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**Title**: Examining the impact of forest protection status on firewood sufficiency in rural Africa.

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**Conflict of Interest**

None.

**Ethical Standards**

Ethical approval was received from the University of York Environment Department Ethics Committee. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

**Summary**

Millions of people living in poverty depend on non-timber forest products (NTFPs), yet forest protection causes displacement, replacement or reduction of NTFP extraction activities, with implications for human welfare. Here, we assess the impact of forest protection on a novel measure of wellbeing that incorporates both objective and subjective components of people's lives. In five villages near forests with mixed protection status in Tanzania, household perceived need for firewood is compared with actual consumption to provide a simple metric of firewood sufficiency. Firewood sufficiency varied with forest protection status, with non-compliance inferred by household ability to meet firewood needs despite forest access restrictions. Fuel-efficient stove ownership improved perceived ability to meet firewood needs, however actual consumption remained unchanged. Firewood sufficiency was significantly lower for those sourcing firewood outside forests, and increased household awareness of the management authority significantly reduced firewood consumption. In a forest landscape of mixed protection status, pressure will likely be displaced to the forest with the least active management authority, affecting their efficiency as non-extractive reserves. Our findings reinforce the need for a landscape approach to forest management planning that accounts for local needs, to avoid leakage to other less well-protected forests and detriment to household welfare.

## Introduction

More than 800 million people worldwide depend on forests for food, fuel and income (TEEB 2010). Traditional woodfuels, including firewood and charcoal, account for 55% of harvested wood (FAO 2013). Between 27% and 34% of pan-tropical traditional woodfuels are harvested unsustainably (Bailis et al. 2015). Forest protection necessitates restrictions on non-timber forest product (NTFP) extraction, with resulting welfare implications for local communities and trade-offs between conservation and human wellbeing (Hosonuma et al. 2012, McShane et al. 2011, Schelhas & Pfeffer 2009).

Economic valuation of the total value of forests at multiple scales can improve understanding of these trade-offs, enabling calculation of the cost-benefit ratio of protection at both global and local levels (Naidoo & Ricketts 2006). Appreciating the economic contribution of NTFPs to wellbeing is essential if compensation is to be provided for restricted extraction, such as through payments for ecosystem services (PES) initiatives (Wunder 2013). However, wellbeing is multi-faceted, and may be defined as 'a state of being with others, which arises where human needs are met, where one can act meaningfully to pursue one's goals, and where one can enjoy a satisfactory quality of life' (McGregor 2008). There is growing consensus that evaluating the impacts of conservation interventions on wellbeing should include both objective and subjective components of people's lives (Agarwala et al. 2014, Lange et al. 2016, Woodhouse et al. 2015). Here, we present a novel approach to the assessment of forest protection trade-offs that incorporates these linked material and perception based indicators of wellbeing, by comparing perceived need for firewood with actual usage.

Examination of forest protection trade-offs must also incorporate concerns for leakage, when the benefit of protecting one forest area is negated by the displacement of resource extraction elsewhere (Ewers & Rodrigues 2008). Robinson and Kajembe (2009) identify four possible effects of forest access restrictions at the village-level: (1) villagers displace extraction elsewhere (leakage), (2) villagers replace extraction with increased purchase from markets, potentially intensifying pressure on other forests supplying those markets, (3) villagers reduce extraction quantities, with potentially negative welfare impacts, and (4) villagers cultivate more resources on their own or village land. In addition to these, we identify two further possible effects whereby (5) villagers do not comply with management and continue extraction activities, and (6) in the case of extraction for fuel, villagers switch to alternatives where available (e.g. gas). To predict these effects and inform management decisions, spatial-temporal models of NTFP use help to define a landscape that does not solely account for ecological characteristics, but includes interactions between these and socioeconomic conditions (Robinson et al. 2011). Models indicate that if labour and resource markets function efficiently, then extraction restrictions will not lead to leakage, however imperfect and costly markets will lead to displacement of activities into unprotected areas (Robinson et al. 2011; Albers & Robinson 2013).

In this paper, we present a novel method for examining the impact of protected status on wellbeing and the implications for leakage. We do this by analysing household ability to meet NTFP needs in the vicinity of forests of mixed protected status in rural Tanzania. NTFPs, such as firewood and charcoal, account for over 90% of total energy consumption in Tanzania (Felix & Gheewala 2011). Fuel-efficient stoves can increase cooking efficiency by 30-75%, and a range of development efforts promote the use of such stoves in Tanzania (Jetter & Kariher 2009, Still et al. 2011). However, on average the population of Tanzania and its largest city Dar es Salaam has increased annually by 2.7% and 5.6% respectively between 2002 and 2012 (NBS 2013). Such population growth is predicted to increase pressure on forest resources, acting as a major driver of forest degradation (Felix & Gheewala 2011, Hosier et al. 1993).

Tanzania is now piloting methods for policies aimed at reducing emissions from deforestation and degradation (REDD+) linked to its existing participatory forest management (PFM) programme (Burgess et al. 2010). Early lessons from REDD+ pilot projects indicate new challenges have emerged, with trade-offs between long-term protection and short-term needs, as well as concerns for leakage (Blomley et al. 2016). With high dependence on firewood for energy in our study villages, we compare household perceived need for firewood with actual consumption to provide a simple metric of ability to meet firewood needs (henceforth: firewood sufficiency). The effect of household variables and forest protection status on firewood sufficiency is analysed, and the implications for wellbeing and leakage in this landscape of forests with mixed protection status assessed.

## Methods

### Study Area

Data were collected in five forest-adjacent villages in the Kilombero and Kilosa districts (Morogoro region; Fig. 1), neighbouring the biodiversity-rich Eastern Arc Mountains (Burgess et al. 2007). Villages were selected to maximise variation in protected status whilst minimising geographic spread, to avoid high variation in ecological and social factors. To preserve household anonymity, villages were identified by number and adjacent forests by their protection status: one forest protected as a National Park

(NP), one under JFM, two under CBFM (CBFM1; CBFM2) and the remaining forest in management transition (transition forest; Table 1).

