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Livelihood and home garden improvements: Strategies to reduce destructive fuelwood harvests from the Manas National Park, India

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Abstract

Fuelwood is the primary energy source for cooking in rural India. Natural forests in protected areas are often accessed by local people to collect this resource. However, the extraction of wood destructs forests, threatens species diversity and may lead to a loss of ecosystem functions. An approach to reduce the anthropogenic pressure on protected areas is to replace the amount of fuelwood harvested from natural forests with fuelwood obtained from alternative sources like home gardens. The aim of the study was to find out, if the livelihoods of local people could be improved and, if home gardens had the potential to function as substituting fuelwood sources, in order to reduce the extraction of fuelwood harvested from the Manas National Park (MNP) in Assam, India. Furthermore, it was investigated how the amount of fuelwood obtained from home gardens could be increased and, if the extent of the dominant cash-crop areca palm (*Areca catechu*) had a decreasing impact on the fuelwood supply by home gardens. Socio-economic household interviews were conducted, and the size of home gardens, as well as an inventory of potential fuelwood trees and of areca palms in home gardens was analyzed. Fuelwood harvests from the MNP decreased with the degree of education of household members and the access to an electric power source. Assamese people encroached the MNP to extract fuelwood more, than members of the aboriginal Bodo tribe. Households located closer to the nearest entry of the MNP, had a higher probability to procure fuelwood from the MNP, compared to households further away from the park. The more fuelwood was procured from home gardens, the less likely it was for households to rely on fuelwood obtained from the MNP. The proportion of fuelwood harvested from home gardens increased with the existing fuelwood stock and with the size of home gardens. The extent of the dominant monocultured areca palm (*Areca catechu*) did not have a negative effect on the amount of fuelwood supplied by home gardens. This study shows that the degradation of the MNP could be reduced by improving the livelihoods of local people through providing electricity and enhancing the general education. Conservation strategies like afforestation actions could increase the fuelwood stocks in home gardens and conservation education could raise community awareness towards the MNP and towards the potential of private fuelwood stocks.

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Introduction

Fuelwood is the most important domestic energy source in rural areas of developing countries like India (Heltberg 2003; Maikhuri 1991; Oli et al. 2015; Wang et al. 2012). This natural resource is obtained from markets, roadsides, common areas and private lands, like home gardens (Jaiswal & Bhattacharya 2013; Nair 1995; Webb & Dhakal 2011). Yet, in regions with poor infrastructure and marginal livelihoods, local people also collect fuelwood from natural forests (Heltberg et al. 2000; Ndayambaje & Mohren 2011; Oli et al. 2015; Wang et al. 2012). The extraction of fuelwood from natural forests comes without financial costs, however it causes damage, destruction and fragmentation of natural habitats (Nyhus & Tilson 2004; Sarma et al. 2008; Soud et al. 2013; Wang et al. 2012). Anthropogenic encroachments threaten natural forests, and can result in the loss of habitats (Idohou et al. 2014; Köhlin et al. 2001; Nyhus & Tilson 2004; Ripple et al. 2014; Webb & Dhakal 2011). Habitat loss can lead to a loss of genetic material, species varieties and entire ecosystems, which provide essential services for the health of the planet and therefore for humans (Jose 2012; Kegode et al. 2017; Primack & Ralls 2012).

To diminish the anthropogenic impact, protected areas are established often represented by flagship species (Horwich et al. 2010; Syiem et al. 2018). Flagship species are not only attractive to the public and therefore raise the attention of the area to support its conservation, but also provide key ecosystem functions (Horwich et al. 2010; Nyhus & Tilson 2004; Soud et al. 2013). The Bengal tiger (*Panthera tigris tigris*), an endangered large carnivore extant in the Indian subcontinent, suffers under the loss of its habitat, especially since it requires a spacious home range, due to a protein-rich diet (Nowell & Jackson 1996; Ripple et al. 2014; Soud et al. 2013). Being an apex predator, the extinction of this big cat could lead to trophic cascades throughout the food web (Nyhus & Tilson 2004; Ripple et al. 2014). Large predator loss may alter natural prey population densities, which again control primary producers that structure the environment. Such modifications of ecosystems can have consequences, ultimately affecting human livelihoods (Jose 2012; Nowell & Jackson 1996; Nyhus & Tilson 2004).

The protection of areas, to maintain natural habitats and endangered species, restricts or prohibits the access of humans (Ndayambaje & Mohren 2011; Russell et al. 2010). However, excluding humans in rural India from natural habitats can be complex since they rely on their surrounding environment as sources for essential natural resources like fuelwood (Meijer et al.

2016; Ndayambaje & Mohren 2011; Saha & Sundriyal 2012; Soud et al. 2013).

The complex issue of restraining humans, who depend on natural resources from their environment, to access protected areas, occurs in the fringe of the Manas National Park (MNP) in the northeast Indian state Assam. Despite the protection of the MNP, which is a natural habitat to the Bengal tiger, human impact threatens the area (Goswami & Ganesh 2011; Sarma et al. 2008). The fight for an independent territory for the aboriginal Bodo tribe during the late 1980's, led to political-ethnic disturbances that substantially degraded the MNP (Horwich et al. 2010). As a consequence the MNP was classified as endangered between 1992 and 2011 (UNEP-WCMC & IUCN 2013) and is still recovering from threatening encroachments during that period (Horwich et al. 2010; Sarma et al. 2008; Soud et al. 2013; Vandekerckhove & Suykens 2008). The poverty of local people at the present time, a consequence of poor infrastructure and marginal livelihoods, increases their dependence on natural resources from the MNP (Oli et al. 2015; Sarma et al. 2008; Tiwari et al. 2017). Additionally, the high and rapidly growing local human population intensifies negative effects on the protected area (Murniati et al. 2001; Ndayambaje & Mohren 2011; Sarma et al. 2008; Wang et al. 2012). Overgrazing by cattle, extensive collection of grass and the extraction of forest resources like fuelwood, destruct the natural habitat of the tiger (Jose 2012; Nowell & Jackson 1996; Ripple et al. 2014; Sarma et al. 2008).

To address the conflict of local people who are depending on, yet threatening the MNP, the Manas Tiger Conservation Programme (MTCP) has been established by local and international organizations. Project activities attempt to improve the livelihood of local people in a way that their social and economic needs are met, independent of natural resources from the MNP (FAO 2017; Horwich et al. 2010; Russell et al. 2010; Tiwari et al. 2017). Educational programs for residents of fringe villages of the MNP focus on raising attention and awareness towards the Bengal tiger, ecological values of its natural habitat and the consequences of anthropogenic pressure on the MNP (Horwich et al. 2010; Murniati et al. 2001). Wood is the main source for cooking fuel, and in such rural areas not all households can afford commercial non-biofuels like liquid petroleum gas (LPG) (Ndayambaje & Mohren 2011; van't Veld et al. 2006; Wang et al. 2012). Therefore, small-scale biogas plants for household uses were introduced and improved cooking stoves (ICS) installed. Nurseries with indigenous fuelwood trees were established and trees were planted in common areas to provide fuelwood in the future.

