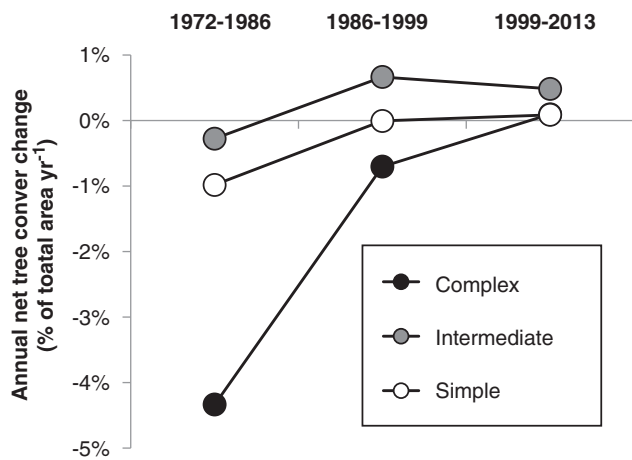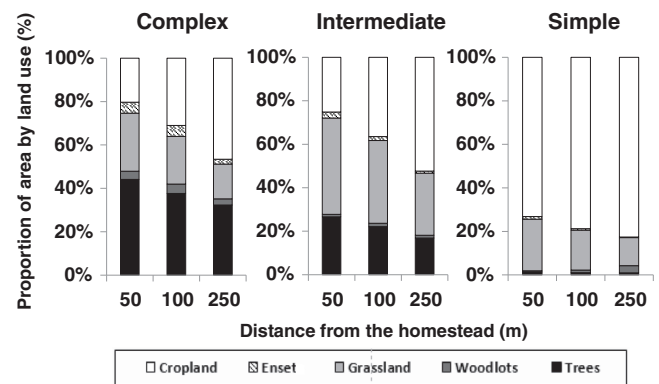
FIGURE 3 Annual net tree cover change in three zones along a gradient of decreasing land cover complexity and tree cover. The annual net change is the annualized percentage that forested areas increased or decreased relative to the total area of a zone. Calculations are based on statistics obtained from LANDSAT imagery

FIGURE 4 Proportion of different land cover types at increasing distance from the homesteads for three zones along a gradient of decreasing land cover complexity and tree cover. To measure the proportions in each land cover type, pixels of different land covers were counted within concentric circles of 50, 100 and 250 m based on 2015 RAPIDEYE imagery. (N = 266 households)

vegetation class decreased until 1986 and expanded thereafter. Both natural forest and woodlots were mainly found inside the Munesa State Forest. State forest woodlots were first observed in 1986 and have expanded since. Classification accuracy for the latest LANDSAT images was 93%.

At different periods and extents for each zone, there was a shift from rapid tree cover loss to slow tree cover gains (Figure 3). Between 1972 and 1986 tree cover in all three zones declined, with the fastest deforestation rate in the complex zone (-4.33% yr^{-1}). Between 1986 and 1999, tree cover gain rate increased in the simple zone (0.66% yr^{-1}), while deforestation virtually stopped in the intermediate zone and drastically reduced its rate in the complex zone (-0.72% yr^{-1}). Between 1999 and 2013 tree cover gains occurred in all three zones with highest gains in the intermediate zone (0.48% yr^{-1}) with lower (similar) gains (0.10% yr^{-1}) in the complex and simple zones.

3.2 | Contemporary land cover patterns

The different patterns of LULC change in the three zones led to differences in landscape composition in 2015, in particular concerning tree and grassland cover. A much greater proportion of the simple zone was represented by cropland (89%) compared to the complex (60%) and intermediate (55%) zones. Conversely, a greater proportion the intermediate zone was represented by grassland (22%) compared to the complex (15%) and simple zones (8%). Natural tree cover was higher in the complex (21%) and intermediate (20%) zones compared to the simple zone (1%). Woodlot cover was similar in the three zones: 1.5%, 1.2% and 1.8% in the complex, intermediate and simple zones, respectively. *Ensete* plantations decreased with increasing cropland specialization, occupying 2.5% of the area in the complex zone, 0.7% in the intermediate zone and 0.2% in the simple zone. The classification accuracy was 96%.

The area covered by perennial vegetation—that is, trees, grassland, *Ensete* and woodlots—tended to increase with increasing proximity to the homesteads (Figure 4). Home gardens generally include *Enset* and trees, and together with grasslands, are often found near the homestead. *Eucalyptus* woodlots in the simple zone showed to be an exception, as their area increased with increasing distance to the homestead.