One year prior to NP gazzettement in 1992, the World Wide Fund for Nature (WWF) and the Tanzanian National Park Authority (TANAPA) began a ten-year project promoting tree nurseries and fuel-efficient stoves in villages on the eastern border of the park, to reduce dependence on the forest (Harrison 2006). During this time TANAPA allowed villagers weekly entry to extract dead firewood. This concession continued until June 2011, when it was banned given concerns for the impact on biodiversity (Rovero et al. 2008). All five study-villages occur in this area east of the NP. Agriculture is the predominant livelihood activity in these districts, and pressure on resources is high (Gorenflo & Orland 2013).

[FIGURE 1 HERE]

[TABLE 1 HERE]

## Data Collection

Between March and December 2011, 500 household questionnaires were administered across study-villages to gauge NTFP use and household-level socio-economic and demographic variables. In each village, focus groups were used to jointly identify village-specific wealth indicators, such as asset ownership, and households assigned to either a high-income or low-income wealth category with the assistance of village councils. Total village household lists were then stratified by sub-village and wealth (after Lund et al. 2008), and random number generation used to select 100 household heads/village as respondents. This number of questionnaires was chosen to maximise variability in responses whilst maintaining a logistically viable sample size.

Questionnaires were administered by enumerators local to each village in the wet (May-June) and dry (November) season to capture seasonal variation in NTFP use. The geographic coordinates of all 500 households were recorded. Multiple questions relating to NTFP use were asked to facilitate triangulation of data. Households were asked to identify their major source of cooking energy, how this was obtained and the monthly quantity consumed. Households were asked to identify all nearby forests, whether they extracted from that forest, and products extracted. Households were also asked to recall their NTFP use each month in that season. Specifically, for each product, households were asked to recall the quantity extracted per month, the frequency of extractions and the extraction location. Households were also asked to recall the quantities purchased, sold and consumed per month. Finally, households were asked the perceived quantity needed per month. The aim of this data collection method was to compare like-for-like quantities, rather than econometric valuation. Rapid assessment methods, such as those employed here, have been shown to have good congruence with more detailed assessment in comparison of interview-based methods (Jones et al. 2008).

## Data Analysis

### NTFP utilisation and protected area compliance

Households were coded into those that either solely extracted NTFPs, solely bought NTFPs or both extracted and bought NTFPs. Extraction location for each product was coded by the forest protection status (NP, CBFM1, CBFM2, JFM, transition) or household agricultural fields or private woodlot (Fields/Private) or purchase (Buy). The percentage of households extracting each NTFP was calculated by extraction location. Compliance with management rules and regulations was inferred through reporting of number of NTFPs extracted, being firewood only or multiple products. This measure of compliance is susceptible to under-reporting, as despite best efforts to elicit truthful answers through data triangulation and use of local enumerators, some households may have under-reported their NTFP use, or indicated extracting from non-forest areas for fear of repercussions.

### Firewood Sufficiency

The mean quantities of firewood extracted, bought, sold, consumed and needed per household were calculated across both wet and dry seasons to provide average monthly rates (bundles/month). Reported household firewood consumption was cross-validated via calculation of quantities extracted, bought and sold. Household firewood sufficiency was calculated by deducting household perceived mean quantity of firewood needed/month from mean quantity consumed/month. This method builds on other household-scale approaches to define firewood sufficiency by going beyond a purely qualitative understanding (Dovie et al. 2004). Whilst moving towards a more rigorous quantitative approach, the method explicitly retains a subjective component common to recent definitions of wellbeing by allowing respondents to estimate their own need (Agarwala et al. 2014, Milner-Gulland et al. 2014). Negative sufficiency indicated a deficit in household firewood needs, zero values indicated that needs were met and positive values indicated a surplus of firewood. Households were then grouped by extraction location, and one-way Analysis of Variance (ANOVA) and Tukey posthoc tests used to compare differences in mean household firewood sufficiency between extraction locations.

Between wet and dry season surveys, the aforementioned firewood collection ban commenced in the NP and also JFM. If households indicated a switch in extraction location from either NP or JFM between surveys, the difference between mean wet season firewood sufficiency and mean dry season firewood sufficiency was tested using Student's t-tests. All statistical analyses were carried out using R (version 3.0.0; http://cran.r-project.org).

## Determinants of Firewood Sufficiency

Further analysis was carried out to determine what factors might predict household firewood need, consumption and sufficiency independently. A broad set of 16 household-level demographic, wealth and environmental predictor variables were chosen based on previous investigations into NTFP consumption correlates (e.g. Foerster et al. 2012; Table 2). All variables were coded from household questionnaire data. Dependence on NTFPs for energy was represented by whether households used firewood alone as their major energy source, or in combination with charcoal. Previous analysis found variation in household awareness of each forest management authority in this study sample, with clear awareness of NP status, yet no awareness of JFM and low engagement in PFM (Latham 2013). Given this, awareness was also included as a binary variable in all models.

[TABLE 2 HERE]

Covariation between predictor variables was assessed using Pearson correlation and Variance Inflation Factors, and all variables were retained (Pearson $P \leq 0.7$ and/or $VIF \leq 5$; Zuur et al. 2010). Variables with uneven spread (occupation, 98% farmer) were excluded from models. Before modelling, variables with a strong skew were transformed as follows: age, hhsize, assets (square root), land (cube root) and response variables firewood need, firewood consumption (log10) and firewood sufficiency (cube root).

Generalised linear models (GLMs) with a Gaussian error function were used to investigate the influence of the same predictor variables on (1) firewood need, (2) firewood consumption, and (3) firewood sufficiency. Spline correlograms (ncf package; Bjornstad 2012) were used to test for spatial-autocorrelation as observations of households facing equivalent socio-economic and environmental factors might not be independent. Significant spatial auto-correlation was present at short lag-distances of 3km, 4km and 4km for need, consumption and sufficiency data, respectively. With only five villages sampled, it was not appropriate to include village as a random factor using generalised linear mixed models (e.g. Crawley 2002). However, spline correlograms of the Pearson residuals suggested spatial correlation was successfully accommodated by each GLM through the inclusion of the extraction_location variable. Minimum adequate models were obtained using backwards-forwards selection based on the Akaike Information Criterion (Murtaugh 2009). Some levels within the categorical variable extraction_location did not contribute to final models, and so seven independent binary variables ('True' or 'False') were created ('Buy', 'Fields/Private', 'Transition', 'CBFM1', 'CBFM2', 'JFM' 'NP'), and backwards-forwards selection repeated. Final models were validated through observation of residual spread. Analyses of deviance were used to test the probability that the amount of deviance explained was not significantly reduced from the full (unreduced) model (p[D]; Zuur et al. 2010). The probability that the slope estimate of each variable was significantly different from zero was determined, based on a t distribution (Quinn & Keough 2002). The False Discovery Rate (FDR; Benjamini & Hochberg 1995) correction of alpha values for repetitive testing was employed on slope estimates for each model in turn, resulting in 95% significance alpha cut-offs of 0.05, 0.039 and 0.025 for need, consumption and sufficiency models, respectively.