One approach to reduce the wood extraction from the MNP is to substitute the amount of fuelwood harvested from the MNP with fuelwood obtained from private home gardens. Home gardens are traditional small-scale agroforestry systems (Andrews & Kannan 2016; FAO 2017; Kumar & Nair 2004; Peyre et al. 2006; Torquebiau 1992) that deliberately combine woody perennials, agriculture crops and livestock (Das & Das 2005; FAO 2017; Galhena et al. 2013; Kumar et al. 1994; Kumar & Nair 2004). Home grown resources like vegetables, fruits, fodder, timber and fuelwood contribute to the peoples' food security and economic income, hence ensure their livelihood (Andrews & Kannan 2016; Das & Das 2005; Idohou et al. 2014; Kumar & Nair 2004; Murthy et al. 2016; Peyre et al. 2006; Singh 1987). The loss of traditional knowledge over time (Idohou et al. 2014) and the subdivision of land among heirs (Kumar & Nair 2004) can lead to a degradation of the home gardens. Plantations of the cash crop areca palm (*Areca catechu*) cover large parts of home gardens (Andrews & Kannan 2016; Das & Das 2005; Kumar & Nair 2004; Peyre et al. 2006; Singh 1987). The areca palm has important socio-cultural, religious and economic values to local people, however its dominance in home gardens might diminish the abundance of trees that could be used as fuelwood (Andrews & Kannan 2016; Das & Das 2005; Williams et al. 2002). Regenerating home gardens could increase the fuelwood supply and replace fuelwood harvested from the MNP. This could reduce the pressure by local people on the MNP, thus increase the health of its ecosystem (Kegode et al. 2017; Meijer et al. 2016; Ndayambaje & Mohren 2011; Tiwari et al. 2017; Wang et al. 2012).

Previous research on home gardens has focused on food security (Galhena et al. 2013; Tiwari et al. 2017), Vitamin A deficiencies (Galhena et al. 2013; Kumar & Nair 2004), species compositions and biodiversity conservation (Das & Das 2005; Jose 2012; Peyre et al. 2006; Syiem et al. 2018), climate change impacts (Galhena et al. 2013; Murthy et al. 2016) and carbon sequestration (Kumar & Nair 2004; Oli et al. 2015). Some studies have also addressed the relationship between socio-economic characteristics of households and the dependence on natural forest resources (Jain & Sajjad 2016; Oli et al. 2015). Yet, little is known about the potential of existing traditional home gardens to substitute fuelwood extracted from natural forests (Meijer et al. 2016; Webb & Dhakal 2011) or the effect of areca palm dominance on the fuelwood supply. The aim of this study was to identify, if the livelihood of people and home gardens bear the potential to be improved, in order to reduce the anthropogenic pressure on the MNP.

I predicted that:

1) The dependence on fuelwood obtained from the MNP by local people was related to socio-economic household characteristics (Heltberg 2003; Jain & Sajjad 2016).
2) Obtaining fuelwood from private home gardens reduced the dependence on fuelwood from the MNP (Kegode et al. 2017; Ndayambaje & Mohren 2011).
3) The size of home gardens and the diversity, abundance and density of trees, used for fuelwood in home gardens increased the fuelwood supply from home gardens (Heltberg et al. 2000; Kegode et al. 2017; Meijer et al. 2016; Tiwari et al. 2017).
4) The extent of the areca palm planting in home gardens decreased the amount of fuelwood obtained from home gardens (Das & Das 2005).

Materials and Methods

Study Area

The study was carried out in villages at the fringe of the Manas National Park (MNP) in the northeast Indian state Assam (Figure 1). The MNP is declared as an important tiger habitat (Nowell & Jackson 1996) and was listed as a World Heritage site by the UNESCO (United Nations Educational, Scientific and Culture Organization) in 1985 (UNEP-WCMC & IUCN 2013). The approximately 500 km² large area forms the core area of the Manas Tiger Reserve (2480 km²) and is contiguous in the north with the Royal Manas National Park of Bhutan (1057 km²) (Goswami & Ganesh 2014).

The villages included in the study were selected from the buffer boundary of the project area of the MTCP (Table 1, Figure 1). This boundary is a 3 km wide belt, incorporating the marginal villages and agricultural lands, south of the border of the MNP. The sample villages (26°40`N to 26°42`N and 91°06`E to 91°07`E) belong to the Bhuyanpara Range in Baksa District.

