Environmental Research Letters

LETTER • OPEN ACCESS

Agriculture is the main driver of deforestation in Tanzania

To cite this article: Nike Doggart *et al* 2020 *Environ. Res. Lett.* **15** 034028

Environmental Research Letters

OPEN ACCESS

RECEIVED
8 September 2019

REVISED
5 January 2020

ACCEPTED FOR PUBLICATION
14 January 2020

PUBLISHED
26 February 2020

LETTER

Agriculture is the main driver of deforestation in Tanzania

Nike Doggart[1,2,3,5], **Theron Morgan-Brown**[2], **Emmanuel Lyimo**[2], **Boniface Mbilinyi**[4], **Charles K Meshack**[2], **Susannah M Sallu**[3] **and Dominick V Spracklen**[1]

[1] Institute for Climate and Atmospheric Science, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, United Kingdom
[2] Tanzania Forest Conservation Group, PO Box 23410, Dar es Salaam, Tanzania
[3] Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds LS2 9JT, United Kingdom
[4] Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture, Morogoro, Tanzania
[5] Author to whom any correspondence should be addressed.

E-mail: ndoggart@tfcg.or.tz

Keywords: deforestation, forest degradation, drivers, charcoal, forest transition model, Tanzania

Supplementary material for this article is available online

Abstract

Reducing deforestation can generate multiple economic, social and ecological benefits by safeguarding the climate and other ecosystem services provided by forests. Understanding the relative contribution of different drivers of deforestation is needed to guide policies seeking to maintain natural forest cover. We assessed 119 randomly selected plots from areas deforested between 2010 and 2017, in Tanzania. Through ground surveys and stakeholder interviews we assessed the proximate deforestation drivers at each point. Crop cultivation was the most commonly observed driver occurring in 89% of plots, compared to livestock grazing (69%) and charcoal (35%). There was evidence of fire in 77% of plots. Most deforestation events involved multiple drivers, with 83% of plots showing signs of two or more drivers. Stakeholder interviews identified agriculture as the primary deforestation driver in 81% of plots, substantially more than charcoal production (12%), timber harvesting (1%) and livestock (1%). Policy-makers in Tanzania have sought to reduce deforestation by reducing demand for charcoal. However, our work demonstrates that agriculture, not charcoal, is the main driver of deforestation in Tanzania. Beyond protected areas, there is no clear policy limiting the conversion of forests to agricultural land. Reducing deforestation in Tanzania requires greater inter-sectoral coordination between the agriculture, livestock, land, energy and forest sectors.

1. Introduction

Deforestation and forest degradation contribute to climate change (IPCC 2014, Baccini *et al* 2012, Scott *et al* 2018). Most net deforestation occurs in the tropics (Hansen *et al* 2013, IPCC 2014, Baccini *et al* 2017, Song *et al* 2018). National policies that aim to reduce deforestation will be more effective if they are informed by accurate and current data on deforestation drivers (Macedo *et al* 2012, Monteiro *et al* 2014). However, many countries have only nominal or ordinal information on the contribution of different deforestation drivers (Hosonuma *et al* 2012). To address this lack of information, the United Nations Framework Convention on Climate Change (UNFCCC) Conferences of Parties requests that Parties identify and address deforestation drivers (UNFCCC 4/CP.15, 1/CP.16, 15/CP.19).

A plethora of definitions exist for forest degradation and deforestation (Lund 2009, 2014, 2015). Deforestation is typically defined as the conversion of forest land to non-forest land (IPCC 2000). Forest degradation is typically defined as loss of forest quality, such as a reduction of aboveground biomass, in areas that remain forest. Proximate drivers of deforestation and forest degradation comprise the actions that directly result in a change in forest condition. Complex causal chains, involving an interplay of economic, political, social, demographic and biophysical pressures, contribute to the proximate drivers (Wehkamp *et al* 2015).

Multiple studies have found that commercial and subsistence agriculture are the main proximate deforestation drivers in tropical countries, with mining, infrastructure and urbanisation also contributing to deforestation (Geist and Lambin 2002, Busch and Ferretti-Gallon 2017, Wehkamp et al 2015). While agriculture for export markets now dominates deforestation pressure in southeast Asia (DeFries *et al* 2010), in Africa, subsistence agriculture and production for local markets are more important (Fisher 2010, Gibbs *et al* 2010, Kissinger *et al* 2012, Rudel 2013, Curtis *et al* 2018, De Sy *et al* 2019). Drivers of forest degradation include fuelwood collection, charcoal production, logging, uncontrolled fire and livestock grazing in forests, since they reduce biomass but do not result in the conversion of the land to a non-forest land use (Hosonuma *et al* 2012).

Tanzania, like many countries in sub-Saharan Africa, is experiencing ongoing deforestation and forest degradation. Tanzania is considered to be an early-transition phase country in the forest transition model (FTM), a trajectory from net-deforestation to net-reforestation that is observed in many countries (Mather 1992). Hosonuma *et al* (2012) define early transition countries as having forest cover between 15% and 50%, and an increasingly rapid rate of forest loss. Tanzania's forest cover is approximately 36% (32 Mha of forest in 2012, URT 2017) while the mean annual deforestation rate for the Tanzanian mainland increased from 1% between 1991 and 2000 (Matthews 2010) to 1.47% between 2002 and 2013 (URT 2017). If Tanzania were to follow the average FTM trajectory, forest area would decline to 13 Mha (15% of the land area), before reaching a post-transition reforestation phase. Inevitably, this would involve substantial losses of forest both inside and outside of protected areas (PA) with concomitant loss of biodiversity and other ecosystem services.

