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The role of smallholder woodlots in global restoration pledges – Lessons from Tanzania

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ABSTRACT

In the past decade, concern for forest loss has spurred ambitious restoration goals for climatic, ecological, and livelihood benefits. Restoration activities typically rely on government-led or large-scale tree planting. A narrow focus on top-down initiatives could promote the recentralization of forestry activities and overlook important contributions by smallholders, especially in Africa. Smallholder tree planting activities are harder to track than institutional efforts. Here we quantify the extent of tree planting on smallholder woodlots in southern and eastern Tanzania, in comparison to large-scale plantations. In Google Earth Pro, we digitized all woodlots in randomly selected areas, and estimated woodlots' area, distribution, and expansion rate. We found that by year 2018, woodlots in the smallest size class (< 1 Ha) made up about half of the overall tree planting extent, covering an area equivalent to the government and corporate plantations. What's more, smallholder woodlots have been planted more recently: 54% of the digitized samples were planted between 2012 and 2015, a sign of woodlots' rising prominence. The vast majority of all planted trees were non-native pine and eucalyptus. Thus far, Tanzanian smallholders are planting trees in response to regional timber demand. Subsidies or incentives linked to global restoration goals could encourage more diverse planting and longer harvesting cycles. Given African countries' recent massive restoration pledges (e.g., Tanzania's 5.2 M Ha), we recommend explicit incorporation of smallholder tree planting to maximize livelihood and governance benefits.

1. Introduction

Deforestation in much of Africa continues to adversely affect climate and ecosystem services (Curtis et al., 2018; Foley et al., 2005). Efforts to halt deforestation must address the wellbeing of local land users, particularly vulnerable smallholders (Adams et al., 2004). In fact, many global initiatives (e.g., Paris Accord, Aichi Targets, New York Declaration on Forests, REDD+) explicitly pledge to protect the rural poor while reducing deforestation (Laestadius et al., 2015). This concern for the poor persists as many global environmental initiatives shift their attention to landscape restoration and the re-establishment of forests' ecological functions (Fagan et al., 2020; Laestadius et al., 2015). Recent global restoration initiatives promote tree planting as a way to create ecological and economic benefits due to trees' capacity to sequester carbon, stabilize soils, and improve incomes (IUCN and WRI, 2014; Miller et al., 2017). Critics of this approach warn that expanded tree-cover should not be equated with social or ecological improvements (Chazdon, 2008; Malkamäki et al., 2018; Veldman et al., 2015). Missing in the debate, particularly for Africa, is empirical evidence on how tree-planting in the name of landscape restoration affects local ecosystems and land users (Fagan et al., 2020). In this paper, we use Tanzania as a case study to look more specifically at how existing smallholder tree planting activities could align with global restoration goals.

Tree planting, including planting woodlots, is a core restoration pathway as stipulated by international landscape restoration guidelines (IUCN and WRI, 2014; Sabogal et al., 2015). Reported activities for initiatives like the Bonn Challenge have largely relied on broad-scale, government-led tree planting (Guariguata and Brancalion, 2014; Murcia et al., 2016). As of 2018, six tropical countries have reported performing restoration on a total of 12.6 M Ha, with > 90% implemented via large-scale tree planting led by governments and NGOs (Borah et al., 2018; Dave et al., 2017).

So far, most countries have responded to the global initiatives by making national restoration pledges in terms of land area (Fagan et al., 2020). Most national pledges do not explicitly define *where* the

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restoration will take place or *who* will perform the restoration of the pledged lands. African countries, for example, have pledged extensive areas for restoration, even exceeding AFR100 goal of 100 M Ha (WRI, 2018). Reported activities thus far show that restoration via tree-planting can take several forms depending on the actor and scale of implementation. In this paper, we distinguish *plantations* and *woodlots* from the more general *tree-planting* activity. *Tree planting* encompases all any tree planting activities, at any scale (IUCN and WRI, 2014). *Plantations* will refer to broad-scale tree planting by a private corporation or an NGO either on purchased land, or on land provided by the government (e.g., in India see Borah et al., 2018). *Woodlots* will refer to smallholder tree planting for firewood, timber, or fruit on their private land, often in small landholdings (< 5 Ha) (e.g., in Rwanda, see Dave et al., 2017). Even though all of these activities have taken place, the *plantations* approach is more common. Smallholder activities are more difficult to coordinate and monitor; thus, so far, they have played a less prominent role in reported restoration activities (e.g., Rwanda's report in Dave et al., 2017).

In short, restoration initiatives are unfolding in a way that will likely privilege larger actors thereby raising three governance concerns. First, the initiatives could promote forest governance recentralization, a setback after nearly three decades of transitioning to decentralized forest management to allow local citizens increased rights and responsibilities (Phelps et al., 2010). Second, large-scale tree planting by international companies has been associated with negative social outcomes including land alienation, loss of previous livelihood options, and disruption of social structures (Malkamäki et al., 2018); with additional criticism as land grabbing and ‘carbon colonialism’ when undertaken by organizations from the global north (Lyons and Westoby, 2014; also see response by Fischer et al., 2016). Third, tree-planting initiatives are presently inattentive to already ongoing bottom-up activities in the form of wide-spread smallholder woodlots, which, if better understood, may have the potential to support broader restoration goals (Nawir et al., 2007).

Smallholders in many parts of the world plant woodlots without global pledges in mind. There is presently a surge in woodlots in some developing countries (e.g., in Vietnam (Nawir et al., 2007), India (Mather, 2007), Indonesia (Torbick et al., 2016), Uganda (L'Roe and Naughton-Treves, 2016), and Ethiopia (Jenbere et al., 2012)). Some countries like India, Vietnam, and China have actively promoted smallholder tree planting (Borah et al., 2018; Frayer et al., 2014; Nawir et al., 2007). In other cases, woodlots have expanded simply in response to regional demand as forest resources become scarce (Mather, 2007; Rudel et al., 2005). In East Africa, the proximate driver of woodlot expansion is the increased demand for timber and fuel wood due to rapid urbanization and population growth (Held et al., 2017; Indufor, 2011; Jacovelli, 2009). The proportion of citizens living in urban areas in Sub-Saharan Africa nearly doubled between 1995 and 2015, and with it the demand for trees for construction timber, charcoal, and firewood (AfDB et al., 2016). In Tanzania, the increased tree products demand occurred while government tree plantations were facing reduced productivity (Ngaga, 2011). As a result, large-scale private plantations and smallholder woodlots have both expanded (Degnet et al., 2018). The recent expansion in woodlots in parts of Tanzania has been called a ‘Timber Rush’ to acknowledge how the growing timber demand has stimulated rural tree planting along with small-scale timber supply enterprises (Friis-Hansen and Pedersen, 2016; Koskinen et al., 2019). The increased demand for poles for rural electrification projects in Uganda, Tanzania, and Kenya has also spurred entrepreneurial growing of large-diameter eucalyptus logs (FDT, (Forestry Development Trust), 2015). As a result of these market forces, smallholders favor fast-growing species of pine, eucalyptus, cypress, or teak that have rapid returns (Arvola et al., 2019).