## Results

NTFP Utilisation and protected area compliance

All households were dependent on NTFPs as their main source of energy; 48% stated use of both firewood and charcoal, 47% stated firewood only and 5% charcoal only. Of the 500 households surveyed, 434 (86.8%) indicated extracting NTFPs, of which 166 (38.2%) households supplemented with additional purchases, and 59 households (11.8%) only purchased NTFPs (Fig. 2; 1.4% unanswered). Over half of households extracting NTFPs obtained these from a forest (n=263; 60.6%); of which 60.8% (32% of total sample) were non-compliant with forest management by indicating extraction of more than just dead firewood. The remainder of households extracting NTFPs did so from agricultural fields or private woodlots (n=156; 35.9%; 3.5% unanswered).

[FIGURE 2 HERE]

Households indicated extracting multiple NTFPs from the PFM forests (JFM, CBFM1 & CBFM2; Fig. 3). All households using these forests, except for one using the CBFM1 forest and two using the CBFM2 forest, indicated non-compliance with the rules and regulations. Households using the transition forest stated similar extraction of NTFPs, although given this forest was not formally protected this type of use could not be categorised for compliance. Of the households extracting from the NP, 95.5% stated extraction of firewood only before the ban was implemented, in line with management.

[FIGURE 3 HERE]

Firewood Sufficiency

Household perceived firewood sufficiency varied from -99.0 to +40.0 bundles/month, with mean household sufficiency of -6.43 (±12.71) bundles/month across all villages. Sufficiency varied significantly between extraction locations (Fig. 4). Households with very low sufficiency (<-10 bundles/month, n=82) all reported modest consumption quantities based on the sample average, yet excessively high perceived need for firewood. The opposite was true for households with very high sufficiency (>+10 bundles/month, n=5), which reported similarly modest quantities of firewood needed yet consumed exceedingly high quantities. Households extracting from JFM had the highest mean sufficiency (0.21±0.83 bundles/month), indicating household firewood needs were on average met. Households extracting from all other locations had negative mean sufficiency, indicating an inability to meet firewood needs, with lowest mean sufficiency in households extracting from CBFM1 (-2.9±0.65 bundles/month). Households extracting from fields or private areas had significantly lower sufficiency than households extracting from all forests except for transition forest and CBFM1, suggesting difficulty in meeting needs when extracting from outside forested areas.

[FIGURE 4 HERE]

All households extracting firewood from NP in the wet season indicated a switch in extraction location to fields or private areas after the ban was enforced, between surveys. Despite this, no significant difference in firewood sufficiency was found between seasons (mean wet season=-2.49±4.65 bundles/month, mean dry season=-2.84±6.54 bundles/month, $t=0.30$, $p=0.78$), although any long-term impacts of the ban might not be reflected within the short timeframe of the study. No such switch was reported by households extracting from JFM in the dry season.

## Determinants of Firewood Need, Consumption and Sufficiency

Extraction location and household demographic, wealth and environmental variables best-predicted firewood need, consumption and sufficiency (Table 3). Household perceived need for and consumption of firewood were significantly reduced if sourced from markets or extracted from CBFM2. Households extracting from fields or private areas, transition forest and CBFM1 had significantly higher perceived need for firewood. Indeed, sufficiency of households extracting from field or private areas and CBFM1 were significantly lower yet not retained in the consumption model, signifying this increased need was not met by quantities consumed from these areas. Households extracting from JFM consumed significantly more firewood, and were significantly more capable of meeting firewood needs.

[TABLE 3 HERE]

Larger households had significantly increased perceived need for and consumed more firewood, while those with more valuable assets perceived a greater need for but consumed less firewood (Table 4). Households owning a fuel-efficient stove had significantly improved ability to meet firewood needs, with significantly lower perceived need for firewood although consumption quantities were unchanged. Household awareness of the forests' management authority significantly reduced firewood consumed, indicating a positive relationship between awareness of protection status and compliance with management.

[TABLE 4 HERE]

## Discussion

Household NTFP extraction provides a general indication of low compliance with forest protection in the study area, with the exception of households extracting from NP. Awareness of NP status was high, and this is reflected by most households extracting firewood only from this forest and the stated switch in extraction location post-ban. The mean deficit in firewood sufficiency of households extracting from NP also reflects compliance, as the restrictions in place limit the quantity households can extract regardless of their perceived need. The opposite is true for households extracting from JFM, as no households were aware of JFM status and findings reflect non-compliant NTFP extraction and no switch in extraction location post-ban. Households extracting from JFM were significantly more likely to meet their resource needs, indicating household extraction was unrestricted by management and use of this forest was as required. Findings indicate support for previous research that found compliance increased with awareness of the forest rules and regulations in Uganda (Nkonya et al. 2008). However, a direct relationship between awareness and compliance cannot be inferred here, and compliance will be influenced by numerous factors such as the status and enforcement of protection in each area (e.g. Rovero 2007).

Households extracting from CBFM1 and CBFM2 also indicated low compliance given high reporting of extracting more than firewood. Unlike JFM households, the majority of CBFM households were aware of these forests' community-based authority; however, very few were actively engaged in management. Interestingly, perceived need for and consumption of firewood was significantly reduced in households extracting from CBFM2. This may indicate some level of success of community-led management in this village, with households more conscious of firewood quantities consumed. Conversely, households extracting from CBFM1 were significantly less likely to meet their firewood needs. The condition of CBFM1 or its distance from the village may have limited the perceived ability of this forest to supply household needs (e.g. Robinson et al. 2002). Indeed, most households in the CBFM1 village reported extraction from the NP, stating access was easier due to distance and firewood extraction permitted before the ban. However, further investigation is required to deduce the reasons for the observed differences in sufficiency between the two CBFM forests. This would necessitate information relating to the ecological condition of each forest, as well as quantitative and qualitative assessment of management effectiveness.