Various studies have explored drivers of deforestation in Tanzania. The global analysis of Curtis *et al* (2018) found that 93%–94% of tree cover loss (at >10% tree cover) in Tanzania between 2010 and 2015 was associated with shifting cultivation, 4%–5% with forestry and 2% with commodity-driven agriculture. At the sub-national level, Willcock *et al* (2016) found the majority of deforestation in Tanzania's Eastern Arc Mountains, was due to conversion to croplands. A recent pan-tropical study, found that small-scale cropland was the dominant deforestation driver in many African countries including Tanzania (De Sy *et al* 2019).

Despite this previous work, quantitative data on the relative contribution of different deforestation drivers at the national-scale in Tanzania, is considered inadequate for policy formulation. In the forestry sector, Tanzania's National Forest Policy (URT 1998) and the National Strategy for Reduced Emissions from Deforestation and forest Degradation (REDD) (URT 2013a), provide only nominal information on proximate deforestation drivers. The National Forest Policy cites '*agriculture, overgrazing, wildfires and charcoal production*' as the main drivers of deforestation, while the National REDD strategy notes the absence of data on the relative importance of deforestation drivers in the country.

Although charcoal production is considered to be a driver of forest degradation rather than deforestation in global studies (Curtis *et al* 2018), policy-makers firmly believe that charcoal production is a major driver of deforestation, in Tanzania (Mwampamba *et al* 2013). For example, the National Energy Policy 2015 sets an explicit objective of removing charcoal from the energy mix, with a view to reducing deforestation (URT 2015). In contrast, outside of the 38% of terrestrial land in PA, there is no clear policy to reduce the conversion of forest land to agricultural land (UNEP-WCMC and IUCN 2019).

Here we present the first national, empirical study of the proximate drivers of deforestation for Tanzania based on a combination of remote sensing, ground surveys and interviews. The objectives of the study were to assess the mix of drivers present in land deforested between 2010 and 2017. Specifically, we aim to inform ongoing policy discussions around the role of charcoal in deforestation (Doggart and Meshack 2017). We therefore include a range of drivers that are typically associated with forest degradation, with a view to improving our understanding of the interplay between drivers of deforestation and forest degradation at deforestation events in multiple land-use areas of Africa. By combining ground surveys and interviews with remote sensing, we provide a level of detail about the land use dynamics occurring in areas of deforestation, that cannot be captured using remote sensing alone, thereby complementing pan-tropical studies (Curtis *et al* 2018, De Sy *et al* 2019). Although our study is focused on Tanzania, the approach and findings have relevance to other countries, particularly to the other 18 early-transition countries in Africa (Hosonuma *et al* 2012).

2. Methods

Drivers were identified by combining analysis of satellite images, ground surveys, and informant interviews. Remote sensing was used to map areas of tree cover loss between 2010 and 2017. We assume that these areas are deforested, though tree cover may return in the future. Ground survey points were selected randomly from these deforested areas in an approach similar to the FAO Forest Resources Assessment dataset used by Gibbs *et al* (2010). For each ground survey point, we recorded the presence of different proximate drivers, the current land-use and a profile of the people involved in the deforestation. We recorded information on both deforestation and forest degradation drivers. The role of forest degradation drivers at deforestation sites was particularly relevant to this study given the policy-linked questions surrounding the relative contributions of charcoal and agriculture in driving deforestation, and a more widespread paucity of data on the co-occurrence of drivers of forest cover change (Mwampamba *et al* 2018). We also recorded signs of fire. Additional details on methods are provided in the supplementary materials, available online at stacks.iop.org/ERL/15/034028/mmedia.

2.1. Remote sensing

We used the freely available Global PALSAR-2/PALSAR/JERS-1 Mosaic product (Shimada *et al* 2014) together with the National Forest Resources Monitoring and Assessment of the Tanzania Mainland (NAFORMA) Land-use/Land-cover (LULC) Map 2010 (MNRT 2015) to map forest cover for all of the Tanzania mainland in 2010 and gross deforestation from 2010 to 2017. Forest was identified according to the Tanzanian definition submitted to the UNFCCC—areas of at least 0.5 ha with greater than 10% canopy cover of trees at least 3 m in height. Woodlands comprise ~93% of Tanzania's forest land cover of which ~81% is open woodland (10%–40% canopy cover) and 19% is closed woodland (>40% canopy cover) (URT 2017). We chose to base the deforestation analysis on L-Band Synthetic Aperture Radar (SAR) data, rather than optical sensor data such as Landsat (e.g. Hansen *et al* 2013) because of the well-documented advantages of L-Band SAR in detecting deforestation in African woodlands (Naidoo *et al* 2016, Bouvet *et al* 2018, McNicol *et al* 2018). The 2010 forest areas were mapped as areas not falling in wetlands, water, or flooded cropland in the 2010 NAFORMA LULC map, and having a minimum horizontal transmitting, vertical receiving (HV) backscatter digital number (DN) value of at least 2100 in 2007–2010 PALSAR data. Different thresholds were applied to identify the cut-off between forest and non-forest, with DN value $\geqslant 2100$ resulting in the most accurate forest map for the country. Deforestation from 2010 to 2017 was then mapped based on four criteria. The area had to be mapped as forest in 2010, have an HV backscatter DN value below 2100 in 2015, 2016, or 2017, show a relative decline in HV backscatter of at least 15% compared to the lowest HV backscatter value between 2007 and 2010, and be orthogonally connected to at least 5 other pixels of deforestation equivalent to 0.375 ha. We adopted a 6-pixel threshold for deforestation to maximise user accuracy whilst still being able to detect small-scale deforestation events. The accuracy of each of the map classes (non-forest, forest persistence, and deforestation) was assessed by visually reviewing Landsat, Sentinel-2, and Google Earth imagery for a random stratified sample of 300 pixels in each map class. A stratified sample was used in order to increase the sample size of the deforestation samples, since it was a rare class and the focus of the study. An independent assessment of roughly 100 points from each map class was conducted with 98% agreement between the two assessments. The accuracy assessment followed that described in Olofsson *et al* (2013, 2014), where the error matrix is presented as estimates of area proportions, in order to account for the stratified sampling design. The accuracy results and error matrix are presented in supplementary table S.1. Canopy height was considered in the accuracy assessment, alongside other criteria, where high resolution imagery allowed canopy height to be estimated.

