Analysis

Towards transferable functions for extraction of Non-timber Forest Products: A case study on charcoal production in Tanzania

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ARTICLE INFO

ABSTRACT

Mapping the distribution of the quantity and value of forest benefits to local communities is useful for forest management, when socio-economic and conservation objectives may need to be traded off. We develop a modelling approach for the economic valuation of annual Non-Timber Forest Product (NTFP) extraction at a large spatial scale, which has 4 main strengths: (1) it is based on household production functions using data of actual household behaviour, (2) it is spatially sensitive, using a range of explanatory variables related to socio-demographic characteristics, population density, resource availability and accessibility, (3) it captures the value of the actual flow rather than the potential stock, and (4) it is generic and can therefore be up-scaled across non-surveyed areas. We illustrate the empirical application of this approach in an analysis of charcoal production in the Eastern Arc Mountains of Tanzania, using a dataset comprising over 1100 observations from 45 villages. The total flow of charcoal benefits is estimated at USD 14 million per year, providing an important source of income to local households, and supplying around 11% of the charcoal used in Dar es Salaam and other major cities. We discuss the potential and limitations of up-scaling micro-level analysis for NTFP valuation.

1. Introduction

Population growth, rising per capita demand and the development process are putting increasing pressure on the natural environment, requiring policy-makers to make choices about trade-offs between ecosystem conservation and economic development (e.g., Adams et al., 2004; Cheung and Sumaila, 2008). A key consideration in such decisions is how the costs and benefits of policy options are distributed across different stakeholders. Ecosystem services, defined as the

aspects of ecosystems utilised (actively or passively) to produce human well-being to beneficiaries (Fisher et al., 2009; MEA, 2005), are provided at different spatial and temporal scales. This means that different beneficiaries can have different and conflicting interests (Hein et al., 2006).

Some prominent ecosystem services associated with forest conservation, such as CO_2 sequestration and biodiversity protection, mostly benefit the global community, whereas the opportunity costs of conservation, such as decreased access to harvested resources, are largely borne by local communities (e.g., Balmford and Whitten, 2003; Wells, 1992). 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). The collection of Non-timber Forest Products (NTFPs) from natural habitats provides

a variety of products used for domestic consumption, as well as a source of complementary cash income and a safety net for people when agricultural yields are low (Angelsen and Wunder, 2003). Relatively small contributions of forest income can be vital to families living close to the poverty line (Vedeld et al., 2004). In Tanzania, for example, 90% of people use biomass for energy and house construction, driven by poverty and lack of means to invest in better quality housing and alternative fuels (World Bank, 2009). The collection of charcoal, the main cooking fuel in urban areas in Tanzania, is also a major cause of forest and woodland degradation. Its extraction follows a spatial pattern, where forests around the capital of Dar es Salaam have been depleted, leading to increased pressure on forests at ever great distance from this city (Ahrends et al., 2010; Hofstad, 1997). Furthermore, the CO_2 emissions from charcoal production and its use contribute to climate change (Bailis, 2009).

The policy demand for large scale evaluation has resulted in a number of studies assessing ecosystem services at global or national scales, e.g. the MEA (2005), Naidoo et al. (2008), Pereira et al. (2010), and Balmford et al. (2011). For policies and initiatives such as REDD + (Strassburg et al., 2009, 2010; UNFCCC, 2006), which aims to mitigate climate change whilst producing co-benefits in terms of biodiversity and poverty alleviation, to be effective, the costs and benefits of forest conservation to stakeholders at different spatial scales need to be assessed. This evaluation should not only encompass the global benefits of climate change mitigation, but also the welfare effects of conservation policies, for example, the potential restrictions on local communities to collect charcoal and other NTFPs. Spatially explicit ecosystem valuation can help to inform policy decisions that involve tradeoffs between the interests of local and international communities (Naidoo and Ricketts, 2006; Turner et al., 2010). Further, it is essential to recognise that the costs and benefits of changes in ecosystem services are conditioned by spatially heterogeneous factors such as resource availability, proximity to markets and population density.

There is a large body of empirical and theoretical literature on NTFP collection which provide highly detailed studies for their respective, typically small-scale, study areas (see Section 2.1). Our approach seeks to complement this knowledge by scaling-up and transferring the results for large scale assessment of NTFP quantities, flows and values, which are necessary for setting policy responses at national levels (Daily et al., 2009). Extensive data collection at non-surveyed locations is often prohibitively expensive, especially for developing countries with tight budgets and pressing environmental and poverty concerns. In order to provide timely and scale relevant information for policy making, there is a need for models that can empirically link household behaviour to the bio-physical and social context relevant to the value of NTFPs, and which can scale-up results over the wider population to estimate the total value of NTFP benefits. The main objective of this paper is to develop a methodological approach (see Section 2) for the economic valuation of charcoal collection at a large scale that controls for spatial variation across household conditions. We take a bottom–up approach which uses survey information on actual household behaviour from multiple locations. This allows us to develop a transferable function for charcoal extraction to assess forest values accruing to local communities, whilst identifying general patterns across different biophysical and socio-economic environments. Our approach has four strengths: (1) it is based on household production functions using data of actual household behaviour,[1] (2) it is spatially sensitive by using survey and price data from multiple sites in combination with spatial information, such as land cover, population and road network data, (3) it captures the real flow rather than the potential stock of values, and (4) it uses a generic model that can be transferred to similar, but non-

surveyed areas for which the data is representative. In essence, our approach combines the strengths of micro-level analysis of household behaviour, whilst allowing for up-scaling.

We apply this approach to estimate the total value of charcoal production in the Eastern Arc Mountains region in Tanzania, a global biodiversity hotspot, which covers 48,000 km^2 and is home to 2.3 million people (Burgess et al., 2007) (see Sections 3 and 4). The resulting value map can be used to inform and target policy decisions to reduce forest degradation. The application demonstrates the potential opportunities and limitations of up-scaling micro-level data in a developing country setting. The conclusion in Section 5 discusses the policy relevance of this paper and gives suggestions for further research to improve large scale NTFP valuation.

2. Methodological Approach

2.1. Literature Review

Much effort has been put into estimating the monetary value of forest resources, including NTFPs, and their contribution to livelihoods (e.g., de Beer and McDermott, 1989; Kamanga et al., 2009; Lepetu et al., 2009; Paumgarten and Shackleton, 2009). In studies in developing countries, the value of forests has generally been assessed in two ways: (1) stock-based (or top–down), starting from forest availability, to forest products to households, or (2) flow-based (or bottom–up), starting at the household level and relating this to forest availability (Batagoda et al., 2000). Whilst top–down approaches can be implemented at large spatial scales, their main limitations are that (a) they value the (potential) stock rather than the (actual) flow of services, and (b) they do not necessarily capture use and non-use values as perceived by local communities (Sheil and Wunder, 2002). The bottom–up approach is a micro-level assessment, which captures aspects of individual decision-making and the factors that affect whether and how much to collect. Many existing empirical NTFP studies at the micro-level are qualitative in nature or only provide average quantities extracted by households, and are often localised in their scope, focusing on a particular forest or community (Croitoru, 2007). They do not capture heterogeneity across forests or communities at different locations with other resource availability and accessibility conditions, which inhibit generalisation of the results and transfer of the models to other locations (Godoy et al., 1993).