3.3 | Tree species and community composition

Of the 50 tree species inventoried, two are endemic to Ethiopia and four are considered of high conservation value by the Ethiopian government. While seven non-native species were encountered, only *Eucalyptus* species were particularly widespread and often found in woodlots. Tree basal area was highest in the complex zone, followed by the intermediate, then the simple zone (Table 1). The proportion of *Eucalyptus* from the total number of sampled trees was higher in the simple zone than in the other zones, but there were no significant differences in the proportion of the total basal area or the total tree density represented by *Eucalyptus*.

3.4 | Historical perceptions: Land use change and its implications on livelihoods

According to FGDs (Figure 5) forest and grassland were said to be the dominant land uses before 1970, when the main livelihood strategy was livestock rearing. Deforestation was said to have occurred slowly during Emperor Haile Selassie's regime (before 1974), when the land was owned by landlords and exploited for the extraction of high value timber. Most of the deforestation occurred after a political regime shift to the Derg socialist regime. The subsequent agrarian reform starting in 1974, and the concomitant land redistribution, provided

TABLE 1 Indicators of tree density (stem density and basal area) for three zones along a gradient of decreasing land cover complexity and tree cover (N = 96 sampling points)

	Complex	Intermediate	Simple	X^2	p-value
Basal area (m²/ha)	5.1 ± 4.2	2.1 ± 1.7	0.6 ± 0.9	34.535	**.0001**
Eucalyptus (mean % basal area)	15% ± 26%	30% ± 36%	21% ± 31%	4.722	.0943
Eucalyptus (% total basal area)	11%	20%	23%	5.285	.712
Stem density (stems/ha)	85.0 ± 97.6	69.6 ± 66.7	36.3 ± 124.7	17.942	**.0001**
Eucalyptus (mean % stem density)	33% ± 38%	47% ± 38%	29% ± 38%	3.489	.1748
Eucalyptus (% total stem count)	66%	68%	93%	24.585	**.0001**

Note: Significant p-values (> .01) in bold.

FIGURE 5 Reproduction of outputs drawn by farmers during three focus group discussions, representing their perception of changes of the main land cover categories in each of the studied zones. Bars indicate the total area of a zone divided in different land cover categories in a certain year; arrows indicate the category to which a land cover changed to over time
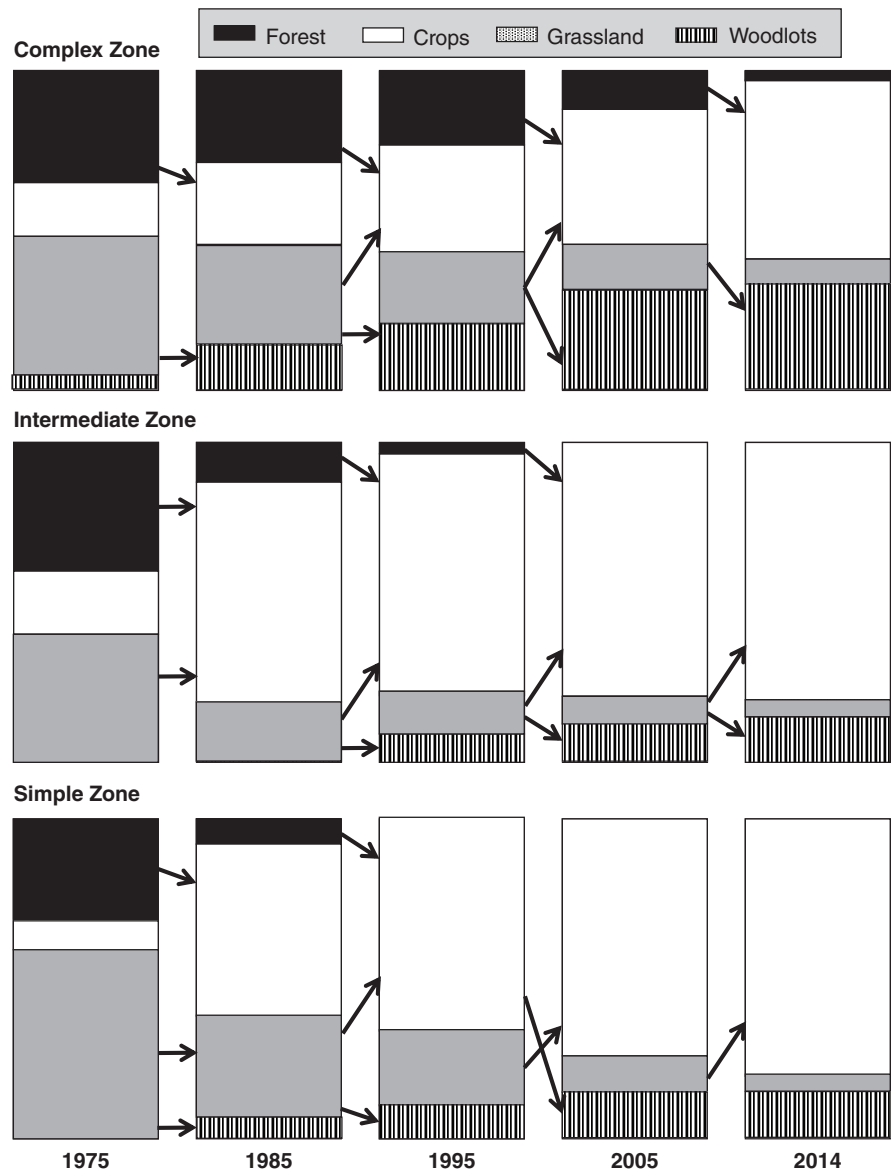
land to residents. Forest clearance was the main strategy to gain access to land during this period ('land to the tillers') (Duriaux & Baudron, 2016).