2.2. Ground survey

To generate the ground survey points, we selected a random sample of 120 pixels from the deforestation map class. The map of deforestation and of the ground survey points are shown in figure 1. The accuracy of the 120 pixels was assessed visually using Landsat, Sentinel-2 and Google Earth imagery to confirm that the area was forest in 2009 or 2010 and non-forest in 2015, 2016 or 2017. Pixels that were inaccurately classified as deforestation were replaced with new random draws. Thirteen pixels were replaced once, and 1 pixel was replaced twice. This was within the margin of error for the reference data area, for the deforestation class (table S.2).

A survey team visited all the ground survey points. At each survey point, two plots were established centred on the deforestation pixel. A smaller plot (25 m × 25 m) was used to assess the current land-cover/land-use, including percentage tree cover, vegetation height and type, and to look for visible signs of drivers and fire. A larger plot (75 m × 75 m) was used to look for physical evidence of charcoal, grazing, and fire. Both plots were assessed by walking transect lines spaced 12.5 m apart running through the plots and along the sides. 360° panorama photographs were taken of each plot. At least one local government official accompanied the team to 95% of the survey points including all points in reserved land ($n = 15$), 78% of points on general land ($n = 9$) and 96% of points on village land ($n = 95$). In addition, village council representatives were present at 81% of the survey sites, including 95% of the points on village land. The survey was designed to describe the frequency with which different drivers occur at the national scale, rather than detecting spatial variations across the country.

2.3. Informant interviews

For each ground survey point a questionnaire survey with a local person was completed. Where possible, the current occupier or land owner was interviewed (15% of interviews). Where the owner/occupier was unavailable, a village council representative or other knowledgeable person was interviewed (63% of interviews), or in the case of land in PA, the PA manager (10% of interviews). The interviews were carried out in, or close to, the ground survey point. In this way the interview could use signs of land use in the plot, such

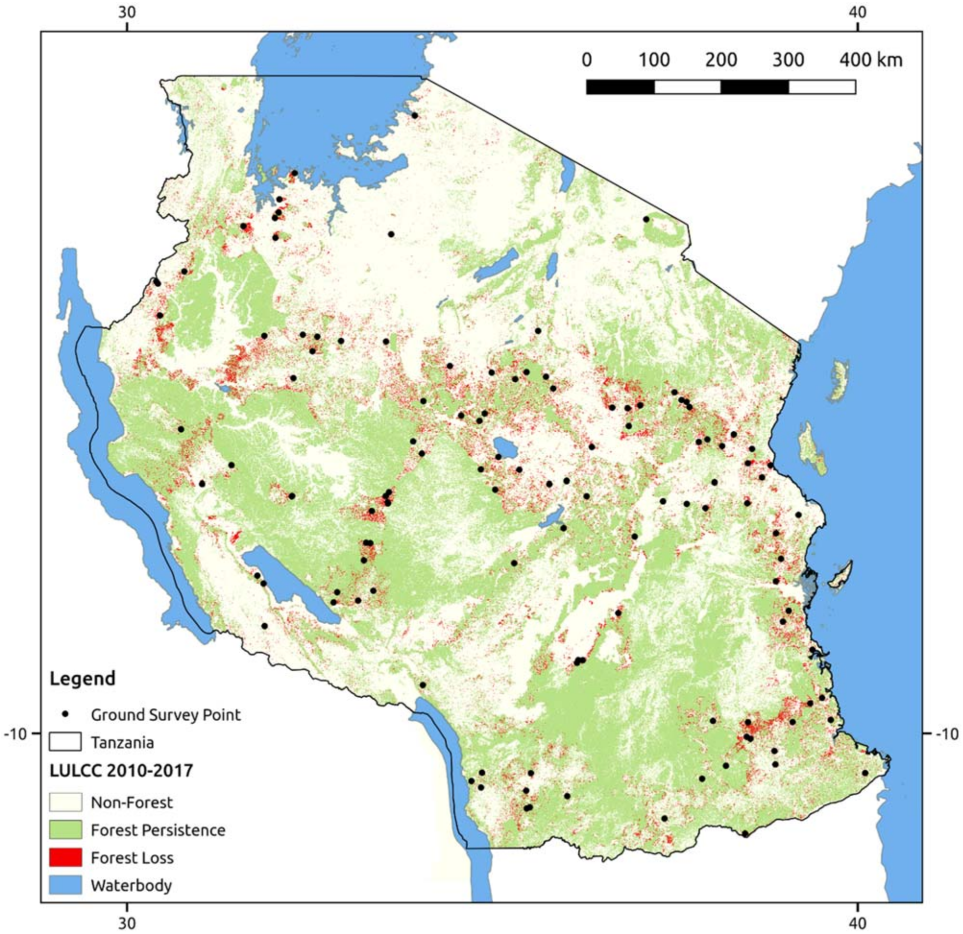

Figure 1. Map of forest loss in Tanzania during 2010–2017 and location of ground survey points.

as crop residues or signs of grazing, as prompts over the course of the interview.