A small number of studies on NTFP collection have developed economic household production models (e.g., Amacher et al., 1996; Köhlin and Parks, 2001; Palmer and MacGregor, 2009). The underlying assumption of these models is that households aim to maximise utility U, by allocating their time L over different utility generating activities such as agriculture, collecting forest products and wage earning activities, combined with other inputs such that they produce commodities C and leisure L_l from which they derive the highest utility, conditioned on household characteristics h (e.g., Gopalakrishnan et al., 2005; Linde-Rahr, 2005; Sankhayan and Hofstad, 2001):

$$Max\ U(C, L_l; h). \tag{1}$$

Utility is subject to a time and budget constraint. The fixed time endowment L is allocated across different activities, including wage labour L_w, subsistence agriculture L_a, time spent on NTFP extraction L_f and leisure L_l:

$$L = L_w, L_a, L_f, L_l. \tag{2}$$

A budget constraint is imposed to ensure that household cash income I is equal to expenditures on an amount of market goods Q_m

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[1] The household production model builds on earlier studies (e.g., Godoy et al., 2000; Peters et al., 1989), and will be further discussed in Section 2.1.

bought at price P_m, where income can be generated from wage labour L_w at wage w, selling agricultural products equal to the amount $(Q_a - D_a)$ sold at price P_a, where D_a represents domestic consumption of total agricultural output Q_a, or selling a quantity of NTFPs equal to $(Q_f - D_f)$, where D_f represents domestic consumption of the total quantity of NTFPs collected Q_f, at price P_f, and exogenous income V (e.g., donations):

$$I = P_m Q_m = L_w W + P_a(Q_a - D_a) + P_f \left(Q_f - D_f \right) + V. \tag{3}$$

Here, we are interested in the household production of forest products, which is a function of the time allocated to extraction L_f, specified as a function of distance to the forest d, and household characteristics h, forest availability F, and resource management conditions R, represented as:

$$Q_f = f \left(L_f(d), h, F, R \right). \tag{4}$$

The assumption is that households allocate their time to collecting forest products such that the shadow costs of time are equal to the utility derived from the NTFPs (Sills et al., 2003). This set of variables can be solved when properly functioning markets exist and selling households act as price-takers, but for NTFPs in rural areas of developing countries, the (wage) labour and NTFP markets are often missing or imperfect. In such cases, production and consumption decisions are non-separable and depend on the same household preferences and time and input endowments. Therefore, analyses fall back on reduced form regression models, which mainly aim to identify explanatory factors of NTFP collection behaviour (Sills et al., 2003).

Some of these reduced models capture spatial interactions of villagers and forests by including a distance variable as a proxy for the opportunity costs of labour and time spent to collect NTFPs (e.g., Amacher et al., 1996; Gunatileke and Chakravorty, 2003; Köhlin and Parks, 2001; López-Feldman and Wilen, 2008; Pattanayak and Sills, 2001). Consequently, NTFP harvesting efforts and forest degradation exhibit spatial patterns. Robinson et al. (2002, 2008) propose approaches to model spatial choices between different harvest locations, which may also provide further insight in 'leakage', i.e. when NTFP collection shifts from protected to unprotected sources following forest protection measures. However, information about harvesting locations of NTFPs is often difficult to obtain in surveys, especially in the case of illegal harvesting in protected areas, including in our case study. Researchers and respondents may also employ different definitions and perceptions of land cover types labelled as 'forests' or 'farmland', or management status and tenure (Lund et al., 2011).

The core challenge that we aim to address in this paper is how to move beyond local-level analyses of forest use, and scale the analysis from micro-level analyses up to regional or national level assessments of ecosystem services, in situations where NTFP and labour markets are imperfect. The approach we present allows for such large-scale mapping of NTFP extraction based on household production functions. Our scaling-up methodological approach therefore relies on a reduced form regression model, which we combine with assumptions informed by survey information to control for some of the data limitations.

2.2. Four-step Methodological Approach

At the core of our methodological approach we utilise production functions of NTFPs, based on a spatially explicit evaluation of actual household NTFP collection or production. These functions can be transferred in order to estimate NTFP extraction across a wide study area for which the primary household data are representative, controlling for differences in socio-economic, institutional, biophysical

and ecological factors. Therefore, the approach is highly reliant on a Geographical Information System (GIS) in each of the four subsequent steps:

(1) Estimating the household production function for NTFP collection;
(2) Transferring this function across the study area;
(3) Aggregating household level extraction over all households in the study area;
(4) Turning NTFP quantities into economic values.

2.3. Step 1: Estimating the Household Production Function for NTFP Collection

The first step involves estimating a (reduced form) household production function following Eq. (4), which explains variation in household-level behaviour of NTFP collection in terms of household characteristics and other factors, including biophysical and ecological variables, and institutional and governance characteristics. Besides theoretical and empirical validity, an important prerequisite in the selection of variables is the availability of secondary data sources for these explanatory variables. The function transfer involved in step 2 of our approach, is only possible if information about the model variables is available for the population that is not included in our sample.

Our dependent variable Q_{jimt} is the quantity of NTFP j extracted by household i living at location m in period t:

$$Q_{jimt} = f \left(h_{imt}, F_{jmt}, R_{jmt} \right) \tag{5}$$

where h is a set of socio-demographic characteristics of household i at location m, F is the (physical) availability of NTFP j to households at location m, and R are resource management conditions that affect resource accessibility faced by households at location m.[2] Here, set h includes labour L_f, and proxies such as household size and composition, and time inputs (distance to forest and collection time), capital (e.g., vehicles to transport the harvested products), and other transaction costs. Furthermore, there may be transportation costs involved in going to market to sell or buy NTFPs. Distance to roads and markets is used as a proxy for the transport costs or accessibility to markets where substitutes for NTFPs can be bought. Other predictors for the demand for NTFP by households are, for example, fuel use and construction and roofing materials.

Set F includes variables reflecting the (physically) available resource pool, which determines how much can be harvested. In the case of fuel wood collection the type as well as the amount of woodland or forest may be relevant, as some species have a higher caloric value than others and are therefore a more suitable energy source (Hartter and Boston, 2007). Population density may serve as a proxy for NTFP demand and subsequent forest degradation as more people compete for the same resources (Ahrends et al., 2010). One of the most important variables in set F is distance to woodland and forest resources, reflecting the opportunity costs of travel time to the harvesting location. To capture the impact on household collection of the distance and availability of forest and woodland, instead of assuming that every forest or woodland patch in a certain range of the village is equally attractive for NTFP collection, we generate a variable reflecting the availability of a resource weighted by the distance from each of the resource patches to the household (see Eq. 6). Forest patches at longer distances d are assumed to contribute less to the total DF variable, reflecting higher costs for locations further away. The smaller the sigma, the higher is the distance-decay effect (the steeper the curve). For low values of sigma (e.g., $\sigma < 1$), any forest or woodland more than approximately 2 km from a household has hardly

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[2] Set M reflects the area where households live who collect NTFP j from the study areas. All M locations are represented by grid cells in a GIS.

any impact on the quantity of NTFP it collects, whereas for higher values of sigma the availability of forest or woodland at larger distances still affects collection quantities and are expected to be found for forest types where the availability of NTFPs is high. This distance decay variable is calculated based on the following equation using a half-normal distribution[3]:

$$DF_i = \sum_{k=1}^{K} \exp\left(-\left(d_{i,k}/\sigma\right)^2\right). \tag{6}$$

Here, DF reflects the total resource availability inversely weighted by distance d from each resource cell k in the vicinity of the location m of household i. Distance d is divided by a sigma value σ, which sets the shape of the distance decay function (the spread of the half-normal distribution). The value of sigma is chosen based on a grid search procedure, re-estimating the model for different values of sigma until the best model fit is found. After taking the exponential, all weighted resource values are summed per household over all K cells around household location m where the range was based on survey information of distance to harvest location. The resulting DF variable is included in the household production function. The main advantage of the DF variable is that, together with the estimated variable coefficient, the shape of the distribution reveals how households balance the cost of travelling to a resource patch k against the quantity of NTFP that can be collected there. The DF variable thereby empirically reveals more about harvesting ranges and locations, which is useful when information about harvesting locations is unavailable as is often the case, including our application. The DF indicator can also be transferred to non-surveyed locations.