Despite these observations of increased smallholder tree planting activities, accurate quantifications of woodlot extent and expansion rates are uncertain. The estimates are uncertain because land use outcomes of many individual smallholders are harder to track than the actions of large institutional actors. For example, the Tanzanian government official reports estimated 0.15 M Ha in smallholder woodlots (FBD, 2011) but others reported 0.18 M Ha (Indufor, 2011) to 0.42 M Ha, (Said, 2016). To generate these statistics, the government relied on municipal foresters' estimates (Ngaga, 2011) or extrapolations from market studies (Indufor, 2011). Newer studies after 2012 have used remote sensing and shown that smallholder woodlots could be between 0.23 and 0.33 M Ha (FDT, (Forestry Development Trust), 2013; Koskinen et al., 2019). These remote sensing maps are one-time observations from years 2013 and 2015. Due to the inherent limitations in spatial and temporal resolution of satellite data, the maps exclude young woodlots and do not describe temporal trends in woodlot establishment. Aggregated to a global level, it is therefore unsurprising that available statistics tend to underestimate the extent of smallholder woodlots (Torbick et al., 2016).

Enduring uncertainties in smallholder woodlots trends could mean missing opportunities for more inclusive landscape restoration policies. Given the ambitious global targets for attaining climatic, ecological, and livelihood benefits via restoration and tree planting, the contribution of smallholders needs to be more explicitly considered. In this paper we present systematic data on the extent, spatial patterns, and temporal trends of smallholder woodlots in Tanzania. Specifically we ask:

1) How do smallholder woodlots compare with government and large-scale plantations in terms of overall extent and regional distribution?
2) Have smallholder woodlots expanded in the landscape in recent years?

We evaluate the results in the context of Tanzania's pledge of restoring 5.2 M Ha of degraded lands by year 2030. We hope our findings inform the potential contribution of smallholder tree planters in national and international landscape restoration campaigns, especially in African countries.

2. Methods

2.1. Study area

We assessed the extent of tree planting in Tanzania, a country that has made a restoration pledge under the AFRI100 initiative of the Bonn Challenge to restore 5.2 M Ha (WRI, 2018). Within Tanzania, our focal study area drew from samples in three regions: the Northern Zone, the Eastern Arc mountains, and the Southern Highlands (1–9°S; 33–38°E) (Fig. 1). We selected the three regions to encompass areas suitable for tree growth. Ecologically, the selected regions have strong climatic gradients driven by elevation changes, with rainfall generally increasing with elevations (up to 2000 mm/yr in the Southern Highlands) (Fick and Hijmans, 2017). High rainfalls and moderate temperatures create suitable environment for tree establishment, with some locations capable of attaining rapid tree growth (mean annual increments up to 60 m^3/ha/yr (Jacovelli, 2009)). The potential for tree growth is evidenced by the presence of remnant montane forests (~ 0.5 M Ha; ~ 3% of study area); some of which are strictly protected and important biodiversity hotspots (Burgess et al., 2007; Newmark, 1998). Even though some illegal logging still occurs in the strictly protected humid forests (Persha and Blomley, 2009), widespread montane forest loss is not contemporary: the majority of the forest conversions that created present-day agriculture mosaics adjacent to the protected forests likely occurred 200–300 years ago (Newmark and Mcneally, 2018).

The study areas share a history of tree planting by three types of actors: central government agencies, private companies, and smallholder residents (Ngaga, 2011). In fact, 65% of Tanzanian government tree plantations are located in our study area (Fig. 1), with the

