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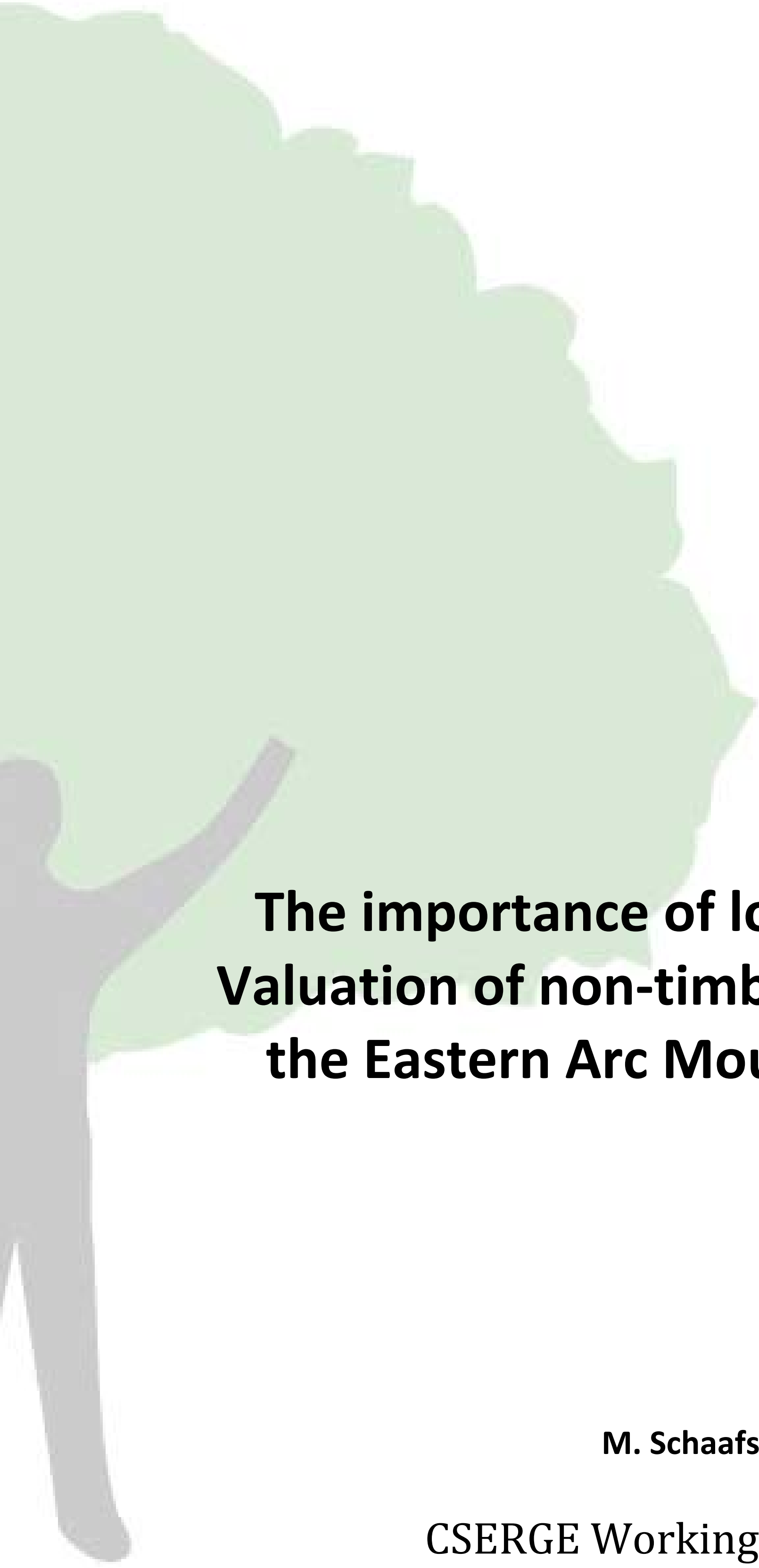

The importance of local forest benefits: Valuation of non-timber forest products in the Eastern Arc Mountains in Tanzania

M. Schaafsma, ***et al***

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THE IMPORTANCE OF LOCAL FOREST BENEFITS: VALUATION OF NON-TIMBER FOREST PRODUCTS IN THE EASTERN ARC MOUNTAINS IN TANZANIA

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Abstract: Understanding the spatial distribution of the quantity and value of Non-Timber Forest Product (NTFP) collection gives insight into the benefits that local communities obtain from forests, and can inform decisions about the selection of forested areas that are eligible for conservation and enforcement of regulations. In this paper we estimate transferable household production functions of NTFP extraction in the Eastern Arc Mountains (EAM) in Tanzania, based on information from several multi-site datasets related to the behaviour of over 2000 households. These micro-level models can be used to predict the value of NTFP collection across a broader spatial scale. The study shows that the total benefit flow of charcoal, firewood, poles and thatch from the EAM to the local population has an estimated value of TSH 59 billion (USD 42 million) per year, and provides an important source of additional income for local communities, especially the poorest. We therefore argue that further restrictions on forest access to promote conservation will require additional policies to prevent a consequent increase in poverty, and an enforced trade-off between conservation and energy supply to rural and urban households.

Keywords: Non-timber forest products, environmental valuation, benefit transfer

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1 INTRODUCTION

More than 800 million people worldwide live in or near tropical forests and savannas, and rely on these ecosystems for fuel, food and income (Chomitz et al. 2007). Tanzania is one of the poorest countries in the world, ranked 148th of the 169 countries on the Human Development Index (UNDP 2010). Eighty-nine percent of the population lives below the $1.25/day poverty line (UNDP 2010). Poverty in Tanzania is mainly a rural phenomenon: 83% of the poor live in rural areas and depend on agriculture or natural resources as their main source of income (NBS 2007). In Tanzania, as in many other sub-Saharan countries, 92% of rural households use firewood as their main cooking fuel, whereas over 50% of the urban population uses charcoal (NBS 2007). The collection of Non-Timber Forest products (NTFPs) for house construction and household use is also widespread, driven by poverty and lack of means to invest in better quality housing and non-forest substitute products. For these communities, NTFPs provide a source of complementary cash income, or a safety net when agricultural yields are low (Angelsen and Wunder 2003). The production of timber, building poles, charcoal and firewood has led to overexploitation of forests and is one of the main drivers (alongside agricultural expansion) of forest degradation and deforestation in Tanzania (Chiesa et al. 2009, URT 2010, Ahrends et al. 2010). Rapid population growth puts an additional increasing pressure on the natural resources in the country, as people need to eat, construct houses and obtain products to provide their livelihoods.

The Eastern Arc Mountains (EAM), which cover about 5% of Tanzania, are recognised as one of the world's biodiversity hotspots (Myers et al. 2000). Tropical forest ecosystems host at least 60% of the terrestrial biodiversity (Dirzo and Raven 2003, Myers et al. 2000) and play an important role in the global carbon cycle. Tropical forests contain around 25% of the carbon in the terrestrial biosphere (Bonan 2008) and their clearance and degradation account for about 17% of annual CO_2 emissions worldwide (IPCC 2006). Concerns about biodiversity conservation and climate change mitigation are therefore leading to rising international demand to reduce degradation and deforestation resulting from the harvesting of timber and NTFPs. However, while the benefits from CO_2 sequestration and biodiversity protection accrue to the entire international community (Balmford and Whitten 2003, Strassburg et al. 2010), the current welfare of local communities in developing countries is likely to decrease if NTFP harvesting is restricted. Allowing or restricting forest access can represent the difference between living above or below the poverty line (Vedeld et al. 2007).

The trade-offs between socio-economic impacts and forest conservation in forest-rich countries with high levels of poverty and forest-dependency are increasingly being considered in international conservation initiatives, including the UN's programme on Reducing Emissions from Deforestation and forest Degradation (REDD+, see UNFCCC 2006, Strassburg et al. 2009) and the Convention on Biodiversity Conservation (CBD 2002). REDD+ is aimed at mitigating climate change for the benefits of the global population by reducing forest degradation, with co-benefits for poverty alleviation. Similarly, the CBD, in aiming to reduce biodiversity loss, recognises the role of biodiversity for human wellbeing and promotes sustainable use and equitable benefit-sharing (CBD 2010). The CBD objectives have been integrated in the Millennium Development Goals and its strategies to reduce extreme poverty (Sachs et al.2009).

In order to achieve equity and poverty alleviation objectives, effective forest conservation policies should not only be informed by the potential for carbon sequestration and biodiversity protection, but also by the distribution of costs and benefits of forest conservation among stakeholders at different spatial scales (Hein et al. 2006, Turner et al. 2010). Understanding the spatial variation in the (opportunity) costs and benefits of conserving ecosystem services, conditioned by factors such as resource availability and population density (Naidoo and Ricketts 2006, Pagiola and Bosquet 2009, Turner et al. 2010), can help to define priority areas where limited budgets for forest and biodiversity conservation would have highest overall benefits (Naidoo et al. 2008). This is especially relevant for the montane and sub-montane forests of the EAM in Tanzania, where the benefits of protection of rare and endangered species could render extractive uses of these forests problematic (Burgess et al. 2007, 2010). However, effective mechanisms for realising stakeholder benefits and their possible redistribution on fairness grounds have to be in place, if forest conservation policies are to be feasible and equitable. The distributional effects of conservation will depend on who is considered to be a stakeholder and how much they gain or lose under a conservation policy.

This paper presents an extensive scale, spatially-explicit analysis of NTFP collection in the EAM of Tanzania. Based on a large dataset from different household surveys, we estimate spatially-explicit, micro-economic models of household NTFP collection, and spatially transfer these models to predict the economic value of the annual flow of NTFP extracted by the population across the study area. In the next section, we discuss the main strengths of our modelling approach. The case study is described in section 3 and the results presented in section 4. In section 5, we discuss the implications of forest conservation policy for other policy objectives such as poverty reduction.

2 SPATIALLY-EXPLICIT NTFP MODELS

The body of socio-economic literature on NTFP collection and forestry dependence is enormous and has been growing rapidly since the 1980s, with increasing policy interest in sustainable development, social forestry, indigenous people's rights, and the commercialisation of forest products (Neumann and Hirsch 2000). Unfortunately, most of these studies are qualitative in nature or describe forest dependency in terms of average quantities extracted by households. They are usually also rather localised, focusing on a particular forest or community (Croitoru 2007). They do not capture heterogeneity across forests, communities and other spatial contexts, which inhibits generalisation of their results and the transfer of the models to other locations, or over more extensive spatial scales (Godoy et al. 1993). This lack of generalisable information induces a risk that NTFP values are omitted from decision-making processes altogether, with potentially serious effects on local welfare in forest-dependent areas. There is hence a clear need for projections at large spatial scales of the values local communities derive from forests, including the collection of NTFPs.

Our bottom-up modelling approach[1] uses survey information on actual household behaviour from multiple locations over a wide spatial scale and different spatial contexts to develop a spatially explicit and transferable household production function. Essentially, our approach involves four steps: (1) estimating the household "production" function of NTFP collection; (2) transferring this function across the total study area; (3) aggregating household level extraction over all households in the study area, and (4) turning NTFP quantities into economic values. This approach has three main advantages. The first is that the annual flows of ecosystem values (rather than a projection linked to the underlying potential stocks) are analysed, reflecting the actual benefits accruing to the local communities. While the potential stock values will not be fully harvestable, it is still open to question what the sustainable resource take rate might be. Harvesting rates will be constrained by physical access problems such as steep slopes, but also because markets may not be sufficiently large (Sheil and Wunder 2002), or prices not sufficiently high to cover extraction costs in remote areas. The second advantage, compared to top-down approaches, is that the modelled household production functions (step 1) are based on micro-level data about individual decision-making and the factors that affect whether and how much to collect. The models therefore empirically capture values as perceived by local communities. Top-down approaches, on the other hand, typically start at forest availability and production to express values per hectare (Batagoda et al. 2000). However, they fail to capture the effect of typical household characteristics that influence the decision to collect NTFPs, such as the time and costs involved in collection, available labour (after fulfilling other income generating activities) and capital, market access and demand, transportation options, and the potential gains to the household budget of selling NTFPs (de Beer and McDermott 1989). The third strength is that our approach uses data from different areas with different socio-economic, spatial and biological conditions which are likely to influence the cost of collection, demand and availability of various NTFPs. NTFP harvesting efforts and forest degradation typically vary spatially (Robinson et al. 2002, 2008). Forest quality, for instance, is often lower near villages or population centres (e.g., Ndangalasi et al. 2007, Ahrends et al. 2010), due to variation in NTFP harvesting behaviour as predicted by economic theory: the distance from the household to the NTFP harvesting location is positively correlated with the opportunity costs of labour and time spent to collect NTFPs (e.g., Amacher et al. 1996, Köhlin and Parks 2001, Pattanayak and Sills 2001). The spatial distribution of harvesting efforts is also affected by forest accessibility, forest protection status and enforcement (Robinson and Lokina 2009, 2011).

