

Out-migration, agricultural abandonment, and community forest management: Drivers of afforestation in privately managed land in Nepal

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ABSTRACT

Nepal's forest cover nearly doubled over the last three decades. While Community Forest (CF) management and agricultural abandonment are primary drivers of forest cover expansion, the contribution of afforestation on privately managed land is not well documented. We mapped forest cover change from 1988 through 2016 in 40 privately managed sites that transitioned from agriculture to forest and assessed how agricultural abandonment influenced private land management and afforestation. We used a mixed method analysis to integrate our 29-year Landsat satellite image-based record of annual forest cover with interview data on historical land cover and land use dynamics from 65 land managers in Bagmati Province. We find that privately managed land accounted for 37% of local forest cover gain, with mean forest area within private forests growing from 9% to 59%. Land managers identified two factors driving these gains on private land: implementation of CF management in adjacent government forests and out-migration. These previously undocumented linkages between forest cover gain on private land and CF management merits further research in community forests and calls for greater policy and technical support for small-scale timber growers and rural households who rely on private forests for income generation.

1. Introduction

Reversing forest loss is key to attaining globally important goals, including carbon sequestration, biodiversity conservation, and the provision of clean air and water, timber, fodder, and fuelwood (Gratzner & Keeton, 2017; Price et al., 2011). Nepal is a prime example of a national effort to combat deforestation. Forest cover in Nepal declined between the 1930s–80s due to mismanagement and a rapid rise in population (Sudhakar Reddy et al., 2018). Deforestation trends in Nepal were reversed in the 1980s, and forest cover extent has nearly doubled over the following three decades (Chhetri et al., 2023; DFRS, 2015). Forest cover gains have benefited the 60% of Nepali households directly dependent on forest resources (Pandey, & Prasad Pokhrel, 2021), while many more households benefited from improved ecosystem services, such as erosion control and clean water (Thwaites et al., 2017).

Significant research has sought to better understand the factors contributing to Nepal's forest recovery (e.g., Paudel et al., 2016; Tripathi et al., 2020; Wagle et al., 2020), a question of global relevance due to the role forest will need to play in combating an array of global challenges (IPCC, 2023). Nepal's community forest (CF) program has had a documented positive impact on forest cover (Smith et al., 2023; Gautam et al., 2002; Jackson et al., 1998; Niraula et al., 2013; Oldekop et al., 2018; Pandey, & Prasad Pokhrel, 2021). Nepal's CF management program began in the 1970s–80s in response to forest resource scarcity and is centered on the government granting forest user groups forest access, management, extraction, and exclusion rights. The provision of rights has been successful in motivating Nepal's forest users to invest in community-based forest management, conservation, and restoration efforts (Thwaites et al., 2017). Today, 22,000 CF user groups, representing 57% of Nepal's population, manage 35% of the country's forests

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(2.3 million ha).

Alongside CF management, widespread out-migration and its effect on changing rural livelihood strategies and agricultural practices have also been shown to contribute to national forest cover change in Nepal (Chhetri et al., 2023; Oldekop et al., 2018) as well as globally (Radel et al., 2019). In Nepal, out-migration is characterized by working-age men traveling from forest-dependent farming communities to domestic and international urban centers in search of employment opportunities (Maharjan et al., 2020; Sunam & McCarthy, 2016). In the mid-1990s and early 2000s, out-migration soared after international labor migration restrictions were lifted and the Nepali civil conflict intensified (Jaquet et al., 2015; Subedi et al., 2021). By the early 2010s, one-third of working-age men lived abroad (Sharma et al., 2014). International remittances currently account for a quarter of all household income in Nepal (Adhikari, & Hobley, 2015; Kc & Race, 2019) and have made households less reliant on income through farming or domestic paid labor.

In rugged mountainous areas where farming is labor-intensive and difficult to mechanize, out-migration has also caused widespread agricultural abandonment (Chaudhary et al., 2016; Kc & Race, 2019; Ojha et al., 2017). Agricultural abandonment is a non-temporary cessation of agriculture (Gradinaru et al., 2020; Pointereau et al., 2008) that, in Nepal, has been associated with a decline in cultivation and agriculture-related forest resource use, such as fodder for livestock feed and fertilizer production and timber for building construction and maintenance (Chhetri et al., 2023). Since 2000, Jaquet et al. (2015), Khanal (2018), Ojha et al. (2017), Paudel et al. (2020), and Subedi et al. (2021) have documented agricultural abandonment across diverse sites in Nepal. Some evidence for forest cover expansion following agricultural abandonment (e.g., afforestation; natural forest expansion), comes from Niraula et al. (2013), Tripathi et al. (2020), and Wagle et al. (2020), who documented it in former agricultural areas in Dolaka, Tanahun, and Kaski districts, all located in the Middle Hills. However, these studies did not directly assess the processes or drivers underlying the forest cover change, nor did they measure the rate or extent of change following agricultural abandonment.

In contrast to the documented links between CF management and afforestation and natural forest expansion in government forests, little is known about the processes contributing to forest cover expansion on private agricultural land. Because afforestation in former agricultural areas can affect social, environmental, and economic systems in Nepal (FAO 2020), increased understanding of forest cover change drivers and dynamics in private lands following agricultural abandonment is needed (Jaquet et al., 2015; Subedi et al., 2021; Wagle et al., 2020). Our study addresses this knowledge gap by examining the specific local social factors that have influenced private land management decision-making and the processes that led to afforestation in former agricultural areas.

Our objectives are to: 1) measure the annual extent and rate of forest cover change in a sample of privately managed agricultural areas; 2) document land cover and land use drivers associated with agricultural abandonment and afforestation and identify the effects of afforestation on local environmental systems and livelihoods with site-specific interview data; and 3) integrate interview and forest cover change data to understand the contribution of agricultural abandonment to afforestation across study sites. To do so, we apply a mixed methods approach that integrates annual, Landsat satellite image-based forest cover data from 1988 to 2016 with open-ended interview data obtained from private land managers and other key informants across 40 sites that transitioned from agriculture to forest in the Charnawati watershed, Bagmati Province, Nepal. This study provides new insights into the linkages between land cover and land management decisions in community and privately managed land and highlights the need for greater support for forest management on private land.

2. Methods and materials

2.1. Study area

This study was conducted in Charnawati watershed (835–3549 masl, 190 km²), Bagmati Province, Nepal (Fig. 1). The largest town, Charikot (population: 22,537; NPHC, 2011), is a center for education, non-farm labor, and international labor recruitment. The watershed is characterized by hilly topography, a monsoon climate, and a mix of forests, agriculture, and built-up areas. Forests extend from alpine to temperate zones with a diverse range of evergreen and deciduous species (DFRS, 2015). Farming is primarily conducted on private lands consisting of irrigated and rain-fed terraces. Staple crops are rice, corn, wheat, legumes, and vegetables (DFRS, 2015).