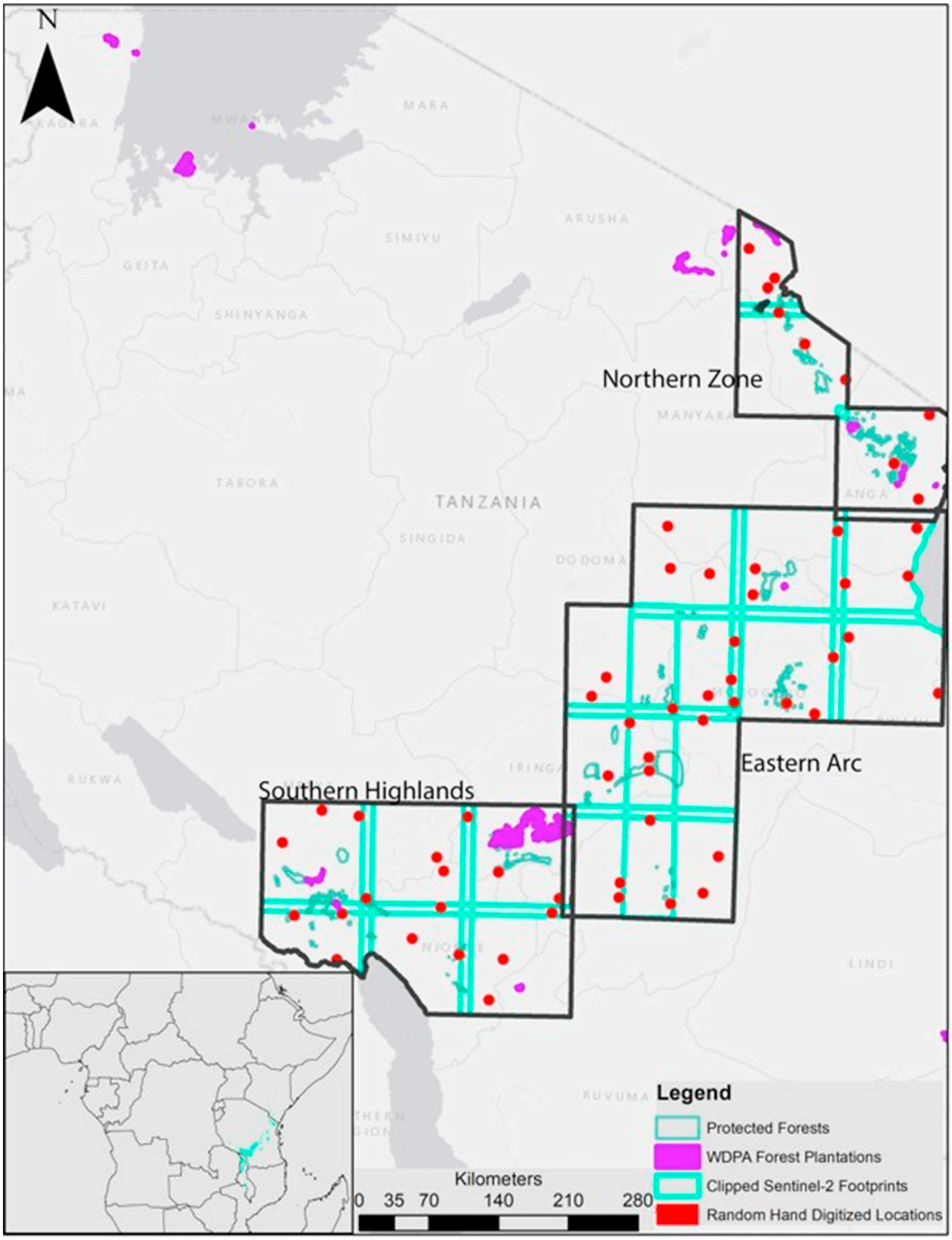

Fig. 1. Study site indicating woodlots digitization locations: 60 randomly placed circles of 100 km^2 each. The site covers the Southern Highlands, the Eastern Arc Mountains, and the Northern Zone of the Rift ecoregion to optimize for areas that are suitable for trees. The context map (bottom-left) shows the Rift ecoregion in Tanzania.

government plantations often abutting, and managed in conjunction with, adjacent natural forests (Jacovelli, 2014). The management of natural forests and government plantations in these humid ecoregions is thus different from the community-based or joint government-community forestry found in drier ecoregions like the miombo woodlands (Matose and Wily, 1996; Persha and Blomley, 2009; Wily and Mbaya, 2001). Additionally, in the past 30 years, private companies have established plantations as well, most of them in the Southern Highlands (Degnet et al., 2018; Indufor, 2011), a trend also seen in other African countries. Smallholder farmers have long established small woodlots, especially in areas located adjacent to the large-scale plantations and tea plantations (Ngaga, 2011), with empirical field studies suggesting additional expansion starting around year 2010 (Friis-Hansen and Pedersen, 2016).

2.2. Data

2.2.1. Hand-digitized woodlots in randomly selected locations

To estimate the extent and distribution of woodlots, we generated a random sample of the study area, and digitized all woodlots within the sampled area via image interpretation on Google Earth Pro. Our visual interpretation method is similar to Petersen et al. (2016); separating woodlots from natural forests using woodlots' distinct visual characteristics in terms of color, texture, and the regular shape of man-made land cover. Visual interpretation of Google Earth imagery is commonly used for collecting training points for classification (e.g., Koskinen et al., 2019). However, some studies have used Google Earth Pro for tree cover quantification in hard to classify areas like drylands (Bastin et al., 2017). In our method, we combined the visual interpretation with random sampling design to be able to estimate overall woodlot area. Definitions of 'woodlot' vary: here we used a commonly accepted one in the East African context that refers to a small (< 5 Ha) uniformly-aged patch of trees that is grown for timber, firewood, and/or fruits, and is clearly planted (Kimambo and Naughton-Treves, 2019; Ngaga, 2011). We did not digitize natural forests.

The random sampling locations were selected using QGIS Random sampling tool, generating three random points per footprint for 20 Sentinel-2 footprints (to be used in a future analysis). This created a total of 60 sampling circles of 0.01 M Ha, each centered on the random point, for a total sample area of 0.6 M Ha, or 3.2% of the study area.

In each random circle, we hand-digitized all woodlots visible in the most recent Google Earth Pro imagery at the time of digitization (year 2018). The availability of up-to-date high-resolution Google Earth images varied by location, with some areas' most recent image dating back to the early 2000s. Thus, we recorded the date the image was acquired and the age category for the woodlot. A unique woodlot was delineated by visual evidence for borders such as fire breaks and farm boundaries (See S 1 for woodlot digitization and age category protocol). Additionally, we placed areas of uniform age and uniform tree texture in unique woodlots and assigned the woodlot an age measure of: "Young", or "Intermediate", or "Mature", based on the tree density. The "Young" category are woodlots with sparse tree density in which round tree crowns and the linear planting texture is still visible; while the "Mature" category indicates dense woodlots where the tree canopy has closed.

2.2.2. Large-scale institutional (government, private corporation) plantations

To quantify the extent and characteristics of the institutional plantations in our study area, we relied on previous publications, the World Database of Protected Areas, and the Tanzania Forestry Services (TFS) GIS department (TFS, 2012). The published reports and the databases, and TFS records each give slightly different acreage for the extent of large-scale institutional plantations. The different acreages result from conflating the extent of the entire management area of a plantation which can include tree-planted areas and areas that are not actively planted with trees. We distinguish these values whenever possible and put together actual extent of large-scale plantation tree cover in the study site.

2.3. Analysis

2.3.1. How do smallholder woodlots compare with government and large-scale plantations in terms of overall extent and regional distribution?

To compare patterns of smallholder woodlots to those of large-scale plantations, we first determined the spatial patterns of smallholder woodlots, and then compiled statistics for large-scale plantations in the study area. We calculated the mean woodlot area for the digitized samples. To check for robustness of our area estimate, we calculated the confidence interval of the mean woodlot area for a probability of 95% by bootstrapping, using the "boot" package from R (Canty and Ripley, 2017). The bootstrap generated 2000 replicates of the same sample size as our data and calculated the mean statistic for each. We calculated the confidence intervals for the mean woodlot area from the bootstrap; using the bias-corrected and accelerated (BCa) method (See S 2 for R code for replication). We report the mean, the upper-bound, and the lower-bound estimation of woodlot area for the samples, then proportionally scale the values to the rest of the study area.