Finally, variables in set R describe forest accessibility, including the management regime of the forest. Better enforcement of conservation policies is expected to increase the costs of NTFP collection, and therefore reduce extraction levels, either directly through costs of licensing, fines or bribery, or indirectly through the risk-premium on illegal collection when avoiding fines (Robinson and Lokina, 2010).

Rather than the total income derived from NTFP extraction, we prefer using the quantity of NTFP j collected per household as the dependent variable for three reasons. First, prices of non-marketed NTFPs are often unknown (to respondents as well as researchers), so (computed) NTFP income data may be less reliable. Although charcoal is mostly marketed in this case study, we start from collected quantities to develop a generic methodology applicable to both marketed and non-marketed NTFPs. Second, there can be considerable differences between NTFPs in, for example, collection frequency and spatial range, labour division within households, land cover suitability, use and marketability. Such differences may not be captured in the regression model when combining NTFP income into a single indicator. Third, modelling collected quantities of individual NTFPs provides more suitable information for the assessment of the sustainability of current harvesting rates when different NTFPs have different harvesting patterns or sources with different growth rates.

2.4. Step 2: Transferring this Function across the Study Area

Having used these variables to derive household production functions for individual NTFPs, step 2 of our approach involves transferring these models across the entire study area. We estimate the extraction of NTFP j per period t by each household i living at location m in the study area. In the prediction, available GIS and census data are used for the explanatory variables of the statistical models. The underlying assumption of this 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). Our approach attempts to combine 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. Function transfer is expected to lead to more accurate results than mean value transfer[4] (Navrud and Ready, 2007), because it allows for the effects of contextual factors (but see Rosenberger and Phipps, 2007; Matthews et al., 2009). The validity of this approach hence depends on the quality of the NTFP collection data and the representativeness of the sample used in Step 1.

Of interest is the NTFP production using resources from the study area. Households living near the edges of the study area are likely to use resources within the study area, and partly elsewhere. To address this, we estimate the proportion of NTFP sourced from the study area by these households, using either empirical data on harvest locations, or, when those data are unavailable, imposed "rules". The rule used in our analysis is based on survey information about time spent travelling to the harvesting location, converted to a distance estimated using an average speed (cross-checked with survey information), and assuming that harvesting effort is equal in all directions around the households' villages (see Appendix I). This rule is then applied to ensure that Q_{jimt}, the quantity extracted per household at location m, reflects the quantity collected from the area of interest. The output of step 2 is a map reflecting the predicted quantity of NTFP collected per household from each cell in the study area, which is sensitive to the biophysical and socio-economic environment of each household.

2.5. Step 3: Aggregating Household Level Extraction over All Households in the Study Area

In step 3, we use population statistics 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:

$$Q_{jmt} = \sum_{i=1}^{I} Q_{jimt}. \tag{7}$$

The total quantity collected of each NTFP j by all households 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, this time depending not only on the spatial variation in ecological, market and socio-demographic variables in the model, but also on the spatial distribution of the population.

2.6. Step 4: Turning NTFP Quantities into Economic Values

The fourth and final step is to attach an economic value to the quantities extracted. Market prices can be used to monetise NTFP extraction, allowing for spatial heterogeneity in prices where relevant.[5] The total value V_{jmt} of the resource extraction in each cell m is then estimated by multiplying the quantity of NTFP collected from the study area by all households in cell m (step 3) by the price P_{jmt} of NTFP j in cell m:

$$V_{jmt} = Q_{jmt} \cdot P_{jmt}. \tag{8}$$

Again, these values can be summed over all M cells to estimate the total value of the extraction of NTFP j from the study area by all

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

[4] Mean value transfers take the mean of ecosystem value of surveyed sites to estimate the value of a non-surveyed site.

[5] Market prices can be used for products that are sold on a regular basis, such as charcoal, but price data may be harder to obtain for products that are mainly used for home consumption. It should be noted that the market price does not reflect the consumer surplus of a product, and using market prices for valuation is a second-best alternative especially when markets are imperfect. Other valuation methods, such as Contingent Valuation, shadow prices or replacement costs can be used instead.

households. This sum reflects the economic value of the actual flow of NTFPs from the study area, both for products sold or used for home consumption.[6] Mapping these values visualises where the economic benefits of NTFP collection are highest. In the next section, we present an application of our approach to charcoal production in the Eastern Arc Mountains in Tanzania.

3. Case Study

3.1. Case Study Area

The Eastern Arc Mountains (hereafter EAM) consist of 13 mountain blocks spreading from southern Kenya to eastern, central and southern Tanzania and cover an area of 48,000 km² (see Fig. 1, derived from Platts et al., 2011). These mountain areas naturally supported woodland and forest habitats, which have been extensively cleared by people, mainly for low intensity agriculture. The EAM area includes open and closed woodlands, as well as woodland areas with scattered cropland. The EAM's forests are characterised by high levels of biodiversity and endemism (Burgess et al., 2007), and there are various types of forest depending on the altitude: lowland forests, sub-montane and montane forests, and upper-montane forests at the highest elevations (Burgess et al., 2007). Approximately 21% of the EAM are gazetted (Swetnam et al., 2011), including 75% of its forests (Platts et al., 2011). The EAM provide a range of ecosystem services with associated human benefits at local, national and international levels, including the provision of fuel wood, the regulation of river flows for drinking water, irrigation and hydropower, and carbon storage.

Tanzania is one of the poorest countries in the world, ranked among the bottom 25% in the Human Development Index (UNDP, 2011). According to census data (NBS, 2007), 34% of households in Tanzania live below the poverty line. The total population of the EAM blocks is estimated at 2.3 million, with an average household size of 4.6 (Platts et al., 2011, based on the 2002 census data). Eighty percent of households depend mainly on agriculture for their income, and most have had either no education at all, or only primary schooling (NBS, 2007).

Local communities in Tanzania collect firewood, wood for charcoal production, poles, thatch, honey, bushmeat, fruits, vegetables and medicines, and use a wide range of species (e.g., Anthon et al., 2008; Kasthala et al., 2008; Luoga et al., 2000; Monela et al., 2005; Robinson and Lokina, 2010; Theilade et al., 2007; Turpie, 2000). The NTFPs that receive most attention in relation to forest conservation are fuel wood (for charcoal and firewood) and poles, with their extraction considered to be one of the main causes (alongside agricultural expansion and logging) of forest degradation (Chiesa et al., 2009; URT, 2010).