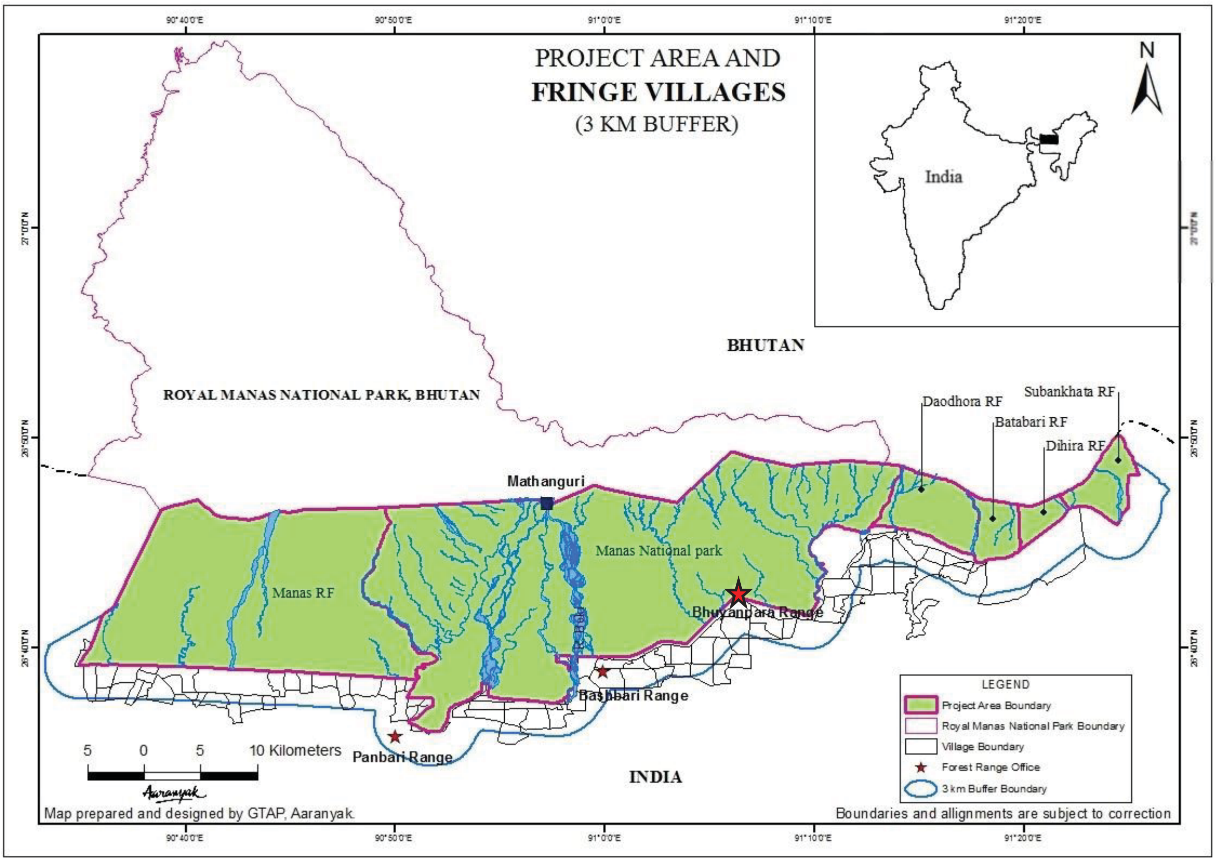

Figure 1: Project area of the Manas Tiger Conservation Programme with the 3km buffer boundary, that comprises villages included in the study, which belong to the Bhuyanpara Range (marked with a large star) adjacent to the Manas National Park.

The altitude of the study area varies between 10 to 170 m above sea level. The climate has tropical characteristics with a relative humidity up to 76% and mean temperatures ranging from 5 °C in the winter up to 37 °C in the summer (Lahkar et al. 2007; WPSI 2002). The southwest monsoon brings heavy rainfalls from mid-June to mid-September and entails annual rainfall rates between 3000 to 4000 mm (Sarma et al. 2015). Being in the foothills of the Bhutan Himalayas and the plains of the Brahmaputra River, the MNP is located within the Himalayan Biodiversity Hotspot (Goswami & Ganesh 2014). Sub-Himalayan alluvial semi-evergreen forest, east-Himalayan mixed moist and dry deciduous forests and grasslands comprise a wide diversity of flora and fauna (Goswami & Ganesh 2014; Horwich et al. 2010; WPSI 2002). Large felids like the Bengal tiger, leopard (*Panthera pardus*) and clouded leopard (*Neofelis nebulosa*) are extant. Various ungulate species like the wild water buffalo (*Bubalus arnee*), gaur (*Bos gaurus*), hog deer

(*Axis porcinus*), swamp deer (*Rucervus duvaucelii*) and pygmy hog (*Porcula salvania*) are prey to the large carnivores. Mega herbivores like the elephant (*Elephas maximus indicus*) and, due to a successful reintroduction during the past decade, the greater one-horned rhino (*Rhinoceros unicornis*) are also found in MNP (Goswami & Ganesh 2014; Gross et al. 2018; Lahkar et al. 2007; WPSI 2002).

Table 1: Village names and ethnicity of residents included in the study.

Village	Total number of households	No. of households included in study	Ethnicity
Santipur	36	8	Bodo
Majrabari	123	18	Bodo
Kusratari	90	10	Bodo
Bhuyanpara	162	18	Assamese
Bamunkhal	80	16	Bodo
Karaibari	86	16	Bodo
Dangpar	80	14	Bodo
Total	**657**	**100**	

The fringe of the MNP is densely populated with approximately 1280 people per km² and the rate of residents is increasing (Gross et al. 2018). The villages are situated in the Bodoland Territorial Areas District of Western Assam and are inhabited by Bodo and Assamese communities. The Bodo community is one of the oldest aboriginal tribal communities in Assam and has a distinct language, culture and heritage (Brahma & Brahma 2014; Talukdar & Gupta 2011). In rural areas members of the Bodo tribe cultivate paddy fields and tea plantations (Gross et al. 2018). Major occupations are silkworm rearing, weaving, pig and poultry farming and crafting of bamboo products (Indian Mirror n.d.). In northeast India a high percentage of the Bodo population is economically underdeveloped and therefore heavily dependent on traditional ethnic knowledge of using natural resources (Bhatt et al. 2016; Brahma & Brahma 2014; Talukdar & Gupta 2011). Home gardens provide essential resources to sustain their livelihoods like homegrown vegetables and legumes that sustain the food security (Sarma et al. 2015; Tiwari &

Tynsong 2011). Multipurpose trees provide fruits, timber, and fuelwood for households and have often medical and ornamental values. The main multipurpose trees that are used as fuelwood found in home gardens are *Toona ciliata*, *Gmelia arborea*, *Magnifera indica*, *Lagerstroemia indica* and *Syzygium cuminii* (Table A1), which are all native to the MNP (Lahkar et al. 2007). The cash crop areca palm, which is not used as fuelwood, is planted in home gardens for other multiple values (Das & Das 2005; Indian Mirror n.d.). Palm leaves are used for fencing and roofing of homes in rural areas. The areca nut, the seed of the areca palm is the main reason for planting the areca palm as a cash crop (Nath et al. 2011). The seed is aromatic and can be addictive, whereby about 15% of the world's population practice the mastication of the areca nut. Chewing the areca nut has religious, medicinal and social purpose, however, its use is known to be harmful to health (Nelson & Heischober 1999). Additionally, it can be processed to red and black dye, due to its tannin content. The areca palm is cultivated for the private supply and as the main source of income from home gardens (Nath et al. 2011; Williams et al. 2002).

Data Collection

The data were collected from June to December 2017 by the means of three approaches: group meetings, household surveys and an inventory of home gardens. Each village was usually inhabited continuously by members of the same ethnicity (Table 1). For this study, villages with the ethnicity Bodo or Assamese were selected, whereas each ethnicity had to occur in at least one village. A total of 100 households out of seven villages were included in the study. The sample had an intensity of a minimum of 10% of the households in each village.

The group meetings and the household surveys (Appendix II) were prepared in English and translated into the local languages Bodo and Assamese by an educated resident field assistant. Group meetings were held in each village to inform locals about the study and to record the most common tree species used as fuelwood that are abundant in home gardens, as well as their use and potential income (Table A1).