2.4. Policy analysis

We updated Doggart and Meshack (2017) by reviewing the latest drafts of the National Environment Policy and the National Forest Policy.

3. Results

The gross annual deforestation rate was calculated as 561 704 ± 99 234 ha yr^{-1} or 1.42%, with a 2010–17 area of forest persistence of 37.7 Mha and an area of forest loss of 3.9 Mha, using the reference data area estimates.

Crop farming was the most frequently recorded driver of deforestation and was present in 89% of plots (figure 2(a)). Other frequently recorded drivers included livestock (69%), domestic fuelwood collection (41%), charcoal production (35%) and harvesting building poles (30%). Plantation forestry, roads, settlements, fuelwood collection for tobacco drying, and timber harvesting were each recorded in ⩽6% of plots. Mining was not recorded as a deforestation driver in any plot. Signs of fire were present in 77% of plots.

Respondents stated that the primary reason for deforestation was 'to create a farm' in 81% of plots, all of which had signs of crop cultivation (figure 2(a)), while charcoal production was cited as being the main reason in 12% of plots, all of which had signs of charcoal production. 'Creating a farm' was cited by informants as being the main reason for deforestation in 67% of plots where charcoal production was recorded ($n = 42$) suggesting that most charcoal production occurs as part of a forest to crop land-use change trajectory. Harvesting timber in a pine plantation and livestock were both cited as the main reason for deforestation in 1% of plots, while respondents were uncertain of the main reason in 5% of plots.

The diversity of drivers per plot ranged from 1 to 6 (mean = 3.2. StDev = 1.4) (figure 2(b)). A single deforestation driver was recorded in 17% of plots. There were 30 different combinations of proximate drivers. The most frequent driver combination was crops-livestock (20% of plots), followed by a crops-only class (13% of plots). Charcoal was recorded most frequently in a crops-livestock-charcoal combination (8% of plots). Charcoal was not recorded as the sole driver in any plot.

Twenty-one crop types were recorded at the deforestation sites either through interviews or

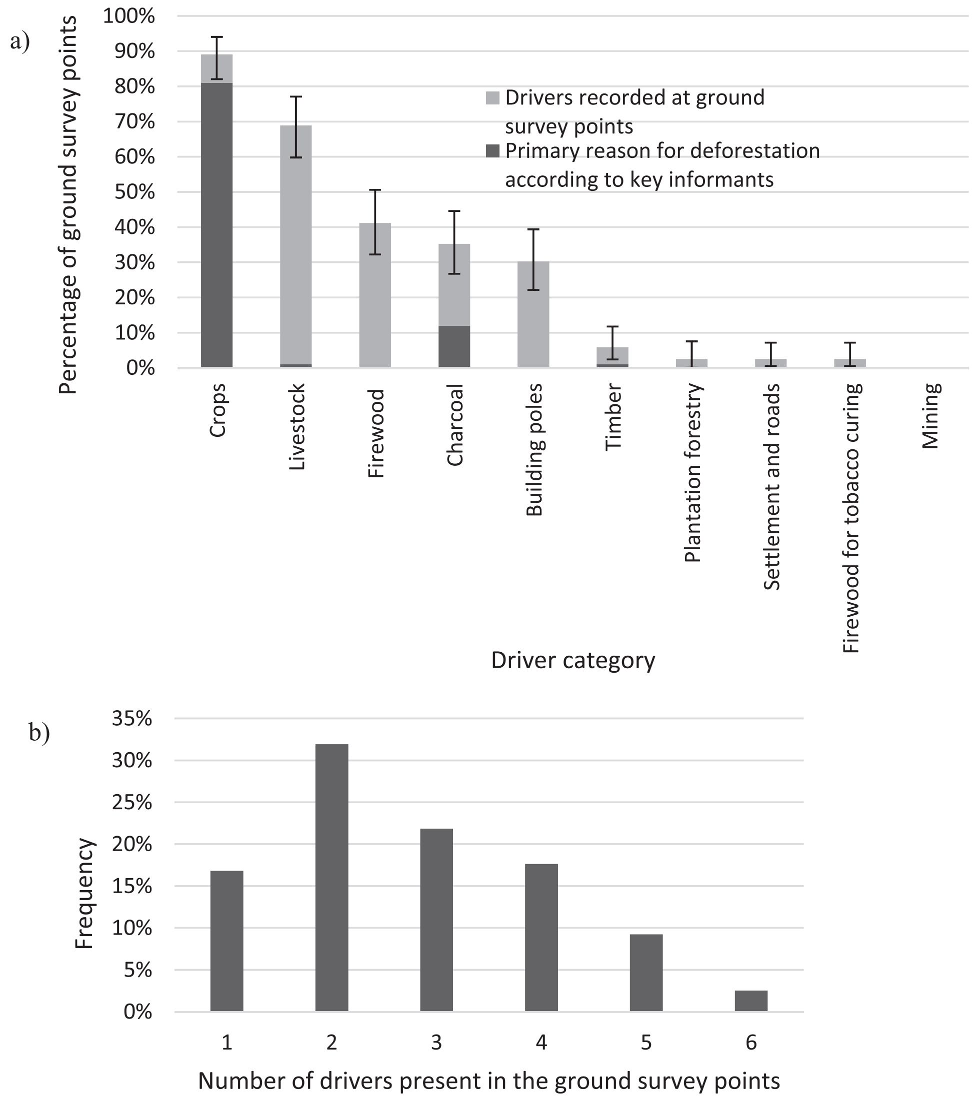

Figure 2. Prevalence of different drivers at the deforestation events included in the survey: (a) prevalence of different drivers with error bars showing the 95% confidence interval and the primary reason for deforestation according to key informants; (b) frequency distribution showing the number of drivers present.

observations, with 48% of all plots containing more than one type of crop (supplementary data table 2). The most commonly grown crops, as a percentage of all plots, were maize (57%), sesame (20%), cowpea (14%), and sorghum (10%). Other crops recorded in <10% of plots include rice, bean, cassava, sunflower, millet, cashew nut and ground nut. Crops were being grown both for subsistence and cash income. Of the 106 plots where agriculture was recorded, 47% were being farmed for both food and cash, 30% for food only, 12% for cash only and 10% were classified as unknown. Of those plots cleared for maize cultivation, 60% were for food and cash, 38% for food only and 1.7% were for cash only. The results point to the prevalence of small-scale mixed agriculture producing food crops for household consumption, often alongside cash crops.

