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Examining the impact of forest protection status on firewood sufficiency in rural Africa

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1 **Summary**

2 Millions of people living in poverty depend on non-timber forest products (NTFPs),

3 yet forest protection causes displacement, replacement or reduction of NTFP

4 extraction activities, with implications for human welfare. Here, we assess the impact

5 of forest protection on a novel measure of wellbeing that incorporates both objective

6 and subjective components of people's lives. In five villages near forests with mixed

7 protection status in Tanzania, household perceived need for firewood is compared

8 with actual consumption to provide a simple metric of firewood sufficiency. Firewood

9 sufficiency varied with forest protection status, with non-compliance inferred by

10 household ability to meet firewood needs despite forest access restrictions. Fuel-

11 efficient stove ownership improved perceived ability to meet firewood needs,

12 however actual consumption remained unchanged. Firewood sufficiency was

13 significantly lower for those sourcing firewood outside forests, and increased

14 household awareness of the management authority significantly reduced firewood

15 consumption. In a forest landscape of mixed protection status, pressure will likely be

16 displaced to the forest with the least active management authority, affecting their

17 efficiency as non-extractive reserves. Our findings reinforce the need for a landscape

18 approach to forest management planning that accounts for local needs, to avoid

19 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.

44   Examination of forest protection trade-offs must also incorporate concerns for

45   leakage, when the benefit of protecting one forest area is negated by the

46   displacement of resource extraction elsewhere (Ewers & Rodrigues 2008). Robinson

47   and Kajembe (2009) identify four possible effects of forest access restrictions at the

48   village-level: (1) villagers displace extraction elsewhere (leakage), (2) villagers

49   replace extraction with increased purchase from markets, potentially intensifying

50   pressure on other forests supplying those markets, (3) villagers reduce extraction

51   quantities, with potentially negative welfare impacts, and (4) villagers cultivate more

52   resources on their own or village land. In addition to these, we identify two further

53   possible effects whereby (5) villagers do not comply with management and continue

54   extraction activities, and (6) in the case of extraction for fuel, villagers switch to

55   alternatives where available (e.g. gas). To predict these effects and inform

56   management decisions, spatial-temporal models of NTFP use help to define a

57   landscape that does not solely account for ecological characteristics, but includes

58   interactions between these and socioeconomic conditions (Robinson *et al.* 2011).

59   Models indicate that if labour and resource markets function efficiently, then

60   extraction restrictions will not lead to leakage, however imperfect and costly markets

61   will lead to displacement of activities into unprotected areas (Robinson *et al.* 2011;

62   Albers & Robinson 2013).

63   In this paper, we present a novel method for examining the impact of protected

64   status on wellbeing and the implications for leakage. We do this by analysing

65   household ability to meet NTFP needs in the vicinity of forests of mixed protected

66   status in rural Tanzania. NTFPs, such as firewood and charcoal, account for over

67   90% of total energy consumption in Tanzania (Felix & Gheewala 2011). Fuel-efficient

68   stoves can increase cooking efficiency by 30-75%, and a range of development

69 efforts promote the use of such stoves in Tanzania (Jetter & Kariher 2009, Still *et al.*

70 2011). However, on average the population of Tanzania and its largest city Dar es

71 Salaam has increased annually by 2.7% and 5.6% respectively between 2002 and

72 2012 (NBS 2013). Such population growth is predicted to increase pressure on

73 forest resources, acting as a major driver of forest degradation (Felix & Gheewala

74 2011, Hosier *et al.* 1993).

75 Tanzania is now piloting methods for policies aimed at reducing emissions from

76 deforestation and degradation (REDD+) linked to its existing participatory forest

77 management (PFM) programme (Burgess *et al.* 2010). Early lessons from REDD+

78 pilot projects indicate new challenges have emerged, with trade-offs between long-

79 term protection and short-term needs, as well as concerns for leakage (Blomley *et al.*

80 2016). With high dependence on firewood for energy in our study villages, we

81 compare household perceived need for firewood with actual consumption to provide

82 a simple metric of ability to meet firewood needs (henceforth: firewood sufficiency).

83 The effect of household variables and forest protection status on firewood sufficiency

84 is analysed, and the implications for wellbeing and leakage in this landscape of

85 forests with mixed protection status assessed.

86

87 **Methods**

88 *Study Area*

89 Data were collected in five forest-adjacent villages in the Kilombero and Kilosa

90 districts (Morogoro region; Fig. 1), neighbouring the biodiversity-rich Eastern Arc

91 Mountains (Burgess *et al.* 2007). Villages were selected to maximise variation in

92 protected status whilst minimising geographic spread, to avoid high variation in

93 ecological and social factors. To preserve household anonymity, villages were

94 identified by number and adjacent forests by their protection status: one forest

95 protected as a National Park (NP), one under JFM, two under CBFM (CBFM1;

96 CBFM2) and the remaining forest in management transition (transition forest; Table

97 1).