Whereas the rural community relies mainly on firewood for cooking, the urban population commonly uses charcoal (around 75% of households in Dar es Salaam and 54% in other urban areas (NBS, 2007)). The total use of charcoal in Dar es Salaam is estimated at approximately 8.7 million 60 kg bags per year (based on estimates of CHAPOSA, 2002; Mwampamba, 2007; Van Beukering et al., 2007; World Bank, 2009), with a total value of TSH 260 billion per year (USD 183 million).[7] About 30% of the supply to Dar (2.64 million bags per year) is estimated to be produced in the wider area around Morogoro, including within the EAM blocks (CHAPOSA, 2002; Malimbwi and Zahabu, 2008). Other urban areas supplied by charcoal from the EAM include Tanga, with a total consumption of ~1 million bags per year and Morogoro town itself (~2.3 million bags per year) (Norconsult, 2002).

Rural communities are seasonally or occasionally involved in charcoal production, to complement household income, and sell their products to middlemen who transport it to the major urban centres (Malimbwi and Zahabu, 2008). Commercial charcoal production is practised in the lower woodland and forest areas of the EAM. It is officially prohibited in all protected areas, whereas licences are required for production in other land, including village and general land. Steep slopes prohibit charcoal collection in some forest areas, because charcoal bags are heavy (60 kg) and usually transported with bicycles or other vehicles. Charcoal production has severely affected the coastal forests and miombo woodlands around Dar es Salaam (Ahrends et al., 2010), and because that area is largely depleted, production has shifted south and inland, with some production centres within the boundaries of the EAM blocks.

3.2. Data

Our dataset is unique in its size and spatial coverage. The data on household NTFP extraction come from four different surveys (see Table 1). These were administered by independent projects in separate areas using different questionnaires, which were carefully pretested. Each survey adopted a stratified random sampling strategy within each village. Villages that are unlikely to source material from the EAM woodlands and forests and which live under different environmental conditions (e.g., lowland areas, or wetlands) were excluded from the dataset — a 40 km range from the EAM blocks was used as a criterion. The resulting sample is widely distributed across the EAM (see Fig. 1), which is important in ensuring that our household production models adequately reflect the spatial variation present across the study area. Although some parts of our study area were not covered by the surveys, the socio-economic, institutional and ecological characteristics of the sampled villages vary sufficiently to reflect the characteristics of the non-surveyed areas. The datasets were standardised to ensure quantity and time units were commensurate, using information provided by original survey reports and existing literature (e.g., Kaale, 2005; Muregerera, 2008)[8] and then merged to provide the final data used in the modelling.

To this primary dataset, we add the spatial variables related to NTFP availability and resource management conditions in sets F and R in Eq. (5). These were calculated using GIS datasets describing land cover and road density as described in Swetnam et al. (2011). These digital datasets exist at high resolution for the study area (landcover at 100 m, roads digitised at 1:50,000) and represent a geodatabase which has been updated and improved specifically for this project. Their coverage and large scale allow detailed measurement of distances from potential NTFP source to our study villages as well as consistent estimates of resource availability within the immediate environs of the surveyed villages.

For the transfer in step 2, secondary data for the explanatory variables related to socio-demographic characteristics (set h in Eq. (5)) were extracted from the census data of the Tanzanian Household Budget Survey 2001/2 and 2007 (NBS, 2002, 2007). In step 3, we used population data from Landscan (2008) estimates and the latest census information (NBS, 2002), following Platts et al. (2011). The population layer was then resampled at 100 m grid resolution in order to maintain the spatial resolution of the land cover data. We also used Platts et al. (2011) for demarcation of the EAM boundaries based on landscape features.

Previous reports (e.g., CHAPOSA, 2002; Hofstad and Sankhayan, 1999; Malimbwi and Zahabu, 2008; Van Beukering et al., 2007)

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[6] Note that these economic values are expressed in terms of gross benefits to charcoal producing households, as the production costs are not deducted.

[7] We used a mean 2010 exchange rate of US$ 1 = TSH 1420 (Bank of Tanzania, 2011) and a mean price of TSH 30,088 per bag in Dar es Salaam (2010 prices, own data, see Section 4.5).

[8] This involved conversion of headloads to bags, expressing all bags in similar weights (30 kg) and assuming constant production throughout the year when produced quantities were reported per month.
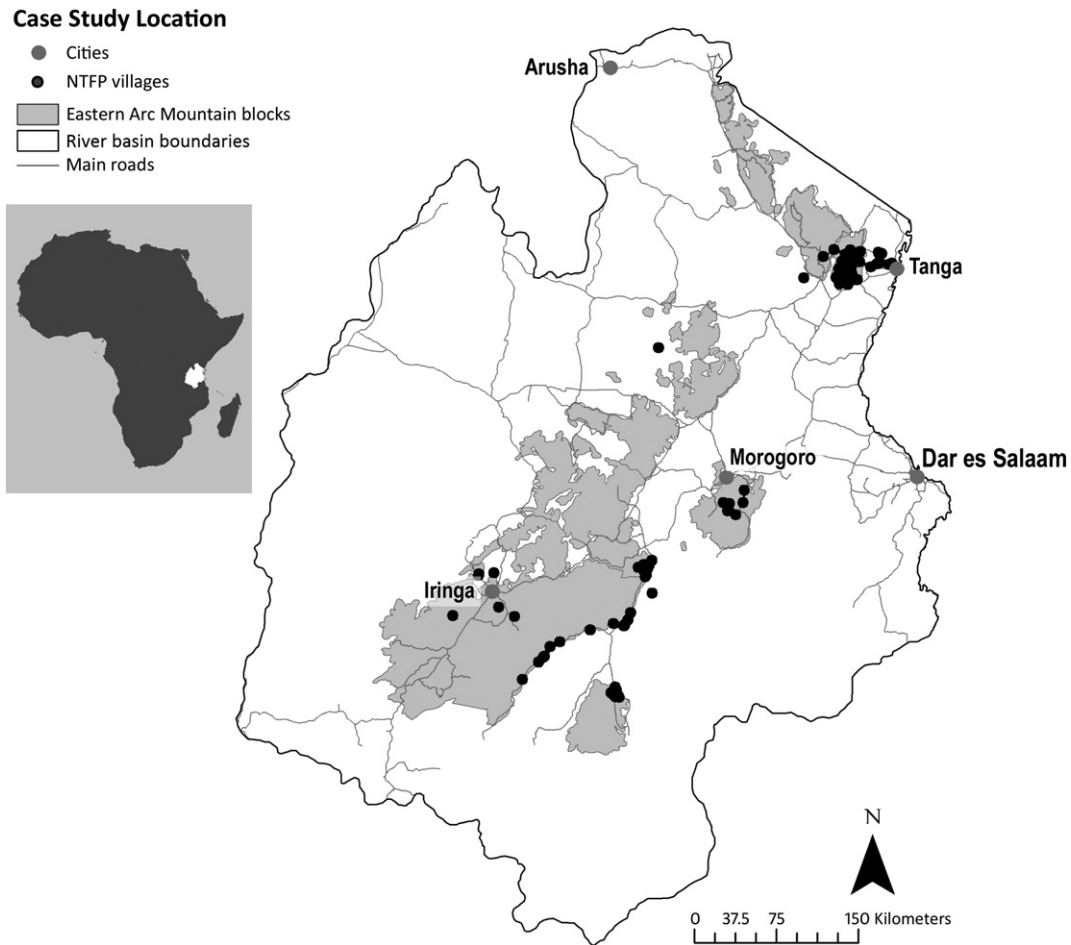
Case Study Location

- ● Cities
- ● NTFP villages
- ▓ Eastern Arc Mountain blocks
- □ River basin boundaries
- — Main roads

Fig. 1. Case study area.Notes: the NTFP villages are villages where the household level data on NTFP collection used in our analysis was collected. The delineation of the Eastern Arc Mountain blocks is based on Platts et al. (2011). The EAM blocks in Kenya were excluded from the analysis. The outer boundary reflects the river basin boundaries of rivers that originate in the EAM.