Determinants of Firewood Utilisation

NTFP dependence has previously been associated with low wealth (Adhikari et al. 2004). Interestingly, we found that increased assets resulted in higher perceived need for firewood whilst actual consumption decreased, perhaps due to a switch to alternative, non-forest sources of energy. Decreased consumption was also observed in households solely purchasing firewood. These households also indicated a lower perceived need for firewood, perhaps reflecting the influence of a financial transaction on perceived firewood need as opposed to extracting the resource at no monetary cost. Nevertheless, findings suggest that perceived firewood need and sufficiency are indeed influenced by subjective characteristics of wellbeing not directly linked to objective fuel requirements; exemplified here by wealthier households aspiring towards greater fuel use than they in fact consumed each month. This highlights the value of our methodology which explicitly incorporates subjective components of wellbeing, firstly by allowing respondents to define their own perceived need and secondly by comparing these perceptions with actual consumption. The excessive firewood deficits and surfeits observed in some households illustrates the degree to which these perceptions can be exaggerated, warranting further examination into the factors influencing both the need for NTFPs and their actual use. For example, the higher perceived need for firewood among households extracting from certain sources might reflect the difficulty in obtaining fuel from those areas, with this increased difficulty creating the sense that more is needed than in fact would actually be used.

Our observed relationship between firewood sufficiency and fuel-efficient stove use presumably resulted from a perception of improved fuel efficiency within these households. It could be argued that households owning stoves might be more engaged in sustainability discussions in the area (e.g. Harrison 2006), and that stove ownership alone has improved perceived wellbeing whilst actual consumption remains unchanged. It has been recommended that policies to conserve tropical forests be conducted in parallel with projects aimed at enhancing fuel-efficiency, such as through the use of modified stoves (Fisher et al. 2011). However, our findings indicate that the actual efficiency-savings of stoves needs careful examination if any perceived benefits are to be realised in practise (e.g. Hanna 2012, Bailis et al. 2015). Such examination would benefit future efforts to enhance more sustainable fuel use in the area. In addition, improving local-awareness of forest protection status and methods in agroforestry is recommended, given the positive relationship indicated between awareness and compliance and the observed decrease in sufficiency when firewood is extracted from agricultural areas.

Implications for Leakage and Wellbeing

The difficulty of the non-forest firewood sources to meet household needs presents long-term concern for leakage. This is especially significant in this area given the firewood ban, and the observed non-compliance within less-well protected forests such as JFM or transition forest. The specific challenges impeding household ability to meet resource needs outside forest areas need to be measured, however land availability for tree planting and alternative energy opportunities in the area are limited (Gorenflo & Orland 2013, pers. obs.). Considering the six effects of resource access restriction previously outlined, the potential for either (1) displacement, (3) reduction or (5) non-compliance are most significant. This has serious implications for either long-term forest protection in the area given leakage or non-compliance, or detriment to local welfare through inability to meet fuel and food demands. This welfare impact is significant given restricted NTFP access in Tanzania is likely to hit the poorest the hardest (Schaafsma et al. 2014), while the potential for leakage presents concern for the area's important biodiversity (Burgess et al. 2007). Such outcomes are especially significant in areas containing forests of mixed protection status. The presence of multiple independent forest authorities creates potential for locally-based management decisions that might not take the larger socio-ecological landscape into consideration. With local-dependence on NTFPs unaddressed, such decisions can have serious implications for forest protection or human wellbeing within the landscape. Within our study area long-term monitoring of household NTFP utilisation is needed to assess the impact of the firewood ban on both household welfare and leakage, given the proximity of other, less-well protected forests. Indeed, considerable leakage of NTFP extraction activities into more distant forests has been observed after PFM implementation in Tanzania (Robinson and Lokina 2011). Thus, findings lend empirical support to growing theory behind the need for a landscape planning approach to forest conservation policies (Robinson et al. 2011).

## Wider Implications

Understanding and addressing the issue of leakage is particularly important for PES and REDD+ if carbon benefits are to be meaningful and permanent. REDD+ in particular is expected to provide poverty alleviation and biodiversity conservation benefits additional to climate change mitigation. Thus, local welfare costs of restricted NTFP use ought to be assessed alongside the global benefit of addressing climate change. Such spatial ecosystem valuation can help evaluate the trade-offs between local and international communities to inform policy (e.g. Schaafsma et al. 2012). In addition, carbon accounting at the national level will need to include the potentially offsetting emissions of displaced NTFP extraction activities (Robinson et al. 2013). Fisher et al. (2011) estimate that the implementation costs of measures to alleviate forest dependency, such as raising agricultural yields and increasing stove use, remain feasible within REDD+ policies despite exceeding the opportunity costs of carbon conservation. However, household energy needs will still need to be met despite compensation through PES or REDD+, and the source of this energy will need to be considered at multiple scales and by multiple forest authorities.

## Figure Legends

Figure 1. Location of the five study-villages and adjacent forests. Adapted using data on Eastern Arc Mountain boundaries and forests from Platts et al. (2011), Protected Area boundaries from UNEP-WCMC (2010), transition forest and Selous Game Reserve boundary with the assistance of the Udzungwa Forest Project, and Village 1 Forest boundaries from WWF (2006). Data on spatial infrastructure with the assistance of the Valuing the Arc project (http://www.valuingthearc.org).

Figure 2. Schematic representation of NTFP use by all households, including extraction location (NA=question unanswered, FW=Households extract firewood only, M=Households extract multiple NTFPs (>1), Bold boxes=non-compliant resource extraction according to rules and regulations defined in Table 1.

Figure 3. Percentage of households extracting each NTFP by extraction location (n=Number of households).