We calculated the size class distribution of the digitized woodlots to infer the possible actors involved in tree planting (eg: smallholder, medium-scale, or large scale). We group the digitized woodlots into 4 size classes: < 1 Ha, 1–5 Ha, 5 -10Ha, and > 10 Ha. We report the contribution of each of the size classes to tree planting extent.

Evaluating the spatial distribution of woodlots is helpful for identifying locations with tree planting momentum, and those where the activity has just begun. Since woodlots may be clustered at a regional scale, we evaluated the spatial distribution of the woodlots within regions. We report the density of woodlots (measured as number of woodlots in per sample) by region: Northern Zone, Eastern Arc and Southern Highlands. We use the density and the distribution of woodlots within samples to describe spatial patterns of woodlots.

Large-scale plantations: To compare the relative contribution of smallholders versus the large-scale institutional plantations to tree planting in the study area, we generate the extent of these institutional large-scale tree plantations by compiling literature values. We report the range of literature values for the extent of large-scale plantations in the study area. We identify the specific locations in our samples that are large-scale institutional plantations. We compare characteristics (average woodlot size, age, and woodlots distribution) between smallholder samples and institutional samples.

2.3.2. Have smallholder woodlots expanded in the landscape in recent years?

To determine if woodlots are an emergent trend, we characterized the present-day age-composition of the digitized woodlots. Google Earth Pro images do not have the same observation date, so the digitized woodlots were a one-time snapshot of various woodlots at different ages and different years. First, we describe the distribution of the woodlot ages by year and by sampling circles. Then, we adjust each woodlot's assigned age class to what it would be if observed in year 2018. Using imagery observation, we estimate that it takes two calendar years for a woodlot to transition from the "Young" to "Intermediate" or "Intermediate" to "Mature" categories (See S 3 for time-lapse). We report the adjusted age composition of the woodlots for the entire sample, and at the regional level (Northern Zone, Eastern Arc, and Southern Highlands).

To estimate the rate of expansion of smallholder woodlots area by year, we estimate planting date and calculate the proportion of woodlots planted in that year. We use the mean annual expansion rate as a possible increase in woodlot area per year, and project the expansion for the duration of the Bonn Challenge pledge (2018–2030).

3. Results

3.1. Small woodlots (< 1Ha) cover an area equivalent to institutional plantations

We found 7,372 woodlots in our sample of 60 randomly selected circles of 0.01 M Ha each. The total area and number of digitized woodlots was not normally distributed (Fig. 2), and 45% of the samples had no woodlots in them. Samples had a total amount of woodlots that ranged from 0 to 9%. (Fig. 2). Mean woodlot coverage in the samples was 0.6% (95% CI: 0.3–1.2%), thus the study area's woodlot extent was 0.11 M Ha (95% CI: 0.06–0.22 M Ha) (Table 1).

The majority of the digitized woodlots (91%) were < 1 Ha (Mean woodlot size is 0.5 Ha; range: 0.005 Ha to 75 Ha). The woodlots < 1 Ha contribute more to the overall tree planted extent than other size classes (mean: 0.3%; 95% CI: 0.1–0.6%) (Table 1). Woodlots > 10 Ha and those between 1 and 5 Ha each contribute at most 0.35% to the overall tree planting (mean: 0.12%, 95% CI: 0.03–0.35%) (Table 1).

Woodlots tended to be clustered at a regional level. The Eastern and the Northern Zones have samples with low density of woodlots, and some with no woodlots (average 11.8 and 19.6 woodlots per sample respectively; 47% and 25% of samples with no woodlots, respectively),

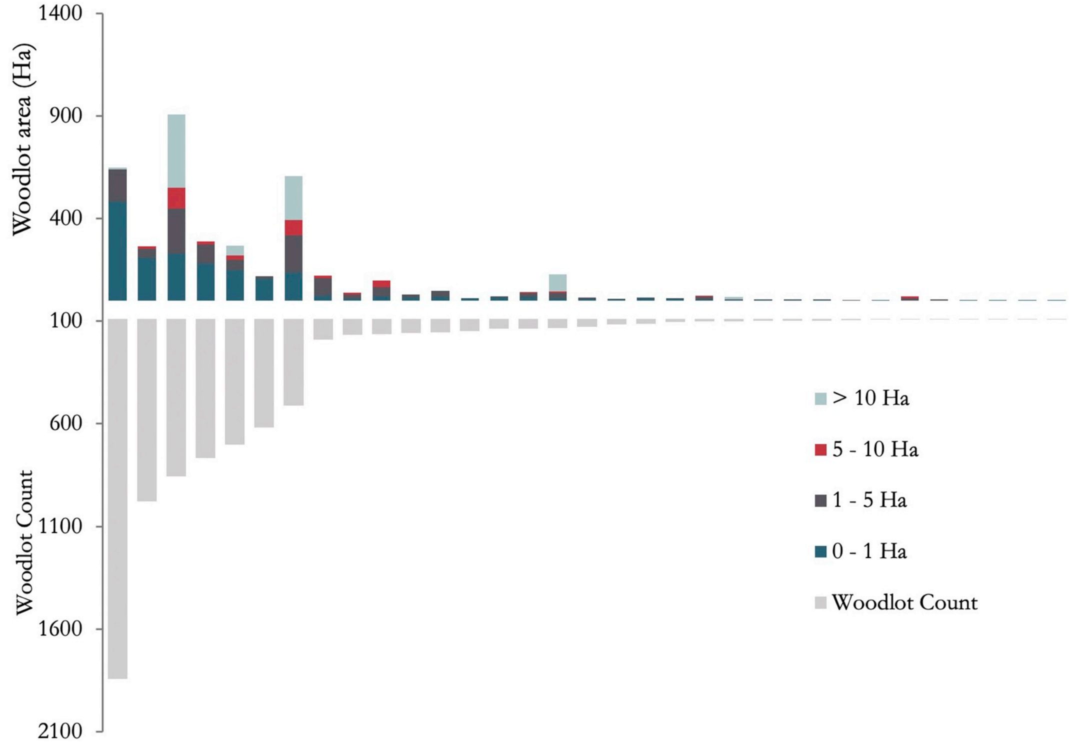

Fig. 2. . Top bar chart: Contribution of different woodlot size classes to the total woodlot area in each sampling location. Only sampling locations with woodlots are shown (n = 33). Different colors represent different woodlot size classes [< 1 Ha, 1–5 Ha, 5 -10Ha, and > 10 Ha]. Bottom bar chart: Woodlot count in each sampling location.

while the Southern region had high-density of woodlots (average: 306.5 woodlots per sample, 45% are samples with no woodlots). The 7 samples that contribute 90% of all digitized woodlots were all in the Southern region (Table 1).