98 One year prior to NP gazzettement in 1992, the World Wide Fund for Nature (WWF)

99 and the Tanzanian National Park Authority (TANAPA) began a ten-year project

100 promoting tree nurseries and fuel-efficient stoves in villages on the eastern border of

101 the park, to reduce dependence on the forest (Harrison 2006). During this time

102 TANAPA allowed villagers weekly entry to extract dead firewood. This concession

103 continued until June 2011, when it was banned given concerns for the impact on

104 biodiversity (Rovero *et al.* 2008). All five study-villages occur in this area east of the

105 NP. Agriculture is the predominant livelihood activity in these districts, and pressure

106 on resources is high (Gorenflo & Orland 2013).

107

108 [FIGURE 1 HERE]

109 [TABLE 1 HERE]

110

111 *Data Collection*

112 Between March and December 2011, 500 household questionnaires were

113 administered across study-villages to gauge NTFP use and household-level socio-

114 economic and demographic variables. In each village, focus groups were used to

115 jointly identify village-specific wealth indicators, such as asset ownership, and

116 households assigned to either a high-income or low-income wealth category with the

117 assistance of village councils. Total village household lists were then stratified by

118 sub-village and wealth (after Lund *et al.* 2008), and random number generation used

119 to select 100 household heads/village as respondents. This number of

120 questionnaires was chosen to maximise variability in responses whilst maintaining a

121 logistically viable sample size.

122 Questionnaires were administered by enumerators local to each village in the wet

123 (May-June) and dry (November) season to capture seasonal variation in NTFP use.

124 The geographic coordinates of all 500 households were recorded. Multiple questions

125 relating to NTFP use were asked to facilitate triangulation of data. Households were

126 asked to identify their major source of cooking energy, how this was obtained and

127 the monthly quantity consumed. Households were asked to identify all nearby

128 forests, whether they extracted from that forest, and products extracted. Households

129 were also asked to recall their NTFP use each month in that season. Specifically, for

130 each product, households were asked to recall the quantity extracted per month, the

131 frequency of extractions and the extraction location. Households were also asked to

132 recall the quantities purchased, sold and consumed per month. Finally, households

133 were asked the perceived quantity needed per month. The aim of this data collection

134 method was to compare like-for-like quantities, rather than econometric valuation.

135 Rapid assessment methods, such as those employed here, have been shown to

136 have good congruence with more detailed assessment in comparison of interview-

137 based methods (Jones *et al.* 2008).

138 *Data Analysis*

139 *NTFP utilisation and protected area compliance*

140 Households were coded into those that either solely extracted NTFPs, solely bought

141 NTFPs or both extracted and bought NTFPs. Extraction location for each product

142 was coded by the forest protection status (NP, CBFM1, CBFM2, JFM, transition) or

143 household agricultural fields or private woodlot (Fields/Private) or purchase (Buy).

144 The percentage of households extracting each NTFP was calculated by extraction

145 location. Compliance with management rules and regulations was inferred through

146 reporting of number of NTFPs extracted, being firewood only or multiple products.

147 This measure of compliance is susceptible to under-reporting, as despite best efforts

148 to elicit truthful answers through data triangulation and use of local enumerators,

149 some households may have under-reported their NTFP use, or indicated extracting

150 from non-forest areas for fear of repercussions.

151 *Firewood Sufficiency*

152 The mean quantities of firewood extracted, bought, sold, consumed and needed per

153 household were calculated across both wet and dry seasons to provide average

154 monthly rates (bundles/month). Reported household firewood consumption was

155 cross-validated via calculation of quantities extracted, bought and sold. Household

156 firewood sufficiency was calculated by deducting household perceived mean quantity

157 of firewood needed/month from mean quantity consumed/month. This method builds

158 on other household-scale approaches to define firewood sufficiency by going beyond

159 a purely qualitative understanding (Dovie *et al.* 2004). Whilst moving towards a more

160 rigorous quantitative approach, the method explicitly retains a subjective component

161 common to recent definitions of wellbeing by allowing respondents to estimate their

162 own need (Agarwala *et al.* 2014, Milner-Gulland *et al.* 2014). Negative sufficiency

163 indicated a deficit in household firewood needs, zero values indicated that needs

164 were met and positive values indicated a surplus of firewood. Households were then

165 grouped by extraction location, and one-way Analysis of Variance (ANOVA) and

166 Tukey posthoc tests used to compare differences in mean household firewood

167 sufficiency between extraction locations.

168 Between wet and dry season surveys, the aforementioned firewood collection ban

169 commenced in the NP and also JFM. If households indicated a switch in extraction

170 location from either NP or JFM between surveys, the difference between mean wet

171 season firewood sufficiency and mean dry season firewood sufficiency was tested

172 using Student's t-tests. All statistical analyses were carried out using R (version

173 3.0.0; http://cran.r-project.org).

174 *Determinants of Firewood Sufficiency*

175 Further analysis was carried out to determine what factors might predict household

176 firewood need, consumption and sufficiency independently. A broad set of 16

177 household-level demographic, wealth and environmental predictor variables were

178 chosen based on previous investigations into NTFP consumption correlates (e.g.