The plots fell in fields at different stages of the agricultural cycle. 68% of plots were actively being farmed while 32% of plots were under fallow. According to respondents, the mean fallow period was 2.7 years (mode = 1 year), ranging from 1 to 8 years. Other studies have recorded average fallow periods of 3–4 years in Tanzania's Morogoro Region (Luoga *et al* 2000, Kilawe *et al* 2018) as well as evidence of shortening fallows and a shift to permanent cultivation in Tanzania (Grogan *et al* 2013, Kilawe *et al* 2018) and elsewhere in Africa (Zaehringer *et al* 2016).

The land-cover trajectory of the plots varied according to the driver. 21% of survey points, cleared primarily for charcoal production, had regenerated back into a forest class by 2018 while only 7% of those cleared primarily for agriculture had returned to forest. Several Tanzanian woodland tree species regenerate vigorously through coppicing (Sangeda and Maleko 2018). Ground survey points could have been regenerating for up to 4 years between 2015 and 2018 given the deforestation definition that required sample points to be non-forest in one or more of the years of 2015–2017.

Information about the residency of the people who originally cleared the forest, was available for 49 plots. In 67% of these plots, the forest was said to have been cleared by people who were not born in the village but had lived in the village for, on average, 8.7 years. The most frequently cited reasons for people to have moved to the area were: to secure better farming land (70% of responses) and to pursue economic opportunities (36% of responses). In most cases (58%), the farmers who were farming the land at the time of the survey were the same people who had cleared the forest. Responses about the gender of those involved in clearing the farms were provided for 50 farms, of which 30 were said to have been cleared jointly by women and men; and 20 were said to have been cleared by men only.

4. Discussion and conclusion

4.1. Quantifying the contribution of proximate drivers to deforestation in Tanzania

Our study demonstrates the primacy of agriculture in driving deforestation, confirming Tanzania-specific results from pan-tropical studies (Curtis *et al* 2018). We identify the main deforestation driver in each of our plots, on the basis of the 'main driver' identified during the informant interviews. Based on this, we attribute the proportion of deforestation to each driver as: agriculture (81%), charcoal (12%), livestock grazing (1%), plantation forestry (1%), and unknown/no clear main driver (5%). Overall our findings indicate that small-scale cultivation of maize, sesame, cowpeas and sorghum are the main proximate drivers of deforestation, predominantly for household consumption or local markets, with export crops contributing only marginally. While charcoal production was the primary reason for deforestation in 12% of plots, in over half of those plots, the land was then used for farming. We found no evidence of charcoal causing deforestation in isolation of other drivers. This confirms that charcoal is rarely a driver of deforestation on its own. Policies targeting charcoal in isolation of agriculture, are unlikely to be effective in reducing deforestation.

The typical deforestation scenario that emerges from the study, is a trajectory from forest land to agricultural land, predominantly (64% of agricultural areas) for maize cultivation usually in combination with one or more additional crops (80% of maize fields had one or more additional crop). In 33% of the agriculture-driven events, charcoal is produced as part of the transition process while livestock grazing, domestic firewood collection and timber harvesting were present in 66%, 42% and 7% respectively of the deforestation events involving agricultural crops. Less commonly (8% of all ground survey points), charcoal is produced outside of a transition from forest to crop cultivation. In such cases, charcoal is always found to co-occur with livestock grazing. Rarer events include 1% of events that only involved livestock grazing.

Our results comprise new evidence that multiple drivers of deforestation and degradation frequently co-occur in areas of deforestation. Whilst the convergence of multiple drivers is recognised by other studies (Geist and Lambin 2002), most previous studies have focused on the main drivers (Hosonuma *et al* 2012). Co-occurrence of drivers will affect the ecological and climate forcing impacts of deforestation events and will require different policy responses (Mwampamba *et al* 2018). The implications of co-occurring drivers of forest change are poorly understood and require further research.

4.2. The role of subsistence versus commercial crops and livestock in deforestation

In terms of agriculture's role in deforestation, our study provides new evidence around the relative contribution of different crops to deforestation, with relevance to agricultural policy. The dichotomies of 'subsistence/commercial' and 'shifting/commodity-driven' agriculture as applied by Hosonuma *et al* (2012) and Curtis *et al* (2018) are difficult to apply in the Tanzanian context. If we consider those distinctions to comprise a continuum rather than a dichotomy, with production for household consumption at one end, and production for commodity export at the other end, then most Tanzanian agriculture remains closer to the 'subsistence' end. In terms of crops present in areas of deforestation, Hosonuma *et al* (2012) describe a shift from subsistence to commercial crops, as countries shift from early to late-transition phases. We found that four crops occurred in deforestation events at least twice as frequently as their overall prevalence in Tanzania: maize, sesame, cowpeas and sorghum (supplementary data table 3) (FAOSTAT 2019). For example, maize is the most widely cultivated crop in the country covering 24% of crop land in Tanzania, but occurred in 64% of agriculture-driven deforestation events. Other crops such as rice, beans, cassava, sunflower, groundnut, cashew nut and millet were recorded in roughly the same proportion of plots, as they comprise of the overall agricultural estate. Of the four crops most frequently detected in deforestation events, sesame is the crop that is most frequently exported, with 18% of production being exported (*ibid*). Tanzania's main export cash crops (excluding cereals) are tobacco, cashew nut, coffee, tea, clove and groundnut. Of these export crops, cashew nut, groundnut and tobacco were the most frequently recorded in 4.2%, 3.4%, and 0.9% respectively, of all plots. Tea, coffee and clove were not recorded. These findings reinforce the conclusion that deforestation, in Tanzania, is largely driven by small-scale, predominantly subsistence agriculture.