The household questionnaire was formulated according to the scheme of previous surveys conducted in the context of the MTCP and the approach used by the Poverty Environment Network (Angelsen et al. 2012). The survey consisted of structured questions on socio-economic factors of households. Data on the household size, degree of education, economic status, infrastructure, gender of the household head, ethnicity, and the amount of fuelwood supplied by each possible source were recorded in the survey. Local people collected, bought and stored fuelwood in bundles. These bundles were 1-1.5 m long and consisted of 12-20 pieces of fuelwood depending on their size (minimum diameter of 5 cm (Das & Das 2005)). The price of two bundles at the market varied between 120-150 Indian Rupees. Respondents were able to refer to and state information about their use of fuelwood in bundles, wherefore it was used as a unit in this study. GPS coordinates of entries of the MNP and each household were recorded handheld, using a GPS (Garmin, GPSMAP® 64).

An inventory of trees, the recording of areca palms and the size of home gardens was conducted for each of the 100 sampled households. During the inventory all potential fuel trees, compiled throughout the group meetings, with a stem diameter > 5cm were counted and identified (Krishen 2013). Photographs were taken, and an herbarium was created of species that could not be identified on the site. A local botanist identified these species afterwards.

Data Analysis

The degree of education is presented by the Literacy Rate and Education Index of household members. The Literacy Rate was calculated according to the definition by the UNESCO (UNESCO Institute for Statistics 2016). The age limits were adjusted according to the age groups used in this study. For the calculation of the Literacy Rate household members of age 14 and above were considered.

$$L = \frac{l}{t} \qquad (1)$$

The Literacy Rate = L was calculated by the fraction of the number of household members that are literate = l in the defined age group, divided by the total number of household members = t in the defined age group.

The Education Index was computed according to the calculation of the Human Development Index (Indicators World Development 2016):

$$Dimension\ Index = \frac{actual\ value - minimum\ value}{maximum\ value - minimum\ value} \quad (2)$$

$$Expected\ years\ of\ schooling\ Index = \frac{e-p}{m-p} = s \quad (3)$$

The expected years of schooling in India is e = 11.7 years, the minimum value is p = 0 and the maximum value for the expected years of schooling is m = 18 (UNESCO Institute for Statistics n.d.).

$$Mean\ years\ of\ schooling\ Index = \frac{x-p}{q-p} = \mathrm{r} \quad (4)$$

The age limit for the mean years of schooling per household = x was adjusted to the age groups used in this study and was calculated for all residents of age 18 and above. The maximum value for the mean years of schooling is q = 15 (Indicators World Development 2016).
Hence, the Education Index = E was calculated as follows.

$$E = \frac{s+r}{2} \quad (5)$$

The economic status is described by the Labor Force Rate, the ownership of agricultural land and the status of being a beneficiary of the MTCP. Beneficiaries of the MTCP were prioritized households that were preferable female-headed, had properties (agricultural land and/or home garden) < 0.2 ha, and an income of less than 6000 INRS per month. Beneficiaries are provided with training and necessary facilitation for livelihood improvement through activities of the MTCP. The Labor Force Rate was calculated according to the definition by the UNESCO (UNESCO Institute for Statistics 2016). The age limits were adjusted according to the age groups used in this study. For the calculation of the Labor Force Rate the household members of age 14 and above were considered.

$$F = \frac{f}{t} \quad (6)$$

The Labor force Rates = F was calculated by the fraction of the number of family members that pursue labor = f in the defined age group, divided by the total number of household members = t in the defined age group.

The infrastructure was described by the installation of liquid petroleum gas stoves, energy saving improved cooking stoves (ICS) and the access to an electric power source.

The annual fuelwood demand was calculated as 30.5 (days) times the sum of fuelwood consumption in bundles in the monsoon season (three months) and non-monsoon season (nine months) (Table 4).

The distance to the nearest entry of the MNP is represented by the length of the airline between the GPS coordinates of each household and the GPS coordinates of the nearest entry of the MNP in km.

The Species Diversity was calculated using the Shannon-Wiener Diversity Index H, where p_i is the relative abundance in the individual species in each home garden (Oli et al. 2015).

$$H = -\sum_{i=1}^{s} p_i \ln p_i \qquad (7)$$

The statistical analysis was conducted in R Studio version 3.3.3 (R Core Team 2017). Before statistical models were built, the response variables and the explanatory variables presented in Table 2 and Table 3 were explored following the protocol of Ieno and Zuur (2015). One household was excluded from the study, as it had an enormous fuelwood demand (2562 bundles per year, mean: 481.44 ± 6.6), which can be explained with the excessive brewing activities, as stated by the household owners.

A Generalized Linear Model (GLM) using a binomial error distribution with a logit link was built (Model 1) to examine the relationship between the dependence on the MNP as a fuelwood source, and the explanatory variables presented in Table 2. The Household size correlated with the demand for fuelwood of households significantly (Table A2; Pearson correlation: 0.31, p-value: 0.002). The correlation between the fuelwood demand and the response variable, the dependence on the MNP as a fuelwood source, was higher (Table A2; Pearson correlation: -0 14, p-value: 0.16), than the correlation between the response variable and the household size (Table A2; Pearson correlation: -0.11, p-value: 0.28). The Education Index correlated with the Literacy Rate (Table A2; Pearson correlation: 0.88, p-value: <0.0001). The correlation between the Education Index and the response variable was higher (Table A2; Pearson correlation: -0.44, p-value: <0.0001), than the correlation between the Literacy Rate and the response variable (Table A2; Pearson Correlation: -0.35, p-value: 0.003). Therefore, the variables Household size and Literacy Rate were excluded from the original model (Model 1). All possible two-way interactions between the explanatory variables were included in the model.

Table 2: Definition of socio-economic factors of households that were tested for their relationship with the dependence of households on the Manas National Park as a fuelwood source and the expected sign of the relationship.

Variable	Definition	Expected sign
	Categorical explanatory variables	
Agriculture	1 if household owned agricultural land (in addition to home gardens), 0 if not	-
Beneficiary	1 if household was a beneficiary of the MTCP, 0 if not	+
Gas	1 if household had access to gas, 0 if no access	-
ICS	1 if household had an improved cooking stove installed, 0 if traditional stove was used	-
Electricity	1 if household had access to electricity, 0 if no access	-
Gender	1 if household was male-headed, 0 if household was female-headed	-
Ethnicity	1 if members of the Bodo tribe inhabited household, 0 if household was inhabited by Assamese people	+
	Continuous explanatory variables	
Household size	Number of members living in one household	+
Fuelwood total	Yearly consumption of fuelwood per household in bundles	+
Education	Education Index of adults of age 18 and above; see (5)	-
Literacy	Literacy Rate of household members of age 14 and above that can read and write a simple sentence; see (1)	-
Labor	Labor force rate of household members of age 14 and above that pursue any kind of occupation; see (6)	-
Distance	Distance of household to nearest entry to MNP	-
Fuelwood HG	Fuelwood proportion obtained from home gardens	-