Our approach thus combines the strengths of micro-level analysis of household behaviour with those of large scale projections of forest values. A limitation of such a large scale projection of ecosystem use is inevitably its accuracy at local levels. The underlying assumption of function transfer is that the relationship between the explanatory and dependent variables is constant between households in and out of the sample (Rosenberger and Stanley 2006). Function transfer is expected to lead to more accurate results than value transfer (Navrud and Ready 2007), where the mean of ecosystem value is taken to estimate the value of a non-surveyed site, because it allows for the effects of contextual factors (but see Rosenberger and Phipps 2006, Matthews et al. 2009). The validity of our approach hence depends on the quality of the NTFP

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[1] A full explanation of this approach is described in Annex I of this paper.

collection data, the representativeness of the sample, and the specification of the NTFP model (Boyle et al. 2009).

Ideally, we would extend our approach with an evaluation of the difference between sustainable and actual harvesting rates. However, a better understanding of sustainable harvesting rates than is currently available is necessary to assess the impact of NTFP harvesting on forest quality and potential incomes over time. For a sustainability analysis at a finer spatial level, additional information would also be needed to pinpoint the exact location where the NTFPs are harvested.

3 CASE STUDY

The EAM consist of 13 mountain blocks spreading from southern Kenya to eastern Tanzania (Figure 1). The dominant natural land cover is miombo woodland, covering approximately 42% of the total area, of which 10% is "disturbed miombo", in the form of woodland with scattered crops. There are various types of forests depending on the altitude: lowland forests at basin levels, sub-montane and montane forests, and upper montane forests at highest elevations (Burgess et al. 2007). The EAM provide a range of ecosystem services with associated human benefits at local, national and international levels. The area is known for its high levels of biodiversity and endemism (Myers et al. 2000, Burgess et al. 2007). The collection of NTFPs is part of the livelihoods of many communities in forested areas. Other important ecosystem services include the provision of fuel wood, the regulation of river flows for drinking water, irrigation and hydropower, and carbon storage (Fisher and Turner 2008, Fisher et al. in press). Approximately 21% of the EAM blocks are gazetted (Swetnam et al. 2011), including 75% of the remaining forests and 24% of undisturbed miombo woodlands (Platts et al. 2011). Pole cutting, charcoal production and timber harvesting are prohibited in Protected Areas and licensed in other gazetted areas. Nevertheless, illegal extraction of NTFPs continues in protected areas, partly a result of the weak enforcement of conservation policies, and partly driven by poverty.

The total population of the EAM blocks is estimated at 2.3 million, with a mean household size of 4.6[2]. In Tanzania, as in many other African countries, all local communities depend to some degree on the collection of NTFPs (e.g., Shackleton and Shackleton 2000, 2006, Ambrose-Oji 2003, Mamo et al. 2007, Kamanga et al. 2009, Palmer and MacGregor 2009). People collect firewood, charcoal, poles, thatch, fruits, vegetables, honey, bush meat, and medicines, and use a wide range of species (e.g., Luoga et al. 2000a, Turpie 2000, Monela et al. 2005, Anthon et al. 2008, URT 2008, Robinson and Lokina 2011). In this study, we focus on the first four of those NTFPs.

Firewood is collected by most households themselves, but only 2% of households sell it (NBS 2003). As demand has increased due to population growth, the availability of dead wood is now limited. Rather than switching to substitute energy sources or using more fuel efficient stoves, people are collecting live wood and drying it in some places (Arnold et al. 2003).

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[2] Based on the 2010 modelled surface of population (Platts et al. 2011).

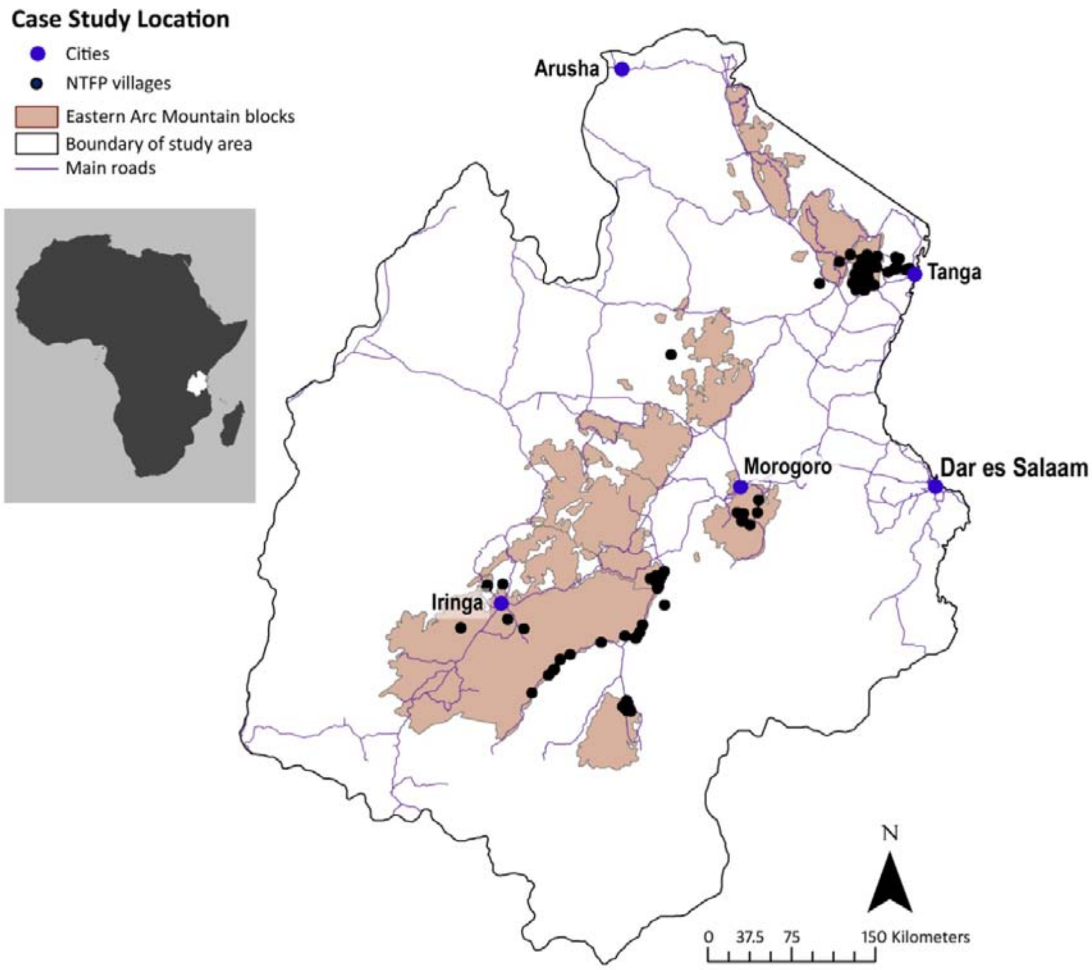

Figure 1 Case study area

Note: The NTFP villages reflect the villages where household data on NTFP collection has been collected in our datasets. The boundary of the study area reflects the larger study area of the Valuing the Arc project. The EAM block delineation, based on Platts et al. (2011), reflects the area for which NTFP values are estimated.

Whereas the rural community relies mainly on firewood for cooking, the urban population commonly uses charcoal (75% of households in Dar es Salaam and 54% in other urban areas, NBS 2007). In the lower woodland and forest areas of the EAM, charcoal production is practised for commercial purposes, mainly by men (Luoga et al. 2000a). According to official statistics (NBS 2003), 40% of charcoal-producing households sell their produce, but this proportion is expected to be higher in reality. Local communities are seasonally or occasionally involved in charcoal production and sell their products to middlemen who transport it to the major urban centres (Malimbwi and Zabahu 2008). Full-time charcoal producers often move around the country to new production sites.

Another important NTFP used by many rural families is poles (Burgess and Clarke 2000, Persha and Blomley 2009), used for the construction of houses. The commercialisation of pole cutting is small with only 6% of collecting households selling their poles (NBS 2003), mainly to neighbours. Due to lower pole availability near to villages in some areas, villagers are less likely to sell poles nowadays (Robinson and Kajembe 2009), with more households preferring to build brick walls, which they sometimes finance by small loans (Freeman 2010). Bricks are currently more expensive than poles and only available to richer families. Since bricks are usually dried using firewood, increasing their use may come at the expensive of increased firewood consumption.

Thatch is widely used for roofing, because it is considered to be cheap and also a traditional building material (Monela et al. 2005). In miombo areas, grass species that provide useful thatching material are abundant (Campbell et al. 2007). Thatch collection is expected to have a less detrimental effect on forests than fuel wood or pole collection, and is an important ecosystem service to local communities. Thatch is not traded on a regular basis.

4 ECONOMIC VALUATION OF ACTUAL NTFP FLOWS

4.1 Forest Income and Dependency

The availability of multiple multi-site datasets of household level observations on NTFP collection in Tanzania provided the opportunity to test and demonstrate our approach. Data from villages within 40 km of the EAM boundaries were selected. This selection resulted in seven different datasets, comprising over 2000 observations from 60 villages (see Appendix I - Data). The sample statistics show that NTFPs are of great importance to villagers in the EAM area. More than 60% of houses are constructed with poles and half of the sample has thatched roofs. For 13% of households the main source of household income is forest related, including timber and NTFP collection. NTFP income (cash and non-cash) accounts for 20% of total household income, which is comparable to the results of a meta-analysis of over 50 NTFP studies worldwide by Vedeld et al. (2007), which estimated that 22% of the income of forest-dependent communities was forest related. The annual median household income of the sample corresponds to $ 1.89 per household per day PPP-corrected,[3] equivalent to a daily income per person far below the poverty line. The number of people living below the poverty line in our sample is higher than census data indicate (38% in rural areas, NBS 2007); nevertheless it is clear that the households in the sample can be considered very poor.

Income is unequally distributed: the GINI-coefficient of our overall sample is 61%.[4] Excluding NTFP income from the calculation increases inequality and the GINI-coefficient to 65%. Thus, access to NTFPs reduces inequality. Splitting the sample into income quartiles (Table 1) shows that NTFP income (cash and non-cash) of the poorer groups is lower in absolute terms[5] but higher relative to the total household income, compared to richer households. This result confirms findings by earlier socio-economic

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[3] Based on the UNDATA (2010) PPP conversion factor of the local currency to international dollars of 2007: TSH 521,600=$ 1. Although the studies were not conducted in the same year, the use of conversion factors applicable to the study years does not have a marked effect on the results.

[4] The Gini coefficient is calculated as follows: $G = \frac{2}{n^2 \bar{x}} \sum_{i=1}^{n} i(x_i - \bar{x})$, where *n* is the number of observations, *i* are the observations ranked in non-decreasing order and *x* is income. A Gini coefficient of 0 percent implies perfect equality, whereas 100 percent implies maximal inequality. According to national statistics, the Gini coefficient in rural areas of Tanzania, based on household expenditure rather than income, is 33% (NBS 2007).

[5] The terms rich and poor should be interpreted with caution, as the mean annual household income of the richest group is only TSH 2 million (PPP $ 4,123).

studies (e.g., Mamo et al. 2007, Kamanga et al. 2009, Cavendish 2000). In our sample, richer households are less involved in the collection of firewood and thatch, but they are more likely to produce charcoal. In terms of quantity, they collect more firewood and poles, compared to poorer households. Differences in quantities for charcoal and thatch are not significant at the 5% level. These figures confirm that NTFPs reduce relative inequality, and are an especially important source of income for the poorest in these communities.