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. For the 4th step of our analysis, where we assign an economic value to the total NTFP production, in 2009 and 2010 we collected detailed data on charcoal prices along two main routes for transporting and selling charcoal (from Morogoro to Dar es Salaam and from Moshi to Tanga). This allowed us to estimate a spatially explicit price model (see Section 4.5).

3.3. Data Limitations

The household level data suffer from some limitations, which are common to NTFP studies (see Godoy et al., 1993; Gram, 2001; Sheil and Wunder, 2002). The first is that data were collected in one-off household surveys which are susceptible to recall problems, with respondents sometimes having difficulty remembering exactly how much NTFP they collected and when, over a certain time period, especially if this period is long and collection is irregular. Second, charcoal production is illegal in protected areas and licensed elsewhere, but most — if not all — charcoal producers operate illegally without the required permits. In spite of the many efforts made in the surveys to gain trust of the respondents and the considerable number of respondents admitting to charcoal production, we cannot preclude underreporting of whether and how much households produce (Vedeld et al., 2007). Our household data may underestimate the total quantity of charcoal production in the EAM. Third, no data were available for charcoal producers who live further outside the

40 km range around the study area but travel to the EAM and stay there for long periods. Although this may be an additional cause of underestimation of total charcoal production in the EAM forests, the importance of charcoal production in the EAM for local communities (who may claim implicit land or use rights to these areas) is reflected in our results. Fourth, many of the datasets provided little detailed or reliable information on exact NTFP harvest locations. In the absence of these data, we use imposed "rules", based on survey information about time spent travelling to the harvesting location. It is not possible to correct for these limitations, especially those related to underreporting and recall, without (costly) additional data collection.

We used the most recent census data on household characteristics at the finest spatial scale available. Household size and composition data was available at ward level, but for other variables only district level statistics were available. For transferring the estimated household production model to assess NTFP harvesting across the study area, we assumed that each household in cell m had the mean value

Table 1
Description of datasets.

Dataset reference	Where
1. ARPIP (URT, 2008)	9 villages in EAM in Iringa Rural, Kilolo, Kilombero, Korogwe, Morogoro Rural and Muheza Districts
2. Hernández-Sirvent (2009)	3 villages in Ulanga District
3. Hepelwa (2009)	27 villages in Muheza and Tanga Districts
4. TAFORI and University of Copenhagen (Ngaga et al., 2009)	6 villages in Iringa Rural, Korogwe and Babati Districts

of the district in which it was located. We deal with the limitations encountered in the application of our approach in Section 4.6.

4. Results

4.1. Sample Characteristics

The final dataset includes 1176 observations from 45 villages. Table 2 presents the descriptive statistics of the sample. The average household consists of five people of which half are males. The education level of the sample is low: 94% of the sample has only completed primary school, or has not had any schooling. Households rely mainly on agriculture for their income. For 6% of households the main source of household income is from harvesting forest products, including timber and NTFP collection. The statistics are roughly in line with published census data (NBS, 2002, 2007) and the sample is hence considered to be largely representative of the rural population of the EAM.

Empirical socio-economic studies on NTFP dependence (e.g., Kamanga et al., 2009; Mamo et al., 2007) often observe that the intensity of forest use varies across income groups, where the poorer groups are relatively more dependent on forest income, but higher income groups receive higher absolute forest revenues. Our results confirm these findings and show that poor households have a higher relative, but lower absolute NTFP income. We split the sample into income quartiles and used non-parametric Kruskal–Wallis tests for differences between these groups. The results show that cash and non-cash NTFP income combined (i.e. the value of both NTFPs sold and used domestically) is lower in absolute terms but higher relative to total household income for poorer groups compared to richer households (Table 3). The differences in NTFP income between the four groups are significant. Richer households are also more likely to produce charcoal, but differences in production quantities between quartiles are not statistically significant.

4.2. Step 1: Household Production Functions for Charcoal

The results of the model are presented in Table 4. 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. We use count-data models to model the quantity of charcoal produced per household. Since only 8% of the households in our sample are involved in charcoal production, the dependent variable includes many zero-observations. Based on the results of the Vuong test[9] and after checking for overdispersion,[10] a zero-inflated negative binomial model was used (Cameron and Trivedi, 2005; Greene, 1994). Since multiple households facing the same contextual factors were interviewed in each village and these observations are unlikely to be independent, we control for the panel structure of the data by estimating cluster robust standard errors, clustering households from the same village. This model consists of two parts, estimated simultaneously: a logit model predicting excess zeros (in our case: the probability that household i is not involved in charcoal production) and a negative binomial model predicting the non-zero data (in our case: the number of 30 kg charcoal bags produced by household i). Note that positive coefficients in the logit model indicate that the variable increases the probability that an observation is zero, i.e. the household belongs to the group of non-producers. Standard errors were corrected for observations clustered in villages. The McFadden's R^2

Table 2
Descriptive statistics of the sample.

Variable		Statistic
Household composition and labour		
Household size — mean		5.5
Number of males per household — mean		2.7
Household education — % of sample with no or only primary education		94
Income		
Main source of household income: agriculture — % of sample		80
Main source of household income: from timber and NTFP — % of sample		6
Total annual household income — TSH * 1000	Mean	829
	Median	420
Total annual household income from NTFP (cash and non-cash) — TSH * 1000	Mean	55
	Median	0
Resource use		
House made of poles — % of sample		73
Roof of house made of thatch — % of sample		47
Main cooking fuel — % of sample using firewood		94
Spatial variables		
Distance to nearest road — mean km		1.0
Open woodland in 10 km buffer — mean ha		2071
Closed woodland in 10 km buffer — mean ha		818
Woodland with scattered crops in 10 km buffer — mean ha		2889
Total woodland in 10 km buffer — mean ha		*5779*
Lowland forest in 10 km buffer — mean ha		1387
Submontane forest in 10 km buffer — mean ha		1553
Montane forest in 10 km buffer — mean ha		109
Upper montane forest in 10 km buffer — mean ha		98
Total forest in 10 km buffer— mean ha		*3146*

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).

The logit model results indicate that five variables, related to household characteristics, forest and woodland accessibility, are significant at the 5% level.[11,12] First, 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 timber and NTFPs are 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.[13,14] 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 also has a negative impact on the probability of household charcoal production, and the higher sigma value of 7.5 implies that the decay in this negative effect related to the distance to sub-montane forests is low, and sub-montane forests beyond 10 km still affect the choice

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[9] The Vuong test can be used to test if models that can accommodate an abundance of zero-observations (so called zero-inflated models) are necessary, by comparing the zero-inflated model with an ordinary negative binomial regression model. For our data, the Vuong test statistic was $z = 6.93$ ($p = 0.001$), implying that a zero-inflated negative binomial model is preferred.