4.3. The role of drivers of forest degradation in deforestation events

Our findings suggest that livestock grazing may play a more significant role in driving deforestation than previously considered. Livestock grazing was identified as the primary reason for deforestation in only 1% of plots, but was recorded in 69% of plots. Livestock grazing was recorded in 92% of the plots where crop cultivation was not recorded, 66% of plots where crops were reported and 83% of events where charcoal was recorded. The number of cattle in Tanzania increased by 4% p.a. between 2010–17 (FAOSTAT 2019), suggesting that the impact of livestock grazing may be increasing. The conditions under which livestock grazing acts as a driver of deforestation or of forest degradation requires further research, a conclusion also reached by Mwampamba *et al* (2018).

Fire is an important tool in rural livelihoods, being used by farmers to clear vegetation in preparation for planting crops, by hunters to flush out prey, by livestock keepers to stimulate fresh grass for grazing, as well as for cultural reasons (Katani *et al* 2014). The study provides new evidence on the extent of fire use in land management in Tanzania. We found a particularly close association between fire and agriculture: fire was recorded in 80% of plots involving conversion of forest land to crop land, compared with only 53% of plots where no signs of agriculture were recorded. Fire was not observed in some areas under cultivation. This may be because signs of burning had been masked by subsequent crop cultivation, and as such, our results may under-estimate the prevalence of fire.

Although the study was not designed to detect differences in the distribution of drivers across the country, we noted that livestock and agriculture were detected in points widely distributed across the country, while charcoal was only consistently absent from the ground survey points south of the Rufiji delta and east of the Selous Game Reserve. This observation should be treated with caution as the authors are aware that charcoal is produced in this area. Further research is needed to detect sub-national spatial patterns in the distribution of drivers.

While there is growing recognition of the significance of forest degradation in global change accounting (Goetz *et al* 2015, Baccini *et al* 2017, Song *et al* 2018), forest degradation was not the focus of the current study and is an area requiring further research. Africa's open woodlands, where tree cover is naturally only 10%–40%, present specific issues around definitions of deforestation and forest degradation. Canopy cover thresholds determine both the extent of land defined as forest and the extent of deforestation. Recovery of canopy cover after forest loss is often very rapid resulting in a fast dynamic between canopy loss and recovery (McNicol *et al* 2018), further blurring the distinction between deforestation and forest degradation. This dynamic matters because the climate impact of deforestation or forest degradation will depend on the land-use trajectory with implications both for climate modelling and for policy (Tongwane and Moeletsi 2018, De Sy *et al* 2019).

4.4. Policy implications

In the absence of empirical data on deforestation drivers at the national scale in Tanzania, policy efforts have focused on reducing charcoal production. Conversion of forests to agricultural land outside of PA has received limited attention and a coordinated policy to reduce deforestation, across energy, agriculture and forestry sectors is lacking. In the energy sector, the National Energy Policy (URT 2015) seeks a transition from woodfuels to electricity and fossil fuels, citing deforestation as a rationale for the shift. There have also been periodic bans on the charcoal trade (World Bank 2009, Zulu and Richardson 2013). Discussions around a charcoal strategy or policy have been ongoing for more than a decade (Doggart and Meshack 2017). Policy implementation tools in the forestry sector have focused on tree planting as an alternative to natural forests for woodfuel biomass, with ambitious targets for the expansion of tree plantations. In contrast, policy implementation tools have not set targets to reduce conversion of natural forests on village land, to agriculture. Community-based forest management (CBFM) is the forestry sector policy tool designed to protect forests on village land, however, CBFM has received minimal support, beyond donor and Non-Governmental Organisation interventions.

In the agriculture sector, the National Agriculture Policy 2013 has a mission of, '*increased volumes of competitive crop products*' to be achieved through a combination of intensification and the expansion of agricultural land. The policy states that '*Whereas 44 million hectares of land are suitable for agricultural production, only 10.8 million hectares (24%) are cultivated… The potential exists for expansion of agricultural area under cultivation.*' The policy states that, '*the ministry responsible for Natural Resources shall support sustainable management of forest resources especially through Participatory Forest Management*'. (URT 2013b.) With this statement, the agriculture policy, deflects responsibility for addressing agriculture-driven deforestation to the neglected policy tool of participatory forest management. Many authors agree that sustainable intensification of agriculture can play an important role in reducing deforestation provided that a deliberate commitment to protecting forests runs alongside the shift in agricultural practices (Ngoma *et al* 2018, Balmford *et al* 2018). This highlights the importance of inter-sectoral cooperation.