Table 1 NTFP collection across income groups

	Quantiles			
Variable	**Poorest**	**Poorer**	**Richer**	**Richest**
Mean total NTFP income (TSH* 1000/year) [a]	28 (34)	57 (61)	83 (102)	220 (523)
Mean household income (TSH* 1000/year) [a]	105 (49)	271 (56)	554 (109)	1,787 (1,391)
% NTFP in total income [a]	26%	22%	15%	12%
	% of households collecting			
Firewood [a]	95% (22%)	98% (14%)	96% (20%)	93% (25%)
Charcoal [a]	4% (20%)	5% (23%)	10% (30%)	12% (32%)
Poles	24% (42%)	22% (41%)	28% (45%)	22% (41%)
Thatch [a]	24% (43%)	22% (42%)	14% (34%)	6% (24%)
	Mean quantity collected			
Firewood (headloads/week) [a]	1.7 (1.5)	2.1 (1.5)	2.3 (1.8)	2.4 (1.9)
Charcoal (30 kg bags/year)	52 (65)	34 (41)	60 (63)	57 (58)
Poles (poles/year) [a]	0.8 (1.1)	0.7 (1.0)	0.6 (1.0)	1.5 (1.8)
Thatch (bundles/year)	5.9 (9.0)	6.0 (6.5)	7.9 (9.1)	17.1 (24.0)

Notes: Household statistics are not corrected for differences in household size or composition, i.e. not based on adult equivalent units, because the necessary data was unavailable. Standard deviations are presented in brackets. Superscript [a] indicates that the differences between the income groups are significant at the 1% level according to Kruskal-Wallis tests (with ties), where the critical value of χ^2 (3 d.f.)= 11.35.

4.2 Spatial Mapping of Economic Values of NTFP Collection in the EAM

The first step of our approach is to estimate a model for the annual quantity collected per household. We use count-data models to estimate these household production functions for three of our focal NTFPs. When only a small proportion of all households collect an NTFP, such as for thatch and charcoal, zero-inflated negative binomial models are employed to accommodate the distribution and the large number of zero observations of the dependent variable (Greene 1994, Cameron and Travedi 2005). For firewood collection, in which 95% of respondents are involved, a negative binomial model is estimated to support the overdispersion of the dependent variable.

We find that firewood collection increases with household size, forest income dependency, and forest availability, and decreases with open woodland availability and distance to roads (Table 2). The number of households collecting thatch increases with distance to roads and thatch use, and decreases with the availability of woodland with scattered crops and lowland forest around the village (Table 3). The quantity of thatch collected increases with the availability of woodland with scattered crops and sub-montane forest around the village. The number of households involved in charcoal production increases with the number of males in the household, forest-income dependency, the availability of open and closed woodland, but decreases with montane forest availability (Table 4). The quantity produced by these household decreases with the availability of closed woodland and montane and upper montane forest. Similar models of the collection of poles were not sufficiently robust. Therefore, we estimate the collection of poles based on the census statistics of pole use for building walls and roofs. Further details are included in the Annex I - Model Results.

Table 2 Results for firewood collection (negative binomial model)

Negative binomial: Number of headloads of firewood/household/week	**Coefficient (z-score)**
Household size (number of household members)	0.154*** (5.34)
Household size squared	-0.008*** (3.57)
Main source of household income is forestry (dummy: 1 if yes, 0 otherwise)	0.167*** (3.02)
All forest in a 10 km buffer (DF indicator, sigma=0.8)	0.00375*** (3.51)
Open woodland in a 10 km buffer (DF indicator, sigma=5)	-0.000114*** (2.58)
Distance to road (ln(km+1))	-0.198*** (4.01)
Constant	1.765*** (8.80)

Notes: Z-values are presented in brackets. Significance of the parameters is marked with asterisks: *** refers to 1%. See Annex I - Model Results for full details and explanation of variables.

Table 3 Results for thatch collection (zero-inflated negative binomial model)

Logit: Choice to collect	**Coefficient (z-score)**
Distance to road (ln(km+1))	0.715** (2.42)
Roof made of thatch (dummy; 1 = yes; 0 = otherwise)	1.990*** (4.15)
Woodland with scattered crops in 10 km buffer around village (ha/1000)	-0.471*** (2.55)
Lowland forest in 10 km buffer around village (ha/1000)	-1.207*** (2.91)
Constant	-3.368*** (7.59)
Negative binomial: Number of bundles collected/household/year[a]	
Woodland with scattered crops in 10 km buffer around village (ha/1000)	0.114*** (3.65)
Sub-montane forest in 10 km buffer around village (ha/1000)	0.237*** (15.49)
Constant	2.215*** (28.78)

Notes: [a] The presentation of the logit results is adapted (signs have been switched) to improve the ease of interpretation. Z-values are presented in brackets. Significance of the parameters is marked with asterisks: *** refers to 1%, ** to 5%. See Annex I - Model Results for full details and explanation of variables.

Table 1 Model results for charcoal production (zero-inflated negative binomial model)

Logit: ***Choice to produce charcoal***	**Coefficient (z-score)**
Number of males in household	0.224*** (3.68)
Forest main source of total household income (dummy)	2.261*** (5.66)
Woodland (open, closed) in 10 km buffer (ha/1000)	0.178*** (2.83)
Montane and upper montane forest in 10 km buffer (DF indicator, sigma=2)	-0.0195** (2.29)
Sub-montane forest in 10 km buffer (DF indicator, sigma=7.5)	-0.00512*** (4.36)
Constant	-3.390*** (6.51)
Negative binomial: ***Number of charcoal bags/household/year***[a]	
Closed Woodland in 10 km buffer (sigma=4)	-0.000789*** (3.61)
Montane and upper montane forest in 10 km buffer (sigma= 5)	-0.00159*** (4.68)
Constant	4.089*** (30.82)

Note: [a] The presentation of the logit results is adapted (signs have been switched) to improve the ease of interpretation. Z-values are presented in brackets. Significance of the parameters is marked with asterisks: *** refers to 1%, ** to 5%. See Annex I - Model Results for full details and explanation of variables.

In the second step of our approach, these four household production functions for firewood and thatch collection, charcoal production and pole cutting, are transferred across the study area. Part of this step involves determining for households living near the edges of the EAM which proportion of their NTFP collection is sourced from within the EAM. In the absence of accurate information about source locations of the NTFPs, we use survey data of travel time to source locations to develop spatial decision-rules to determine the proportion of NTFP collection that could be attributed to the EAM.

The third step is to aggregate these values per household over the entire population to assess the total annual quantity of NTFPs collected. Finally, these aggregated figures are then assigned an economic value using NTFP market prices, allowing for spatial heterogeneity in prices if possible and relevant. For firewood, poles and thatch, which are not traded on a regular basis, price information was difficult to obtain and also rarely reported in either the published or unpublished literature. We use the conservative modal price estimates based on the available information from our dataset to value the different NTFP flows (see Annex I - Table VII). Since these products are mostly sold at local markets or to neighbours (see Section 3), we assume that prices were not dependent on transport costs and do not vary across space. Charcoal prices vary spatially and therefore we develop a modelled price map to value charcoal production (see Annex I – *Charcoal Prices*).

The results show that the total value flow of the actual annual extraction of NTFPs considered in this study collected from the EAM blocks is estimated at TSH 59 billion (USD 42 million) per year (see Table 5), equivalent to almost TSH 26,000 per capita per year (USD 18).[6] Compared to the official statistics of mean rural expenditure per capita in rural areas of TSH 213,000 per year (NBS 2007), total modelled NTFP collection contributes on average around 12% to rural incomes.[7] Firewood provides the main source of cooking fuel for the majority of households and is found to be the most important NTFP for households in the EAM, with a total annual quantity collected of approximately 72 million headloads. In economic terms, firewood collection contributes TSH 16,000 to the annual household budget, and the flow of benefits is in total TSH 36 billion per year (USD 25 million). Pole collection contributes around TSH 957 per capita. The total annual quantity is 3.7 million poles, with a total value of TSH 2.2 billion per year (USD 1.6 million). Thatch collection has the lowest annual value with TSH 220 million (USD 0.16 million). Whereas firewood, poles and thatch are mainly collected for consumption purposes and contribute to non-cash household income, charcoal production is a tradable good and provides a source of cash income. The annual flow of benefits to charcoal producers in and around the EAM is 21 billion TSH per year (USD 15 million). Due to a lack of accurate data about source locations, it is impossible to attribute these benefits to particular areas, such as open access forests, Forest Reserves or other gazetted lands.

The results for the four NTFPs are combined in Figure 2, which depicts the annual economic value of NTFP collection from the EAM. The forests in the study area are also included, showing, for instance, that the NTFP values are particularly high near the forest in the Usambara Mountains in the north (to the west of Tanga) and the Uluguru Mountains near the city of Morogoro. These areas are characterised by high population density.

Table 5 Aggregate quantities and economic values of NTFP collection in the EAM

	Quantity per year (*1000)	**Value in TSH (*1mln)/ year (USD*1000/year) [a]**	**Value per capita (TSH) [b] (USD/year) [a]**
Firewood	71,939 headloads	35,969 (25,330)	15,639 (11)
Charcoal	2,869 bags	20,929 (14,739)	9,100 (6)
Thatch	734 bundles	220 (155)	96 (0)
Poles	3,670 poles	2,202 (1,551)	957 (1)
Total		*59,320* *(41,775)*	*25,792* *(18)*

Notes: [a] Based on a mean 2010 exchange rate of US$ 1= TSH 1420 (Bank of Tanzania 2011).
[b] Based on the population estimate of 2.3 million people.

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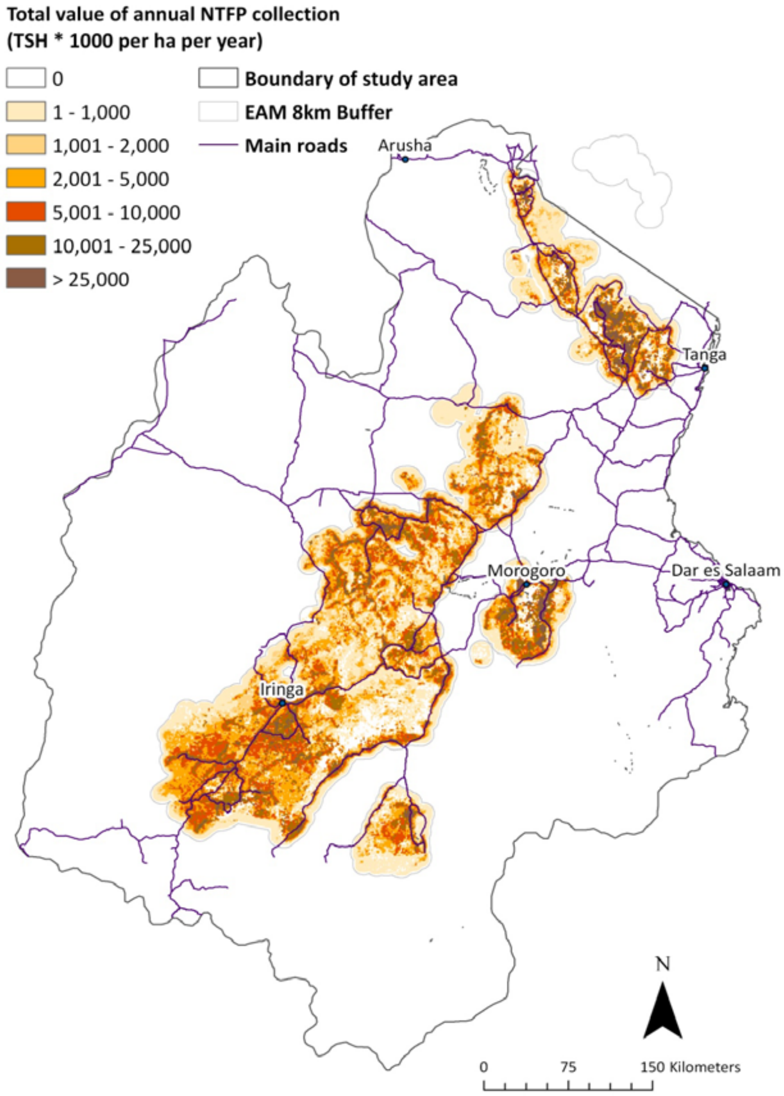
[6] Based on a mean 2010 exchange rate of US$ 1= TSH 1420 (Bank of Tanzania 2011).

[7] This is a conservative estimate based on national rural expenditure statistics. Compared to the sample average of income per capita, NTFP collection contributes around 15 percent.