[10] For Poisson models, the data is overdispersed if the variance is larger than the mean. The variance of our dependent variable (quantity of charcoal collected per household per year) was around 100 times larger than the mean.

[11] The main reason for producing significant-only models is the use of the models for out-of-sample prediction of charcoal extraction across the wider study area.

[12] Various spatial variables, such as population density, road network, and land use, showed high levels of correlation, which would cause problems for model estimation. If any two (spatial) variables were significant but correlated, land cover variables were preferred and included in the model in order to reflect the role of forest and woodland in NTFP collection.

[13] 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.

[14] The distance at which 95% of the total quantity of charcoal produced comes from beyond the EAM frontiers is 8 km. Based on this information, we calculated the distance from each village to those forest and woodland cells of 1 ha within the 10 km buffer for practicality (mainly GIS computing potential).

Table 3
NTFP collection across income groups.

Quantiles (based on household income)	Poorest	Poorer	Richer	Richest	χ^2 (3 d.f.)
Mean total NTFP income (TSH∗1000/year)[a]	19	37	69	149	1252
Mean household income (TSH∗1000/year)[a]	105	290	588	2388	68
% NTFP in total income[a]	20	13	11	9	15
% households collecting charcoal[a]	6	7	15	12	21
Mean quantity of charcoal collected (bags of 30 kg/year)	52	33	58	60	4

[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 $\chi2$ (3 d.f.) = 11.35.

Table 4
Model results for charcoal production per household per year.

	Coefficient (z-score)
Logit:	
Dependent variable: choice to not-produce charcoal	
Number of males in household	−0.224***
	(3.68)
Main source of household income: from timber and NTFP (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% and ** to 5%. 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.

for 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.[15]

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, but the coefficient of this variable is small.[16] 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.

We tested a range of other variables related to household wealth, for which we had a priori expectations about their correlation with charcoal production, such as ownership of land or vehicles for charcoal transportation, income level and education, but none of these was found to be significant. Although distance to roads was not significant in our household production model, distance to markets is one of the explanatory variables in our charcoal price model and hence affects the overall economic benefits from charcoal production (see Section 4.5).[17]

4.3. Step 2: Function Transfer across Study Area

Before we can estimate the quantity of charcoal collected per household over the non-surveyed population of the study area in the EAM blocks, we first need to determine how much charcoal extracted by households near the boundary of the EAM is sourced from the EAM blocks. Unfortunately, none of the surveys systematically assessed the source location of products. The available survey data suggest that 60% of the households producing charcoal use wood from protected forests and woodlands, including protected areas and forest reserves, 20% from open access forest and woodland and 45% from farmland.[18] The general patterns suggest that respondents use multiple sources for charcoal collection, not only forests and woodland. Therefore, we would overestimate the value of forests if we attributed all NTFP values to open access forests and woodlands, or all to protected forest reserves, as examples. The large proportion of charcoal from gazetted forest areas, where charcoal production is illegal, is striking. The results indicate an availability of suitable stock within these reserves, a lack of enforcement to prevent illegal extraction, and significant pressure on forests to supply large urban areas with charcoal for cooking, that overrides the risk of being caught and any resulting penalties that might be incurred.

In the absence of survey data on source location, we imposed a rule to generate a probability map reflecting the probability that household i in cell m near the EAM block boundary produces charcoal using wood from the EAM blocks. This map was based on available survey data about travel time to the harvesting location (mean one-way time to charcoal source = 77 min, mode = 60 min). We converted these time data to distance estimates, assuming an average speed of 4 km h^{-1} and equal collection rates in all directions from the village to generate a two-dimensional mapping of the harvesting probabilities around the household location (see Appendix I). Based on this surface, the distance at which 95% of the total quantity of charcoal produced comes from beyond the EAM boundaries is at 8 km distance from the boundary. This rule was used to generate internal and external buffer zones around the EAM boundaries, where the probability of collecting within the EAM is equal to 0.5 at the EAM boundary.

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[15] 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.

[16] Closed woodland is included in both parts of the model. Overall, the effect of closed woodlands in a 10 km range around the village has a positive effect on charcoal production per household due to the higher coefficient in the logit model.

[17] We tested for different types of roads, e.g. major highways, secondary roads, roads passable all year round, and also used a cost–distance function in GIS, based on accessibility, road type and quality, slope and elevation. None of these variables was found to be significant.

[18] The percentages do not add up to 100% because respondents could list multiple sources.

Annual quantity of charcoal produced per household (30 kg bags per household per year)
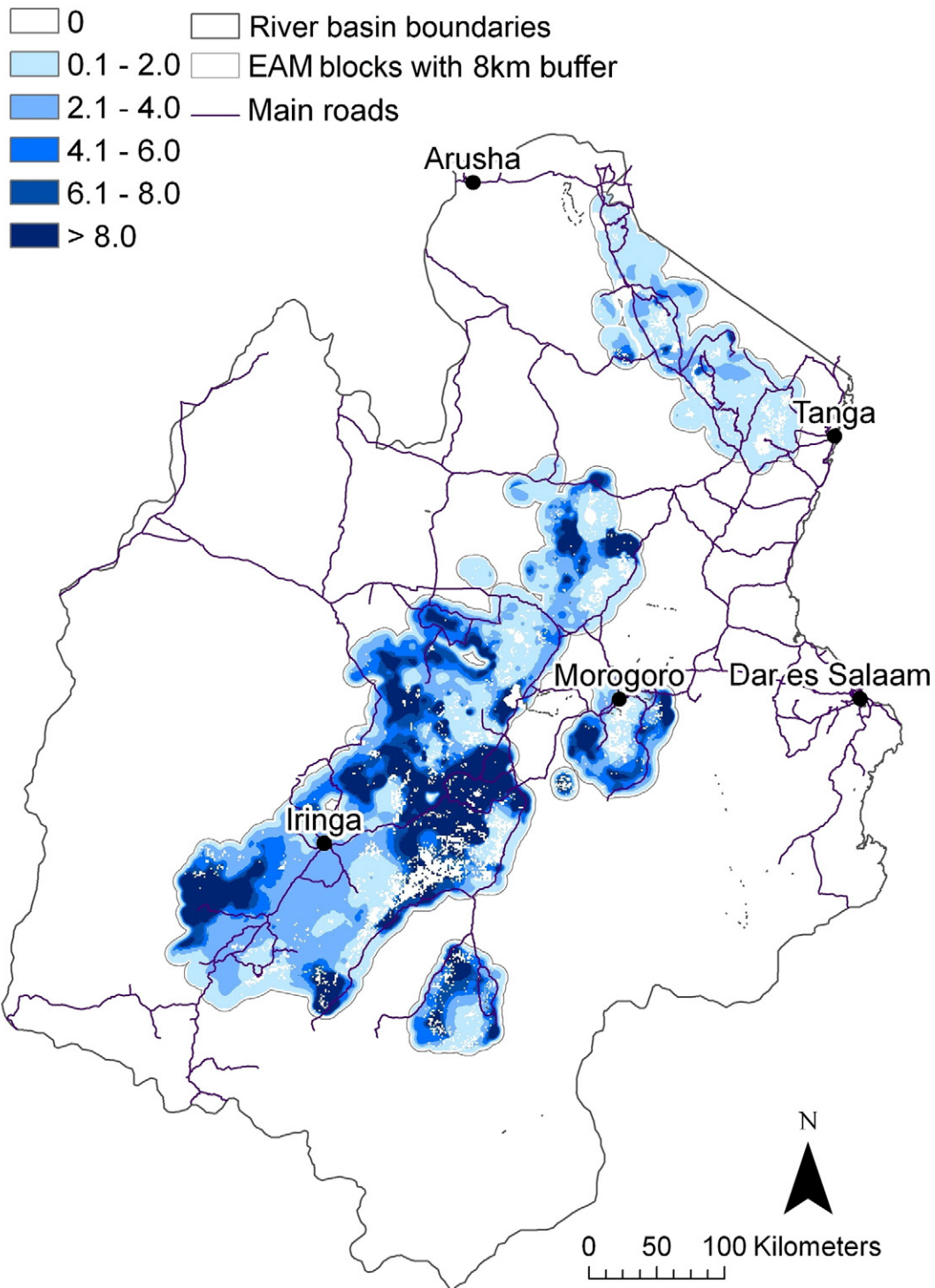