From government reports and literature values, we found fifteen large-scale plantations in our study area (Fig. 1, Table 2) Eight belong to the government, and seven belong to private companies. The government plantations landholding covered a total of 0.11 M Ha, while the private companies' plantations landholding covered between 0.07 M Ha and 0.15 M Ha (Table 2). The government plantations in our study area represent 65% of all government plantations in Tanzania. The tree-planted areas differ from overall landholding size of the institutional plantations, since the overall landholdings also include: 1) areas for future expansion that have not been planted with trees yet, and 2) native forest patches that are managed alongside with the plantations. The actual tree-planted area ranges from a total of 0.1 M Ha to 0.13 M Ha (0.4% to 0.7% of the study area) with the government plantations accounting for 0.06 M Ha to 0.08 M Ha and private companies covering 0.04 M Ha to 0.05 M Ha. (Table 2). Our upper-bound estimation of the proportion of the landscape with woodlots < 1 Ha (0.11 M Ha; 0.6%) is equivalent to the landscape proportion of the government and corporate plantations combined (0.13 M Ha; 0.7% of the study area).

Digitized samples in areas with institutional plantations had larger, more contiguous tree planting areas than the samples that were in smallholder areas. Institutional plantations areas had woodlots in the largest size class, averaging 22.3 Ha per woodlot. The institutional woodlots also tended to be in the oldest size class (77% as "Mature").

Table 1
Estimated extent of woodlots for the entire study area, by each of the three sub-regions (Southern Highlands, Eastern Arc, Northern Zone) and by size the class of the woodlots. The range for each category (upper and lower bound values) is estimated by bootstrapping at a 95% confidence interval.

	Average woodlot count	Overall woodlot extent (Ha; (% study area))	Extent of woodlots < 1 Ha (Ha; (%))	Extent of woodlots 1–5 Ha (Ha; (%))	Extent of woodlots 5–10 Ha (Ha; (%))	Extent of woodlots > 10 Ha (Ha; (%))
Overall (*n* = 60)	120.9	114,863; (0.6%)	52,615; (0.3%)	32,662; (0.2%)	9096; (0.05%)	22,224; (0.12%)
Overall Range (min-max)	0–2006	55,585–224,892 (0.3%–1.2%)	26,810–110,880 (0.1% - 0.6%)	16,600–61,971 (0.1%–0.3%)	4080–21,057 (0.02%–0.11%)	5021–64,490 (0.03%–0.35%)
Southern Highlands (*n* = 22)	306.5	86,513; (1.5%)	40,378; (0.7%)	23,090; (0.4%)	6784; (0.11%)	16,242; (0.28%)
Southern Highlands Range	0–2006	43,005–168,823 (0.75% - 3%)	18,492–80,333 (0.3% - 1.4%)	10,959–42,976 (0.19% - 0.75%)	2564–16,117 (0.04%–0.28%)	1490–50,698[a] (0.03% - 0.9%)
Northern Zone (*n* = 8)	19.6	5696; (0.2%)	1198; (0.04%)	1529; (0.06%)	174; (0.006%)	2787; (0.1%)
Northern Zone Range	0–56	1034–18,286[a†] (0.04%–0.68%)	370–2521 (0.01% - 0.09%)	505–4104[a] (0.02%–0.15%)	0–349 (0%–0.01%)	0–8365 (0–0.3%)
Eastern Arc (*n* = 30)	11.8	8878; (0.08%)	3395; (0.03%)	3618; (0.03%)	997; (0.01%)	403; (0.003%)
Eastern Arc Range	0–80	4592–14,420 (0.04% - 0.13%)	1899–6356 (0.02% - 0.06%)	1730–7385 (0.02%–0.07%)	307–2281 (0.002% - 0.02%)	0–1167 (0% - 0.01%)

[a] Bootstrapping confidence intervals are unstable due to small sample size. See Discussion (4.1) for implications of clustering on confidence intervals.

Table 2
Extent and location of large-scale government and corporate plantations found in the study area.

Name of Plantation	Region	Year Established	Planted Area (Ha) (FBD, 2011)	Planted Area (Ha) (Ngaga, 2011)	Expansion Area (Ha) (Ngaga, 2011)	Planted Area (Ha) (Said, 2016)	Expansion Area (Ha) (Said, 2016)	Overall Area (WDPA, 2018)	WDPA Outline
Government Plantations									
Sao Hill	S.Highlands	1939	41,604	45,000	41,000	57,574	28,429	52,605	YES
Kiwira	S.Highlands	1960	2637	2784	45	2756	28	1782	YES
Longuza	E.Arc	1952	2450	2450	200	2073	267	2808	YES
Mtibwa	E.Arc	1961	1410	1410	75	2341	28	901	YES
Lusungulu	E.Arc	Proposed	–	–	–		9000	2236	YES
North Kilimanjaro (Rongai)	N.Zone	1926	6200	6754	200	6489	1075	8124	YES
Shume	E.Arc	1907	3804	4591	140	4353	72	15,637	YES
Kawetire	S.Highlands	1937	1956	1956	520	2911	798	4077	YES
Total (Government)			60,061	64,945	42,180	78,497	39,697	88,170	
Proportion of study area (%)			0.3	0.3	0.2	0.4	0.2	0.5	
Corporate Plantations									
Green Resources LTD	S.Highlands		12,000	12,000	70,000	18,352	18,420	–	NO
Kilombero Valley Teak Company	S.Highlands		8000	8150	1500	8200	7360	–	NO
New Forest Company	S.Highlands		1400	1500	4000	1500	9000	–	NO
Tanganyika Wattle Company	S.Highlands		14,000	14,500	–	14,656	904	–	NO
Mufindi Paper Mills	S.Highlands		3500	3600	30,000	6000	28,980	–	NO
Matelekeza Chang'a	S.Highlands			–	–	6000	520	–	NO
Unilever Tea (Tz) LTD	S.Highlands			–	–	–	–	–	NO
Total (corporate)			38,900	39,750	105,500	54,708	65,184	–	
Overall Total institutional			98,961	104,695	147,680	133,205	104,881		
Proportion of study area (%)			0.4	0.6	0.8	0.7	0.6		

The institutional plantations whose establishment dates are known were started several decades ago, with some dating to 1930s (Table 2). Within a sample, the institutional woodlots tended to be spatially contiguous; only separated by demarcated roads or fire breaks (the mean separation distance is ~ 86 m, which is 5 times smaller than the average width of the institutional woodlots, ~ 396 m). Smallholder woodlots < 1 Ha are on average 66 m apart; but the average width of each woodlot is 47 m. The smallholder woodlots tend to be separated by other land uses, creating a more heterogeneous landscape (Fig. 3).