A GLM with a quasibinomial error distribution, accounting for overdispersion in the data, was built (Model 2) to examine the relationship between the proportion of fuelwood obtained from home gardens and the explanatory variables presented in Table 3. The size of home gardens correlated with the abundance of trees (Table A2; Pearson Correlation: 0.59, p-value: <0.0001), the density of trees (Table A2; Pearson Correlation: -0.33, p-value: <0.0001) and with the number of areca palm individuals (Table A2; Pearson correlation: 0.55, p-value: 0.007). The correlation between the size of home garden and the response variable, the proportion of fuelwood obtained from home gardens, was higher (Table A2; Pearson correlation: 0.45, p-value: <0.0001), than the correlation between the response variable and the abundance of trees (Table A2; Pearson correlation: 0.33, p-value: 0.001) and of areca palms (Table A2; Pearson correlation: 0.35, p-value: 0.0004). The density of trees did not correlate significantly with the proportion of fuelwood harvested from home gardens (Table A2; Pearson correlation: 0.00, p-value: 0.98). The proportion of areca palm individuals per trees represented significantly the density of areca palms (Table A2; Pearson correlation: 0.41, p-value: <0.0001) and had a higher correlation with the response variable (Table A2; Pearson correlation: -0.03, p-value: 0.76), than the density of areca palms (Table A2; Pearson correlation: -0.01, p-value: 0.92). The variables Counts of Trees, Trees/m², Counts of areca palms and Areca/m² were therefore excluded from the original model (Model 2). All possible two-way interactions between the explanatory variables were included in the model.

The original models (Model 1 and Model 2) were simplified in a stepwise-backward procedure excluding non-significant interactions and variables at the $p < 0.05$ confidence interval.

Table 3: Definition of ecological characteristics of home gardens that were tested for their relationship with the dependence of households on the Manas National Park as a fuelwood source and the expected sign of the relationship.

Variable	Definition	Expected sign
Species Diversity	Diversity of tree species in home gardens; see (7)	-
Size of home gardens	Size of home garden area without housing area in ha	+
Counts of trees	Number of trees that had the potential to be used as fuelwood in home gardens with a diameter > 5cm	+
Counts of areca palms	Number of areca palm individuals in home gardens	-
Areca palm/trees	Proportion of areca palm individuals per trees in home gardens	-
Trees/m²	Density of trees in home garden	+
Areca palms/m²	Density of areca palms in home garden	-

Results

All households (N = 99) used fuelwood as the main energy source for cooking, as a light source, for heating during winter months and occasionally for brewing activities. Sources of fuelwood were the MNP, home gardens, local markets and others (Table 4).

Table 4: Average amount (± SE) of fuelwood (in bundles/year) obtained by each ethnicity in total and from each source. Average amount (± SE) (in bundles/year) and average proportion (± SE) (in %) of fuelwood obtained from each source in total. MNP = Manas National Park.

		Sources			
Ethnicity	Total fuelwood	MNP	Home garden	Market	Others
Bodo	496.5 (± 5.3)	119.0 (± 5.9)	250.02 (± 5.11)	107.8 (± 5.6)	19.7 (± 7.9)
Assamese	413.8 (± 1.3)	160.6 (± 1.2)	171.9 (± 1.3)	74.6 (± 1.5)	6.78 (± 3.4)
Total	481.44 (± 6.6)	126.54 (± 7.1)	235.82 (± 6.36)	101.7 (± 6.9)	17.33 (± 10.1)
Proportion		26.3 (±1.5)	49.0 (± 1.3)	21.1 (± 1.5)	3.6 (± 2.1)

Fifty-seven households obtained fuelwood from several sources, the remaining households exclusively procured fuelwood from one source. The MNP was entered by 44 (44.5%) households to collect fuelwood. The households that entered the MNP to extract fuelwood procured on average 62.5% (±5%) of their fuelwood supply from the MNP. The extracted fuelwood from the MNP accounted for 26.3% of the total fuelwood supply (Table 4, Figure 2). Home gardens provided fuelwood for 76 households and were the exclusive fuelwood source for 27 households. In total, 49% of the fuelwood was obtained from home gardens. Fuelwood was acquired from local markets by 39 and from other sources by five households.

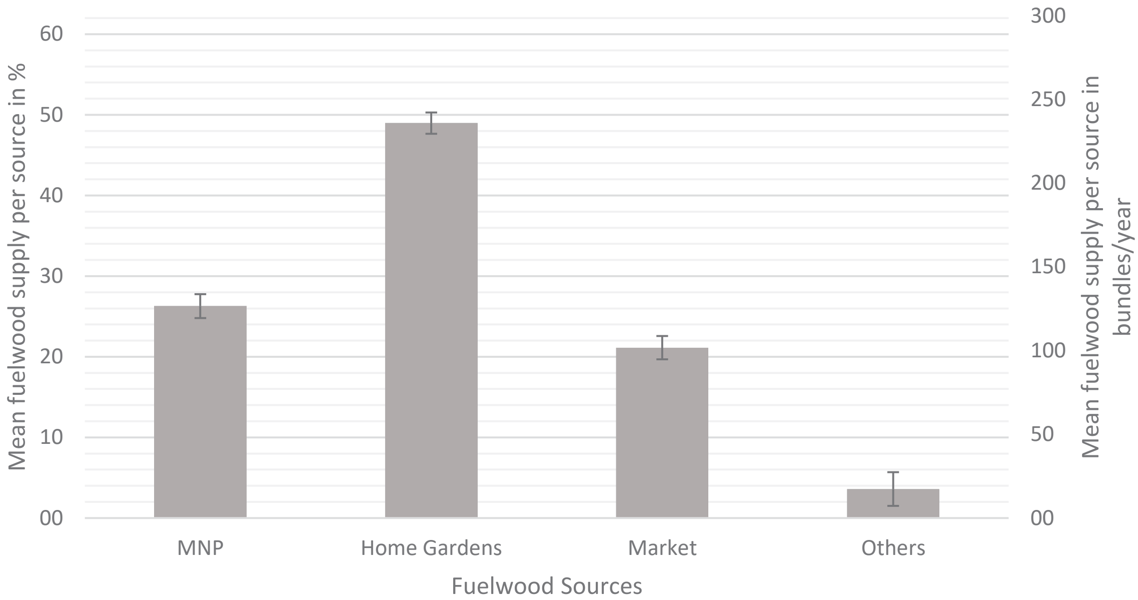

Figure 2: Average proportion (± SE) of fuelwood supply by each source in % and bundles/year (Table 4); MNP = Manas National Park.