Historically, Charnawati watershed residents have depended on local forest resources for a variety of purposes: timber and thatch for home construction, firewood for cooking and heating, fodder for animal feed, and grass and manure were composted to create fertilizer. In the 1970s–80s, forest resource shortages became a significant problem leading to the introduction of CF management in the 1990s (Smith et al., 2023; Niraula et al., 2013). Nepal's community forestry program grants groups of forest users access, management, extraction, and exclusion rights over a local forest area, these are known as community forests. Private forests are privately owned and managed forested areas. Forests under community or private management and agricultural lands are often near each other (Fig. 2), providing farmers easy access to forest resources. Additionally, local farmers and community members are typically also CF users, and CF management and farming depend on the same pool of household labor.

During field visits from October to December of 2017 and 2018, we identified 40 sites that had transitioned from agriculture to forest since the 1990s. The identification of these sites involved a two-step process. First, using this study's forest cover data, generated from Landsat imagery (methods described in section 2.3), we identified areas over 1 ha that were afforested since 1988 and were outside CF boundaries (ICIMOD, 2010a, 2010b; Niraula et al., 2013). Then we digitized the boundaries of the aforementioned afforested areas and ground-truthed the boundary data on subsequent field visits. Second, through preliminary interviews, we confirmed that each chosen site that transitioned from agriculture to forest was privately managed and outside of CF management. The resulting 40 study sites range from 1.5 to 20 ha (average 6.6 ha), are all less than 250 m from the nearest CF boundary, and are dispersed throughout Devithan (12 sites), Charnawati (12 sites), and Khortali (16 sites) (Fig. 1). These clusters of private forests correspond to a neighboring CF user community to ensure a degree of consistency regarding the potential impact of CF management and to provide a reference point to compare the forest change we measured in our private study forests. While we do not have the data to evaluate if our study sites are statistically representative of all of Nepal, we can say the conditions, specifically related to CF management, out-migration, and forest cover expansion, are found across Nepal, suggesting our findings are relevant for other regions in Nepal.

2.2. Mixed methods design

A variety of research on human-environmental interactions (Gosnell et al., 2020; Lund et al., 2015; Walters, 2017) utilizes land cover and land use histories and spatial data on land cover change to document the historical processes linking social phenomena (e.g., out-migration; forest management policy) to changes in land cover and land use (e.g., agricultural abandonment; afforestation). We applied a similar explanatory mixed methods approach that combines satellite-derived forest cover change data with interview data on local land management and land use histories (Creswell & Vicki, 2017) (Fig. 3).

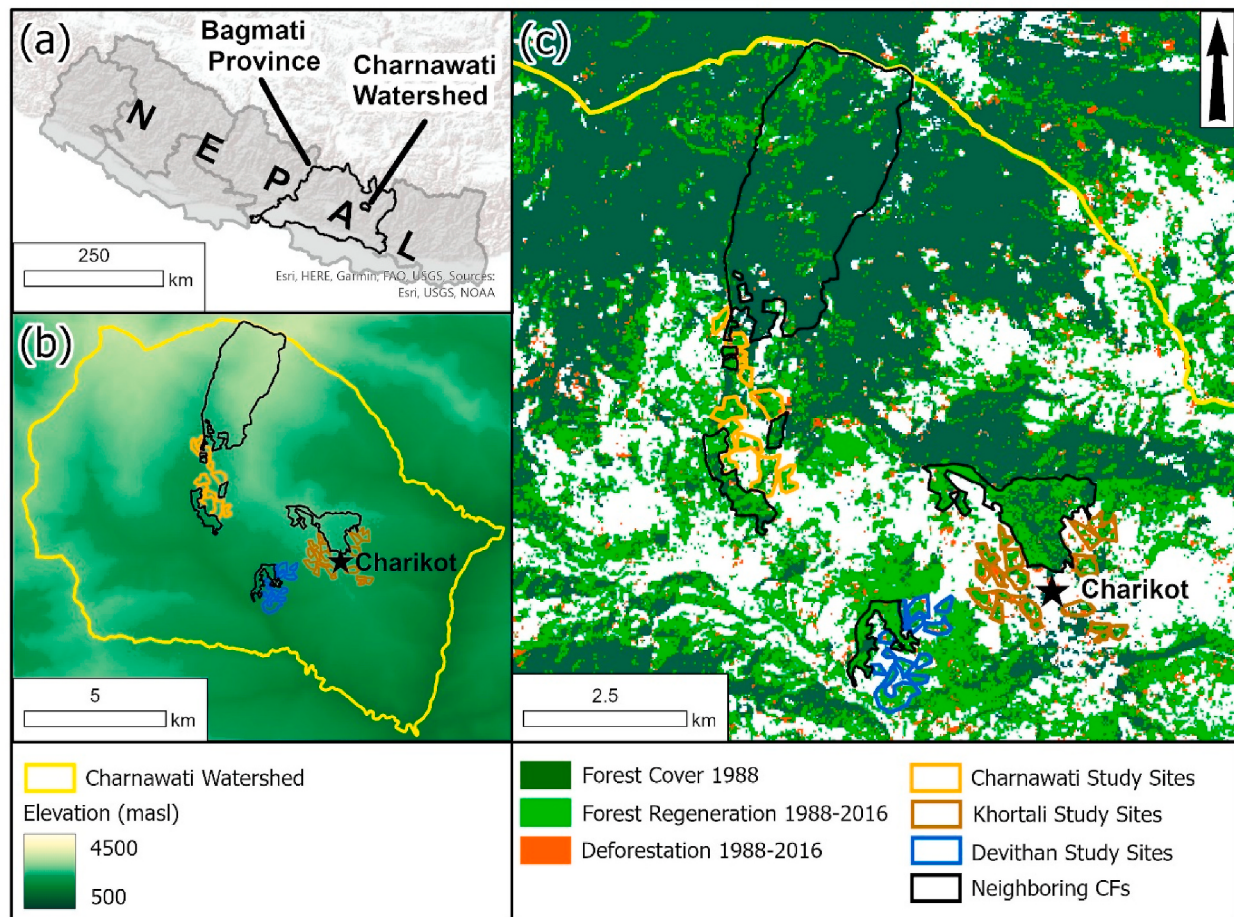


Fig. 1. An overview of Nepal, Charnawati watershed, and the Community Forests (CF) and private forests in this study. (a) Location of Charnawati watershed within Nepal. (b) CFs and privately managed areas within Charnawati watershed. (c) Charnawati, Devithan, and Khortali private forests (40 total) and adjacent CFs (3 total). Source: Nepal boundary from the Survey Department of Nepal, watershed and CF boundary from ICIMOD (2010a, 2010b) and Niraula et al. (2013), and forest cover data from this study's satellite image analysis (resolution: 30 m²).