According to FGDs, in the three zones LULC change followed similar patterns of conversion of forest and grassland to cropland, but at different times and following different rates (Figure 5). Forest was converted to cropland in all sites and all but disappeared in the simple zone by 1995 and in the intermediate zone by 2005, while there were still remnants in the complex zone by 2014, the end of the studied period. Grassland conversion to cropland has been common from 1975 to date, while its conversion to *Eucalyptus* woodlots occurred in the three zones at different periods. In the simple zone,

TABLE 2 Impacts of historical land cover changes on the elements most important for wellbeing as described during Focus Group Discussions (FGD)

Land use change processes	Food	Water	Construction materials	Livestock	Income	Fuel
Forest to cropland	+	−	−	−	+	−
Forest clearing process			+		+	
Grassland to cropland	+	0	−	−	+	0
Grassland to woodlot	0	−	+	−	+	+
Enset establishment	+	0	0	+	+	+

Note: The elements more important for wellbeing are ranked from left to right following FGD participants perception. The impacts are considered positive (+), neutral (0) or negative (−).

some cropland was converted to *Eucalyptus* woodlots between 1995 and 2005, but cropland still expanded through grassland conversion. In general terms, cropland has increased continuously at the expense of forest and grassland, while *Eucalyptus* has increased mainly through conversion of grassland.

During the set of FGDs that created historical trendlines, elders estimated the population in 1970 to be 20, 37 and 30 people for one of the villages in Zone 1, Zone 2 and Zone 3, respectively. In comparison, household surveys carried by the research team in 2015 (Baudron et al., 2017) showed a total population of 359, 369 and 255 inhabitants for the same villages in Zone 1, Zone 2 and Zone 3, respectively. This represents an approximate population growth ranging from 850% to 1795%.

The most important elements for wellbeing mentioned during the FGDs were, from the most to the least important: food availability (in amount and quality), access to water in rivers and streams (for both human and livestock), construction materials, livestock ownership, income, and fuelwood (Table 2). The shift from forest and grassland to cropland was perceived to have increased food production, dietary diversity and income but to have led to a decline in livestock numbers, and a reduced availability of construction materials, fuelwood and water. During the period of intense forest clearance, livelihoods shifted from herding to crop production; income increased while construction materials were readily available. Livestock numbers—both per farm and per village—were said to have decreased constantly because of conversion of grasslands and forests to cropland and woodlots. The establishment of *Enset* in homegardens was the only LULC change process that impacted livestock numbers positively but was not enough to offset the loss of the other feed sources. Overall, the changes in livelihoods and LULC that have taken place since the 1970s were perceived as positive, especially for food production, dietary diversity and income.

4 | DISCUSSION

4.1 | Farmers gaining, losing and recovering services

During the study period, farmers changed their land uses to increase the livelihood benefits they derived from the landscape, provisioning ecosystem services in particular—that is, material goods obtained from

the ecosystem. Deforestation improved food and income provisioning, at the expense of water, construction materials, livestock and fuel. Through reforestation (Figure 3), farmers recovered some of the services lost during land conversion (Table 2). Although this study cannot provide direct attribution of the causes of LULC change, it does showcase the importance of accounting for landscape multi-functionality and ecosystem services when understanding forest transitions and LULC change in human-dominated landscapes.