179 Foerster *et al.* 2012; Table 2). All variables were coded from household

180 questionnaire data. Dependence on NTFPs for energy was represented by whether

181 households used firewood alone as their major energy source, or in combination with

182 charcoal. Previous analysis found variation in household awareness of each forest

183 management authority in this study sample, with clear awareness of NP status, yet

184 no awareness of JFM and low engagement in PFM (Latham 2013). Given this,

185 awareness was also included as a binary variable in all models.

186

187   [TABLE 2 HERE]

188

189   Covariation between predictor variables was assessed using Pearson correlation

190   and Variance Inflation Factors, and all variables were retained (Pearson P≤0.7

191   and/or VIF≤5; Zuur *et al.* 2010). Variables with uneven spread (occupation, 98%

192   farmer) were excluded from models. Before modelling, variables with a strong skew

193   were transformed as follows: age, hhsize, assets (square root), land (cube root) and

194   response variables firewood need, firewood consumption (log10) and firewood

195   sufficiency (cube root).

196   Generalised linear models (GLMs) with a Gaussian error function were used to

197   investigate the influence of the same predictor variables on (1) firewood need, (2)

198   firewood consumption, and (3) firewood sufficiency. Spline correlograms (ncf

199   package; Bjornstad 2012) were used to test for spatial-autocorrelation as

200   observations of households facing equivalent socio-economic and environmental

201   factors might not be independent. Significant spatial auto-correlation was present at

202   short lag-distances of 3km, 4km and 4km for need, consumption and sufficiency

203   data, respectively. With only five villages sampled, it was not appropriate to include

204   village as a random factor using generalised linear mixed models (e.g. Crawley

205   2002). However, spline correlograms of the Pearson residuals suggested spatial

206   correlation was successfully accommodated by each GLM through the inclusion of

207   the extraction_location variable.

208   Minimum adequate models were obtained using backwards-forwards selection

209   based on the Akaike Information Criterion (Murtaugh 2009). Some levels within the

210   categorical variable extraction_location did not contribute to final models, and so

211   seven independent binary variables ('True' or 'False') were created ('Buy',

212   'Fields/Private', 'Transition', 'CBFM1', 'CBFM2', 'JFM' 'NP'), and backwards-forwards

213   selection repeated. Final models were validated through observation of residual

214   spread. Analyses of deviance were used to test the probability that the amount of

215   deviance explained was not significantly reduced from the full (unreduced) model

216   (p[D]; Zuur et al. 2010). The probability that the slope estimate of each variable was

217   significantly different from zero was determined, based on a *t* distribution (Quinn &

218   Keough 2002). The False Discovery Rate (FDR; Benjamini & Hochberg 1995)

219   correction of alpha values for repetitive testing was employed on slope estimates for

220   each model in turn, resulting in 95% significance alpha cut-offs of 0.05, 0.039 and

221   0.025 for need, consumption and sufficiency models, respectively.

222

223   **Results**

224   *NTFP Utilisation and protected area compliance*

225   All households were dependent on NTFPs as their main source of energy; 48%

226   stated use of both firewood and charcoal, 47% stated firewood only and 5% charcoal

227   only. Of the 500 households surveyed, 434 (86.8%) indicated extracting NTFPs, of

228   which 166 (38.2%) households supplemented with additional purchases, and 59

229   households (11.8%) only purchased NTFPs (Fig. 2; 1.4% unanswered). Over half of

230   households extracting NTFPs obtained these from a forest (n=263; 60.6%); of which

231   60.8% (32% of total sample) were non-compliant with forest management by

232   indicating extraction of more than just dead firewood. The remainder of households

233   extracting NTFPs did so from agricultural fields or private woodlots (n=156; 35.9%;

234   3.5% unanswered).

235

236   [FIGURE 2 HERE]

237

238 Households indicated extracting multiple NTFPs from the PFM forests (JFM, CBFM1

239 & CBFM2; Fig. 3). All households using these forests, except for one using the

240 CBFM1 forest and two using the CBFM2 forest, indicated non-compliance with the

241 rules and regulations. Households using the transition forest stated similar extraction

242 of NTFPs, although given this forest was not formally protected this type of use could

243 not be categorised for compliance. Of the households extracting from the NP, 95.5%

244 stated extraction of firewood only before the ban was implemented, in line with

245 management.

246

247 [FIGURE 3 HERE]

248

249 *Firewood Sufficiency*

250 Household perceived firewood sufficiency varied from -99.0 to +40.0 bundles/month,

251 with mean household sufficiency of -6.43 (±12.71) bundles/month across all villages.

252 Sufficiency varied significantly between extraction locations (Fig. 4). Households with

253 very low sufficiency (<-10 bundles/month, n=82) all reported modest consumption

254 quantities based on the sample average, yet excessively high perceived need for

255 firewood. The opposite was true for households with very high sufficiency (>+10

256 bundles/month, n=5), which reported similarly modest quantities of firewood needed

257 yet consumed exceedingly high quantities. Households extracting from JFM had the

258 highest mean sufficiency (0.21±0.83 bundles/month), indicating household firewood

259 needs were on average met. Households extracting from all other locations had

260 negative mean sufficiency, indicating an inability to meet firewood needs, with lowest

261 mean sufficiency in households extracting from CBFM1 (-2.9±0.65 bundles/month).