2.3. Component 1: mapping annual forest cover in privately managed lands

Nepal's mountainous environment makes measuring forest cover change particularly challenging. For this study, we used forest cover data from Van Den Hoek et al. (2021). To generate this data Van Den Hoek et al. (2021) analyzed Landsat 5, 7, and 8 Tier 1 Surface Reflectance images across Nepal from 1988 to 2016. A semi-empirical correction approach, outlined in Hurni et al. (2019), was applied to the imagery to correct for topographic illumination variance, and the approach from Roy et al. (2016) was utilized to harmonize the spectral values. Then, following the methodology described in Hurni et al. (2019), seasonal composites were created, and the LandTrendr algorithm was used to determine annual pixel-level trends (Kennedy et al., 2018). A Random Forest classifier model was used to generate the forest/non-forest land cover maps. To generate the data to train the model, Van Den Hoek et al. (2021) conducted a stratified random sample of Nepal-wide, land cover data from 1990 (ICIMOD, 2014) and 2010 (Uddin et al., 2015); both data sets were derived from Landsat imagery (resolution: 30 m²). Sample sites were visually interpreted using Landsat and very high-resolution reference imagery in Google Earth Engine. Sites were classified as forest if at least 50% of the forest canopy was closed, and non-forest if less than 50% of the canopy was closed. The model was trained using 16 spectral (blue, green, red, NIR, SWIR 1, SWIR 2, Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Normalized Burn Ratio (NBR), and

Tasseled Cap Brightness, Greenness Wetness, and Angle) and SRTM DEM derived topographic (elevation (masl), slope (degrees), and aspect (degrees)) predictor variables. The forest cover classification model, built in Google Earth Engine, with one thousand decision trees in out-of-bag (OOB) mode, had an overall accuracy of 90.0%. The classification model, based on sample data from across years, was applied across the data set, thus the overall accuracy is relevant for all years. The resulting forest/non-forest land cover maps had a spatial resolution of 30 m². We measured yearly percent forest cover, rate of change, and long-term forest cover trends within each study site and neighboring CF.

2.4. Component 2: identifying land use histories and drivers of local land cover change

We identified each study site and corresponding land managers through geospatial analysis and introductory interviews described in section 2.1. Semi-structured open-ended interviews were conducted with 53 land managers from 40 study sites and 12 key informants active in local watershed and forest management initiatives between 1980 and 2020. In 29 sites, land managers had continuously farmed or managed the site since 1988. In the other 11 sites, we interviewed current and former managers. Our interviews helped build a land cover and land use history for each site to better understand various socio-economic and environmental processes contributing to abandonment and afforestation.

Each site's land cover and land use history, changes in management



Fig. 2. Example of a landscape and homestead in Bagmati Province, Nepal. (a) Clusters of homes dot the landscape dominated by intermixed trees and agriculture, and (b) Small house and barn adjacent to rice terraces and a patch of trees. Author's photos.

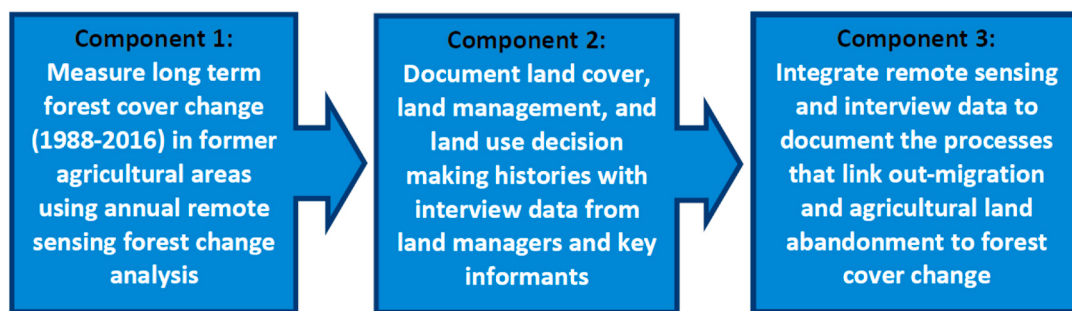


Fig. 3. Summary of mixed methods approach to data collection and analysis.

following the start of community forestry and out-migration, and the impact of forest cover change on local environmental systems and livelihoods were documented through qualitative interviews conducted from December 2019 to March 2020, see Appendix A, Interview Protocol. Respondents discussed: 1) social and environmental factors (e.g., forest resource shortages; out-migration induced labor shortages; changes in commodity prices) that led to agricultural abandonment and/or afforestation, 2) management activities that followed the start of CF management and out-migration (e.g., banning cattle grazing; planting trees; cessation of agricultural activities) and led to agricultural abandonment and/or afforestation, and 3) perceived social and environmental effects of forest cover expansion, such as greater access to forest resources, improved ecosystem services, or increased dependence on imported commodities. The year of agricultural abandonment, a key data point for our analysis, was defined as the year agricultural land use ceased at a given site. However, abandonment was usually preceded by forest management in the periphery of agricultural areas and a gradual decline in the frequency of, and area under, cultivation. To verify key dates associated with land cover and land use changes, we cross-referenced respondent information with well-known historical events

(e.g., the 1990 democratic movement; the 2008 national elections).

Interviews lasted between 30 and 90 min, and a list of questions and follow-up probes were employed to structure and maintain consistency among the interviews. In addition, visual field observations on tree species distribution, predominant age classes, under and overstory conditions, and the prevalence of abandoned agricultural terraces were collected at every site. Observations provided additional site-specific information and reference points when discussing land cover and land use histories with interview participants and when analyzing the forest change data.

The lead author conducted interviews in Nepali with the assistance of an interpreter who then provided translation and transcription. All field observations and interview transcripts were entered into QSR International's Nvivo 12 software to facilitate qualitative data analysis. Initial coding evaluated the data for trends in historical land use and land cover; further coding revealed emergent trends around impacts and drivers of land cover and land user change. This process was repeated iteratively to ensure consistency in the analysis across the data set. In addition, we used the interview data on land use, land cover, historical management, and dates associated with changes in these variables to

create environmental histories for each study site. The environmental histories were paired with forest change data from each site to evaluate the relationship between historical land use, land cover and management, and land cover change measured with the use of forest cover data (see section 2.3 for a description of the methods). In addition, by integrating site-level environmental histories and forest cover data, we were able to use the forest cover data to confirm afforestation patterns reported by land managers and link reported land change drivers with forest cover change. The quotes presented in the results represent themes across our data set and are representative examples of themes found throughout the data set. The study was conducted with institutional review board (IRB) approval at Oregon State University.

2.5. Component 3: integrating forest cover change and land management data

We linked forest cover changes (Component 1) with discrete land management activities and land cover and land use histories (Component 2) to evaluate site-specific effects of drivers of forest cover change. We used forest cover and management data to compare percent forest cover and rate of change before and after agricultural abandonment in privately managed lands to establish whether and when forest cover area saturated within each study site. For example, in one study site, land managers reported that the site afforested for approximately ten years following agricultural abandonment in 2000 before the forest cover area stabilized. These interview data on afforestation timing matched the remote sensing data that showed a steady increase in forest cover from 40% in 2000 to 80% by 2009. Forest cover remained around 80% through 2016. This comparison and verification approach allowed us to attribute satellite-derived forest cover change timing and trends to site-specific drivers and cross-check forest cover dynamics reported by land managers across our sites.