Although the LULC change that took place in the study area since the 1970s resulted in increased income and improved food security— that is, adequate household food provisioning described during FGDs as "...enough food throughout the year for all household members"—they also resulted in a decrease in water availability in rivers, livestock numbers, construction materials and fuelwood availability (Table 2). As a response to the decreasing availability of these resources—highlighted as key to wellbeing during FGDs—farmers started a reforestation process through farmer-managed natural regeneration and *Eucalyptus* establishment (Table 1). In Ethiopia, Ango et al. (2014) demonstrated that farmer managed trees and forest actively to promote ecosystem services and reduce disservices. The sum of these farm level decisions will impact the overall landscape and again the livelihoods of its inhabitants.

Our results echo those of other studies in overlapping and nearby areas in terms of LULC change and its impact on ecosystem services: an increase of cropland and food production occur at the expense of forest, tree rich areas and grassland and their related services (Ariti et al., 2015; Kebede et al., 2019; Kindu, Schneider, Teketay, & Knoke, 2016). Our study only focused on provisioning services identified by farmers as the most important elements for their wellbeing, which were impacted by LULC change. Although our research shows the recovery, at least to some extent, of these provisioning services—with the exception of water in streams—other services are likely to be lost—that is, erosion control, biological control and pollination. Kindu et al. (2016) explored the LULC change and related change in provisioning, supporting and regulating ecosystem services between 1973 and 2012 in an area overlapping with our study area, finding a 27.8% reduction of their economic value.

4.2 | What is the right balance of land uses?

This research as well as previous studies in the same study area (Baudron et al., 2017, 2019; Duriaux Chavarría et al., 2018) suggest

that the complex zone might represent an optimal landscape in terms of outcomes for the farm and household such as livestock ownership and productivity, fuelwood availability, diversity of income sources, equality, and dietary diversity. During the FGDs, the key elements for rural livelihoods (Table 2) were compared among the three zones with the goal of elucidating which mix of land cover types (e.g., Figure 6a, b) is likely to provide the most desirable bundle of ecosystem services. The simple zone was perceived as having higher crop and overall food productivity compared to the other zones, but fewer crop types such as *Ensete*, lower dietary diversity, and reduced livestock products. The complex zone was perceived as having more livestock, livestock productivity and higher dietary diversity. Duriaux Chavarría et al. (2018) found no differences in overall farm or crop productivity between the zones as suggested by farmers, but their measurements agree with the perceptions of larger livestock herds and greater livestock productivity in the complex zone. Baudron et al. (2017) agree in that dietary diversity was greatest in the complex zone due to higher livestock density and more homegardens.

Construction materials and fuelwood were perceived to be readily available in the complex zone, very limited in the simple zone, with the intermediate zone somewhere in between. Baudron et al. (2017) found

that fuelwood consumption was higher in the complex and intermediate zones while in the simple zone households needed to purchase fuelwood. Although the access to fuelwood from the forest from households in the complex zone might have a positive impact on their livelihoods, it is paramount to further study the sustainability of the extraction over time to ensure that the forest resource base is not degraded.

Participants in the FGDs could not define which zone generated better incomes, mentioning that this varied by household. Yet they reported higher availability of livestock, *Enset*, trees on farms, and access to common forest in the complex and intermediate zones allowing for greater income diversity and availability in times of need—e.g., in an emergency, when needing to invest in crop inputs, support for children going to school—and thus overall more stability in the household income. Duriaux Chavarría et al. (2018) found a more equal distribution of livestock in the complex zone, suggesting that this could translate into a better availability of income in times of need; they also found farming systems in the complex zone to be more resilient, suggesting a more secure and diverse production, likely to impact income positively.

Overall, the landscape configuration in the complex zone—that is, a diverse agricultural matrix with high tree cover and forest presence—was the most beneficial for local livelihoods. Our results suggest that

FIGURE 6 Different elements of perennial vegetation in the agricultural landscape. View of the agricultural land and the tree component in the (a) complex and (b) simple zones; (c) a homegarden with *Enset*—false banana—plants in the left, potato in the front and a small *Eucalyptus* woodlot in the back; (d) remnant trees in the field (front left), natural regeneration in a hedgerow (back left), *Eucalyptus* next to the road (back center) and *Eucalyptus* woodlot (right). Photo credits: Frédéric Baudron [Colour figure can be viewed at wileyonlinelibrary.com]

promoting more complex landscape configurations can translate into improved local livelihoods through the provisioning of key ecosystem services, highlighting the role of landscape approaches for development. Still, promoting the abovementioned benefits might prove difficult to reproduce in other zones without access to common areas and especially forests, which were mentioned as a fundamental source of the services.