Figure 4. Mean household monthly firewood sufficiency, and 95% confidence intervals based on the t distribution, by extraction location in order of increasing protection status. Letters indicate significant differences in sufficiency between associated extraction locations based on one-way analysis of variance and subsequent Tukey's honest significant differences (Tukey's HSD $^{***}p<0.001$, $^{**}p<0.01$, $^{*}p<0.05$).

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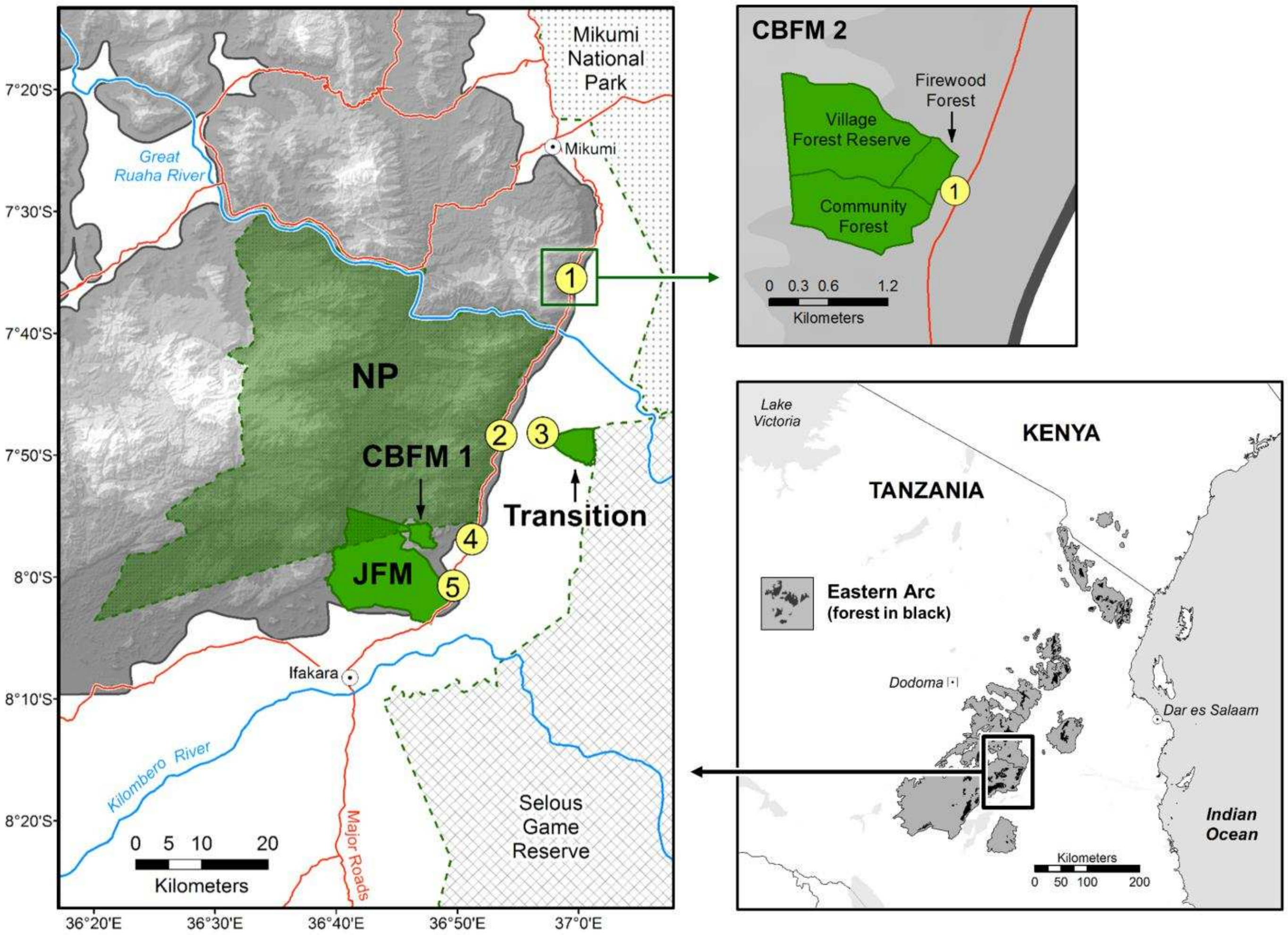


Figure 1. Location of the five study-villages and adjacent forests. Adapted using data on Eastern Arc Mountain boundaries and forests from Platts et al. (2011), Protected Area boundaries from UNEP-WCMC (2010), Transition forest and Selous Game Reserve boundary with the assistance of the Udzungwa Forest Project, and Village 1 Forest boundaries from WWF (2006). Data on spatial infrastructure with the assistance of the Valuing the Arc project (http://www.valuingthearc.org).