Figure 2 Total value of annual NTFP collection (TSH * 1000 per ha per year)



5 DISCUSSION AND POLICY RECOMMENDATIONS

Analysing the spatial distribution of NTFP collection can help inform the selection of eligible areas for further forest conservation and enforcement of regulations. It shows where the costs of forest conservation (if harvesting restrictions were effectively enforced), in terms of NTFP income losses to the local population, would be high, which would require a trade-off with the benefits of climate change mitigation and biodiversity conservation for the global community. As our study shows, the total quantity of NTFPs collected, and hence the pressure on forests, is highest in areas with high population densities.[8] Forest policies that would reduce NTFP harvesting rates in such areas would be most effective in terms of potential carbon sequestration, and generate high benefits for the global community in terms of biodiversity conservation and climate change mitigation. Since current extraction rates in some areas are unlikely

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[8] Although our models do not give insight into the exact location where NTFPs are collected, forests near villages will be most affected by NTFP harvesting, as people collect at a relatively small distance from their village.

to be sustainable (Mwampamba 2007) and might lead to depletion of forest stocks, effective sustainable forest management might be able to secure a minimum flow of harvestable NTFPs and local income in the longer term, if it provides in. However, at the same time, intensified forest protection and enforcement would lead to high short-term costs for the local population and a large number of stakeholders bearing losses. Moreover, these people do not have the means to bridge the time gap between short-term costs and potential long-term benefits. Enforcement of stricter protection policies would be expensive and, because of poverty and population pressure, probably increase illegal harvesting rates and may therefore not be cost-effective or equitable. The inequality of the impact on forest-communities generally (of which around 80% live below the poverty line) and the poorest members in particular (who depend relatively more on forests than the richer members) is even more dramatic when related to per capita income. Hence, forest policy design involves complicated trade-offs between socio-economic and ecological objectives, with implicit concerns about the distribution of costs and benefits across stakeholders at global, national and local (intra-community) levels.

For forest management to be sustainable, both ecological and socio-economic objectives have to be met. The links between poverty and conservation are complex (Adams et al. 2004), but win-win solutions that improve human welfare in the short term and conserve nature are hard to realise in practice (Adams et al. 2004, McShane et al. 2010), and often trade-off decisions between ecosystem conservation and economic development have to be made (Sachs et al. 2009, Blom et al. 2010). The well-known Tinbergen-rule in economics says that a policy would be more efficient if for each objective at least one instrument is available (Tinbergen 1952). Any secondary objective requires an additional, correcting instrument. Hence, if conservation is the primary goal, additional policy instruments have to be developed to prevent a deterioration of or, if possible, an improvement in the poverty situation. And *vice versa*: if poverty alleviation is the main objective, additional regulation has to be put in place to ensure ecological sustainability. As an example, Payments for Ecosystem Services (PES) schemes mainly designed to contribute to poverty alleviation are less effective in terms of generating ecosystem services. However, by combining PES with other instruments aimed at socio-economic objectives (Wunder et al. 2008), the legitimacy (Corbera et al. 2007) and ultimately the efficiency and equity outcomes of PES may be improved (Engel et al. 2008, Pagiola and Platais 2007, OECD 2007).

Often, the global distribution of conservation benefits is unequal and the costs are mainly borne by local communities (Brandon et al. 2005, Balmford and Whitten 2003). A more effective and equitable outcome of forest conservation policies requires that the benefits of conservation at the global scale are captured and redistributed to compensate local losses (Naidoo and Adamowicz 2005). Benefit capture at such a scale involves formal market based mechanisms, including taxes, fees and PES (Fisher et al. 2008), which provide economic incentives to reduce negative external effects of resource use. REDD+ might provide the financial resources for payments to compensate for forest benefits foregone due to harvesting restrictions, or to reward contributions to forest protection (Pfleigner 2011, Burgess et al. 2010, Blomley and Iddi 2009). Without proper economic incentives, it is unlikely that forest dependent communities will change their harvesting behaviour. Currently, such incentives are absent in Tanzania, which may explain why NTFP and timber collection continues in Protected Areas, and why participating villages do not adhere to joint management agreements (Veltheim and Kijazi 2002, Topp-Jørgensen et al. 2005, Blomley et al. 2009).

At the national and intra-community level, payments may increase the unequal distribution of welfare (Zilberman et al. 2008) and thereby hamper policy effectiveness if the poorest groups do not take part in, and hence not benefit from, the payments scheme. The poorest in society often depend most directly on the natural resources, as in our case, and are therefore most vulnerable to increased restrictions on NTFP extraction (Cavendish 2000). An evaluation of nine communities in Tanzania showed that neither Joint Forest Management (JFM - typically in areas with high biodiversity values, where only dead wood collection is allowed) nor Community-Based Forest Management projects (CBFM - typically in more degraded areas, where NTFP collection is allowed) have been able to ensure an equitable distribution of the benefits and costs of forest management (MNRT 2008, Vyamana 2009). The benefit sharing mechanisms in current schemes (both JFM and CBFM) are not considered to be viable in the longer term, because their severe official restrictions on NTFP collection leave local communities with low and unclearly defined benefits (Blomley and Iddi 2009). Moreover, although CBFM was intended to transfer responsibilities and benefits of conservation to local communities, in reality they have not been pro-poor(est) and tend to exclude the poor from benefiting. The transaction costs and (upfront) investments of such schemes to people from lower income class are relatively high compared to richer groups (Meshack et al. 2006). Instead, local elites are rewarded for the time and effort put into village committees and forest management and tend to gain most from CBFM in Tanzania (Blomley et al. 2009), similar to CBFM projects elsewhere (Kellert et al. 2000, Sommerville et al. 2010). If the poorest community members cannot participate in rulemaking, achieving sustainable forest management with legitimate and fair incentive structures that is supported by all groups among the local population, will be difficult (Persha et al. 2011). However, the process of establishing participatory forest management schemes may also change (existing) problems of elite capture, and give the poor the opportunity to learn to exercise their democratic rights and over time gain influence (Saito-Jensen et al. 2010).

A further impediment for poor rural households to benefit from compensation schemes, is the current property right system, on which many market-based mechanisms including PES are based (Fisher et al. 2008, Wunder et al. 2008). Although the legal and policy framework in Tanzania is one of the most advanced in Africa, tenure arrangements are still not sufficiently secure for the poor to market their land (Korongo Ltd and REPOA 2003). If REDD+ is implemented using a PES-like compensation mechanism for NTFP harvesting based on property rights, only those few large-scale forest owners with secure rights may benefit, and inequality and conflict over resources may increase (Sunderlin et al. 2009). Further recognition of local individual and/or community rights to the ecosystem services provided by forest, and development of the legal system to secure these rights, will be necessary for the poor to benefit from such payments (Clements et al. 2010).

Since population growth and the demand for energy continue to increase, a final consideration is whether both the urban and rural population will be able to switch to non-forest energy sources before most of the forests have been cut down beyond their threshold levels (Chiesa et al. 2009, Mwampamba 2007). However, simplistic, total restrictions on fuelwood collection to reduce deforestation and mitigate climate change may serve to exacerbate the nationwide energy problem, because alternative sources of energy, such as jatropha or electricity, are hardly available or very costly, both in urban and rural areas (Wiskerke et al. 2010), and sustainable harvesting levels of fuelwood are unlikely to be sufficient to supply a growing population. Providing direct financial payments as compensation for benefits foregone will not be effective if no substitute products are available. It seems, therefore, unrealistic to attempt a complete ban on fuelwood collection as it would be impossible to enforce.

Accepting that conservation objectives may have to be compromised in places, a more realistic solution would be to allow for NTFP and timber collection in some areas, while simultaneously stimulating the adoption of more efficient charcoal and firewood stoves in order to limit demand and reduce pressure on forests (Fisher et al. 2011, Hofstad et al. 2009). Similarly, pole cutting could be reduced by stimulating the use of bricks to build houses, for instance, supported by micro-credit schemes (Zabahu 2008, Freeman 2010). Since private investments in fuelwood supply are likely to remain unprofitable under current fuelwood prices, licence requirements and de facto open access of the remaining forests and woodlands (Wiskerke et al. 2010), additional policies on the supply side could be developed to encourage, for instance, more efficient charcoal production methods and fuelwood and pole plantations.

Beyond the forest sector, poverty alleviation initiatives focused at productivity improvements in the agricultural sector could help to reduce agricultural encroachment of forests and forest-dependency. Options include subsidizing fertilizers, pesticides, seeds and technology, improving market access and reducing taxes and levies on agricultural products, combined with projects to increase technical skills, which are currently the main obstacles for profitable small-scale farming (Korongo Ltd and REPOA 2003). Since new production methods, substitute products and income generating activities require capital, incentives should be sufficient to ensure that the poorest have access to substitute products (Pirard et al. 2010). Overall, a strong institutional framework is required to achieve sustainable, effective and equitable forest management, where different governmental sectors, including energy and agriculture, cooperate to address the various drivers of poverty and deforestation. In light of current institutional structures and limited budgets, improving the conservation of the EAM calls for the international community to support the redistribution of conservation benefits, and provide financial and technological transfers, including access to alternative energy sources. In order to deal with existing problems related to property rights and elite capture, transfers should be directly paid to those people who would change their behaviour upon receiving incentives, where payments should be conditional on effective contribution to forest conservation. An equitable and effective transfer scheme should attempt to reach the poorest, who are facing highest relative losses, but the transaction costs may be high. Changing national and international institutional arrangements is an enormous, long-term challenge. The main recommendation for more practical actions in the short-term is to attempt to circumvent problems related to property rights, elite capture and limited or costly alternatives to NTFPs into account, and involving the poorest in affected communities.

6 SUMMARY AND CONCLUSIONS

NTFP collection in the EAM in Tanzania is an important source of income for many local communities. Based on a large pooled dataset of different household surveys, this study highlights that the annual value of NTFP collection varies across households and geographical areas. Our approach, based on consideration of spatial characteristics, such as forest availability and distance to roads and markets, allows us to generate spatially-explicit household production function that are transferable over the total study area. The resulting value maps demonstrate that the importance of spatially-explicit approaches becomes ever more apparent when the spatial distribution of the population is taken into account when applying the household production model over a wide area and aggregating the mean quantity collected over the total population.

The total benefits of NTFP collection accruing to the local population are approximately TSH 59 billion per year (USD 42 million), with firewood and charcoal collection as the largest contributors. Using the data of a national household survey, roughly comparable results of TSH 48 billion (USD 33 million) were obtained (Schaafsma in prep). This figure shows the magnitude of the economic loss that local households would bear if NTFP collection was fully and effectively banned across the EAM and surrounding areas. Without any interventions, current unsustainable extraction rates and overharvesting in some areas are likely to worsen the longer-term poverty situation. However, in the short-term, before potential local benefits of sustainable forest management occur, imposing stricter forest access regulation will also increase poverty levels. Considering that the relative contribution varies across income groups and is higher for the poorer part of the population, any policy that changes forest access and NTFP collection possibilities is hence likely to hit the poorest hardest. Reducing current NTFP collection rates in an equitable manner requires the design of payments schemes that actively involve and compensate the losers from conservations efforts.

The rapid deforestation rate spurs a sense of urgency to protect forests. However, the design of effective, equitable and efficient forest policies to reduce current harvesting levels involves complicated trade-offs between ecology and poverty objectives, and decisions on who will benefit or loose. It requires a policy mix involving interventions across forest, energy and agriculture sectors. Moreover, unprecedented levels of legally binding cooperation are needed between governance levels to promote an equitable sharing of costs and benefits of forest conservation between the international community, the national and local governments in Tanzania, and rural as well as urban households who need to change their harvest of NTFPs and energy consumption.

The results presented here are part of a wider programme of work in progress, in which we aim to assess the benefits of forest protection, such as carbon sequestration and biodiversity conservation, and the opportunity costs of forest protection related to alternative land uses, such as agriculture. This should allow policy makers to compare the estimated total value of NTFP harvest to other ecosystem services under different land use scenarios.

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Annex I Data and methods

Data

Our household extraction data come from seven different surveys. These surveys were conducted for independent projects in separate areas using different questionnaires. An overview of the dataset characteristics is given in Table I. Villages unlikely to source from EAM woodlands and forests were excluded from the dataset – a 40 km range was used as a criterion. Figure 1 shows the locations of villages where household interviews about NTFP collection were conducted. The spatial distribution of the sample is important to ensure that differences in spatial context across the study area are captured in the household production models. Within each village and each project, a stratified random sampling strategy was followed, which ensures that our sample is representative. Although remote parts of our study area are not well-covered by the surveys, the socio-economic, institutional, ecological and spatial characteristics of the sampled villages vary sufficiently to reflect the characteristics of the non-surveyed areas. The datasets were merged and a range of assumptions was made to standardise quantity units, such as bags, headloads and bundles, and time units across datasets. We used existing literature and information provided by original survey reports to guide these assumptions (e.g., Bembridge and Tarlton 1990, Kaale 2005, BACAS 2007, Muregerera 2008, Wiskerke et al. 2010).