4.3 | More people, more perennial vegetation: A reforestation pathway

It is commonly believed that population increase leads directly to deforestation (Boyd & Slaymaker, 2000). However, our study demonstrated that population may grow in parallel with increased cover of perennial vegetation. The proportion of trees, grassland, *Enset* and woodlot cover tends to increase closer to the homesteads (Figure 4). Based on the association between trees, grassland, *Enset*, woodlots and the proximity to the homestead, it can be hypothesized that a population increase will lead to an increase in cover by perennial vegetation types. Indeed, it was mentioned during the FGDs that an increase in grazing area and homegardens—which include trees and *Enset* (Figure 6c)—is expected as younger families establish new homesteads. The aforementioned land uses are associated with daily tasks—fuelwood collection, tending to livestock, milking, collection of manure and cultivation of *Enset* fields—and this spatial arrangement might be a strategy to centralize assets to guard livestock against theft/wildlife and reduce labour burden by reducing the travel time to carry out daily tasks.

Tiffen et al. (1994) in their book "More people, less erosion" described the processes that lead to a natural regeneration and improved environment due to population increase and their actions. The same phenomenon has been observed in Guinea, where local communities were blamed for a shift in vegetation from pristine humid forest to savannah. It was later demonstrated that population increases actually promoted reforestation in locations where edaphic conditions would otherwise not allow natural establishment and regeneration of humid forest (Fairhead et al., 1995). Nyssen et al. (2009) showed that in Tigray region of Ethiopia, land rehabilitation occurred through an increase of vegetation cover—mainly *Eucalyptus*—in parallel with a tenfold increase in population. Desalegn et al. (2014) found that in another area of Ethiopia, *Eucalyptus* cover increased with settlement expansion, resulting in decreased burden of fuelwood transport over long distances—especially for women—and an increase in income as well as provisioning of other ecosystem services such as wind breaks.

Another example of restoration associated with population growth is farmer managed natural regeneration (FMNR). FMNR is based on the regeneration of native trees (Haglund et al., 2011), and although the planting of *Eucalyptus* was observed as the main mechanism for vegetation regeneration, natural regeneration of native trees also played an important role according to FGDs (Figure 6a, b and d). Many individual stems of native tree species had small basal areas, an indication they were not remnants of the original forest but likely the result of regeneration. FMNR is more effective when benefits to local communities are the main driver, used in combination with easy and accessible technology to promote diffusion through the community (Rinaudo, 2007). Similarly, in Ethiopia *Eucalyptus* was established largely without extension efforts because of its economic value and attractive traits; highlighting the 'demonstration effect' in others' farms (Ango, 2010).

Our results demonstrate a compelling juxtaposition with some of the literature on forest transitions. Often, forest transitions occur through interacting reforestation pathways described in the literature as 'forest scarcity', 'state forest policy', 'economic development', 'globalization' and 'smallholder intensification' (Lambin & Meyfroidt, 2010; Meyfroidt et al., 2018). Although in the study area the 'smallholder tree-based intensification pathway' occurred as described in the literature: 'under the influence of smallholder land use systems that actively manage the multifunctionality of ecosystems' (Lambin & Meyfroidt, 2010), restoration did not occur on abandoned land but on productive land. It did not evolve over millennia but occurred within decades. In addition, its main objective was not risk reduction through diversification but the recovery of key provisioning services.

Furthermore, a different reforestation pathway was identified in this study. Homestead establishment was a pathway identified by farmers during FGDs and supported by the remote sensing analysis (Figure 4). This pathway is characterized by new homesteads being established in areas with low tree densities—that is, cropland, grasslands—whereby households then establish trees, grassland, *Enset* and woodlots in close proximity, resulting in larger areas of perennial vegetation—including trees—in the landscape. This pathway would probably only occur under specific conditions: the establishment of new homesteads must occur in agricultural land and not forest, and trees must have importance for local livelihoods for the provisioning services (i.e., there is interest/necessity to plant trees near the homestead).