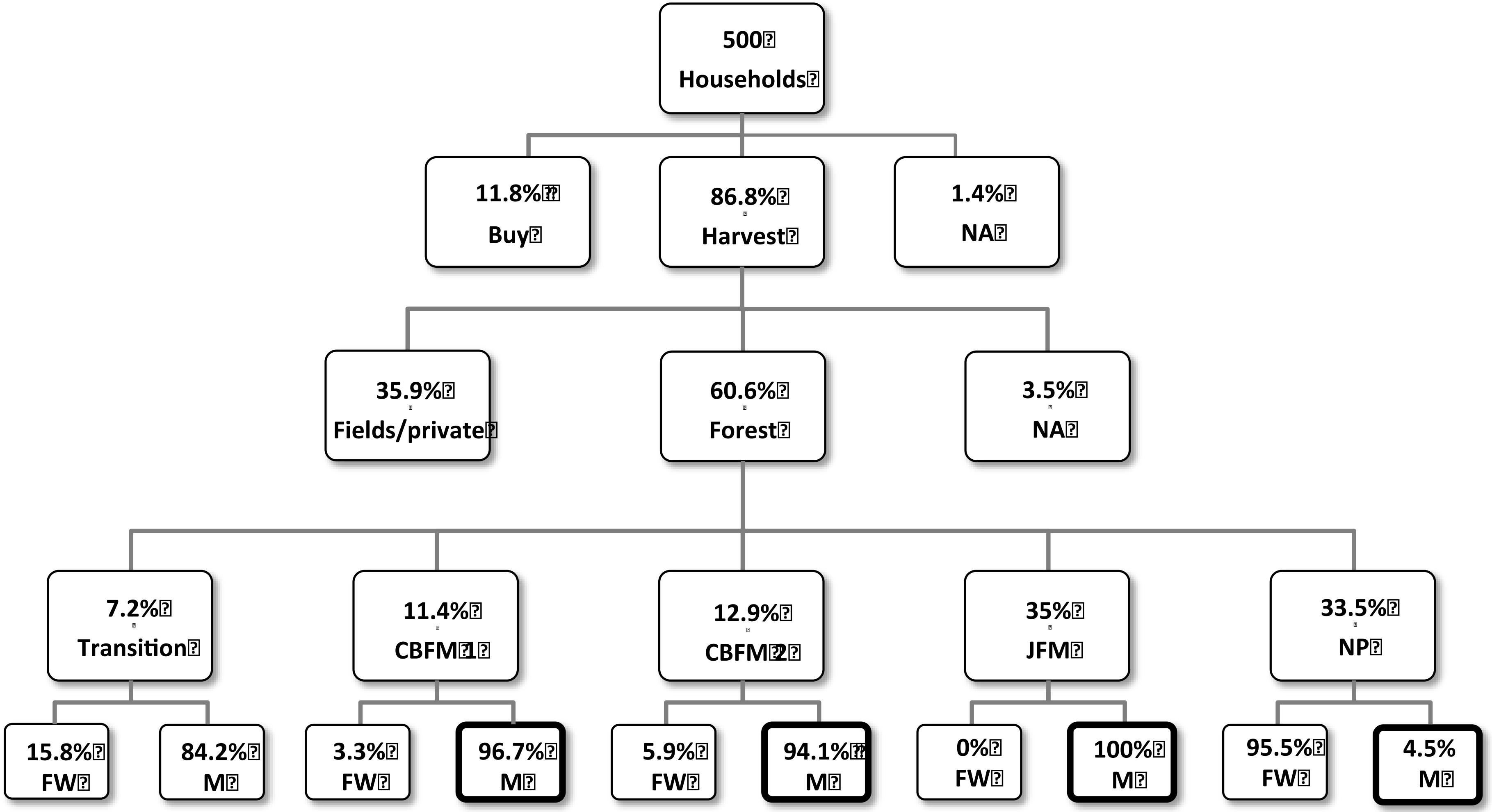


Figure 2. Schematic representation of NTFP use by all households, including extraction location (NA=question unanswered, FW=Households extract firewood only, M=Households extract multiple NTFPs (>1), Bold boxes=non-compliant resource extraction according to rules and regulations defined in Table 1.

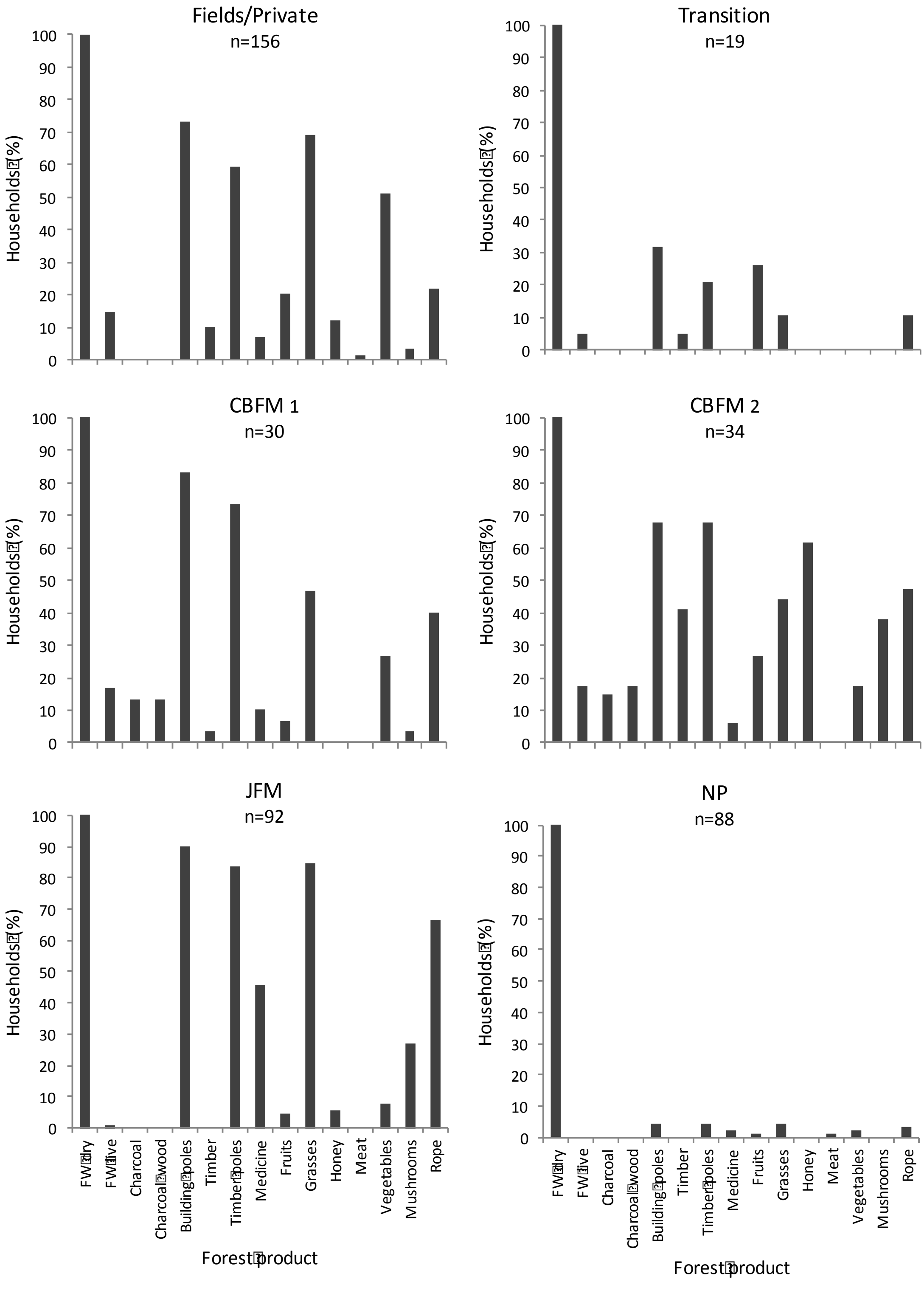


Figure 3. Percentage of households extracting each forest product by extraction location (n=Number of households).