3. Results

3.1. Trajectories of forest cover expansion

In 1988, our 40 privately managed study sites were primarily used for agriculture, with a low level of forest cover, averaging 9% (SD: 10%) within each site. While CF management started at different times in different regions, beginning in 1993 in Charnawati, 2000 in Devithan, and 1994 in Khortali, on average forest cover remained low on private land, 12.5% (SD: 12%), before the start of CF management. Following these respective start dates, forest cover in the privately managed sites increased, reaching an average of 42% (SD: 18.5%) by each site's year of agricultural abandonment. After abandonment, forest cover continued expanding, reaching an average of 59% (SD: 15.5) across the 40 study sites by 2016. Overall, 37% of forest cover gain in the study area occurred in the 40 privately managed sites; 63% occurred in neighboring CFs.

Charnawati's 12 sites had a mean forest cover of 15% (SD: 9.5%) between 1988 and the introduction of CF management in neighboring forests in 1993. From the start of CF management until agricultural abandonment at each site in Charnawati (range: 1995–2012, mean: 2004), forest cover expanded to an average of 45% (SD: 20%). After abandonment, forest cover grew to an average of 73% (SD: 11) by 2016. 46% (SD: 30%) of forest cover gain followed the start of CF management in neighboring CFs and preceded agricultural

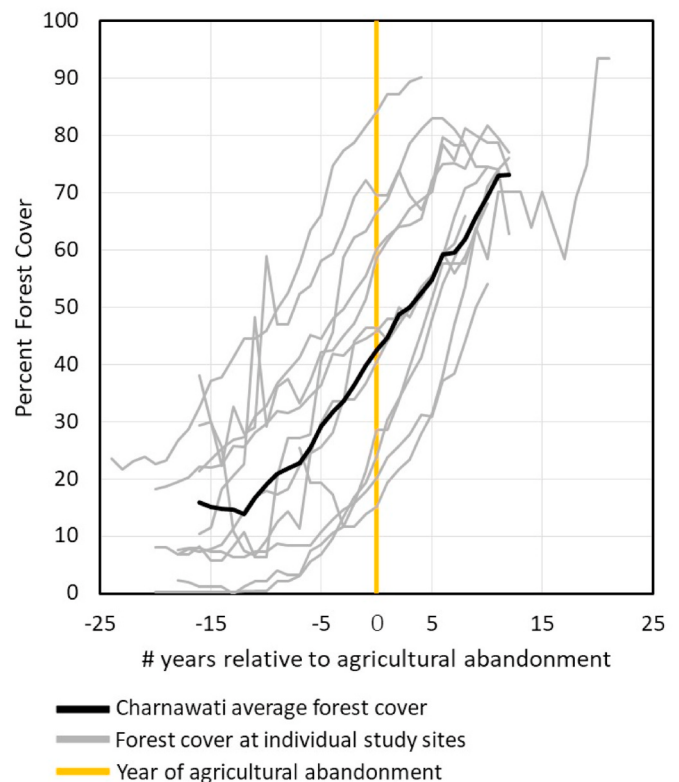


Fig. 4. Forest cover change trajectories in Charnawati area's 12 sites (gray lines) with respect to each site's year of agricultural abandonment (yellow line). Average forest cover area (black line).

abandonment, and 54% (SD: 30%) followed (Fig. 4). Forest cover in nine of 12 Charnawati sites continued to increase until 2016 (Appendix A, Fig. 1). Forest cover in the remaining three sites slightly decreased or declined following 2011. Throughout the study, 68.5% of forest cover gain in Charnawati occurred in privately managed study sites, and 31.5% occurred in the neighboring CF.

In the 12 study sites in the Devithan area, average forest cover was 1% (SD: 1%) before CF management began in 2000. From the start of CF management until agricultural abandonment at each site (range: 2006–2009, mean: 2007), forest cover expanded to an average of 28% (SD: 13%) of the study site's extent. Following abandonment, forest cover continued increasing, achieving an average of 58% (SD: 12%) by 2016. Across Devithan's 12 sites, 49% (SD: 27%) of total forest cover gain between 1988 and 2016 followed the start of CF management in neighboring forests and predated agricultural abandonment; 51% (SD: 27%) followed abandonment (Fig. 5). While nine of 12 sites continued to increase in forest cover through the end of the study, three sites stabilized around 60% forest cover; one site, owing to road construction, declined slightly from 75% to 55% forest cover over the last three years, 2013–2016 (Appendix A, Fig. 2). Throughout the study, 50.5% of forest cover gain in Devithan occurred in the 12 privately managed sites; 49.5% occurred in the neighboring CF.

Khortali's forest cover rose from 11% to 16% (SD: 11%) by the start of CF management in neighboring forests in 1994. Between the start of CF management and agricultural abandonment at each site (range:

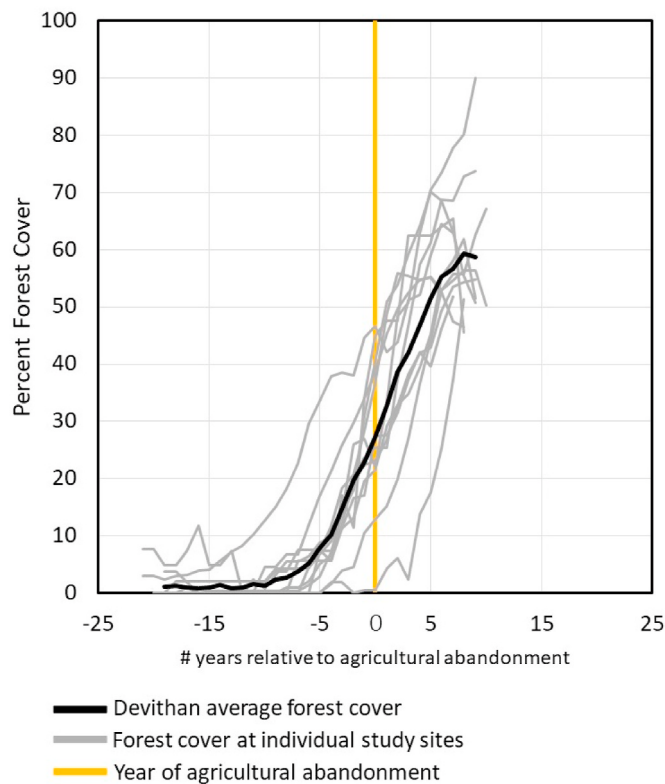


Fig. 5. Forest cover change trajectories in Devithan area's 12 sites (gray lines) with respect to each site's year of agricultural abandonment (yellow line). Average forest cover area (black line).