Dependence of households on fuelwood extracted from the Manas National Park

Households that encroached the MNP for fuelwood had a significantly lower Education Index (0.5 ± 0.02), compared to households that did not enter the MNP to collect fuelwood (0.6 ± 0.01) (Table 5, Figure 3). Fewer of the electrified households (31 ± 4.5 households; 36.5% of electrified households) entered the MNP to harvest fuelwood, than of the households with no electric power source (13 ± 1 households; 93% of not electrified households). Less households of the aboriginal Bodo tribe (34 ± 4 households; 42% of Bodo households) were dependent on fuelwood collected from the MNP than households inhabited by Assamese members (10 ± 2 households; 56% of Assamese households). Households that relied on the MNP for fuelwood were located significantly closer (0.84 ± 0.08 km) to the nearest entry of the MNP, than households that did not depend on fuelwood extracted from the MNP (1.08 ± 0.06 km).

There was no relationship found between the dependence on fuelwood from the MNP by households, and the amount of fuelwood used per household in one year, the Labor Force Rate, the ownership of agricultural land, the status of a beneficiary of the MTCP, the construction of an improved cooking stove, the access to gas or the gender of the head of the household. None of the interactions between the variables related significantly with the dependency on fuelwood from the MNP.

Table 5: Variables influencing the dependence on fuelwood obtained from the Manas National Park (MNP). Fuelwood total, Beneficiary, Agriculture, Labor force, ICS (improved cooking stove), Gas and Gender were not included in the most parsimonious model; Education = Education Index of household members of age 18 and above, Distance = Distance between the households and nearest entry to the MNP, Fuelwood HG = Fuelwood proportion obtained from home gardens.

Variable	Estimate	SE	P-value
Intercept	15.57	3.232	< 0.0001 ***
Education	-12.956	3.5	0.0002 ***
Electricity (vs. no electricity)	-3.384	1.157	0.0034 **
Ethnicity Bodo (vs. Assamese)	-2.319	0.937	0.013 *
Distance	-2.773	0.865	0.0013 ***
Fuelwood HG	-2.875	0.842	0.0006 ***

$R^2 = 0.486$
* Significant at 0.1 level; ** Significant at 0.05 level; *** Significant at 0.01 level

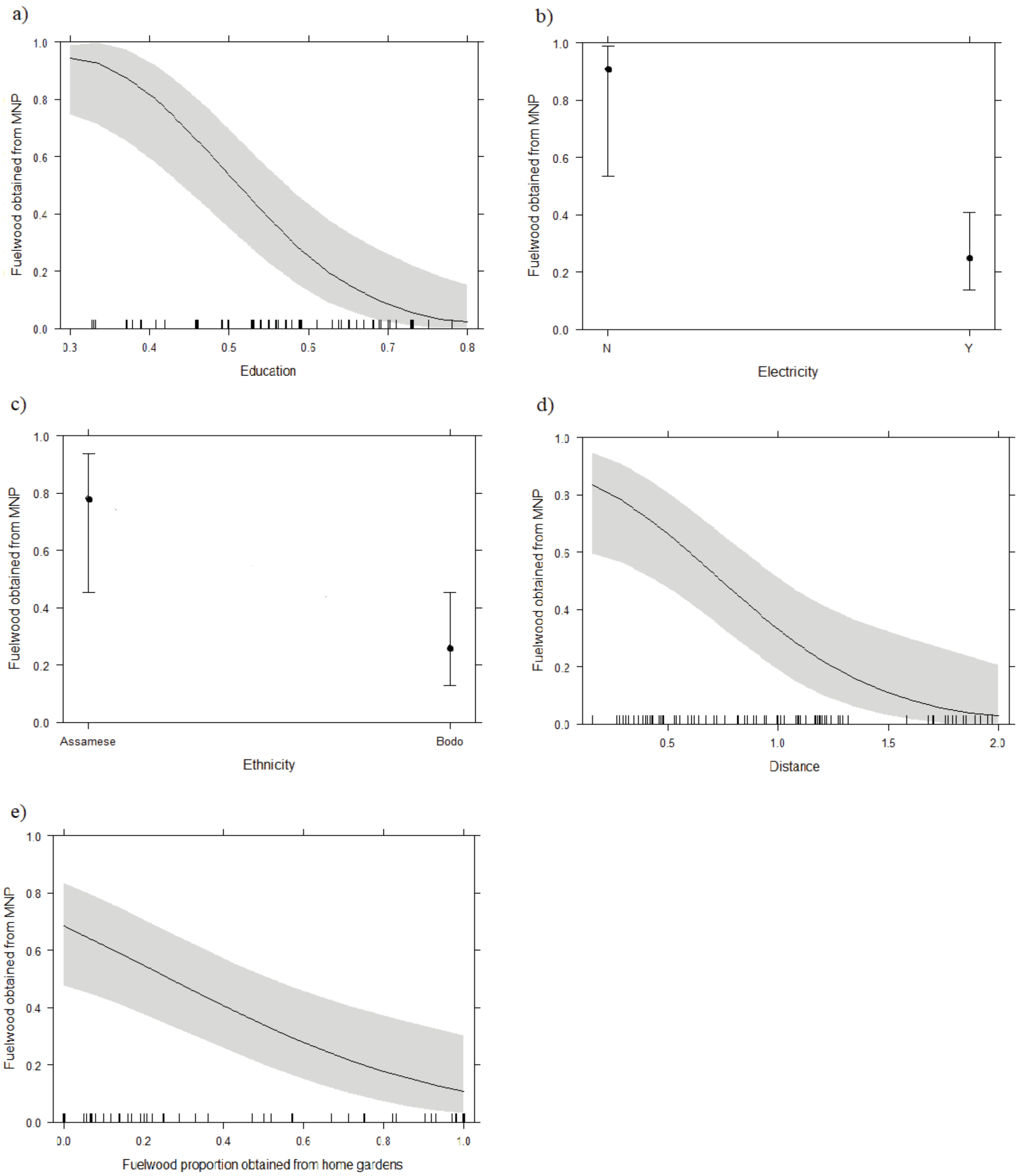

Figure 3: Effects of a) the education index, b) access to electricity (median ± SE), c) the ethnicity (Bodo vs. Assamese; median ± SE), d) the distance to the nearest entry to the Manas National Park (MNP) and e) proportion of fuelwood obtained from home gardens by households, resident in the vicinity of the MNP, on the dependence on the MNP as a fuelwood source. Trendlines (±SE) are based on GLM.

Home gardens as fuelwood sources

The higher the amount of fuelwood supplied by home gardens was, the less did households depend on the MNP as a fuelwood source (Table 5, Figure 3). Households that were depending on the MNP as a fuelwood source, obtained 29.6% (±5%) of their fuelwood from home gardens. Households that did not encroach the MNP to extract fuelwood, procured 63.6% (±5.8%) of their fuelwood proportion from their home gardens. The contingent of fuelwood harvested from home gardens increased with the size of the home gardens (Table 6, Figure 4).