Table I Description of datasets

Dataset	Where	When	No. Hh[a]
1. IVM (Hess et al. 2008)	5 villages near Uluguru Mountains, 3 districts	Autumn 2006	212
2. ARPIP (URT 2008)	9 villages in EAM in Iringa Rural, Kilolo, Kilombero, Korogwe, Morogoro Rural and Muheza Districts	Autumn 2007	368
3. Freeman (2010), Hernández-Sirvent (2009)	3 villages in Ulanga District	July 2009	96
4. Kilonzo (2009)	3 villages in Kilombero and Morogoro Districts	2008	90
5. Hepelwa (in prep)	27 villages in Muheza and Tanga districts	2008-2009	764
6. UMEMCP (2010)	4 villages in Morogoro Rural and Mvomero Districts	Autumn 2009	242
7. TAFORI, Sokoine University of Agriculture and University of Copenhagen (Ngaga et al. 2009)	6 villages in Iringa Rural, Korogwe and Babati Districts	2009	240

Note: [a] In some cases the original datasets contain more observations, but only those villages in or near the EAM were included in our analysis.

The data suffer from several limitations, some of which are common to NTFP studies (see Godoy et al. 1993, Gram 2001, Sheil and Wunder 2002). The first issue is that data were collected in one-off household surveys which are susceptible to problems with recall. These relate to difficulties that respondents may have with remembering exactly how much NTFP they collected and when, over a certain time period, especially if this period is long. Second, some NTFPs are illegal to collect, which may result in large underreporting of both the choice to collect and the quantities extracted (Vedeld et al. 2007). Third, many of the datasets did not provide any or sufficiently detailed and reliable information on exact NTFP harvest locations. Finally, high variability across the datasets with respect to their inclusion of various other NTFPs, such as food and medicines, prohibited the estimation of robust statistical models for these products. This study, therefore, gives an incomplete picture of the total value of NTFPs in the EAM. Summing the total value of the four NTFPs analysed here would result in an underestimate of the total value of NTFPs in the EAM.

Secondary data for the explanatory variables, necessary for the function transfer, include census data based on the Tanzanian Household Budget Survey 2001/2 and 2007 (NBS 2003, 2007), available at regional or district level, and the same spatial data as used in Swetnam et al. (2011). Population data come from Landscan (2008) estimates and the latest census information (NBS 2002), following Platts et al. (2011). We also use this paper for the demarcation of the EAM blocks based on landscape features.

Sample Characteristics

The total dataset includes 2012 household level observations from 60 villages. Table II presents the descriptive statistics of the sample. The mean household consists of five people of which half are males. The education level of the sample is low: 95% of the sample has only completed primary school, or has not had any schooling. Households rely mainly on agriculture for their income. These statistics are roughly in line with those of the Tanzanian census data for rural areas (NBS 2007) and the sample is hence considered to be largely representative of the rural population of the EAM.

Table II Descriptive statistics of the sample

Variable		**Sample[a]**	**NBS 2007**
Household composition and labour			
Household size - mean		5.1 (2.3)	5
Number of males per household – mean		2.5 (1.6)	n.a.
Household education – % of sample with no or only primary education		95 (21)	94
Land and income			
Main source of household income: agriculture - % of sample		73 (44)	70
Main source of household income: forestry (timber, NTFP) - % of sample		13 (33)	4
Total annual income per household – TSH * 1000	Mean Median	667 (955) 360	1256[b] n.a.
Total annual income per capita – TSH * 1000	Mean Median	178 (482) 80	213[b] 174[b]
Total annual income per household from NTFP –TSH * 1000	Mean Median	75 (127) 36	n.a. n.a.
Resource use			
House made of poles - % of sample		62 (48)	39[c]
Roof of the house made of thatch - % of sample		49 (50)	57
Main cooking fuel - % of sample using firewood		94 (24)	92
Spatial variables			**n.a.**
Distance to nearest road – km		1.9 (2.6)	
Open woodland in 10 km buffer - ha		1982 (3122)	
Closed woodland in 10 km buffer - ha		886 (2367)	
Woodland with scattered crops in 10 km buffer - ha		2336 (3432)	
Total woodland in 10 km buffer- ha		*5205 (5718)*	
Lowland forest in 10 km buffer – ha		925 (1553)	
Submontane forest in 10 km buffer - ha		1002 (1678)	
Montane forest in 10 km buffer – ha		899 (1559)	
Uppermontane forest in 10 km buffer - ha		1574 (3135)	
Total forest in 10 km buffer-ha		*4400 (4545)*	

Notes: [a] Standard deviations are presented in brackets. [b] Based on household expenditure data (not income). [c] This statistic is very low compared to the agricultural census data, according to which 66% of rural families in the EAM districts use poles (NBS 2003). We therefore used district specific data of the Household Budget Survey 2007 in the estimation of pole collection (authors' own calculations, dataset HBS available online: http://www.scribd.com).

Methods

Step 1. Estimating Household "Production" Functions of NTFP Collection

The underlying economic assumption of this first step in estimating household production functions is that households aim to maximise utility by allocating labour across different income generating activities, including agriculture, employment and forestry, conditional on their socio-economic, ecological, spatial, institutional and governance characteristics. Our dependent variable Q_{jimt} is the quantity of NTFP *j* extracted by household *i* at location *m* in period *t*:

$$Q_{jimt} = f(X_{im}, Y_{jm}, Z_{jm}) \tag{1}$$

The household production functions explain the extraction of NTFPs by households in the study area in terms of a set of household characteristics *X,* such as labour, capital, and household demand for NTFPs, and distance to markets reflecting transportation costs. *Y* variables are those related to the resource availability of NTFP *j* at location *m*, such as distance to the forests, which are used as a proxy for the opportunity costs of time to travel to the place where NTFP can be collected. *Z* variables describe the resource management conditions at location *m*, for instance whether the forest or woodland is officially protected, which is expected to affect the quantity of NTFP extracted through resource accessibility.

Estimating the Impact of Forest and Woodland Availability

The distance to and availability of the resource were combined into a single indicator, by weighing every grid cell of forest or woodland by its distance to the village, using a half-normal distribution function:[9]

$$DF_i = \sum^{f} e^{\left[-\left(\frac{d_{if}}{\sigma}\right)\left(\frac{d_{if}}{\sigma}\right)\right]} \tag{2}$$

Here, *DF* reflects the total forest or woodland availability weighted by distance to household *i*. The distance *d* to each forest or woodland cell *f* around the village of household *i* is divided by an arbitrary sigma value *σ*, which sets the shape (spread) of the half-normal distribution. Together with the estimated variable coefficient, the shape of the distribution reveals how households balance the cost of travelling to each of the forest or woodland patches against the quantity of NTFP that can be collected at each patch.

For practicality (mainly GIS computing potential) and given the limited reported distances over which NTFPs are collected, we restricted the number of distance observations around each village to those forest and woodland cells within the 10 km buffer. In estimating the models, the final sigma value was chosen based on the best model fit. We used a grid search procedure, re-estimating the model for different values of sigma until the best model fit was found. The smaller the sigma, the higher is the distance-decay effect (the steeper the curve). For sigma=0.8 (the lowest sigma-value in

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[9] Alternatively, exponential or logarithmic functions could be used.

our models), any forest or woodland more than approximately 2 km from a household has hardly any impact on the quantity of NTFP it collects, whereas for a value of sigma=7.5 (the highest sigma-value in our models), the availability of forest or woodland beyond 10 km still affects collection quantities.

Model Results

We use count-data models to model the quantity of NTFP collected per household. We tested for overdispersion[10] in the distribution of the dependent variables to see if negative-binomial instead of Poisson models would be more appropriate (Greene 1994, Cameron and Travedi 2005), and employed Vuong tests[11] to test if zero-inflated models were necessary to accommodate an abundance of zero-observations. Excess zeros in the dependent variable arise as not all households are involved in the collection of NTFP *j*. A zero-inflated negative binomial model consists of two parts, estimated simultaneously: one logit model predicting excess zeros (in our case: the probability that household *i* is not involved in the collection of NTFP *j*) and a negative binomial model predicting the count data (in our case: the number of units of NTFP *j* collected by household *i*). Note that, usually, positive coefficients in the logit model indicate that the variable increases the probability that an observation is zero, i.e. the household does not collect NTFP *j*, but we have reversed the signs in the tables to improve the ease of interpretation. Positive coefficients in the logit model in the table therefore imply that the variable increases the probability that a household collects NTFP *j*.

We use a stepwise procedure, similar to backward exclusion, starting with models including all variables in the exploratory phase, then excluding variables until only significant ones remain. The main reason for producing these significant-only models is the use of the models for out-of-sample prediction of NTFP extraction across the wider study area. In the specification of the models, we only include variables that were theoretically expected to be important explanatory factors of NTFP collection, and for which secondary (census) data were available to enable transfer. Spatial variables, such as population density, distance to roads and land use characteristics, are typically correlated. To avoid correlation between explanatory variables in the statistical analysis, if any two spatial variables were correlated, we preferred to include land cover variables in order to capture the relationship between resource availability and NTFP collection, and show the importance of these natural resources to local communities.

The models were estimated in STATA10. The models for firewood, charcoal and thatch result in a reasonable model fit given the data limitations discussed above. Modelling pole cutting at household level did not result in robust model estimates, and we therefore used an alternative approach.

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[10] Overdispersion implies that there is more variability in the dataset than would be expected. For Poisson models, the data is called overdispersed if the variance is larger than the mean.

[11] The Vuong test compares the zero-inflated model with an ordinary negative binomial regression model.

Firewood

Ninety-five percent of the households in the dataset collected firewood, of which 4% sell (some of) the quantity collected. In the model, the dependent variable is the number of headloads of firewood collected per household per week.[12] Given the high participation rate in firewood collection, Vuong and overdispersion test results indicated that a negative binomial model was appropriate.[13] We included a random effect to control for the panel structure of the data, as multiple households facing the same contextual factors were interviewed in each village. All datasets were used and the final model is based on 1910 observations from 60 villages. The results are presented in Table III. Six variables are found to be significant. Larger households collect more firewood than smaller households, which confirms the expectation that larger households need more firewood to prepare their meals and can allocate more labour to firewood collection. The quadratic term shows that the marginal quantity collected per additional household member decreases, which may reflect an efficiency gain in cooking. Households whose main source of income is forest related (including timber and NTFP) collect more firewood.

Three spatial variables predict spatial heterogeneity in the pattern of NTFP extraction. Households living further away from a road collect less firewood, which may arise because higher commercial activity along roads, using firewood as an input, increases the demand. Two spatial variables reflecting distance to and quantity of available forest and woodland are found to be significant in the model. Firstly, households with more forest within a 10 km radius around their village, weighted by its distance to the village, collect more firewood (see equation 2).[14,15] The sigma value of 0.8 indicates, however, that forest around the village only increases the quantity collected if it is located within approximately 2 km of the village. These households have easier access to firewood, hence lower collection costs. Secondly, open woodland has a negative effect on the total quantity collected. Households with more open woodland forest within a 10 km radius, weighted by the distance to the village, collect less firewood. This may reflect lower firewood availability in open woodland compared to the average type of land cover. The impact of an additional hectare of open woodland on firewood collection extends beyond 10 km, as the sigma value of 5 indicates. For several variables related to household wealth, such as the ownership of various assets (e.g., land, cattle), income level and education, for which we had *a priori* expectations, no significant effects were found.

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[12] The main reason to use the number of headloads per week rather than per year was the distribution of the dependent variable. Some datasets provided annual estimates based on a weekly collection (*52) and others used monthly estimates (*12), resulting in multiple peaks in the distribution. Conversion to weekly estimates and using integer numbers resulted in a smoother distribution of the dependent variable and better modelling results.

[13] A Vuong test as specified in STATA (with household size as the explanatory variable in the logit model), resulted in a z-test statistic of $z=-0.01$ ($Pr>z=0.50$), hence the zero-inflated negative binomial model is not favoured over the standard negative binomial model. The variance of the dependent variable was 1.5 times larger than the mean, and therefore a Poisson model could not be used.

[14] As all types of forest (lowland, submontane, montane and uppermontane) were significant and showed the same sign when included separately in the models, we combined them to a single variable to increase the number of observations with forest in a 10 km buffer and to reduce the number of variables to be estimated.

[15] We expected that higher, and hence colder, villages would require more firewood for heating. Altitude was correlated with forest availability and therefore not included in the model. The parameter for forest availability may hence partly reflect the effect of altitude.