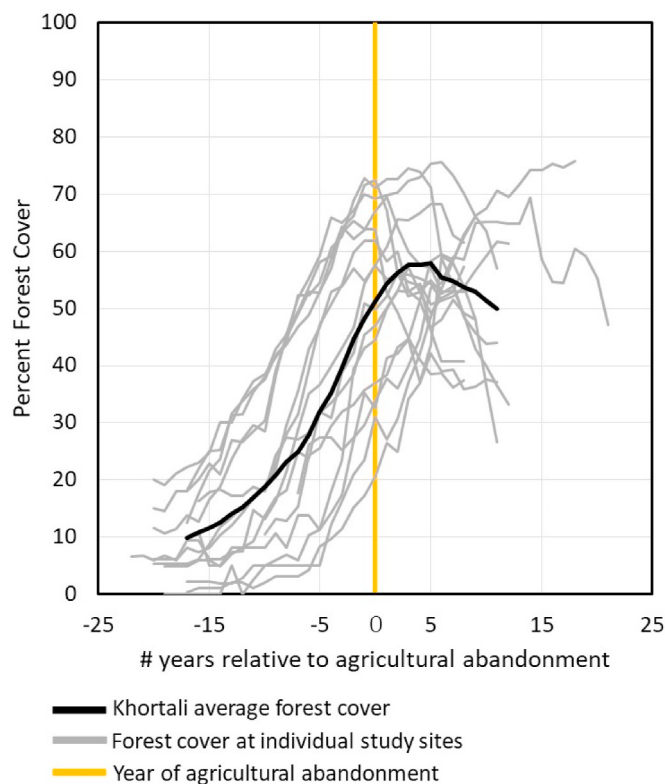


Fig. 6. Forest cover change trajectories in Khortali area's 16 sites (gray lines) with respect to each site's year of agricultural abandonment (yellow line). Average forest cover area (black line).

1995–2008, mean: 2006), mean forest cover increased to 51% (SD: 16%). After abandonment, average forest cover climbed slightly and subsequently declined to 50% (SD: 14%) by 2016. Across Khortali's 16 sites, 65% (SD: 20%) of total forest cover gain followed the start of CF management in neighboring forests and preceded agricultural abandonment (Fig. 6). Following abandonment, site-level forest cover trends diverged: forest cover increased in three sites, decreased in six sites, and marginally changed in seven sites (Appendix A, Fig. 3). Throughout the study, 33% of forest cover gain in Khortali occurred in the 16 privately managed sites, and 67% occurred in the neighboring CF.

To further elucidate the forest change patterns described above, we explore an individual site whose change patterns are typical of our 40 study sites, site 3, Devithan cluster, (27.65°, 86.02°), (Fig. 7). The upper lobe of site 3 is a steep ravine unsuitable for agricultural use, while the lower lobe is terraced and was cultivated at the outset of the study. In 1988 and 1995 (Fig. 7a and b), before the start of CF management in neighboring forests in 2000, forest cover in this site was below 10% and limited to the upper lobe; the lower lobe was almost free of forest cover. By 2002 (Fig. 7c), just after the start of CF management, a slight increase occurred in forest cover in the lower lobe as farmers started to cultivate tree varieties suitable for fodder and firewood production along the terrace walls in the lower lobe.

Through the early 2000s, farmers expanded cultivation of forest products within site 3's lower lobe while continuing to cultivate corn and rice within the terraces. Leading up to 2009, when agriculture was abandoned, forest cover had expanded to a large share of the lower lobe, yet farmers continued to cultivate a small diversity of crops (Fig. 7d). Following agricultural abandonment in 2009, forest cover continued expanding, and trees began naturally growing in abandoned agricultural terraces. By 2016 (Figs. 7e), 65% of site 3 was forested, and many of the remaining open areas had maturing saplings, suggesting they were transitioning to forest.

3.2. Drivers and processes of forest cover expansion: community forest management and agricultural abandonment

Through the integration of Landsat derived forest cover data and interview data on historical use and land management, we identified two primary drivers of afforestation across our study sites: the introduction of community forest management and agricultural abandonment. Starting in the mid-1980s, the introduction of CF management in neighboring CFs led to cultivation of forest resources in areas immediately adjacent to agricultural fields. This change led to the gradual expansion of forest cover leading up to agricultural abandonment, (see the left half of Fig. 8). By the mid-1990s increased outmigration and resultant labor shortages began to force farmers to cease agricultural activities. These events were followed by further expansion of forest cover in predominantly agricultural areas; however, this phase included the afforestation of former agricultural fields (see the right half of Fig. 8).

Afforestation on private lands was rarely unmanaged. Before CF management, our 40 study sites averaged 12.5% (SD: 12%) forest cover. To address forest resource shortages due to degradation, CF user groups heavily restricted fodder, firewood, and timber extraction from community forests over the first five to 10 years of management and encouraged their users to plant or nurture trees on their private land to provide alternative sources for timber, fodder, and firewood. Land managers across our study sites reported that these activities contributed to forest cover gains that preceded agricultural abandonment. A manager reported:

"When the community forest was established and people saw what it could do, they started to plant forest resources in their own private land. Now that we grow our own resources, things have become much easier, and we no longer need to travel long distances." Devithan area 3, February 2020

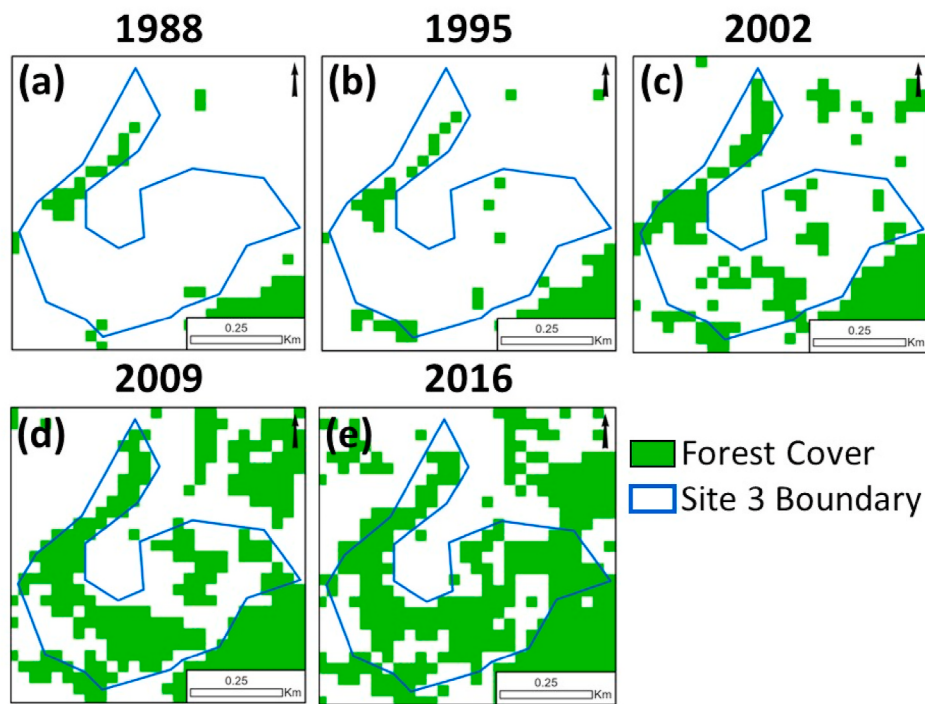


Fig. 7. The spread of forest cover across Site 3 of the Devithan cluster from 1988 to 2016. Source: Boundaries and forest cover data from this study's satellite image analysis.