262   Households extracting from fields or private areas had significantly lower sufficiency

263   than households extracting from all forests except for transition forest and CBFM1,

264   suggesting difficulty in meeting needs when extracting from outside forested areas.

265

266   [FIGURE 4 HERE]

267

268   All households extracting firewood from NP in the wet season indicated a switch in

269   extraction location to fields or private areas after the ban was enforced, between

270   surveys. Despite this, no significant difference in firewood sufficiency was found

271   between seasons (mean wet season=-2.49±4.65 bundles/month, mean dry season=-

272   2.84±6.54 bundles/month, t=0.30, p=0.78), although any long-term impacts of the

273   ban might not be reflected within the short timeframe of the study. No such switch

274   was reported by households extracting from JFM in the dry season.

275   *Determinants of Firewood Need, Consumption and Sufficiency*

276   Extraction location and household demographic, wealth and environmental variables

277   best-predicted firewood need, consumption and sufficiency (Table 3). Household

278   perceived need for and consumption of firewood were significantly reduced if

279   sourced from markets or extracted from CBFM2. Households extracting from fields

280   or private areas, transition forest and CBFM1 had significantly higher perceived need

281   for firewood. Indeed, sufficiency of households extracting from field or private areas

282   and CBFM1 were significantly lower yet not retained in the consumption model,

283   signifying this increased need was not met by quantities consumed from these

284   areas. Households extracting from JFM consumed significantly more firewood, and

285   were significantly more capable of meeting firewood needs.

286

287   [TABLE 3 HERE]

288

289   Larger households had significantly increased perceived need for and consumed

290   more firewood, while those with more valuable assets perceived a greater need for

291   but consumed less firewood (Table 4). Households owning a fuel-efficient stove had

292   significantly improved ability to meet firewood needs, with significantly lower

293   perceived need for firewood although consumption quantities were unchanged.

294   Household awareness of the forests' management authority significantly reduced

295   firewood consumed, indicating a positive relationship between awareness of

296   protection status and compliance with management.

297

298   [TABLE 4 HERE]

299

300   **Discussion**

301   Household NTFP extraction provides a general indication of low compliance with

302   forest protection in the study area, with the exception of households extracting from

303   NP. Awareness of NP status was high, and this is reflected by most households

304   extracting firewood only from this forest and the stated switch in extraction location

305   post-ban. The mean deficit in firewood sufficiency of households extracting from NP

306   also reflects compliance, as the restrictions in place limit the quantity households can

307   extract regardless of their perceived need. The opposite is true for households

308   extracting from JFM, as no households were aware of JFM status and findings

309   reflect non-compliant NTFP extraction and no switch in extraction location post-ban.

310   Households extracting from JFM were significantly more likely to meet their resource

311 needs, indicating household extraction was unrestricted by management and use of

312 this forest was as required. Findings indicate support for previous research that

313 found compliance increased with awareness of the forest rules and regulations in

314 Uganda (Nkonya *et al.* 2008). However, a direct relationship between awareness

315 and compliance cannot be inferred here, and compliance will be influenced by

316 numerous factors such as the status and enforcement of protection in each area

317 (e.g. Rovero 2007).

318 Households extracting from CBFM1 and CBFM2 also indicated low compliance

319 given high reporting of extracting more than firewood. Unlike JFM households, the

320 majority of CBFM households were aware of these forests' community-based

321 authority; however, very few were actively engaged in management. Interestingly,

322 perceived need for and consumption of firewood was significantly reduced in

323 households extracting from CBFM2. This may indicate some level of success of

324 community-led management in this village, with households more conscious of

325 firewood quantities consumed. Conversely, households extracting from CBFM1 were

326 significantly less likely to meet their firewood needs. The condition of CBFM1 or its

327 distance from the village may have limited the perceived ability of this forest to

328 supply household needs (e.g. Robinson *et al.* 2002). Indeed, most households in the

329 CBFM1 village reported extraction from the NP, stating access was easier due to

330 distance and firewood extraction permitted before the ban. However, further

331 investigation is required to deduce the reasons for the observed differences in

332 sufficiency between the two CBFM forests. This would necessitate information

333 relating to the ecological condition of each forest, as well as quantitative and

334 qualitative assessment of management effectiveness.

335   *Determinants of Firewood Utilisation*

336   NTFP dependence has previously been associated with low wealth (Adhikari *et al.*

337   2004). Interestingly, we found that increased assets resulted in higher perceived

338   need for firewood whilst actual consumption decreased, perhaps due to a switch to

339   alternative, non-forest sources of energy. Decreased consumption was also

340   observed in households solely purchasing firewood. These households also

341   indicated a lower perceived need for firewood, perhaps reflecting the influence of a

342   financial transaction on perceived firewood need as opposed to extracting the

343   resource at no monetary cost. Nevertheless, findings suggest that perceived

344   firewood need and sufficiency are indeed influenced by subjective characteristics of

345   wellbeing not directly linked to objective fuel requirements; exemplified here by

346   wealthier households aspiring towards greater fuel use than they in fact consumed

347   each month. This highlights the value of our methodology which explicitly

348   incorporates subjective components of wellbeing, firstly by allowing respondents to

349   define their own perceived need and secondly by comparing these perceptions with

350   actual consumption. The excessive firewood deficits and surfeits observed in some

351   households illustrates the degree to which these perceptions can be exaggerated,

352   warranting further examination into the factors influencing both the need for NTFPs

353   and their actual use. For example, the higher perceived need for firewood among

354   households extracting from certain sources might reflect the difficulty in obtaining

355   fuel from those areas, with this increased difficulty creating the sense that more is

356   needed than in fact would actually be used.