Table 6: The effect of the size of home gardens on the proportion of fuelwood provided by home gardens. Species Diversity, Areca palms/m², Areca palms/trees were not included in the most parsimonious model.

Variable	Estimate	SE	P-value
Intercept	- 1.57	0.342	< 0.0001 ***
Size home gardens	10.312	2.3	< 0.0001 ***

R^2 = 0.23

* Significant at 0.1 level; ** Significant at 0.05 level; *** Significant at 0.01 level

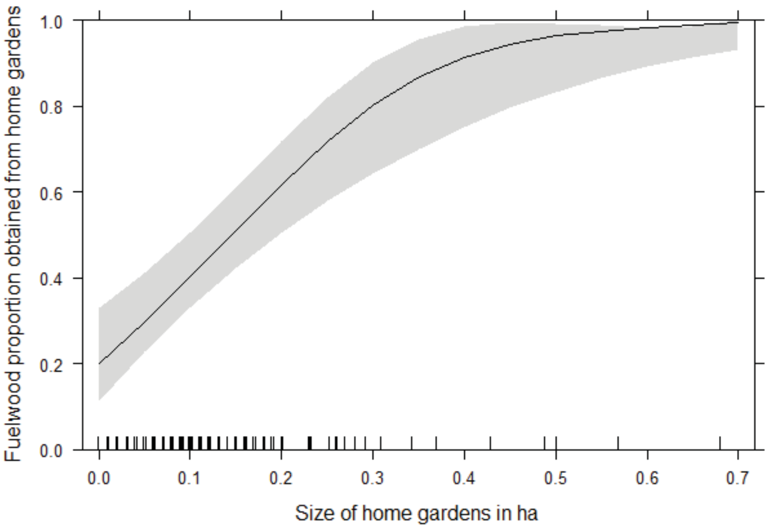

Figure 4: The effect of the size of home gardens in fringe villages of the Manas National Park on the proportion of fuelwood supplied by home gardens (Table 4). Trendline (±SE) was based on GLM.

The mean size of home gardens that provided 100% of the fuelwood demand was 0.22 ha (± 0.03 ha) (Figure 5). Home gardens that did not supply any fuelwood had an average size of 0.08 ha (± 0.01 ha). The size of home gardens represented the abundance of trees in gardens significantly. Households that obtained fuelwood exclusively from their home gardens had an average of 88.8 (± 11.8) trees in their gardens. Home gardens that were not used as fuelwood sources by owners had an average fuelwood stock of 40.7 (± 7.7) trees. Households that did not enter the MNP to extract fuelwood had an average 74.8 (± 6.8) trees in home gardens and households that entered the MNP had a mean of 52.6 (± 5.2) trees. Overall there were 55 different species of potential fuelwood trees recorded in home gardens (Table A1). The tree species stated in the group meetings, to be preferred as fuelwood sources were *Gmelina arborea, Syzygium cuminii, Lagerstroemia indica* and *Albizia procera.* These favored species were also found under the seven most abundant species documented in home gardens, which accounted for 56.3% of all trees recorded in this study. There was no relationship found between the proportion of fuelwood that was provided from home gardens and the species diversity and the density of trees or the interaction of the variables included in Model 2.

Figure 5: The relationship between the size of home gardens and the abundance of trees in home gardens. FWHG 100% are households that obtained fuelwood exclusively from home gardens, MNP are households that depended on the Manas National Park as a fuelwood source (not necessarily 100%), Other are households that obtained fuelwood from markets, other sources and less than 100% from home gardens.

The abundance of areca palms in home gardens was related significantly to the size of home gardens. Home gardens that supplied 100% of the fuelwood consumed by the respective households had an average stock of 111.2 (± 16.6) areca palm individuals. There were on average 38.8 (±7.6) areca palms recorded in home gardens, where households did not procure any fuelwood from (Figure 6). Households that were independent of the MNP as a fuelwood source had on average 79.5 (± 9.5) areca palms in their home gardens, and households that entered the MNP to harvest fuelwood had an average of 68.8 (± 8.4) areca palms. There was no relationship found between the proportion of fuelwood procured from home gardens and the proportion of areca palm individuals per trees in home gardens.

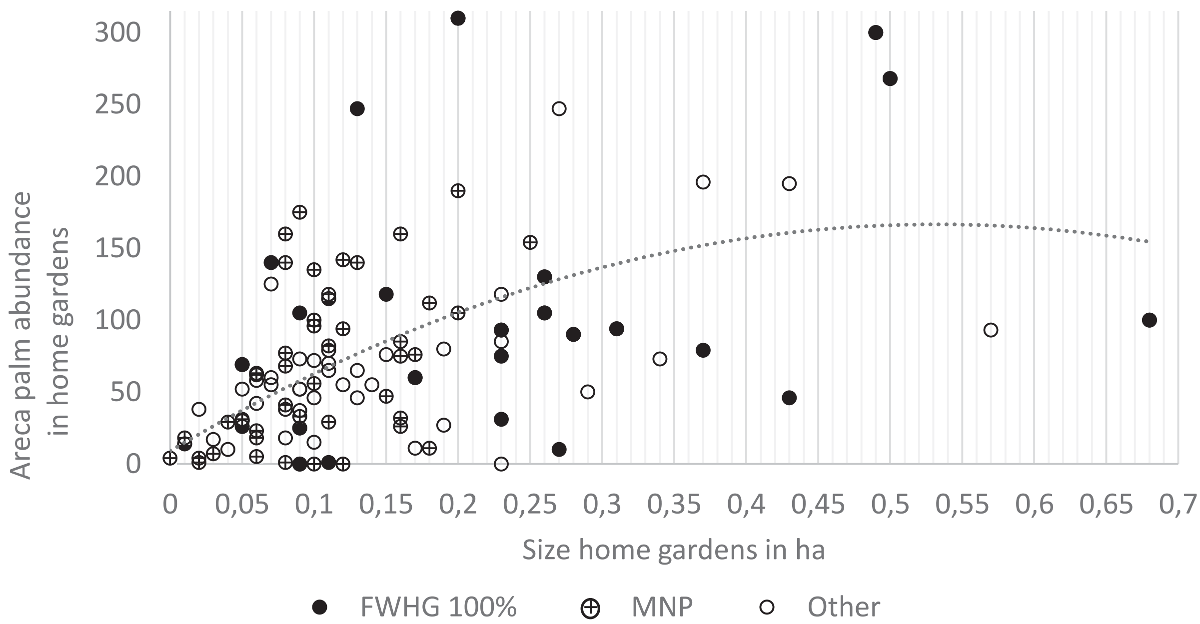

Figure 6: The relationship between the size of home gardens and the abundance of areca palms in home gardens. Other are households that obtained fuelwood from markets, other sources and less than 100% from home gardens, FWHG 100% are households that obtained fuelwood exclusively from home gardens, MNP are households that depended on the Manas National Park as a fuelwood source (not necessarily 100%).