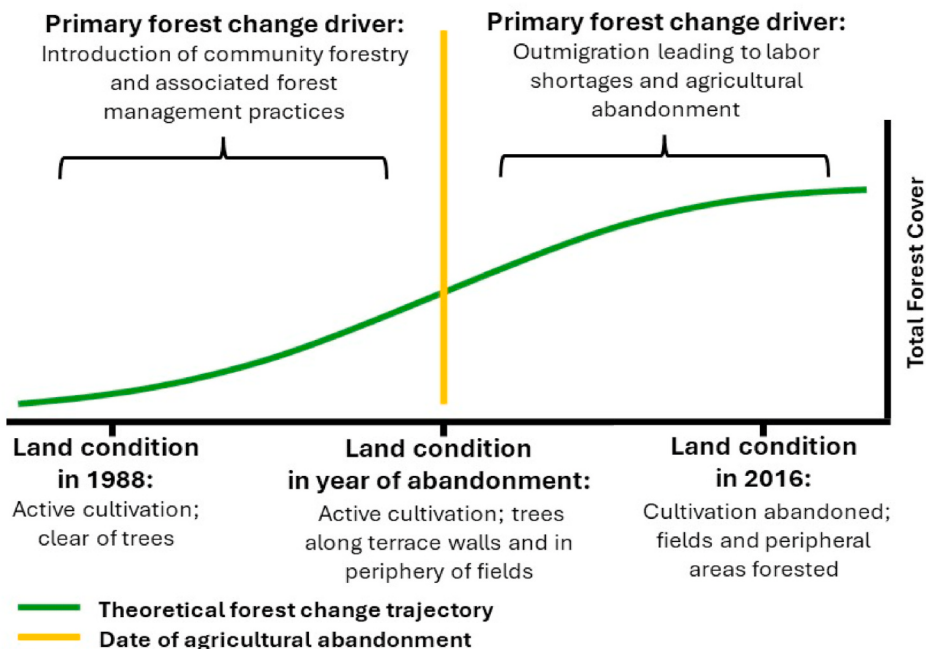


Fig. 8. Conceptualization of forest cover change and associated drivers on private land in rural Nepal. The transition from agricultural fields to forest was first driven by the introduction of community forest management (left side) and then driven by agricultural abandonment (right side).

Private landowners also shifted from open grazing of livestock on private land to gathering fodder and stall feeding, a practice started following the introduction of CF management, to prevent goats and cattle from indiscriminately consuming new vegetation growth. This action removed one of the main factors hindering the growth of shrubs and trees on private land. A land manager reported:

“Banning open grazing led people like me to plant different species of grass and shrubs that were good for livestock. We got these new plants from government nurseries and were able to grow sufficient fodder for our livestock. Planting new vegetation and stall feeding our livestock led areas around our farm to slowly become forested.” Khortali area 7 March 2020

Land managers grew forest resources on private land using seedlings

from government and community nurseries. Seedlings were planted on grazing pasture and adjacent to terraced fields, and homesteads. In the one to 19 years (mean: 10) after CF management and before agricultural abandonment, forest cover rose by an average of 32% (SD: 16.5%) across study sites. Afforestation during this time occurred around, not within, agricultural terraces, indicating a complementary livelihood strategy. In all 40 sites, private landowners managed small wooded areas to produce fodder, firewood, and lumber to supplement supply from surrounding CFs. A manager noted:

"The middle third of my land was not very productive for farming or grazing, so I converted it to private forest. Now I have fodder to feed my cattle, and I can make compost fertilizer for my fields. Using my own land to grow forest resources helps supplement what I get from the CF." Devithan area 11, February 2020

Informants reported that by the late 1990s, community members started to migrate to urban areas in Nepal and overseas for work. Initially, migrants returned during planting and harvesting seasons to support their family's farm. Over time, as the labor pool shrank, farmers gradually stopped growing grain, vegetables, and cattle on their private land and looked for less labor-intensive alternatives.

"We used to have enough manpower to farm as much as we could. Slowly the loss of manpower reduced what we could farm, and we let the forest grow up and we planted the species we found useful. We can utilize these forest resources even though we don't have as many people to work as we did in the past." Charnawati area 9, February 2020

In addition, those who remained found it challenging to make a living as a farmer because it was difficult and expensive to hire seasonal farm laborers. A farmer described the economics in this way:

"This area is hilly, the soil is poor and we don't have good irrigation systems. So the food production was quite low. On top of that, there is also a lack of manpower now. One can earn 1000 rupees [Nepali currency] per day working in construction. If you farm and have to hire a person and pay him 1000 rupees a day, by the end of the year, there won't be enough crops to even profit 500 rupees. So you would suffer a huge loss." Charnawati area 3, February 2020

In contrast, migrant remittances can sustain a family. Labor costs and remittance income influenced land use decision-making at all 40 sites. Landowners said remittance income is typically used to pay for forest resource replacements such as cooking gas to replace firewood, cement to replace lumber, gas-powered tillers to replace ox-drawn plows, and imported chicken feed to replace livestock that relied on forest fodder. Out-migration and agricultural abandonment, remittance income, and forest resource alternatives lower local demand for forest resources leading to additional forest cover gains in the 2000s. A landowner stated:

"The financial status of my community has improved a lot, our sons and daughters working different jobs abroad send money through remittances. Many people like me use gas stoves and almost everyone has access to electricity, so we can use various electrical appliances. Because of these reasons, these days, people like me hardly go to the forest to collect forest resources." Khortali area 1 March 2020

At the start of agricultural abandonment, the average forest cover in our study sites was 42% (SD: 18.5%). By 2016 average forest cover across study sites reached 59% (SD: 15.5). Abandoned agricultural fields and pastures transitioned to forest cover in three ways: natural afforestation, guided afforestation, and afforestation through agroforestry. With natural afforestation, trees, and other vegetation grew back from the existing seedbed after grazing and cultivation ceased. Natural afforestation was described as follows:

"After people stopped farming, first bushes started appearing and then the plants started growing and after that, those plants turned into the trees

and that's how the forest was formed; that's how the change occurred." Charnawati area 9, March 2020

In some naturally afforesting areas, farmers guided the process to favor forest resources they considered most valuable. Pastures and terraces were actively managed for timber and fodder species by clearing away competing vegetation and restricting grazing. A landowner stated:

"We let the forest grow naturally, but, based on our knowledge of the plants and trees that grow in this region, we chose to keep the species that would benefit us in the future and clear out the ones that wouldn't benefit us." Devithan area 3, March 2020

Afforestation with tree farms or mixed agroforestry systems was the most common pathway. Typically, landowners planted pine or alder, both fast-growing species well suited for the area. Alder was often paired with shade-tolerant cardamom, a cash crop.