357   Our observed relationship between firewood sufficiency and fuel-efficient stove use

358   presumably resulted from a perception of improved fuel efficiency within these

359   households. It could be argued that households owning stoves might be more

360 engaged in sustainability discussions in the area (e.g. Harrison 2006), and that stove

361 ownership alone has improved perceived wellbeing whilst actual consumption

362 remains unchanged. It has been recommended that policies to conserve tropical

363 forests be conducted in parallel with projects aimed at enhancing fuel-efficiency,

364 such as through the use of modified stoves (Fisher *et al.* 2011). However, our

365 findings indicate that the actual efficiency-savings of stoves needs careful

366 examination if any perceived benefits are to be realised in practise (e.g. Hanna 2012,

367 Bailis *et al.* 2015). Such examination would benefit future efforts to enhance more

368 sustainable fuel use in the area. In addition, improving local-awareness of forest

369 protection status and methods in agroforestry is recommended, given the positive

370 relationship indicated between awareness and compliance and the observed

371 decrease in sufficiency when firewood is extracted from agricultural areas.

372 *Implications for Leakage and Wellbeing*

373 The difficulty of the non-forest firewood sources to meet household needs presents

374 long-term concern for leakage. This is especially significant in this area given the

375 firewood ban, and the observed non-compliance within less-well protected forests

376 such as JFM or transition forest. The specific challenges impeding household ability

377 to meet resource needs outside forest areas need to be measured, however land

378 availability for tree planting and alternative energy opportunities in the area are

379 limited (Gorenflo & Orland 2013, pers. obs.). Considering the six effects of resource

380 access restriction previously outlined, the potential for either (1) displacement, (3)

381 reduction or (5) non-compliance are most significant. This has serious implications

382 for either long-term forest protection in the area given leakage or non-compliance, or

383 detriment to local welfare through inability to meet fuel and food demands. This

384 welfare impact is significant given restricted NTFP access in Tanzania is likely to hit

385   the poorest the hardest (Schaafsma *et al.* 2014), while the potential for leakage

386   presents concern for the area's important biodiversity (Burgess *et al.* 2007). Such

387   outcomes are especially significant in areas containing forests of mixed protection

388   status. The presence of multiple independent forest authorities creates potential for

389   locally-based management decisions that might not take the larger socio-ecological

390   landscape into consideration. With local-dependence on NTFPs unaddressed, such

391   decisions can have serious implications for forest protection or human wellbeing

392   within the landscape. Within our study area long-term monitoring of household NTFP

393   utilisation is needed to assess the impact of the firewood ban on both household

394   welfare and leakage, given the proximity of other, less-well protected forests. Indeed,

395   considerable leakage of NTFP extraction activities into more distant forests has been

396   observed after PFM implementation in Tanzania (Robinson and Lokina 2011). Thus,

397   findings lend empirical support to growing theory behind the need for a landscape

398   planning approach to forest conservation policies (Robinson *et al.* 2011).

399   *Wider Implications*

400   Understanding and addressing the issue of leakage is particularly important for PES

401   and REDD+ if carbon benefits are to be meaningful and permanent. REDD+ in

402   particular is expected to provide poverty alleviation and biodiversity conservation

403   benefits additional to climate change mitigation. Thus, local welfare costs of

404   restricted NTFP use ought to be assessed alongside the global benefit of addressing

405   climate change. Such spatial ecosystem valuation can help evaluate the trade-offs

406   between local and international communities to inform policy (e.g. Schaafsma *et al.*

407   2012). In addition, carbon accounting at the national level will need to include the

408   potentially offsetting emissions of displaced NTFP extraction activities (Robinson *et*

409   *al.* 2013). Fisher *et al.* (2011) estimate that the implementation costs of measures to

410 alleviate forest dependency, such as raising agricultural yields and increasing stove

411 use, remain feasible within REDD+ policies despite exceeding the opportunity costs

412 of carbon conservation. However, household energy needs will still need to be met

413 despite compensation through PES or REDD+, and the source of this energy will

414 need to be considered at multiple scales and by multiple forest authorities.

415 **Figure Legends**
416
417 Figure 1. Location of the five study-villages and adjacent forests. Adapted using data

418 on Eastern Arc Mountain boundaries and forests from Platts et al. (2011), Protected

419 Area boundaries from UNEP-WCMC (2010), transition forest and Selous Game

420 Reserve boundary with the assistance of the Udzungwa Forest Project, and Village 1

421 Forest boundaries from WWF (2006). Data on spatial infrastructure with the

422 assistance of the Valuing the Arc project (http://www.valuingthearc.org).