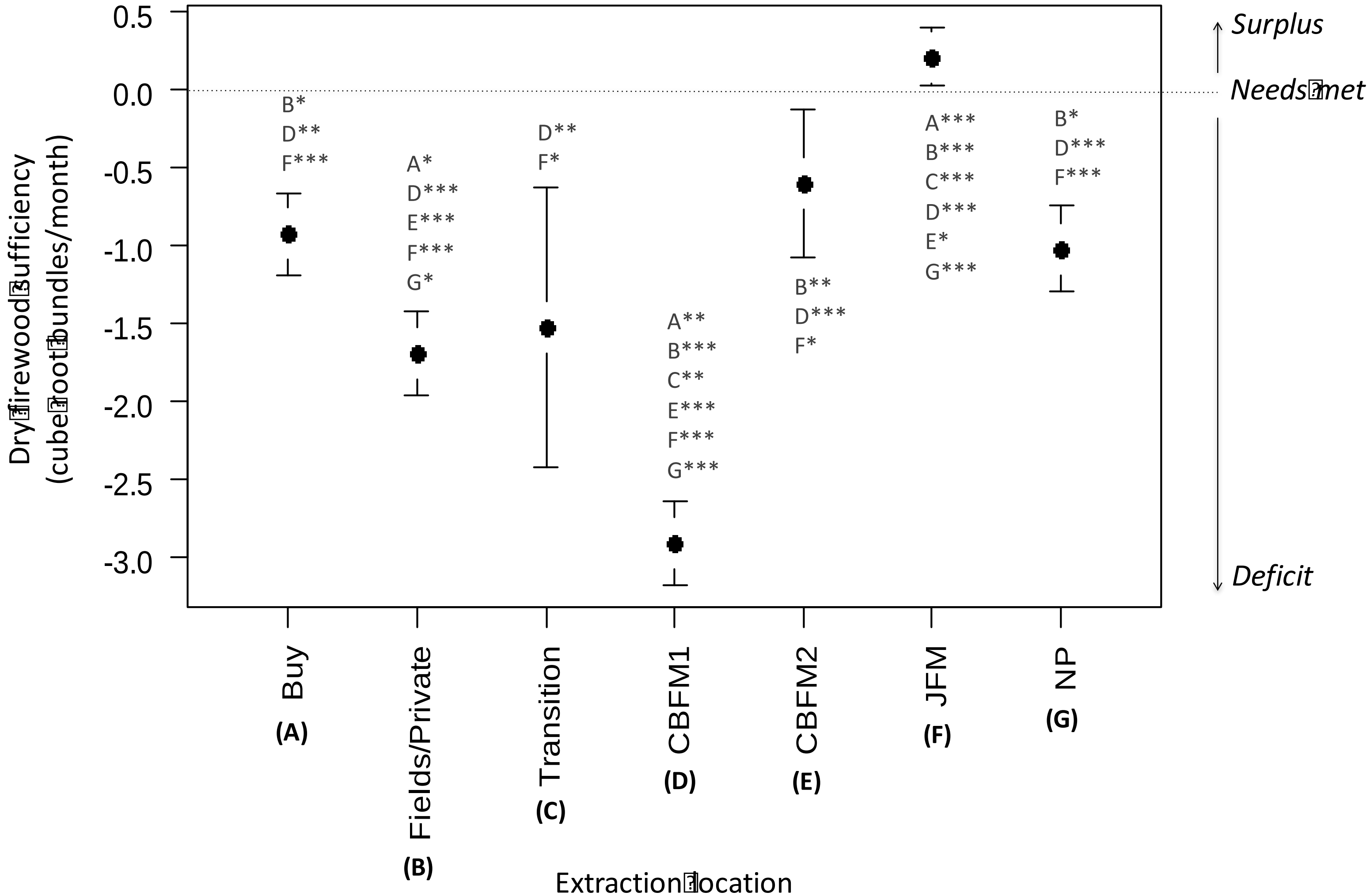


Figure 4. Mean household monthly firewood sufficiency, and 95% confidence intervals based on the t distribution, by extraction location in order of increasing protection status. Letters indicate significant differences in sufficiency between associated extraction locations based on one-way analysis of variance and subsequent Tukey's honest significant differences (Tukey's HSD ***p<0.001, **p<0.01, *p<0.05).

Table 1. Description of study-villages and adjacent forests. NP = National Park, CBFM = Community-Based Forest Management, JFM = Joint Forest Management, TANAPA = Tanzania National Park Authority, R&R = Rules and Regulations, VFR = Village Forest Reserve, FWF = Firewood Forest, CGF = Community Group Forest. [a]Number of households; [b]Numbers in parenthesis indicate distance to forest from central village meeting place; [c]Defined through interview with forest authority representatives.

| Village | Village Size [a] | Mean House-hold Size | Dominant Tribe(s) | Forest Protected Status [b] | Forest Authority | Rules and Regulations [c] |
|---|---|---|---|---|---|---|
| 1 | 757 | 4.2 | Vidunda | CBFM 2; Village Forest (0.2km) | Village 1 | Village forest divided into three areas:<br>VFR – no resource extraction allowed<br>FWF – only dead firewood extraction allowed two days a week<br>CGF - no resource extraction allowed |
| 2 | 259 | 4.8 | Ngindo<br>Pogoro<br>Ndamba | NP; IUCN category II (0.3km) | TANAPA | Women allowed entry once a week to extract dead firewood, no cutting tools allowed.<br>Ban enforced in July 2011 after which no resource extraction allowed. |
| 3 | 289 | 3.1 | Hehe<br>Pogoro<br>Ngindo | Transition; No formal protection (0.7km) | None | No formal R&R regarding resource use |
| 4 | 1275 | 4.1 | Pogoro<br>Ngoni<br>Bunga<br>Hehe | CBFM 1; Village Forest (5.4km) | Village 4 | Only dead firewood extraction allowed (i.e. no cutting tools) |
| 5 | 576 | 5.5 | Pogoro<br>Ngindo | JFM; Forest Reserve IUCN category IV (1.4km) | Kilombero District Council & Village 5 | Only dead firewood extraction allowed (i.e. no cutting tools).<br>Ban introduced in July 2011 after which no resource collection allowed |