"We planted species that were suitable based on the soil, water, and location. Some places we planted reeds, others bamboo or pine trees. We managed the land depending on our needs." Khortali area 16, March 2020

These pathways operated on a continuum. A naturally afforesting plot, for example, may also include bamboo or alder planted on the edge, or an area afforested with alder may have significant natural shrub and tree growth in the understory. Forest management may also change over time, with some areas shifting from natural afforestation to more intensive management and vice versa. Local demand, the market price for forest resources, and the cost and availability of labor all influenced management decisions. Timber farming remains an appealing land use because it requires minimal labor inputs. Landowners who harvested their trees sold them to nearby sawmills and companies, which provided the personnel, trucks, and machinery needed to harvest, transport, and process the trees into plywood, timber, and furniture.

While overall forest cover rose after agricultural abandonment, forest change trends diverged over the last five years of the research (2011–2016). Forest cover increased or stabilized in 23 of 24 sites in Charnawati and Devithan (Figs. 4 and 5), averaging 65.5% (SD: 13.5%) by 2016. Land managers plan to continue to invest in timber production due to labor shortages. Increases in wildlife crop-raiding since the late-2000s will likely further contribute to agricultural abandonment and afforestation. A landowner stated:

"The wild animals come and eat our crops in the field. The monkeys will even enter our homes and eat all the harvest goods that we have collected and stored. They will even carry away a pot full of cooked rice. Because of these problems, many people are compelled to quit farming and plant trees. They hope to get some income from those trees in the future rather than getting their crops destroyed by the wildlife and getting nothing." Charnawati area 3, March 2020

Khortali's forest change patterns have diverged from those in Charnawati and Devithan since 2010. Between 2011 and 2016, forest cover increased or remained stable in 10 of 16 Khortali sites, with an average of 55% (SD: 11.5%) in 2016. In six sites, forest cover dropped by 3% per year from 2011 to 2016, reaching 41.5% (SD: 9.5%) by 2016 (Fig. 6). Forest cover declined in Khortali due to development in and around Charikot, the region's major urban center. Charikot has become a center for education, business, healthcare, and tourism leading landowners to clear agricultural fields that afforested to make way for road and building construction or for a return to cultivation with cash crops (e.g., cauliflower, green beans, tomatoes) for sale in urban markets.

4. Discussion

4.1. Linking afforestation and its drivers on private land

Overall, 37% of forest cover gain between 1988 and 2016 occurred

on private land in Devithan, Charnawati, and Khortali study areas; the remaining 63% was documented in neighboring community forests. While the literature on forest change in Nepal has largely focused on areas under CF management (Niraula et al., 2013; Oldekop et al., 2019; Tripathi et al., 2020; Wagle et al., 2020), our findings suggest that former agricultural areas are a larger source of increased forest cover than previously understood. These findings fit well with the broader literature on agricultural abandonment and forest change in similar ecosystems which document the vulnerability of agricultural areas to abandonment (Haddaway et al., 2014; Subedi et al., 2022; Verma et al., 2021), forest cover increase (de Rouw et al., 2023), and the complex, often contextually dependent drivers of abandonment and forest change in mountainous environments globally (Benayas et al., 2007; Prishchepov et al., 2021; Verma et al., 2021).

The integration of land cover, land use histories, and annual forest cover data confirm and complicate what is known about forest cover expansion in former agricultural areas. Land managers corroborated satellite-derived trends attributing early forest cover expansion to CF management and subsequent increases to agriculture abandonment. Annual forest cover and interview data helped us identify how CF management and agricultural abandonment influenced forest cover change. These data provided clear evidence of the long-term influence of CF and abandonment on forest cover following their introduction. Our interview data suggest it is misleading to assume the intended use and associated drivers of satellite-detected land cover changes without also examining ground-truthed data. For example, field visits and interview data documented that areas we mapped as forests were still under cultivation, thus suggesting the land may have mixed-use and cover during the transition between agriculture and forest. Documenting the exact dates of this land use co-occurrence required field visits or detailed interview data that most locations lacked because the transition phase occurred five or more years before data collection in 2019–2020.

4.2. Land abandonment and afforestation dynamics on private land

In all 40 study sites, we documented the influence of CF management on forest cover expansion in privately managed agriculture areas. Existing research on CF management and forest cover change in Nepal (Gautam et al., 2002; Jackson et al., 1998; Niraula et al., 2013) has primarily documented forest cover change in areas under CF management. Our data suggest that adopting CF management influenced forest cover expansion in and around privately managed agricultural areas before agricultural abandonment occurred, an interaction not well documented in Nepal or globally. In Nepal Gautam et al. (2002), Niraula et al. (2013), and Tripathi et al. (2020) suggest that CF management contributed to the expansion of forest cover on private land but did not clearly link the start of CF management in government forests and subsequent forest cover gain on private land. In addition, work by Ordóñez et al. (2023) was one of the first studies to estimate the causal effects of CF management on land cover change. Increasing evidence exists that CF management can influence land cover and land use beyond CF boundaries; we suggest further study of the role collective action has played in these processes globally. Land managers across our 40 study sites uniformly identified forest conservation measures, especially CF management, as early, indirect drivers of forest cover expansion on private land. In addition to instituting CF management in government forests, Nepal's CF program encouraged land managers to supplement forest resources from their CF by growing fodder, firewood, and timber in marginally productive agricultural areas along agricultural terraces and in former pasture land. Outreach from the local District Forest Office and CF user groups, as well as independent initiatives from users who were inspired by afforestation and natural forest cover expansion in nearby CFs, led to significant local investment in afforestation on private land.

Our results also contribute to the literature on agricultural abandonment by documenting long-term afforestation trends following

abandonment. Earlier literature on agricultural abandonment in Nepal (Chhetri et al., 2023; Jaquet et al., 2015; Ojha et al., 2017; Subedi et al., 2021; Wagle et al., 2020) primarily documented increases in forest cover following abandonment of specific sites or measured landscape-wide forest cover gain during the 2000s and 2010s, a period of widespread out-migration and abandonment. In contrast, our use of spatially explicit agricultural plots, CF boundaries, and interview data, allowed us to document that substantial forest cover expansion occurred in agricultural areas before agricultural abandonment. Migration has been identified as a driver of land use and land cover change across the globe (Bell et al., 2010; Radel et al., 2019; Angelsen et al., 2020). Our research suggests this is the case in Nepal and that migration's impact on land cover change was enhanced by the presence of CF management. Although migration in Nepal has been generally associated with positive changes in the local environment (e.g., forest cover expansion), it has also been linked with patterns of degradation and decline (Hermans & McLeman, 2021). In addition, while existing research often frames abandonment and subsequent forest cover gain as passive processes (Jaquet et al., 2015; Ojha et al., 2017; Subedi et al., 2021), we documented how farmers purposely transitioned to timber production in response to labor costs and commodity prices and in reflection of the success of CF management, to which they contributed as CF users. It is important to note that in contrast to previous studies on agricultural abandonment and forest cover change, our research was conducted in areas where accurate CF boundary data were available, therefore allowing us to assess CF's impact on agricultural areas as well as to contrast overall forest change between areas under CF and private management.