423

424 Figure 2. Schematic representation of NTFP use by all households, including

425 extraction location (NA=question unanswered, FW=Households extract firewood

426 only, M=Households extract multiple NTFPs (>1), Bold boxes=non-compliant

427 resource extraction according to rules and regulations defined in Table 1.

428

429 Figure 3. Percentage of households extracting each NTFP by extraction location

430 (n=Number of households).

431

432 Figure 4. Mean household monthly firewood sufficiency, and 95% confidence

433 intervals based on the t distribution, by extraction location in order of increasing

434 protection status. Letters indicate significant differences in sufficiency between

435 associated extraction locations based on one-way analysis of variance and

436 subsequent Tukey's honest significant differences (Tukey's HSD ***$p<0.001$,

437 **$p<0.01$, *$p<0.05$).

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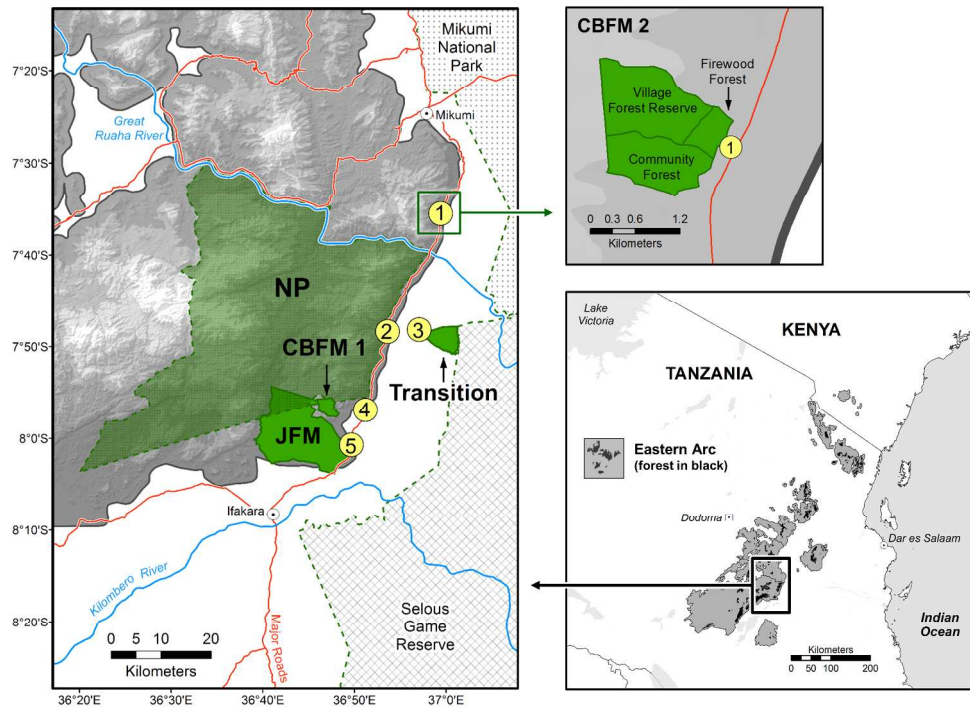
Figure 1. Location of the five study-villages and adjacent forests. Adapted using data on Eastern Arc Mountain boundaries and forests from Platts et al. (2011), Protected Area boundaries from UNEP-WCMC (2010), Transition forest and Selous Game Reserve boundary with the assistance of the Udzungwa Forest 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).
Fig. 1
254x190mm (300 x 300 DPI)