3.2. Smallholder woodlots are rapidly expanding, with 54% of the digitized woodlots planted between 2012 and 2015

To estimate woodlot planting date, we adjusted the age of the woodlots based on the Google Earth Pro's image date. Without adjusting the woodlot age to the year in which we did the digitizing (2018), it is still evident that most tree planting is recent. 75% of the digitized woodlots came from imagery dated after year 2016, therefore the woodlot ages in those samples are reported as observed (Table 3). For those age-unadjusted woodlots, the age compositions are: Young: 27%, Intermediate: 31% and Mature 40% (Table 3; also see S3 for sample-by-sample distribution of imagery dates).

We estimate that more than half of the digitized woodlots were established after 2012 (Table 3). For woodlots < 1 Ha, this is proportionally equivalent to 0.08 M Ha in a period of three years (2012–2015). If we assume that smallholders will continue to plant trees at these observed rates, they may plant another 0.02 M Ha to trees in the duration of the Bonn Challenge (2018–2030), for a total woodlot extent of 0.4 M Ha. Thus, smallholder woodlots could contribute 7% to the country's overall restoration target, unaided. As the digitized woodlots averaged 0.5 Ha per woodlot, this expansion could represent 0.75 M individual woodlots, and thus potentially represent activities of hundreds of thousands of farmers. The estimated woodlot contribution could be higher since our analysis was not able to detect new woodlots in old satellite imagery, and if woodlots expand in an accelerating rate (See Section 4.1 of Discussion).

4. Discussion

Smallholders are active and emerging tree planters in Tanzania. The majority of the woodlots in the study area at the time of our study (year 2018) were < 1 Ha and planted between 2012 and 2015. The total extent of smallholder woodlots (0.6% of study area) is equivalent to that of institutional tree plantations (government + corporate: 0.7% of study area).

4.1. Estimating woodlots extent and expansion rate

Our mean estimate of the extent of tree planting exceeds area from earlier reports (e.g., Ngaga, 2011) but is smaller than in other recent studies, partly due to differences in scale and scope of analysis (Koskinen et al., 2019; Said, 2016). In terms of scale, our study randomly sampled a broad area, as opposed to targeting areas where tree planting is concentrated. Given that tree-planting at present is spatially clustered, and relatively rare, random sampling followed by a confidence interval calculation is the most robust approach even though the many null observations result in wide confidence intervals and risk underestimating the phenomena (McGarvey et al., 2016). We calculated that 0.6% of the study area was planted in trees, with an upper-bound estimate of 1.2%. Other studies (e.g., Koskinen et al. (2019)) have estimated woodlot and plantations extent of up to ~ 1% (0.24 ± 0.09 M Ha) in the southern Highlands of Tanzania. Our study area and Koskinen et al. (2019) differ slightly in scope, with a spatial overlap of 53%. The concordance in woodlot area estimates corroborates the approximate extent of tree planting activities in the region, while the differences highlight the sensitivity of landcover analyses to