4.3. Disentangling drivers and vulnerabilities to deforestation

We make additional contributions to the understanding of land abandonment and land cover change (de Rouw, et al., 2023; Mantero et al., 2020; Subedi et al., 2022) by documenting novel relationships between drivers of abandonment and afforestation. While we could not explicitly separate the impact of CF management and out-migration driven abandonment on forest cover change, land manager narratives suggest these drivers were not dependent on each other. CF management drove early forest cover expansion but not agricultural abandonment. Rather, land managers identified out-migration driven labor shortages as the primary driver of agricultural abandonment. Labor shortages also encouraged investment in timber production; a land use requiring minimal labor investments. While CF management mainly affected livestock pasture and marginally productive agricultural areas, and out-migration driven abandonment primarily affected highly productive terraced agricultural areas, the impacts of CF and out-migration were not limited to either marginal or highly productive agricultural areas.

While forest cover steadily expanded across our 40 study sites between 1988 and 2016, interview and annual satellite-derived forest cover change data show that these newly afforested areas are vulnerable to deforestation. This situation is unlike in surrounding CFs, where timber harvesting is strictly regulated. While from the early 1990s to the late 2010s, forest cover increased throughout all 40 sample sites, three diverse forest cover trends evolved over the last five years (2011–2016) of the study: 20 of 40 sites increased forest cover, 13 stabilized, and seven declined in cover. Although most sites increased or maintained forest cover through 2016, land managers were willing to adopt more profitable land uses if available. For example, forest loss due to urbanization and cash crop farming in and around Charikot suggests forest cover gains on private land are vulnerable to reversal. However, in 33 of 40 study sites, increased wildlife abundance and biodiversity, which are known to be associated with abandonment (Otero et al., 2015), have led to increased crop-raiding, contributed to agricultural abandonment, and will likely prevent or limit the re-introduction of traditional agriculture. Despite the potential for change, our findings indicate that most abandoned and forested regions will likely remain so. This conclusion is

consistent with earlier research looking at land abandonment across the globe, reporting that abandoned agricultural sites are often less productive and rarely recultivated (Corbelle-Rico et al., 2022).

4.4. Policy implications

Our results identify the need for policies that recognize the vulnerabilities and role of afforestation outside CFs. For example, timber farming has become an alternative income strategy for persons who have abandoned traditional farming. Land managers would profit from policies that encourage monetizing existing timber resources and investing in new modes of commercial forestry. Policies and technical assistance to help private forest owners sell their timber could also be integrated with initiatives to boost commercial harvesting in community forests. Lack of road access required to carry timber to market will exclude some locations from commercial timber farming. Therefore, some areas may have difficulty monetizing timber production. Finally, despite widespread agricultural abandonment, local food is still in demand, but wildlife crop-raiding has made it difficult to grow most food crops in some locations. We suggest financial and technical support for wildlife exclusion around farms, the introduction of wildlife-resistant crops, and wildlife population management where needed.

4.5. Study limitations

This study has several limitations. First, while we only sampled 40 sites in one region of Nepal, we believe our findings are broadly applicable in areas where CF management and labor shortages are present. Our findings, however, may be less applicable at locations near major urban centers like Kathmandu, Pokhara, or Narayangarh, or in areas where farming is more easily mechanized, thus negating the impact of out-migration on agriculture. Second, mapping forest cover change in small forested patches in a diverse landscape is challenging. The duration of our study and the clear long-term forest change patterns we observed bolstered the reliability of our results. This approach might not be as reliable for detecting small overall changes in forest cover over short time periods. We also omitted small areas of forest gain that were less than 1 ha. Third, we were unable to cross-check the abandonment date provided in interviews. High-resolution satellite imagery was only available since 2009, and historical land use records were unavailable. However, we cross-referenced the abandonment date with social and political events (e.g., the 2008 constitutional elections) and study site observations (e.g., the general age, condition, and composition of trees at each site) during interviews to verify the dates. Fourth, while we could link forest cover changes to CF management and out-migration driven agriculture abandonment, we could not completely separate the impact of these drivers. This issue created uncertainty about the total proportion of forest cover attributable to each factor and the impact of each on forest cover change if only one driver was present. Finally, climate change is predicted to have a negative impact on mountainous forests globally (Albrich, Werner & Seidl, 2020; Forzieri et al., 2022), however, its impact on CF forest cover in Nepal has not been well studied but is predicted to have a negative impact (Paudel et al., 2021).

5. Conclusion

This study contributes to global research on agricultural abandonment and forest cover change in Nepal but is likely relevant to other locations, particularly mountainous regions in developing countries. We provide place-based understandings of the extent, rate, current, and likely future forest cover trends in former farming areas and the reasons and processes that led to those changes. Additionally, we document the influence of government forest policies, out-migration, and livelihood changes in encouraging afforestation in privately managed former agricultural areas.

In our 40 study sites, forest cover increased six-fold between 1988

(23 ha) and 2016 (128 ha) on private agricultural land. 37% of our study area's forest cover gain was on private land, while 63% was in community forests. Interview data point to two dominant, albeit indirect, drivers of forest cover expansion on privately managed lands: CF management and out-migration driven agricultural abandonment. CF management encouraged local land managers to afforest or nurture natural forest expansion on their private agricultural land to supplement CF forest supplies. Agricultural abandonment occurred after CF management was introduced in nearby forests and resulted from labor shortages driven by out-migration. Farmers guided the shift from agriculture to forests by managing for firewood, forage, lumber, and other marketable forest resources and removing undesired species. While land managers predict a continued expansion of forest cover on private land, these newly forested areas are vulnerable to deforestation. Land managers are willing to clear forests if more profitable land uses emerge. Our findings highlight the importance of investing in forest management policies and local forest department administrative capacity that supports income generation and forest conservation in emerging private forests.

CRedit authorship contribution statement

Alexander C. Smith: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Reem Hajjar:** Writing – review & editing. **Keshav R. Kanel:** Writing – review & editing. **Jefferson Fox:** Writing – review & editing, Resources, Funding acquisition. **Sumit Tuladhar:** Project administration, Investigation, Data curation. **Jamon Van Den Hoek:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Data curation.

Declaration of competing interest

None.

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Appendix A. Supplementary data

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