Although Tanzania's policies in land, agriculture, environment, water, energy and forests, recognise the benefits of protecting forests, a more coordinated and deliberate policy is needed to balance the protection of forests and the ecosystem services that they provide, with strategies to achieve increased production of crops and livestock. The current emphasis on controlling trade in charcoal and timber is unlikely to be effective, as a strategy to reduce deforestation, but could reduce forest degradation, particularly where compliance efforts target PA. Achieving a more coordinated policy response requires a clearer national vision around the allocation of land and a shift towards more inter-sectoral cooperation in addressing the multiple drivers of deforestation and forest degradation. Without a deliberate policy shift, there is a risk that Tanzania will follow the trajectory followed by so many other countries towards a natural forest cover of only 15%, with concomitant losses of Tanzania's unique biodiversity and other ecosystem services.

Acknowledgments

The authors acknowledge the Critical Ecosystem Partnership Fund for its support for this research. This work received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No. 771492). We also acknowledge UK's Economic and Social Research Council funding to Sallu, facilitating her contribution as part of the ESRC Centre for Climate Change Economics and Policy (ES/K006576/1 and ES/R009708/1). Spracklen was also funded through a Natural Environment Research Council (NERC) Grant (NE/M003574/1) and acknowledges a Philip Leverhulme Prize. We thank two anonymous reviewers for their constructive comments.

Data availability statement

The data that support the findings of this study are openly available in the supplementary material and at https://doi.org/10.25412/iop.11395185.v1.

ORCID iDs

Nike Doggart https://orcid.org/0000-0003-3367-5437

References

Baccini A *et al* 2012 Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps *Nat. Clim. Change* **2** 182–5

Baccini A, Walker W, Carvalho L, Farina M, Sulla-Menashe D and Houghton R A 2017 Tropical forests are a net carbon source based on aboveground measurements of gain and loss *Science* **358** 230–4

Balmford A *et al* 2018 The environmental costs and benefits of high-yield farming *Nat. Sustainability* **1** 477–85

Bouvet A, Mermoz S, Le Toan T, Villard L, Mathieu R, Naidoo L and Asner G P 2018 An above-ground biomass map of African savannahs and woodlands at 25 m resolution derived from ALOS PALSAR *Remote Sens. Environ.* **206** 156–73

Busch J and Ferretti-Gallon K 2017 What drives deforestation and what stops it ? A meta-analysis *Rev. Environ. Econ. Policy* **11** 3–23

Curtis P B, Slay C M, Harris N L, Tyukavina A and Hansen M C 2018 Classifying drivers of global forest loss *Science* **361** 1108–11

DeFries R S, Rudel T K, Uriarte M and Hansen M C 2010 Deforestation driven by urban population growth and agricultural trade in the twenty-first century *Nat. Geosci.* **3** 178–81

De Sy V *et al* 2019 Tropical deforestation drivers and associated carbon emission factors derived from remote sensing data *Environ. Res. Lett.* **14** 094022

Doggart N and Meshack C K 2017 The marginalization of natural forests in the policies of a modernising African nation: applying nexus thinking to an analysis of Tanzanian policies on charcoal *Frontiers Environ. Sci.* **5** 1–3

Fisher B 2010 African exception to drivers of deforestation *Nat. Geosci.* **3** 375–6

FAOSTAT 2012 Food and Agriculture Organization of the United Nations Database (Rome, Italy: FAO) (Retrieved: 30 May 2019)

Geist H J and Lambin E F 2002 Proximate causes and underlying driving forces of tropical deforestation *BioScience* **52** 143–50

Gibbs H K, Ruesch A S, Achard F, Clayton M K, Holmgren P, Ramankutty N and Foley J A 2010 Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s *Proc. Natl Acad. Sci.* **107** 16732–7

Goetz S J, Hansen M, Houghton R A, Walker W, Laporte N and Busch J 2015 Measurement and monitoring needs, capabilities and potential for addressing reduced emissions from deforestation and forest degradation under REDD+ *Environ. Res. Lett.* **10** 123001

Grogan K, Birch-Thomsen T and Lyimo J 2013 Transition of shifting cultivation and its impact on people's livelihoods in the miombo woodlands of Northern Zambia and South-Western Tanzania *Hum. Ecology* **41** 77–92

Hansen M C *et al* 2013 High-resolution global maps of 21st-century forest cover change *Science* **342** 850–3

Hosonuma N, Herold M, De Sy V, Fries R S D, Brockhaus M, Verchot L, Angelsen A and Romijn E 2012 An assessment of deforestation and forest degradation drivers in developing countries *Environ. Res. Lett.* **7** 044009

IPCC 2000 *Land Use, Land-Use Change and Forestry: a Special Report of the Intergovernmental Panel on Climate Change* ed R T Watson *et al* (Geneva, Switzerland: IPCC) p 375

IPCC 2014 *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* ed R K Pachauri and L A Meyer (Geneva, Switzerland: IPCC) p 151 Core Writing Team

Katani J Z, Madoffe S S, Amanzi N S, Rija A A, Midtgaard F, Mbeyale G, Zahabu E and Tarimo B C 2014 Assessment of fire prevalence and reduction strategies in Miombo woodlands of Eastern Tanzania *Tanzania J. Forestry Nat. Conservation* **84** 24–37

Kilawe C J, Mertz O, Dos Santos A S, Birch-Thomsen T and Maliondo S M 2018 Transformation of shifting cultivation: Extent, driving forces and impacts on livelihoods in Tanzania *Appl. Geogr.* **94** 84–94

Kissinger G, Herold M and De Sy V 2012 *Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD + Policymakers* (Vancouver Canada: Lexeme Consulting)

Lund H G 2009 *What is a Degraded Forest?* White Paper on Forest Degradation Definitions. Prepared for FAO. p 39

Lund H G 2014 Revised. Definitions of Old Growth, Pristine, Climax, Ancient Forests, Degradation, Desertification, Forest Fragmentation, and Similar Terms. [Online publication] (Gainesville, VA: Forest Information Services)

Lund H G 2015 Rev* Definitions of Forest, Deforestation, Afforestation, and Reforestation (Gainesville, VA: Forest Information Services) (Note, this paper has been continuously updated since 1998.)