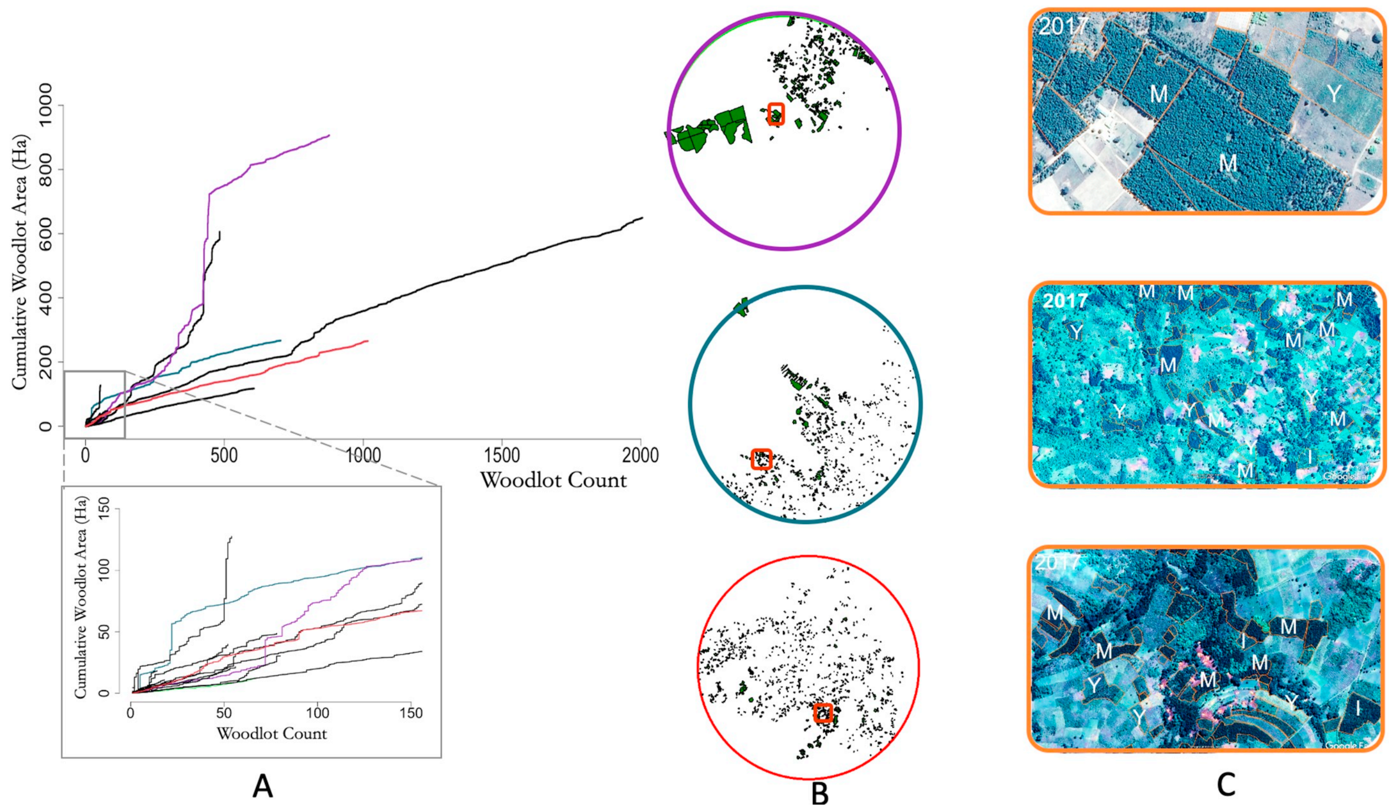

Fig. 3. A) Cumulative woodlot area for each of the randomly selected sampling locations. The curves are not normalized but describe within-sample woodlot size distribution; showing how different woodlot sizes contribute to total tree planted area. Plot inset shows sampling circles with few woodlots. B) Three examples (corresponding to the purple, the cyan and the red cumulative area charts) show the spatial distribution of woodlots . C) Digitized woodlots corresponding to the indicated squares in the sampling locations. "Y" indicates sparsest, youngest woodlots, "I" woodlots of intermediate age, and "M" densest, mature woodlots. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 3
The age of woodlots based on the observed image date on Google Earth Pro, and the observed age class for the digitized woodlot. The ages of woodlots from imagery after 2016 are reported as observed.

Observed Google Earth Image Date	Observed Age Class	Adjusted Age Class (to YR 2018)	Number of Woodlots	Estimated Planting Date
2008	Young	Mature	16	< 2011
2010	Young	Mature	2	< 2011
2011	Intermediate	Mature	3	< 2011
2011	Mature	Mature	6	< 2011
2011	Young	Mature	79	< 2011
2012	Intermediate	Mature	199	< 2011
2012	Mature	Mature	132	< 2011
2012	Young	Mature	286	< 2011
2013	Intermediate	Mature	17	< 2011
2013	Mature	Mature	65	< 2011
2013	Young	Mature	33	< 2011
2014	Intermediate	Mature	3	< 2011
2014	Mature	Mature	8	< 2011
2014	Young	Mature	34	< 2011
2015	Intermediate	Mature	19	< 2011
2015	Mature	Mature	29	< 2011
2015	Young	Intermediate	161	2012–2014
2016	Intermediate	Mature	74	< 2011
2016	Mature	Mature	129	< 2011
2016	Young	Intermediate	420	2012–2014
2017	Mature	Mature	2193	< 2011
2017	Intermediate	Intermediate	999	2012–2014
2017	Young	Young	2270	2015–2017
2018	Mature	Mature	1	< 2011
2018	Intermediate	Intermediate	4	2012–2014
2018	Young	Young	78	2015–2017

scale and scope.

The majority, 54%, of the woodlots were planted within a half-decade of our study year (2018). Smallholders have planted woodlots smaller than one hectare at an average rate of 20,000 Ha/year during 2012–2015. Ours is apparently the first attempt to measure the rate of woodlot expansion in the region by age and at a resolution < 1 Ha. Our analysis assumes that the young woodlots are newly established as opposed to being part of a harvesting-and-replanting cycle. Our assumption and our finding that woodlots are expanding rapidly are corroborated by field studies that document these trends (Friis-Hansen and Pedersen, 2016; Said, 2016). Nevertheless, the rate of woodlot expansion could still be an underestimate due to the difficulty of detecting very young and intercropped trees, as well as woodlots in locations with low image quality, and the lack of recent imagery in some locations (See S 4 for imagery acquisition years). The high-resolution Google Earth Pro imagery provided us an easily accessible data source for quantifying this fine-scale land use change, but the varied image acquisition date presented analytical challenges in terms of data gaps (Bastin et al., 2017).

4.2. Smallholders as an increasingly important actor in the tree-planting landscape

Across East Africa, woodlots are becoming more prevalent because of increased urban demand for timber, electric poles for rural electrification programs, firewood, and charcoal (Arvola et al., 2019; Kimambo and Naughton-Treves, 2019). Tanzania, for example, is forecast to have a deficit of 3.2 million m^3 in round-wood equivalent by 2035, a shortfall which will necessitate the tripling of extant plantations (Indufor, 2011). Market experts predict that these deficits will be met by smallholder woodlots, thus woodlots' extent will likely continue to increase (Arvola et al., 2019; Held et al., 2017). Woodlot expansion is likely to be concentrated in the regions' highlands and lake zones where ecological conditions are most suitable for tree growth (Jacovelli, 2014).

Although we could not differentiate among actors planting woodlots less than one hectare in size, we note that the blanket term of 'smallholder woodlots' conceals complex dynamics of who is planting woodlots. Sub-Saharan Africa is experiencing rapid changes in land ownership and distribution, in part due to the emerging land markets and new commercializing African farmers (Deininger et al., 2015; Hall et al., 2017; Jayne et al., 2015). Accordingly, citizens' ability to participate in tree planting depends on land access. Among rural farmers, those with more land and more off-farm income are more likely to establish woodlots (Jenbere et al., 2012; Kimambo and Naughton-Treves, 2019; L'Roe and Naughton-Treves, 2016). Furthermore, local institutions such as churches and schools as well as urban-based entrepreneurs also look to woodlots as an economic opportunity and contribute to the expansion of rural tree planting (Lusasi et al., 2019). There is more heterogeneity in the motivations and actions of the woodlot planters than is suggested by the small woodlot sizes.