Table III Model results for firewood collection per household per week

***Negative binomial*:** **Number of bundles of firewood/household/week**			**Coefficient**
Household size (number of household members)			0.154*** (5.34)
Household size squared			-0.008*** (3.57)
Main source of household income is forestry (dummy)			0.167*** (3.02)
All forest in a 10 km buffer (DF indicator, sigma=0.8)			0.00375*** (3.51)
Open woodland (DF indicator, sigma=5)			-0.000114*** (2.58)
Distance to road in a 10 km buffer (ln(km+1))			-0.198*** (4.01)
Constant			1.765*** (8.80)
Model statistics			
Ln (r)	5.165	r	174.98
Ln (s)	3.689	s	40.00
Log likelihood			-3356
Number of observations			1910
Wald chi2(6)	109.48	Prob>chi2	0.001
LR- test vs. pooled: chi2(1)	42.95	Prob>=chi2	0.001

Note: The model is estimated in STATA10. Z-values are presented in brackets. Significance of the parameters is marked with asterisks: *** refers to 1%. In negative binomial panel models, the inverse of the dispersion is assumed to follow a random beta (r,s) distribution. The Wald test result indicates that the overall model is significant. The Likelihood ratio test result indicates that the panel effect is significant.

Thatch

Around 16% of the households have collected thatch over the year preceding the survey, but only 4 households out of 103 sometimes sold it. Given this low participation rate and the overdispersed dependent variable,[16] a zero-inflated negative binomial was estimated. We did not attempt to estimated single parameters for the distance-availability indicators for forest or woodland, because the effect of distance (opportunity costs of time) is expected to be lower for those products for which demand is inelastic, for instance, when there are few substitution possibilities (Arnold et al. 2003), or which are as infrequently collected as thatch. Four of the seven datasets contained information about thatch collection (sets 1, 2, 3 and 5). The results presented in Table IV are based on 1348 observations from 51 villages. As the upper part of Table 6 shows, the probability that a household collects thatch depends on three spatial variables and the construction material of the house. Households who use thatch to construct their roofs are more likely to collect thatch. The first significant spatial

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[16] The variance of the dependent variable was 21 times larger than the mean quantity of thatch collected.

variable indicates that the probability that households collect thatch is higher when households live further away from roads. This result may reflect that households in remote areas are more dependent on natural resources, as they have lower market access both for income generation and buying alternative roofing material. The availability of lowland forest in a 10 km buffer around the village decreases the probability that households collect thatch. A similar but smaller effect is found for the availability of woodland with scattered crops. However, as can be seen in the lower part of the table, higher availability of woodlands with scattered crops increases the quantity of thatch collected annually, but the net-effect of woodlands is expected to be negative. The model also shows that households living in areas with more sub-montane forest in a 10 km buffer collect more thatch.

Table IV Model results for thatch collection per household per year

Logit: ***Choice to not-collect***			**Coefficient**
Distance to road (ln(km+1))			0.715** (2.42)
Woodland with scattered crops in 10 km buffer around village (ha/1000)			-0.471*** (2.55)
Lowland forest in 10 km buffer around village (ha/1000)			-1.207*** (2.91)
Roof made of thatch (dummy; 1=yes; 0 otherwise)			1.990*** (4.15)
Constant			-3.368*** (7.59)
Negative binomial ***Number of bundles collected/household/year***			
Woodland with scattered crops in 10 km buffer around village (ha/1000)			0.114*** (3.65)
Sub-montane forest in 10 km buffer around village (ha/1000)			0.237*** (15.49)
Constant			2.215*** (28.78)
Model statistics			
Ln (alpha)	-1.628	Alpha	0.196
Number of observations			1348
Number of nonzero observations			103
Log likelihood (pseudo)			-547
Wald chi2(2)	284.15	Prob>chi2	0.001

Notes: Model is estimated in STATA10. Z-values are presented in brackets. In a zero-inflated negative binomial model, alpha is the over-dispersion parameter. The results show that alpha is different from zero (95% confidence interval of alpha is 0.00-45.32), which indicates that the overdispersion is only just significant. Additional tests in STATA (e.g., the countfit function) indicated that the zero-inflated negative binomial resulted in better fit than Poisson or non-inflated models. The McFadden's R^2 indicator is 23%, which Veall and Zimmermann (1996) suggest to be comparable to an OLS- R^2 of 41%.

Poles

Twenty-two percent of the respondents said they were involved in pole cutting, but only 5% said they sold their poles. Unfortunately, the estimation of household production functions for poles did not produce robust model results with sufficient explanatory power. This is probably due to low data reliability due to recall problems. Collecting poles to build or repair houses is not such a frequent activity as charcoal or firewood collection, which may explain why the number of respondents that could accurately recall pole collection in the year prior to the survey was low. In addition, because of the illegal nature of pole collection inside Protected Areas or without licenses, people may have been unwilling to admit to the activity. According to Marshall (2008), pole cutting mainly takes place on weekends or during the night when the risk of being caught by forest patrol is smallest. Even when we exclude the datasets for which the number of respondents collecting poles is far below the census statistics (66%, NBS 2003), no satisfying modelling results are obtained.

As an alternative, we assess pole cutting and associated values by looking at one of the main uses of poles, namely the construction of walls and roof frames for houses. According to the HBS 2007 statistics, on average 55% of households in the districts of the EAM live in houses with wooden roof frames and 44% of the households live in houses with pole walls. These statistics vary across districts, with highest numbers for Pwani and lowest for Kilimanjaro district. The construction of walls and roof for a typical house is estimated to require about 400 medium and larger poles (350 for the walls and 50 for roof frames), together with a number of withies (Luoga et al. 2000b, Turpie 2000). Such houses have a lifetime of around 25 years. To estimate the use of poles across all households in the study area, we used the following model:

Q poles=Q(poles for walls) + Q(poles for roof frames) = number of households in cell *m* * [(%of households in that district using poles for constructing walls * 350 poles * 1/25) + (% of households in that district using poles for constructing roof frames * 50 poles * 1/25)].

The implicit assumption is that households living in the EAM area collect the poles they need themselves from the EAM or buy them from other households collecting in the EAM area. We ignore pole collection for other purposes besides house construction, and for commercial purposes supplying households outside the study area. Therefore, the numbers presented in this paper may underestimate the total value of pole cutting.

Charcoal[17]

Eight percent of all households in the dataset had been involved in charcoal production during the year prior to the surveys, and most of these households (89%) had sold their products. Given this low participation rate and the overdispersed dependent variable (quantity of charcoal collected per household),[18] a zero-inflated negative binomial was estimated. Four of the seven datasets contained information about thatch collection (sets 2, 3, 5 and 7). The final model is based on 1176 observations. The results are presented in Table V. In the logit model five variables, related to household characteristics, forest and woodland accessibility, are significant at the 5% level. First,

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[17] The results of the charcoal model are also reported in Schaafsma et al. 2011.

[18] The variance of the dependent variable was 21 times larger than the mean quantity of thatch collected.

households with more male members are more likely to produce charcoal, which reflects that charcoal production is mainly an income generating activity practised by men (Luoga et al. 2000). Households whose main source of income is from forests (including timber and NTFPs) are also more likely to produce charcoal. Resource availability plays an important role in the household production model. First, households with more open or closed woodland in a 10 km buffer around the village are more likely to be involved in charcoal production.[19] Second, the area of montane and upper montane forest in a 10 km buffer, weighted by the distance to the village, has a negative effect on the probability that a household produces charcoal. The sigma value of 2 implies that forest hectares beyond ~5.5 km have hardly any additional impact on charcoal production choices compared to other types of land cover. The availability of sub-montane forests around the village of the respondent has a larger impact, as indicated by the higher coefficient in combination with the higher sigma value. Here, the sigma value of 7.5 implies that sub-montane forests beyond 10 km still affect charcoal production. These montane forest types are not suitable for charcoal production, because they generally have protected status, and transport is difficult due to their steep slopes. To avoid correlation, explanatory variables related to slope and the management regime of the forests were not included in our model. Since the model predicts lower collection rates in forested areas, the overall pattern will partially account for slope and management regime effects.[20]

In the negative binomial model, which explains how much charcoal is produced per household, two variables were significant. First, as well as being less likely to produce charcoal at all, households with more montane and upper montane forest nearby produce fewer bags of charcoal. Second, households with more closed woodland nearby produce fewer bags than other households. The sigma values of 4 and 5 indicate that these land cover types have a positive weighted value up to around 11 km and 13 km, respectively, from the villages.

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[19] For this variable, no sigma value was estimated, because it did not increase the model fit. The model fit increased using our distance-weighted approach for the remaining forest and woodland indicators.

[20] In addition, the population density in National Parks and Game Reserves is set equal to zero (Platts et al. 2011). In those areas, the aggregated quantity extracted in step 4 will be equal to zero.

Table V Model results for charcoal production per household per year

Logit: ***Dependent variable: Choice to not-produce charcoal***			**Coefficient** **(z-score)**
Number of males in household			-0.224*** (3.68)
Forest products main source of total household income (dummy)			-2.261*** (5.66)
Woodland (open, closed) in 10 km buffer (ha/1000)			-0.178*** (2.83)
Montane and upper montane forest in 10 km buffer (sigma=2)			0.0195** (2.29)
Sub-montane forest in 10 km buffer (sigma=7.5)			0.00512*** (4.36)
Constant			3.390*** (6.51)
Negative binomial: ***Dependent variable: Number of charcoal bags/hh/year***			
Closed Woodland in 10 km buffer (sigma=4)			-0.000789*** (3.61)
Montane and upper montane forest in 10 km buffer (sigma= 5)			-0.00159*** (4.68)
Constant			4.089*** (30.82)
Model statistics			
Ln(alpha)	0.017	Alpha	1.017
Non-zero observations			98
Total number of observations			1176
Log likelihood (pseudo)			-715
Wald chi2(2)	24.82	Prob > chi2	0.001

Notes: The model is estimated in STATA10. Significance of the parameters is marked with asterisks: *** refers to 1%. In a zero-inflated negative binomial model, alpha is the overdispersion parameter. The results show that alpha is different from zero (95% confidence interval of alpha is 0.79-1.29), which indicates that there is significant overdispersion. The McFadden's R^2 indicator is 13.2% and the Cragg-Uhler R^2 is 22.5%, which corresponds roughly to a regular OLS-R^2 of approximately 25% (Veall and Zimmermann 1996).

Table VI Main source locations of NTFPs

	Firewood (n=1648)	Charcoal (n=78)	Thatch (n=212)	Poles (n=441)
Protected forest and woodland	35%	63%	2%	35%
Open-access forest and woodland	63%	18%	42%	29%
Farmland	36%	45%	4%	50%

Notes: n indicates the number of households collecting the associated NTFP. The percentages do not add up to 100% because respondents could list multiple sources. The protected forest and woodland category includes community forests, Protected Areas and reserves, Community Based Forest Management and Joint Forest Management areas. Open forest and woodland includes all non-protected forest and woodland areas.

Step 2. Function Transfer across Study Area

Step 2 is aimed at generating maps that reflect the quantity of NTFP collected per household from the study area, which is sensitive to the spatial context of each household, following the model variables. Part of this step is to determine the share of NTFP collection sourced from the study area by those households living near its edges of it (Step 2a). After the proportion of NTFP sourced from the EAM is determined, Step 2b involves the transfer of the household production function across all households collecting in the EAM.

Step 2a. Determining NTFP Collection within the EAM: Creating "Imposed Rules" for the Buffers

None of the datasets provides detailed information about the source location of each of the products, so it remains unclear how much of the total quantity of NTFPs is sourced in the forests and woodlands of the EAM. Table VI presents an overview of what is known about source locations, based on the information available from some of the studies. The general patterns suggest that besides open-access woodland and forest, a considerable proportion of the NTFPs are collected on respondents' own farmland and from protected areas, including forest reserves. Therefore, we would overestimate the value of forests if we attributed all NTFP values to open access forests and woodlands.[21]

Lacking reliable empirical data on harvesting location, we used "imposed rules" based on information on travel time spent to reach the harvesting location (converted to distance) and assuming an average walking speed of 4 km per hour), and assuming equal harvesting rates in all directions. More specifically, this involved 4 steps (see Figure II):

(1) we used the cumulative distribution function of the distribution of the survey data on (one-way) walking distances to model the probability that household i at location m harvests NTFP j at location (grid cell) x at distance y;
(2) we divided this probability related to distance, by the number of cells at distance y to generate a two-dimensional probability map (i.e. a probability circle around the household i) (e.g., Walsh et al. 2001);
(3) we estimated the proportion of the probability circle covered by the EAM, assuming that the EAM border is a straight line perpendicular to household i at location m;
(4) we estimated the distance z at which this probability proportion was lower than 5%, by summing the probability in the EAM proportion of the circle.