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: VFR – no resource extraction allowed FWF – only dead firewood extraction allowed two days a week CGF - no resource extraction allowed
2	259	4.8	Ngindo Pogoro Ndamba	NP; IUCN category II (0.3km)	TANAPA	Women allowed entry once a week to extract dead firewood, no cutting tools allowed. Ban enforced in July 2011 after which no resource extraction allowed.
3	289	3.1	Hehe Pogoro Ngindo	Transition; No formal protection (0.7km)	None	No formal R&R regarding resource use
4	1275	4.1	Pogoro Ngoni Bunga Hehe	CBFM 1; Village Forest (5.4km)	Village 4	Only dead firewood extraction allowed (i.e. no cutting tools)
5	576	5.5	Pogoro Ngindo	JFM; Forest Reserve IUCN category IV (1.4km)	Kilombero District Council & Village 5	Only dead firewood extraction allowed (i.e. no cutting tools). 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)
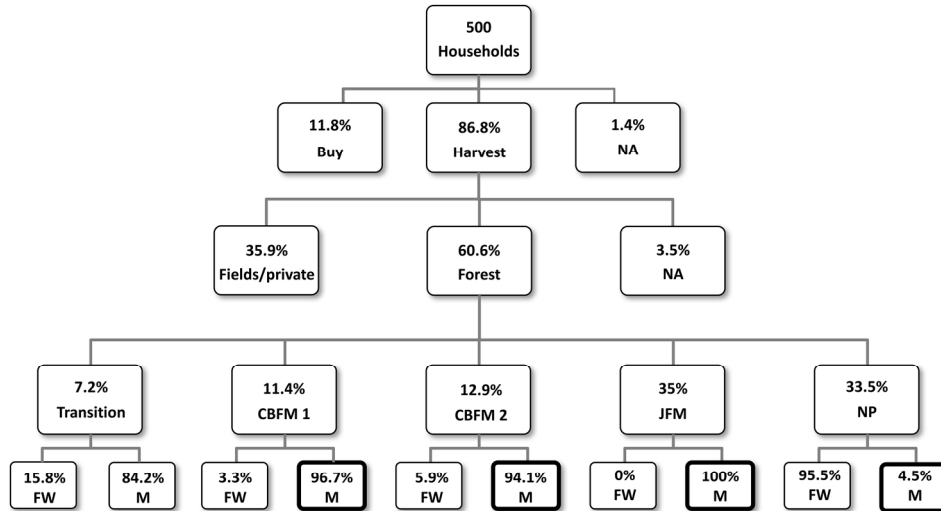
Figure 2. Schematic representation of NTFP use by all households, including extraction location (NA=question unanswered, FW=Households extract firewood only, M=Households extract multiple NTFPs (>1), Bold boxes=non-compliant resource extraction according to rules and regulations defined in Table 1.
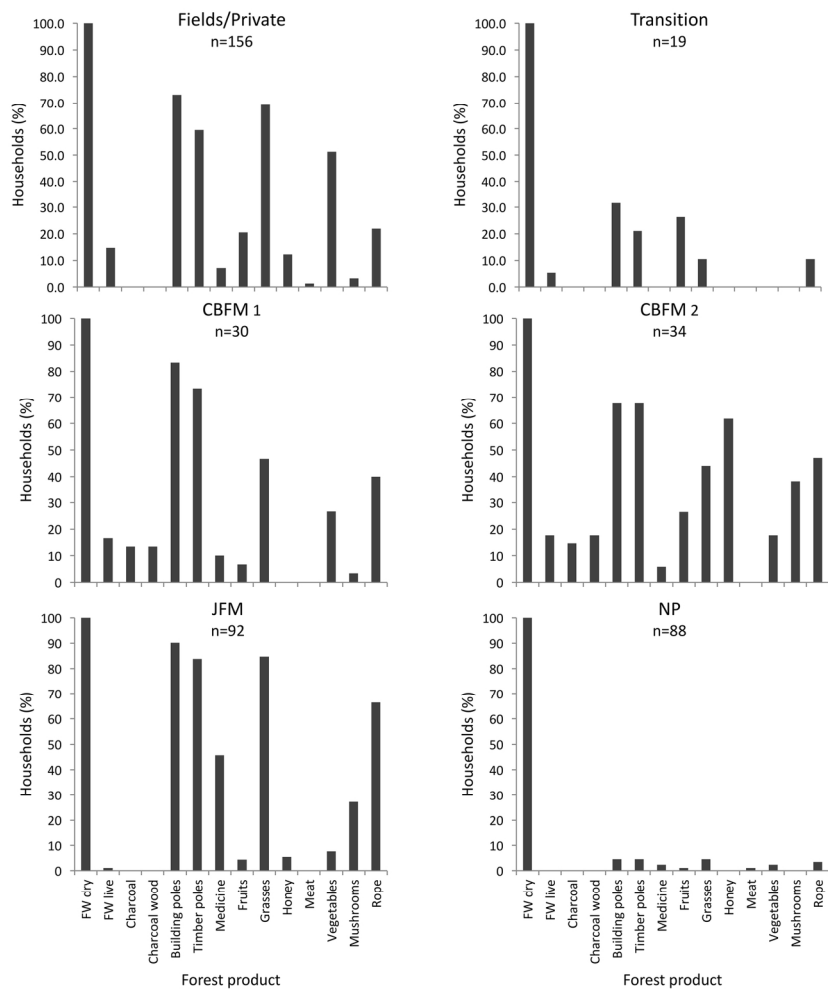
Fig. 2

90x67mm (600 x 600 DPI)