4.4 | Farmer-led reforestation, novel ecosystems and biodiversity trade-offs

The simple zone, with the lowest proportion of tree cover, had the highest proportion of *Eucalyptus*, pointing to the importance of *Eucalyptus* for tree cover regeneration in the most deforested conditions. *Eucalyptus* and *Ensete* were introduced to the area by local inhabitants during the period under investigation (1970 to 2014). The LULC change process—shift from a highly forested area to an area dominated by cropland with a high proportion of exotic tree species—has led to what could be considered a 'novel ecosystem'. A novel ecosystem differs in composition and/or function from present and past ecosystems and is often linked to LULC change and agriculture (Hobbs et al., 2009). There is much discussion about the negative implications of novel ecosystems in general (Miller & Bestelmeyer, 2016) and *Eucalyptus* in particular (Poore & Fries, 1985; Sunder, 1993). On-the-other-hand, in Ethiopia *Eucalyptus* establishment has been found to have an indirect positive impact on soil and water conservation mainly through

the reduction of soil runoff (Mhiret et al., 2019; Nyssen et al., 2009). Jenbere et al. (2012) studied *Eucalyptus* expansion in nearby farms and found expansion occurred despite farmers' awareness of the detrimental ecological effects of *Eucalyptus*. They also mentioned that tree planting in this area is a strategy "...employed by rural households to diversify income sources, meet their own wood products demands and secure more sustainable livelihoods" and that the main reasons driving expansion of Eucalyptus were "...rising demand for wood, desire for income from selling poles, increasing distance from the forests and woodlands to access wood products for subsistence, and increasing frequency of drought that affects crop and livestock production" (Jenbere et al., 2012). Similar results were found in a study by Milkias et al. (2014), in which farmers ranked construction materials, income and fuelwood provision as the main reasons for planting *Eucalyptus*. Indeed, the products of *Eucalyptus* not only recover the diminishing availability of construction materials and fuelwood due to previous deforestation, but also reduce the pressure on forest and native trees allowing conservation and regeneration. According to FGD participants, *Eucalyptus* were planted primarily in waterlogged grasslands, followed by cropland areas with low agricultural potential. Future research should quantify the possible biodiversity trade-offs resulting from the plantation of exotic tree species like *Eucalyptus*, but also compare scenarios with or without *Eucalyptus* reforestation to understand its overall effect on biodiversity and the bundle of ecosystem services it provides.

5 | CONCLUSIONS

This study provides empirical evidence of restoration pathways where farmer-led reforestation leads to the recovery of key provisioning services, with simultaneous population increase. LULC changes are affected by the changing need for ecosystem services of landscape users. After two decades of deforestation and cropland expansion, residents of the study area shifted to reforestation through *Eucalyptus* planting and farmer managed natural regeneration. This was as a response to the growing scarcity of fuelwood and construction materials resulting from deforestation. In a landscape dominated by cropland, the benefit of such reforestation appears disproportionately high for people—for example, greater livestock numbers, improved resilience and diversification of income sources – but also for biodiversity (Baudron et al., 2019).

Population increase promoted reforestation ('more people, more trees'), as the multiplication of homesteads also led to an increase of the number of natural trees, woodlots and *Ensete* plantations, which are all traditionally maintained around the homestead to provide key services for the household. This could represent a forest transition pathway (Meyfroidt et al., 2018) applicable to other landscapes with similar situations. However, it is incorrect to assume that an increase in population will always lead to environmental regeneration. We believe this reforestation pathway would only occur if new homesteads are established in agricultural land and not in natural vegetation, and only where services provided by trees and other perennial vegetation are valued in local livelihoods. Research in other landscapes could help identify how common this pathway is and its potential for landscape restoration projects in a world characterized by a growing population.

Previous studies in the area identified the importance of common-access forest, grazing areas and trees for sustainable intensification of agriculture (Duriaux Chavarría et al., 2018) and dietary diversity (Baudron et al., 2017). However, it is important to identify the threshold of extractions before resource degradation occurs as well as the rules and institutions (local and state governance) that would allow this. Further research is needed in the study site to identify this knowledge gap and ensure the sustainability of the system.

Finally, while regeneration may occur in ways not always approved by conservationists—e.g., *Eucalyptus*—these 'novel ecosystems' might be a better option than simpler agricultural configurations with scant trees and perennial land uses (grassland, *Ensete*). Interdisciplinary landscape approaches could be a framework guiding regeneration in agricultural landscapes that help identify the land use balance that brings the most positive impact to both livelihoods and biodiversity. Further research using this approach could make use of 'natural experiments' to provide better scientific information to guide policy making and landscape re-designs to maximize the parallel development goals of humankind.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

DATA AVAILABILITY STATEMENT

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

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