For firewood and poles, the distance at which 95% of the total quantity collected comes from beyond the EAM frontiers is 4 km from the EAM boundaries, and for charcoal the distance is 8 km. For thatch, no data were available, so we assumed that the decision-rule for poles would be most applicable to thatch collection. The imposed decision-rules were then applied to ensure that Q_{jimt} reflects the quantity collected from within the EAM boundaries for each of the NTFPs.

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[21] The large share of NTFPs coming from protected areas and forest reserves is remarkable, especially for charcoal, and to a lesser extent for poles, because in these areas the collection of these products is illegal or licensed. The results indicate a lack of enforcement of protected areas, and pressure on both general and protected forests are from NTFP collection. Firewood collection is restricted to one or two days a week in some of the gazetted areas to allow households to collect the quantities they need, but the results may also reflect demand being mainly dependent on household size with larger households being willing to take risks to fulfil their demand.

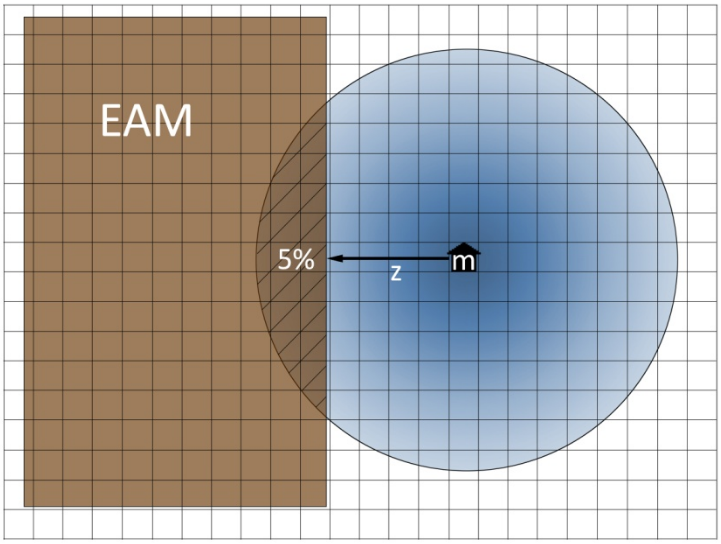

Figure II Schematic figure of the variables of the imposed rules

Note: The circle around cell *m* reflects the range in which household *i* at location *m* is expected to collect NTFP *j* according to survey data. The 5% indicates that 5% of the total quantity collected by the household is likely to be sourced from the dashed area in the EAM. The *z* value is the distance to the EAM border and is used to define the buffer zones.

To reflect these decision-rules in the mapped results in the GIS, we generated internal and external buffer zones around the EAM block boundaries, of ±4 km or ±8 km, according to the NTFP under consideration. The resulting "contours" were used to generate a 100 m grid surfaces where:

- the value of all cells within the internal buffer = 1
- the value of all cells outside of the external buffer = 0
- the values of cells between the internal and external buffers formed a constant gradient between 1 and 0, with values of 0.5 at the EAM boundary (reflecting the assumption that households at the boundary would have an equal opportunity of collecting NTFPs inside or outside the EAM block).

These surfaces could then be multiplied by the relevant modelled product collection surfaces to further improve the estimate of product collected within the EAM.

Step 2b. Function Transfer

Using the models for each NTFP, the decision-rules, census statistics and spatial variables for the explanatory variables in the models, we predict the quantity of NTFP *j* per period *t* extracted from the EAM by each household *i* living in each grid cell *m* in the study area at a 1 ha scale.[22] For the spatial variables included in the models, we took each household's location to be that of its village. When transferring the models across the study area, we found it computationally impractical to estimate the variables reflecting woodland and forest availability (including the DF-variables) separately for each populated cell in the EAM. Therefore, we calculated the spatial statistics for these variables for all settlements in the EAM blocks and buffer zones, using a map with point

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[22] Note that the maps do not show how much of the NTFPs is produced by each cell of woodland or forest. Instead, they show the quantity collected per household from within the EAM.

locations for all settlements. For all remaining cells in the study area, we used interpolation.

As an example, the results for firewood are depicted in Figure III. This shows the annual household production for an average household living in each cell of our study area. The map clearly shows that the mean quantity of firewood collected is higher for households near roads, for instance, south-east of the city of Iringa.

Step 3. Aggregation

In the third step, we use the mapped population statistics (see Figure I, Platts et al. 2011) to estimate the total extraction in each grid cell by summing Q_{jimt} over the total number of households in each cell m in the study area. The total quantity collected of each NTFP j is the sum of Q_{jmt} over all cells M. The resulting estimates can again be mapped to show how NTFP collection varies across space, not only depending on the spatial variation in ecological and socio-demographic variables in the model, but also in population density. Figure IV shows the results of this step for firewood. Because in much of the EAM population density is below 1 household per ha (see Figure I), aggregated NTFP collection is correspondingly low in some areas. This step demonstrates that population distribution is a very important factor in determining the spatial distribution of NTFP collection and therefore the pressure on forest resources. These effects are more visible at the finer scale of Figure V, which depicts the total annual quantity of firewood collected in the area around Morogoro. The same procedure is repeated for charcoal (Figure VI), thatch (Figure VII) and poles (Figure VIII). For poles (for which we were unable to fit a satisfactory production function), the spatial variation in the aggregate quantity of poles used is simply caused by the spatial distribution of the population, and differences between district on the use of poles for housing according to census data.

Step 4. Valuation

For estimation of the total value of NTFP extraction (see Section 4.2), the total value of the resource extraction in each cell m is estimated by multiplying the quantity of NTFP collected from the study area by all its households (step 3) by the price of NTFP j in cell m. Table VII presents the number of observations, mean and mode of the price of the three NTFPs available from our datasets.

Table VII Prices for NTFPs

	Mean (TSH) (st.dev)	Mode (TSH)	Number of observations
Firewood (per headload)	1111 (879)	500	21
Thatch (per bundle)	356 (123)	300	35
Poles (per pole)	529 (170)	600	45

Charcoal Prices

Previous reports (e.g., CHAPOSA 2002, Malimbwi and Zabahu 2008, Van Beukering et al. 2007) suggest that prices vary spatially, being lowest adjacent to forests,and increasing in price closer to the cities where the charcoal is consumed, as a result of transportation costs, taxes, bribes and licences. In 2009 and 2010 we collected detailed data on spatial variation in charcoal prices along two main routes for transporting and selling charcoal (from Morogoro to Dar es Salaam and from Moshi to Tanga) (n=302 observations). This allowed us to estimate a spatially explicit price model. Recorded prices vary from TSH 4,000 to TSH 45,000 per 60 kg bag, with a mean price of TSH 30,088 (USD 21) per bag in Dar es Salaam and TSH 16,584 (USD 12) elsewhere. We estimate a panel regression model which explained variation in the local market price of charcoal in terms of three explanatory variables: (1) the distance from the market to Dar es Salaam, reflecting the transportation costs (mainly fuel) from producers to end-users (2) a dummy for prices recorded in Dar es Salaam, picking up the taxes, bribes and levies that have to be paid to import products into Dar, and (3) the year of recording, reflecting inflation. Our best -fit model was:

$$\text{Price} = 30365 + 6140 * \text{Dar-dummy} - 3131 * \ln(\text{Distance to Dar harbour (km+1)}) + 2454 * \text{Year2010-dummy}. \qquad (5)$$

The model fit was good ($R^2 = 66\%$), and the three explanatory variables were each significant (at $\alpha=1\%$), with the expected sign. This model was in turn used to generate a price surface with which we valued the quantity of charcoal produced by households living at location *m*. Because most households sell their charcoal at the production sites or at home to middlemen rather than taking it to local or regional markets (Malimbwi and Zabahu 2008), and households live relatively close to the production sites, this model provides a better prediction of the price that households in the EAM obtain than market prices in Dar es Salaam. The latter would not give a good approximation of producers' revenues, because end-user prices are much higher than producer prices, due to the intervention of middlemen and the added value of transport.

Confidence intervals

To provide sensible confidence intervals for the total aggregate quantity and value of NTFP collected, one would have to assume that households are independent across and within cells, the average standard error of the sample applies to all cells and all households, and ignore the standard errors of the mapped population per cell and the standard error of prices. Furthermore, the standard errors of the different NTFP quantities and values cannot simply be added. Therefore, we do not believe that we can provide sensible standard errors of the estimates in Table 5.

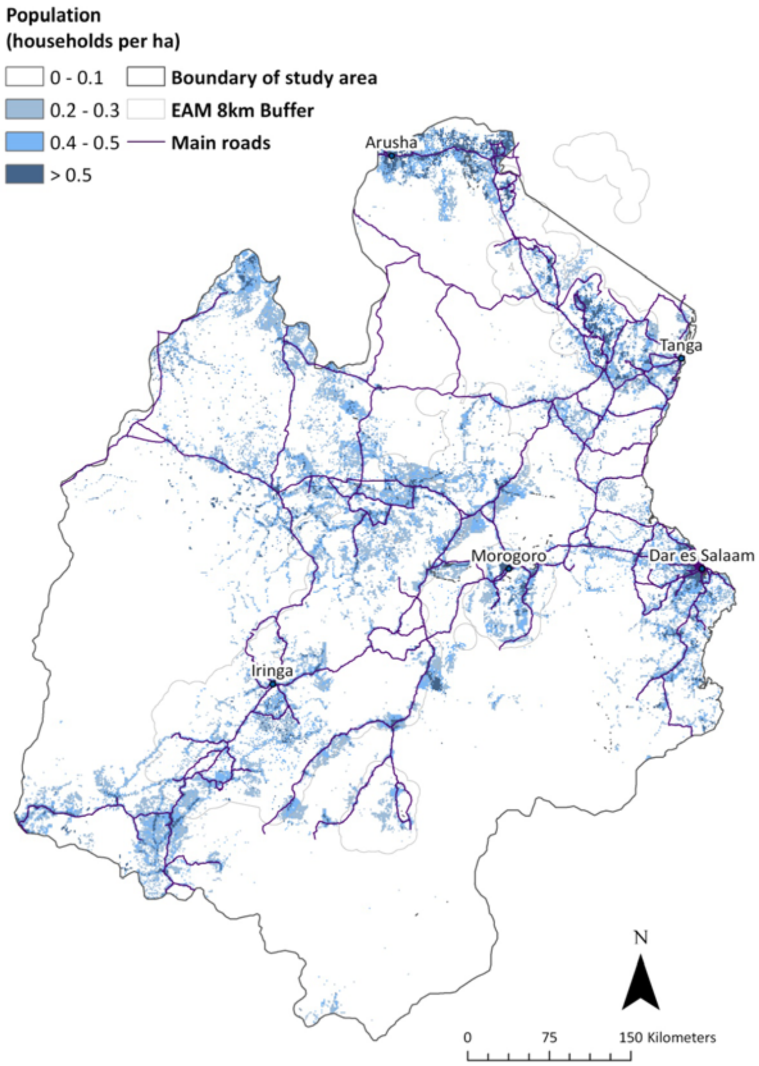

Figure I Number of households per ha

Source: Platts et al. (2011). The boundary of the study area indicates the study area of the Valuing the Arc project.