Figure 3. Percentage of households extracting each forest product by extraction location (n=Number of households).
Fig. 3
83x82mm (600 x 600 DPI)
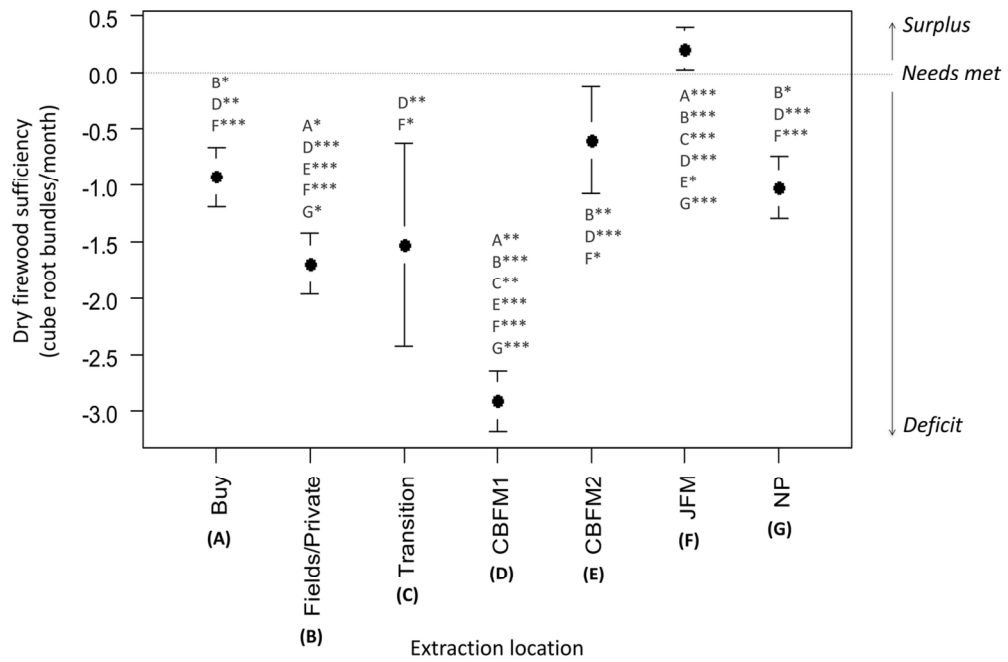
Figure 4. Mean household monthly firewood sufficiency, and 95% confidence intervals based on the t distribution, by extraction location in order of increasing protection status. Letters indicate significant differences in sufficiency between associated extraction locations based on one-way analysis of variance and subsequent Tukey's honest significant differences (Tukey's HSD ***p<0.001, **p<0.01, *p<0.05).

Fig. 4

59x41mm (600 x 600 DPI)

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' α_{FDR}=0.05, 'Consumption' α_{FDR}=0.039, 'Sufficiency' α_{FDR}=0.025).

Model	Predictor Variables	Model Statistics
Need (AIC = - 24.305, $\%D$ = 48.2, p[D] = 0.93)	**Extraction Location: CBFM 1[+]**	**p <0.0001 ($\%D_V$ =8.67)**
	Extraction Location: Buy[-]	**p <0.0001 ($\%D_V$ =6.50)**
	Extraction Location: CBFM 2[-]	**p <0.0001 ($\%D_V$ =4.89)**
	Extraction Location: Fields/Private[+]	**p <0.0001 ($\%D_V$ =4.02)**
	Extraction Location: Transition[+]	**p <0.0001 ($\%D_V$ =2.54)**
	Fuel-efficient stove ownership[-]	**p = 0.0038 ($\%D_V$ =1.30)**
	Household size[+]	**p = 0.0062 ($\%D_V$ =1.17)**
	Total asset value[+]	**p = 0.015 ($\%D_V$ =0.92)**
Consumption (AIC = -159.82, $\%D$ = 39.2, p[D] = 0.95)	**Extraction Location: Buy[-]**	**p <0.0001 ($\%D_V$ =6.25)**
	Extraction Location: JFM[+]	**p <0.0001 ($\%D_V$ =3.23)**
	Extraction Location: CBFM 2[-]	**p = 0.00022 ($\%D_V$ =2.51)**
	Household size[+]	**p = 0.00043 ($\%D_V$ =2.28)**
	Total asset value[-]	**p = 0.0058 ($\%D_V$ =1.39)**
	Extraction Location: Transition[+]	**p = 0.027 ($\%D_V$ =0.88)**
	Aware of authority[-]	**p = 0.039 ($\%D_V$ =0.77)**
	Area land owned[+]	p = 0.058 ($\%D_V$ =0.65)
	Household head age[-]	p = 0.059 ($\%D_V$ =0.64)
Sufficiency (AIC = 1052.4, $\%D$ = 41.8, p[D] = 0.93)	**Extraction Location: CBFM 1[-]**	**p <0.0001 ($\%D_V$ =8.35)**
	Extraction Location: Fields/Private[-]	**p <0.0001 ($\%D_V$ =3.08)**
	Fuel-efficient stove ownership[+]	**p = 0.0021 ($\%D_V$ =1.65)**
	Extraction Location: JFM[+]	**p = 0.0046 ($\%D_V$ =1.4)**
	Extraction Location: Transition[-]	p = 0.035 ($\%D_V$ =0.77)
	Household head age[-]	p = 0.051 ($\%D_V$ =0.66)
	Aware of authority[-]	p = 0.055 ($\%D_V$ =0.64)
	Planted trees/woodlot[+]	p = 0.068 ($\%D_V$ =0.58)

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> α_{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	⬆	⬆	⬇ (grey)
CBFM 1	⬆	*NA*	⬇
CBFM 2	⬇	⬇	*NA*
JFM	*NA*	⬆	⬆
Stove	⬇	*NA*	⬆
Aware	*NA*	⬇	⬇ (grey)
Assets	⬆	⬇	*NA*
Household size	⬆	⬆	*NA*
Age	*NA*	⬆ (grey)	⬇
Land	*NA*	⬆ (grey)	*NA*
Woodlot	*NA*	*NA*	⬆ (grey)