Table 2. Description of household predictor variables. M = Male, F = Female, Y = Yes, N = No. 1TZS was equal to mean 0.000635USD during the period of data collection (March-December 2011).

| Type | Variable | Description |
|---|---|---|
| Demographic | age | Age of household head |
| | gender | Gender of household head (M or F) |
| | education | Number of years household head in formal education |
| | occupation | Occupation of household head |
| | born | Household head born in village (Y or N) |
| | hhsize | Size of household (number of residents) |
| | hhwomen | Proportion of female residents |
| Wealth | land | Area of land attributed to household (hectares) |
| | hse_material | Main material of household (brick or mud) |
| | assets | Total household material asset value (*1000 Tanzanian shilling) |
| | incomes | Number of household income sources |
| Environmental | stove | Presence/absence of fuel-efficient stove (Y or N) |
| | woodlot | Household planted trees/woodlot (Y or N) |
| | energy | Household source of energy (Firewood alone or firewood and charcoal) |
| | aware | Household awareness of forest authority (Y or N) |
| | extraction_location | Household source of firewood (Buy, Fields/Private, Transition, CBFM1, CBFM2, JFM, NP) |

Table 3. Linear regression models, based on backward-forward selection using AIC, of household firewood (1) Need, (2) Consumption (log10 bundles/month) and (3) Sufficiency (cube root bundles/month) versus demographic, wealth and environmental predictor variables. Statistics include the probability of deviation from a slope of zero (p), direction of the trend (positive$^{+}$, negative$^{-}$), the percent deviance explained by each variable (%$D_V$), AIC, the percent deviance explained by the model (%D) and the probability of decreased deviance explained from the full model (p[D]), following analysis of deviance. Bold type indicates significant variables following FDR correction for repetitive testing (‘Need’ $\alpha_{FDR}$=0.05, ‘Consumption’ $\alpha_{FDR}$=0.039, ‘Sufficiency’ $\alpha_{FDR}$=0.025).

| Model | Predictor Variables | Model Statistics |
|---|---|---|
| Need | **Extraction Location: CBFM 1$^{+}$** | **p <0.0001 (%$D_V$** |
| (AIC = - | **Extraction Location: Buy$^{-}$** | **p <0.0001 (%$D_V$** |
| %D = 48.2, | **Extraction Location: CBFM 2$^{-}$** | **p <0.0001 (%$D_V$** |
| p[D] = 0.93) | **Extraction Location:** | **p <0.0001 (%$D_V$** |
| | **Extraction Location:** | **p <0.0001 (%$D_V$** |
| | **Fuel-efficient stove ownership$^{-}$** | **p = 0.0038 (%$D_V$** |
| | **Household size$^{+}$** | **p = 0.0062 (%$D_V$** |
| | **Total asset value$^{+}$** | **p = 0.015 (%$D_V$** |
| Consumption | **Extraction Location: Buy$^{-}$** | **p <0.0001 (%$D_V$** |
| (AIC = - | **Extraction Location: JFM$^{+}$** | **p <0.0001 (%$D_V$** |
| %D = 39.2, | **Extraction Location: CBFM 2$^{-}$** | **p = 0.00022 (%$D_V$** |
| p[D] = 0.95) | **Household size$^{+}$** | **p = 0.00043 (%$D_V$** |
| | **Total asset value$^{-}$** | **p = 0.0058 (%$D_V$** |
| | **Extraction Location:** | **p = 0.027 (%$D_V$** |
| | **Aware of authority$^{-}$** | **p = 0.039 (%$D_V$** |
| | Area land owned$^{+}$ | p = 0.058 (%$D_V$ =0.65) |
| | Household head age$^{-}$ | p = 0.059 (%$D_V$ =0.64) |
| Sufficiency | **Extraction Location: CBFM 1$^{-}$** | **p <0.0001 (%$D_V$** |
| (AIC = 1052.4, | **Extraction Location:** | **p <0.0001 (%$D_V$** |
| %D = 41.8, | **Fuel-efficient stove ownership$^{+}$** | **p = 0.0021 (%$D_V$** |
| p[D] = 0.93) | **Extraction Location: JFM$^{+}$** | **p = 0.0046 (%$D_V$** |
| | Extraction Location: Transition$^{-}$ | p = 0.035 (%$D_V$ |
| | Household head age$^{-}$ | p = 0.051 (%$D_V$ |
| | Aware of authority$^{-}$ | p = 0.055 (%$D_V$ =0.64) |
| | Planted trees/woodlot$^{+}$ | p = 0.068 (%$D_V$ |

Table 4. Demographic, wealth and environmental variables that best predicted household firewood need, consumption and sufficiency based on linear regression models. Arrows indicate the direction of the relationship between explanatory and response variables (black arrows indicate significant relationships following FDR correction, grey arrows non-significant relationships ($p > \alpha_{FDR}$), and NA indicates that variable was not retained in that minimum adequate model after backwards-forwards AIC selection. See Table 3 for model details).

| Variable | Need | Consumption | Sufficiency |
|---|---|---|---|
| Buy | ⇩ | ⇩ | *NA* |
| Fields/Private | ⇧ | *NA* | ⇩ |
| Transition | ⇧ | ⇧ | ⇩ |
| CBFM 1 | ⇧ | *NA* | ⇩ |
| CBFM 2 | ⇩ | ⇩ | *NA* |
| JFM | *NA* | ⇧ | ⇧ |
| Stove | ⇩ | *NA* | ⇧ |
| Aware | *NA* | ⇩ | ⇩ |
| Assets | ⇧ | ⇩ | *NA* |
| Household size | ⇧ | ⇧ | *NA* |
| Age | *NA* | ⇧ | ⇩ |
| Land | *NA* | ⇧ | *NA* |
| Woodlot | *NA* | *NA* | ⇧ |