Fig. 2. Annual quantity of charcoal produced per household (30 kg bags per household per year).

Using this rule and the household production function, we estimate the quantity of charcoal extracted per household in each cell of the EAM blocks and buffer zone, using census statistics and our GIS databases for the explanatory variables. The results are depicted in Fig. 2,[19] which shows spatial variation in charcoal production depending on the dominant land cover and differences in household characteristics across areas. For instance, the mean quantity of charcoal produced is higher for households near woodland, and lower near montane forests.[20]

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[19] Note that Fig. 2 shows the predicted values per household living in each cell, including for those cells which are not populated.

[20] A land cover map is available from Swetnam et al. (2011).

4.4. Step 3: Aggregation

In this step, we calculate the total number of charcoal bags produced per annum by households in the EAM as per Eq. (3), taking into account the spatial distribution of households. The resulting map (Fig. 3) reflects the sensitivity of charcoal collection to differences in population density across the EAM blocks, with aggregated production low in areas with few households. The estimated total annual household production of charcoal from the EAM is ~2.9 million 30 kg bags.

4.5. Step 4: Economic Valuation of NTFP Flows

The final step is to estimate the economic value of the annual quantity of charcoal produced by households, by multiplying the

Fig. 3. Total annual quantity of charcoal produced (30 kg bags per ha per year).

aggregate quantities in step 3 by the price of charcoal. The recorded price data shows that prices vary from TSH 4000 to TSH 45,000 per 60 kg bag across the study area, with a mean price of TSH 30,088 (USD 21) per bag in Dar es Salaam and TSH 16,584 (USD 12) elsewhere (n = 302 observations). We estimate a panel regression model which explains 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 (Dar-dummy = 1 for observations from Dar es Salaam, and 0 otherwise), picking up the taxes, bribes and levies that have to be paid to bring products into Dar, and (3) the year of data
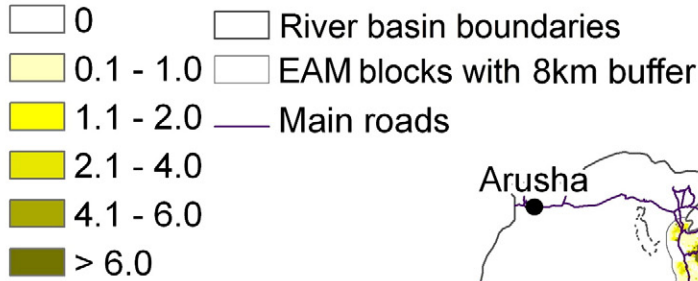

Fig. 4. Total annual value of charcoal produced (TSH∗1000 per ha per year).

collection (year2010-dummy = 1 for observations from 2010, 0 for 2009), reflecting inflation during the period of data collection.[21] Our best-fit model of the average price per bag is specified as follows, with standard errors presented in brackets:

$$\text{Price} = 30365(2413) + 6140(1622) * \text{Dar} - \text{dummy}$$
$$- 3131(465) * \ln(\text{Distance to Dar harbour (km} + 1)) \qquad (9)$$
$$+ 2454(599) * \text{Year } 2010 - \text{dummy}.$$

The model fit is good ($R^2 = 66\%$), and the three explanatory variables are each significant (at $\alpha = 1\%$), with the expected sign. This model is in turn used to generate a price surface with which we valued the quantity of charcoal produced by households living at location m, as in Eq. (8). 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 Zahabu, 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 using market prices in Dar es Salaam alone. 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. The resulting map (Fig. 4) shows how the economic value of charcoal collection varies across the EAM not only with land cover and household variables and population density, but also with price.

Summing these values to estimate the total value of the extraction of charcoal from the EAM suggests that the annual production of charcoal from the EAM is worth approximately TSH 21 billion per year (in 2010 prices, USD 14 million). This figure includes charcoal sold as well as any charcoal consumed at home.

4.6. Limitations and Needs for Future Research

The application of our methodology to a case study on charcoal production in Tanzania shows that the limitations of our NTFP harvesting data (see Section 3.3) require the adoption of a number of assumptions in order to develop a transferable household production function.

It was sufficient for the objective of this paper to use a reduced form model (see Section 2.1). Data for full empirical operationalisation of theoretical household production functions were not available, including data on income from alternative sources. Our approach requires a large sample with sufficient spatial distribution to be representative for the study area. Therefore, we created a unique dataset by combining four different surveys, with the disadvantage that some potentially relevant variables that were not consistently included across surveys could not be included as explanatory factors in the statistical model. Where possible, the use of identical questionnaires is preferable. In addition, the model variable selection was restricted by the availability of secondary data for the explanatory variables from non-surveyed areas, necessary for transferring the model across space (Bateman et al., 2011). The availability of GIS-based biophysical and socio-demographic data at fine spatial resolutions can be limited in developing countries.

We restricted the up-scaling exercise to the EAM area for which our survey data was representative. The reliability of the results could be improved in some areas if time and money were available to improve the spatial coverage of the dataset. Further research into the charcoal production elsewhere would be very relevant for Tanzanian policy makers at the national level, especially in the lowland areas between the EAM blocks and the capital Dar es Salaam, where charcoal production is expected to be higher because of the

availability of woodlands and the proximity to the capital Dar es Salaam. Dar es Salaam is the main market for charcoal due to its large population (2.9 million people in 2007, NBS, 2007).

For future surveys, we would recommend repeated surveys throughout the year, which may help to overcome recall problems and triangulate previously collected data. If empirical data are available about the differences in collected quantities over time, the models in this paper, which now only give a snapshot of a year, could capture dynamic effects, such as seasonality. Ideally, geo-referenced information about harvesting locations would be available. The use of maps in surveys to indicate harvesting locations may facilitate the collection of more accurate data on harvesting locations, and enable modelling of combined location and distance choices, as proposed by Robinson et al. (2002). This remains a challenge for illegal NTFP collection (Lund et al., 2011). Alternatively, forest surveys could be used to cross-check household data on harvesting locations with an assessment of the level of resource degradation. However, this is only possible if the effects of NTFP collection are observable in the field, such as stumps or charcoal kilns, but problematic for NTFPs such as firewood. This is an issue for the assessment of sustainability of NTFP harvesting, because different types of forest and woodland have different levels of sustainable offtake.