4.3. What is the role of smallholder woodlots in international landscape restoration initiatives?

Thus far, local markets, not international initiatives, are spurring Tanzanian smallholders to plant woodlots. Nonetheless, it is worth exploring the means by which pledging countries could benefit from, and support smallholder activities. Of the set of international initiatives promoting tree-planting, the Bonn Challenge is best suited for incorporating smallholders in Tanzania and other sub-Saharan Africa countries. Thus far, Africa's 54 countries have together pledged 170 M Ha to restoration (FLR and IUCN, 2017). Tanzania has pledged 5.2 M Ha (6% of its territory). If present-day expansion rates continue in Tanzania, smallholder woodlots would cover ~0.4 M Ha by 2030. Adding existing government and corporate plantations sums to only ~12% of Tanzania's restoration pledge. How and where the country expects to meet the remaining 88% of the pledged goal is an open question. Many different actors and types of landscapes will need to be incorporated to ensure goals are met equitably and effectively (Fagan et al., 2020). Thus far, in their pledges, countries rarely specify what kinds of landscapes will be restored, who will be undertaking the work, and where it will take place (FLR and IUCN, 2017). In the process of determining how the restoration pledges will be met, countries have an opportunity to incorporate smallholder woodlots.

From an ecological perspective, woodlots have an uncertain role for habitat restoration. In general, ecologists have cautioned against equating tree planting with restoration, especially when non-native trees are planted in monocultures (Veldman et al., 2015; Wood et al., 2014). Despite this, several countries focus on tree-planting to measure restoration achievements (e.g., number of seedlings planted (35 million seedlings across 20,000 Ha in Brazil (Dave et al., 2017)) or total area planted in trees (e.g., 9.8 M Ha in India (Borah et al., 2018)). Furthermore, Forested Landscape Restoration guidelines, and the Bonn Challenge 'best practices' documents emphasize tree planting as a core feature of restoration of deforested or agricultural lands (FLR, IUCN, 2015; IUCN and WRI, 2014), including non-native woodlots or agroforestry where appropriate (Sabogal et al., 2015). Whereas international agencies' emphasis on tree planting in restoration programs justifies attention to woodlots, woodlots will have different restoration implications depending on the land cover and land use they replace (Veldman et al., 2015). Smallholders in countries such as Tanzania generally have short-term investment horizons, which is why they prefer to plant fast-growing, easily marketed trees like pine and eucalyptus (Arvola et al., 2019). Promoting native forest restoration on smallholder lands is thus difficult and likely requires special incentives (Nawir et al., 2007).

From an equity perspective, expanding the smallholder tree planting could be a way for African countries to advance their ambitious tree-planting goals while minimizing displacement. India, for example, reports planting trees on 9.8 M Ha since 2011, 94% via government-led efforts (Borah et al., 2018). However, such a centralized approach runs counter to long-standing efforts to decentralize natural resource management in Africa (Persha and Blomley, 2009; Phelps et al., 2010). Large-scale tree planting undertaken by government agencies or corporations can have adverse socio-economic impacts (Lyons and Westoby, 2014; Malkamäki et al., 2018). Working with smallholder tree planters may be a more promising and less heavy-handed approach.

Finally, there is the vexing question of whether supporting ongoing woodlot trends attains additionality. Some programs, such as REDD+, required evidence that the funds invested (e.g., in tree planting) spur an outcome that would not have been achieved otherwise (Wunder, 2007). Additionality has been less central to the Bonn Challenge, because credit has mostly gone to organizations able to demonstrate that their activities count toward fulfilling restoration goals (Hagmann et al., 2018). This is true even when agencies' activities were undertaken before the country made its Bonn Challenge pledge (Borah et al., 2018; Dave et al., 2017), and even when activities were originally based on initiatives unrelated to restoration (Pistorius et al., 2017). In pledge fulfillment accounting so far, there is no clear distinction between activities that have occurred independent of the restoration pledges and those that occurred because of it. Thus, smallholders should be similarly considered for restoration funding even when they develop their woodlots independent of the global restoration pledges, especially given that restoration initiatives wish to promote desired landcover trends while also improving livelihoods.

4.4. Additional considerations for incorporating smallholder woodlots into global tree-planting pledges

Supporting existing smallholder woodlots requires organizing many distributed actors and nudging them toward closer alignment with restoration goals. Organizing smallholders could be achieved via existing village- and district-level timber associations (Tirivayi et al., 2018). These organizations could subsidize and distribute tree seedlings from species that have strong economic potential and are more ecologically desirable (Nawir et al., 2007). Locations where tree planting already occurs can be provided with extension support for nurturing and protection of native tree species in order to enrich the diversity of woodlots (Nguyen et al., 2014). Smallholders could even be paid subsidies to encourage longer rotation times, which would improve carbon sequestration, and improve timber yields (Indufor, 2011). Such subsidies could also be used to encourage ecologically appropriate zoning. For example, woodlots could be subsidized in certain areas such as formerly cultivated lands that are undesirable for food crop production (Telila et al., 2015).

A practical concern for how to incorporate woodlots into landscape restoration would be where funds for such an endeavor would come from, and what would happen if the local demand for tree products collapsed. Identifying funding sources is beyond the scope of this paper but there are many precedents of financial assistance for smallholder-based tree planting from central governments, NGOs, and the European Union (Jacovelli, 2009; Komaza, 2016). Relying solely on external payments to incentivize tree-planting comes with risk. REDD+ payments in Tanzania, for example, created high local expectations followed by disappointment when the payments were not sustained (Massarella et al., 2018). Other similar payments-based environmental management programs face frequent interruptions and shocks (Etchart et al., 2019). Given market forecasts for timber demand and the likely role of smallholders in meeting them, it may be more tenable to tether broad-scale tree-planting efforts to the woodlot expansion trend.

5. Conclusion

Smallholders are active and emerging tree planters in Tanzania and beyond, and deserve consideration in international restoration initiatives. Smallholder woodlots already cover an extent equivalent to government and corporate plantations and they are rapidly expanding. Given that the average woodlot size is smaller than 1 Ha, the coverage we measured reveals the actions of thousands of individuals, and thus signals an opportunity for wide-spread smallholder incorporation. Farmers already undertaking tree planting could benefit from restoration financing by receiving woodlot establishment subsidies and extension support for better tree farm management. Woodlots can meet restoration and carbon sequestration goals if they are established in appropriate location and use sound management practices. Most importantly, leveraging existing trends and momentum among a broad range of actors that include smallholders could be a more socially viable option for meeting ambitious national tree-planting goals rather than relying solely on large-scale projects. Though the woodlots are individually small, they can play a large role in African forestry policy.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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