Luoga E J, Wilkowski E T F and Balkwill K 2000 Subsistence use of wood products and shifting cultivation within a miombo woodland of eastern Tanzania, with some notes on commercial uses *South Afr. J. Bot.* **66** 72–85

Macedo M N, DeFries R S, Morton D C, Stickler C M, Galford G L and Shimabukuro Y E 2012 Decoupling of deforestation and soy production in the southern Amazon during the late 2000s *Proc. Natl Acad. Sci.* **109** 1341–6

Mather A S 1992 The forest transition *Area* **24** 367–79

Matthews R B 2010 Development and application of methodologies for reduced emissions from deforestation and forest degradation (REDD) *Report* (Aberdeen and Nairobi: Macaulay Land Use Research Institute and World Agroforestry Centre)

McNicol I M, Ryan C M and Mitchard E T A 2018 Carbon losses from deforestation and widespread degradation offset by extensive growth in African woodlands *Nat. Commun.* **9** 3045

MNRT (Ministry of Natural Resources and Tourism) 2015 *National forest Resources Monitoring and Assessment of Tanzania Mainland: Main Results* (Tanzania: Dar es Salaam) p 106

Monteiro M S A, da S R, Seixas C and Vieira S A 2014 The politics of Amazonian deforestation: environmental policy and climate change knowledge: The politics of Amazonian deforestation *Wiley Interdiscip. Rev. Clim. Change* **5** 689–701

Mwampamba T H, Ghilardi A, Sander K and Chaix K J 2013 Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries *Energy Sustainable Dev.* **17** 75–85

Mwampamba T H, Loes N, van Schaik M B and Castillo-Hernandez L A 2018 Incorporating ecohydrological processes into an analysis of charcoal-livestock production systems in the Tropics: an alternative interpretation of the water-energy-food Nexus *Frontiers Environ. Sci.* **6** 99

Naidoo L, Mathieu R, Main R, Wessels K and Asner G P 2016 L-band synthetic aperture radar imagery performs better than optical datasets at retrieving woody fractional cover in deciduous, dry savannahs *Int. J. Appl. Earth Obs. Geoinf.* **52** 54–64

Ngoma H, Angelsen A, Carter S and Roman-Cuesta R M 2018 Climate-smart agriculture: Will higher yields lead to lower deforestation? *Transforming REDD+: Lessons and New Directions* ed A Angelsen, C Martius, V De Sy, A E Duchelle, A M Larson and T T Pham (Indonesia: CIFOR)

Olofsson P, Foody G M, Stehman S V and Woodcock C E 2013 Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation *Remote Sens. Environ.* **129** 122–31

Olofsson P, Foody G M, Herold M, Stehman S V, Woodcock C E and Wulder M A 2014 Good practices for estimating area and assessing accuracy of land change *Remote Sens. Environ.* **148** 42–57

Rudel T K 2013 The national determinants of deforestation in sub-Saharan Africa *Phil. Trans. R. Soc.* B **368** 20120405

Sangeda A Z and Maleko D D 2018 Regeneration effectiveness post tree harvesting in natural miombo woodlands Tanzania *J. Plant Sci. Agric. Res.* **2** 1–10

Scott C E *et al* 2018 Impact on short-lived climate forcers increases projected warming due to deforestation *Nat. Commun.* **9** 157

Shimada M, Itoh T, Motooka T, Watanabe M, Shiraishi T, Thapa R and Lucas R 2014 New global forest/non-forest maps from ALOS PALSAR data 2007–2010 *Remote Sens. Environ.* **155** 13–31

Song X P, Hansen M C, Stehman S V, Potapov P , V, Tyukavina A, Vermote E F and Townshend J R 2018 Global land change from 1982 to 2016 *Nature* **560** 639–43

Tongwane M I and Moeletsi M E 2018 A review of greenhouse gas emissions from the agriculture sector in Africa *Agric. Syst.* **166** 124–34

UNEP-WCMC and IUCN 2019 Protected Planet: The World Database on Protected Areas (WDPA) (Cambridge, UK: UNEP-WCMC and IUCN)

URT 1998 United Republic of Tanzania, National Forest Policy

URT 2013a United Republic of Tanzania, National Strategy for Reduced Emissions from Deforestation and forest Degradation

URT 2013b United Republic of Tanzania, National Agriculture Policy

URT 2015 United Republic of Tanzania, National Energy Policy

URT 2017 United Republic of Tanzania, Tanzania's forest reference emission level submission to the UNFCCC

Wehkamp J, Aquino A, Fuss S and Reed E W 2015 Analyzing the perception of deforestation drivers by African policy makers in light of possible REDD + policy responses *Forest Policy Econ.* **59** 7–18

Willcock S *et al* 2016 Land cover change and carbon emissions over 100 years in an African biodiversity hotspot *Glob. Change Biol.* **22** 2787–800

World Bank 2009 *Environmental Crisis or Sustainable Development Opportunity? Transforming the Charcoal Sector in Tanzania* (Washington, DC: The World Bank)

Zaehringer J G, Hett C, Ramamonjisoa B and Messerli P 2016 Beyond deforestation monitoring in conservation hotspots: analysing landscape mosaic dynamics in north-eastern Madagascar *Appl. Geogr.* **68** 9–19

Zulu L C and Richardson R B 2013 Charcoal, livelihoods, and poverty reduction: evidence from sub-Saharan Africa *Energy Sustainable Dev.* **17** 127–37