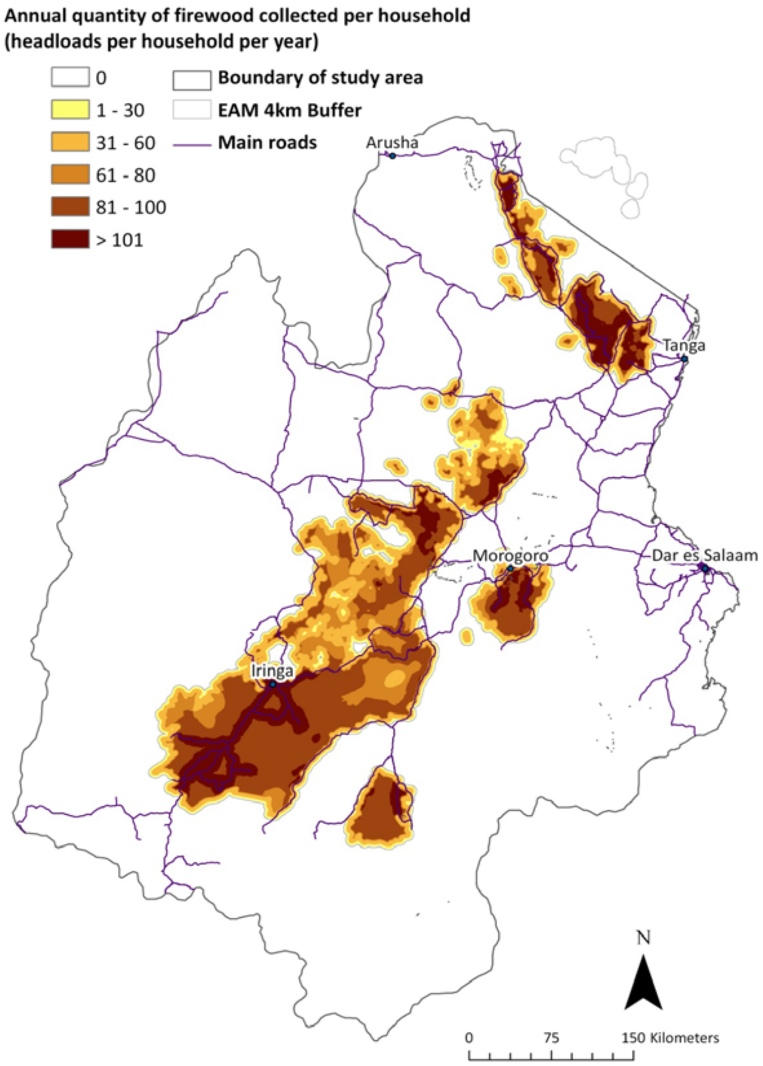

Figure III Annual quantity of firewood collected per household (headloads per household per year)

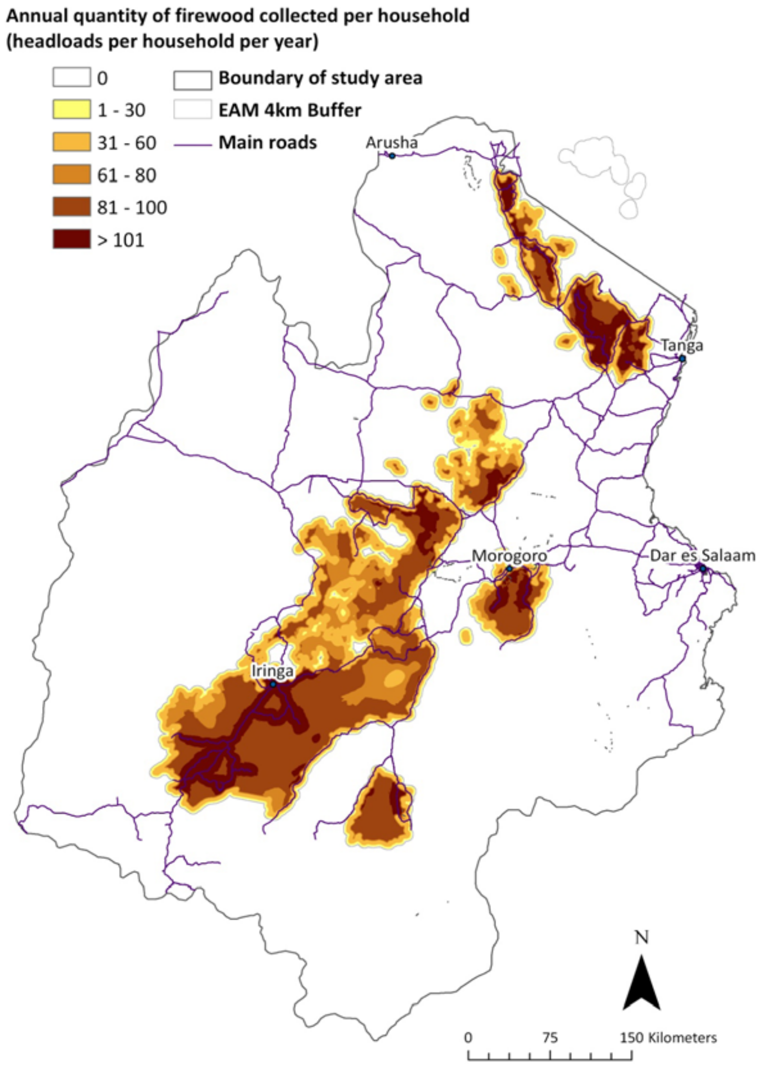

Figure III Annual quantity of firewood collected per household (headloads per household per year)

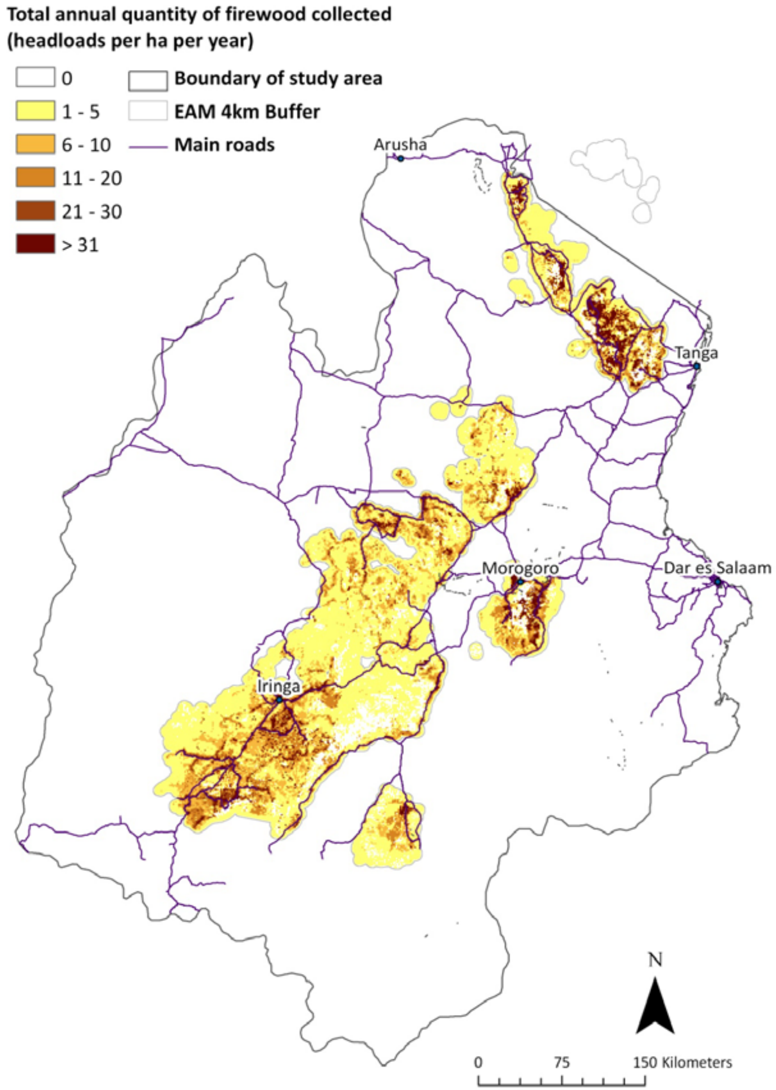

Figure IV Total annual quantity of firewood collected (headloads per ha per year)

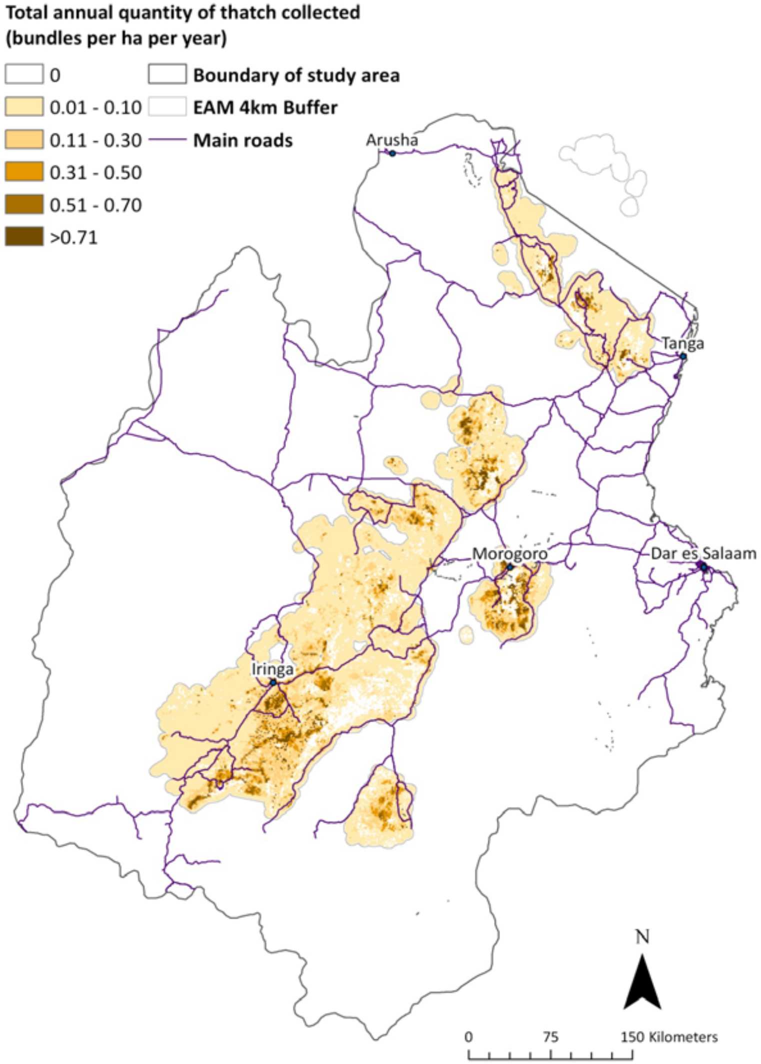

Figure VII Total annual quantity of thatch collected (bundles per ha per year)

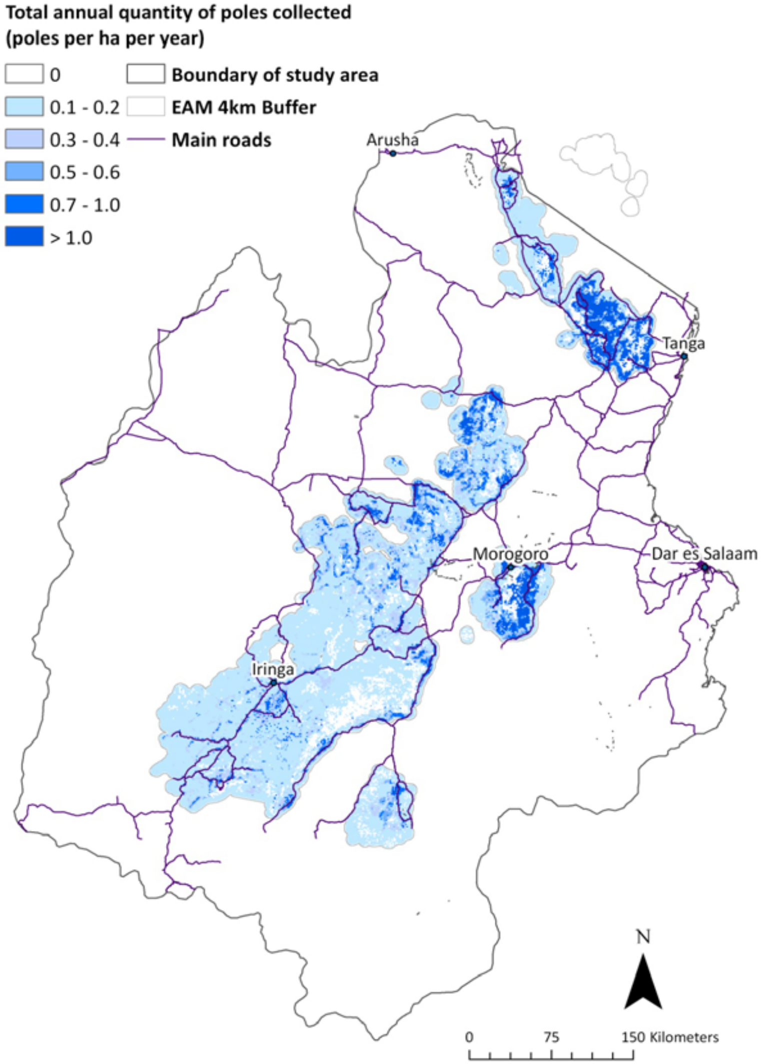

Figure VIII Total annual quantity of poles collected (poles per ha per year)