5. Conclusions

Understanding the spatial distribution of the quantity and value of NTFP collection gives insight into the forest benefits to local communities. In this paper, we have presented a methodological approach to the estimation of transferable models of NTFP extraction which is (a) based on household production functions for NTFPs using empirical data on household behaviour, (b) spatially sensitive, (c) focused on flow rather than stock value, and (d) transferable to non-surveyed areas for which the primary data is representative. The main objective of our approach is to scale-up household-level survey data to regional or national levels and provide larger scale assessments of NTFP quantities and values. Mapping the local benefits of charcoal as well as other NTFPs may provide insight in the relationship between livelihoods and environment and the spatial variation in this relationship.

The analysis presented in this study focused on the Eastern Arc Mountains in Tanzania, recognised as one of the world's hotspots of forest biodiversity. Based on a large pooled dataset of different household surveys, this study highlights that the consideration of spatially heterogeneous characteristics, such as forest availability, is highly important to understand the variation in charcoal production across households and geographical areas. The paper demonstrates that the importance of spatially explicit functions becomes ever more apparent when transferring the household production model over a wide area and aggregating the quantity collected over the total population, showing that pressure on forests is affected by population density. The application also makes evident that analyses of NTFP collection in a developing country setting are limited by data availability and reliability related to the nature of the good and the harvesting activity (see Sections 3.3 and 4.6).

The estimated total flow of charcoal benefits to the local population from the Eastern Arc Mountain region generally is approximately TSH 21 billion per year (in 2010 prices, USD 14 million). This revenue provides an important source of cash income for local communities. Current levels of charcoal extraction are considered to be unsustainable, which may also diminish the potential for pole and firewood extraction and lead to conflicting stakes at local level. The total quantity of charcoal produced by households in the EAM blocks is estimated at 1.45 million 60 kg bags, equivalent to approximately 11% of the combined annual charcoal consumption in Dar es Salaam and the cities of Morogoro and Tanga, the main markets for charcoal

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[21] In reality, charcoal is consumed in other urban areas besides Dar es Salaam and a price surface will have local optima near these cities. We did not have sufficient data to capture these local optima.

from the EAM blocks. As a result of increasing urbanisation and the depletion of coastal woodlands around Dar es Salaam (Ahrends et al., 2010), charcoal production is expected to place even greater pressure on woodlands and forests in the EAM in the future.

As charcoal production is illegal or licensed, and the Tanzanian Forest Act 2002, which gives more forest rights to villagers conditional on sustainable management, so far has been ineffectively implemented, there seems little economic sense for villagers to investment in forest protection. As this and other studies show (Blomley and Iddi, 2009; Burgess et al., 2010; Pfleigner, 2011), harvesting restrictions are currently not adopted by local communities. A proper compensation scheme for benefits foregone or a combination of better protected ownership and opportunities to generate revenues from forest products could generate incentives for villagers to contribute to sustainable forest management (Clements et al., 2010; Hofstad, 2008). Unless compensation payments or other economic incentives for forest protection are provided, poor communities dependent on charcoal production and other NTFPs for their livelihoods cannot be expected to change their forest production activities (Godoy et al., 2000). The maps of charcoal production presented in this paper may help to understand where the costs of forest conservation, in terms of local people's losses of NTFP-derived income, may outweigh the benefits. Such information is relevant in the initial scoping stage of conservation policy development and livelihood impact assessments. The maps enable the comparison of NTFP values with other ecosystem services, such as carbon sequestration or biodiversity, to determine where increased enforcement efforts and funds would be most needed, and could help to select priority areas for further, properly compensated, legitimate forest protection. Moreover, NTFP-related policies cannot be separated from broader development issues, including agricultural development, infrastructure and energy supply. The approach described in this paper has been developed to guide such regional and national assessments. Further local analyses are recommended for the development of community-level compensation schemes for REDD + or PES.

The approach described in this paper seeks to help ameliorate the current policy analysis problems faced by many natural resource rich countries, like Tanzania, which urgently require data on the quantity and value of the ecosystem services provided by their remaining natural habitats to assist with decisions regarding the potential trade-off between conservation and economic development, and to take advantage of emerging market mechanisms. In view of the lack of extensive datasets, our approach was to test the feasibility of an up-scaling method that could provide reasonable information at the national policy level, utilising existing small-scale datasets. Whilst our approach is clearly not without limitations in terms of data and the simplifying assumptions (rules) that we had to impose, it reports a first step towards a valid and reliable method. Future work will aim to ameliorate some of the limitations listed above, including the sustainability of harvesting and the benefits of charcoal collection over time by comparing current extraction levels with biomass stocks and growth rates, and to assess the value of other NTFPs that are widely collected in the study area.

Acknowledgements

Appendix I

None of the datasets provides detailed information about the source location of charcoal and distance for each unit of NTFP produced. Lacking reliable empirical data on harvesting location, we use "imposed rules" based on information on travel time spent to travelling to the harvesting location, converted to distance using an average walking speed of 4 km per hour (cross-checked with survey information about walking distances), and assuming that harvesting rates are equal in all directions. More specifically, this involved 4 steps (see Appendix Fig. 1):

(1) we use 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) at distance y;
(2) we divide 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., 2003);
(3) we estimate 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 estimate the distance z at which this probability proportion $\leq 5\%$, by summing the probability in the EAM proportion of the circle (dashed area).

Following this procedure, the distance at which 95% of the total quantity of charcoal comes from beyond the EAM frontiers is 8 km from the EAM boundaries. The imposed decision-rule is then applied to ensure that Q_{jimt} reflects the quantity collected from within the EAM boundaries.

To reflect this decision-rule in the mapped results in the GIS, we generate internal and external buffer zones around the EAM block boundaries of ± 8 km. The resulting "contours" are 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 $= 0$, and 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 are then multiplied
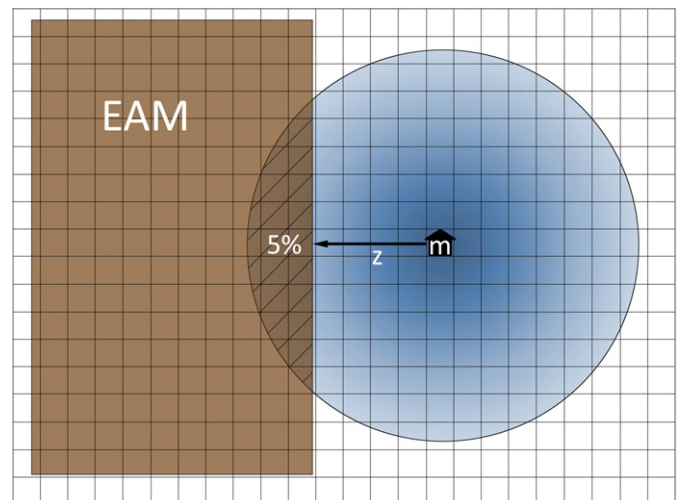
Appendix Fig. 1. Schematic figure of the variables of the imposed rules. Note: The circle around cell m reflects the range in which household i at location m is expected to collect NTFP j according to survey data. The 5% indicates that 5% of the total quantity collected by the household is likely to 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.

by the modelled product collection surfaces of step 2 to further improve the estimate of product collected within the EAM.

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