Discussion

Approximately 15% of the households in the selected villages were sampled in this study, of which 44.5% indicated to enter the MNP to harvest fuelwood. The local people illegally extracted about 26% of the total demand of fuelwood, from the MNP. Home gardens provided 49% of the total fuelwood supply and were the exclusive source for 27 households. It could be proposed that the dependence of villagers, resident in the fringe of the MNP, on fuelwood harvested from the MNP, and the potential of home gardens, to function as supplant alternative fuelwood sources, were reliably represented by this study. Improving the livelihood through installing electric power sources to all households and providing a better general education may decrease the dependency of households on fuelwood procured from the MNP. The implementation of conservation strategies like conservation education and afforestation activities could increase the potential of home gardens to replace fuelwood collected from the MNP.

Socio-economic determinants of harvesting fuelwood from the Manas National Park

The more members lived in one household, the more fuelwood was consumed per year. It was predicted that a higher demand for fuelwood increased the probability that households encroached the MNP to harvest fuelwood. However, the yearly fuelwood demand did not affect, whether households relied on the MNP as a fuelwood source. Jain and Sajjad (2016) also found that the demand for fuelwood did not influence the extraction of fuelwood from natural forest in Rajasthan in northern India. Other studies have found that when the household size increased, the demand for fuelwood augmented and more people were available to collect fuelwood from natural forests (Hedge & Enters 2000; Heltberg et al. 2000; Köhlin et al. 2001; Webb & Dhakal 2011). The findings of the present study indicate that local people encroached the MNP to collect fuelwood, regardless of how much fuelwood they used and of the labor that could possibly collect resources from the MNP.

Households inhabited by members with a higher education degree were less likely to depend on fuelwood harvested from the MNP. The education increased with the number of people that pursue labor in households, which supports previous research that higher degrees of education can lead to better occupation opportunities (Hedge & Enters 2000; Jain & Sajjad 2016; Murniati et al. 2001). A better economic status might increase the possibility that households purchase alternative energy like gas or obtain fuelwood from local markets, instead of collecting fuelwood from the MNP (Hedge & Enters 2000; Jain & Sajjad 2016; Murniati et al. 2001; Wang et al. 2012; Webb & Dhakal 2011). However, there was no relationship found between the dependence of households on fuelwood procured from the MNP and the economic status of households. Heltberg (2003) also found that in rural India the consumption of fuelwood was consistent among households, albeit differences in economic statuses occurred.

A better infrastructure was predicted to reduce the demand for fuelwood, and therefore the need to harvest fuelwood from the MNP (Heltberg et al. 2000; Iiyama et al. 2014; Maikhuri 1991; Wang et al. 2012). However, the access to liquid petroleum gas and the installation of improved cooking stoves did not impact, whether household members encroached the MNP to collect fuelwood. The access to an electric power source reduced the probability that households encroached the MNP to extract fuelwood. The electrification might be connected to the construction of power lines rather than to financial resources, as some households with an electric power source also used gas to cook. Gas cylinders were often introduced recently before the data were collected, wherefore it should be further investigated how the availability of gas affects the collection of fuelwood from the MNP. These findings could imply that household members with a higher education did not procure fuelwood from the MNP, regardless of their demand for fuelwood, their economic status and infrastructure.

A reason why the degree of education played a significant role, concerning the illegal collection of fuelwood from the MNP, may be because a higher education might increase the awareness of local people towards the importance of their environment (Maikhuri 1991; Talukdar & Gupta 2017). General education provides basic knowledge about the local nature and might implicate respect and consciousness towards the MNP. Bajracharya et al. (2005) concluded that participants of environmental education in Nepal had an increased awareness about conservation and the negative consequences of the extraction of natural resources from protected areas. Conservation activities of the Golden Langur Conservation Project successfully raised community awareness towards the Manas Biosphere Reserve, which lays within the MNP, and created interest to protect the natural environment (Horwich et al. 2010). In the study area educational conservation activities in the context of the MTCP inform local people about their impact on the natural environment. It can be proposed that through enhanced general education and further activities of the MTCP the attitude of local people towards conservation might change, and it could play a vital role, whether people join illegal fuelwood extraction activities.

In rural northeast India it is common that women are responsible for household chores and men perform labor to earn income. Households are often only female-headed when the husband has passed away (Adhikari et al. 2004). Female-headed households were prioritized as beneficiaries of the MTCP, as they were expected to have a lower economic status. However, there was no relation found between the gender of the households head and the dependence on fuelwood extracted from the MNP. Bandyopadhyay and Shyamsundar (2004) also found that, besides their expectations there was no gender bias concerning the fuelwood harvest from forests. Nair (1995) stated that women might be more willing to find alternatives to forest wood, as they are more concerned about the fuelwood supply than men. It is common that women allocate their time for harvesting fuelwood and using it to cook for the family. Van't Veld et al. (2006) found that women coped with fuelwood scarcity by using and producing more fuelwood from private lands like home gardens. The findings of the present study support the conclusion that the economic status did not affect the dependency on fuelwood harvested from the MNP, because although female-headed households might have a poorer livelihood than male-headed households, they didn't encroach the MNP more than male-headed households.

Members of the aboriginal Bodo tribe are known to have a poor developed livelihood and to rely on resources from natural forests. However, fewer households that were inhabited by Bodos encroached the MNP to harvest fuelwood, compared to households inhabited by Assamese people. Potentially, Bodos were more aware of destructive consequences of illegal resource harvests because of their unique religious connection to nature. Talukdar and Gupta (2017) however, found that in the Chakrashila Wildlife Sanctuary about 120 km south of the MNP members of the Bodo tribe entered the natural forests more frequently than members of other ethnicities. Yet, Talukdar and Gupta (2017) also mentioned that the higher frequency of resource collection by Bodos could be related to the distance to the protected area. In the present study the interaction between the ethnicity and the distance to the MNP did not show a relationship with the dependency on fuelwood from the MNP. Therefore, the difference between the ethnicities concerning the dependency on fuelwood collected from the MNP should be further studied.

Regardless of the ethnicity, the distance to the nearest entry of the MNP, had a decreasing effect on the dependency of households on fuelwood from the MNP. This supports previous research on the relation between the harvest of natural resources from forests and the location of households, as with the distance to the forest the harvesting effort increased (Bhatt et al. 2016; Hedge & Enters 2000; Köhlin et al. 2001; Maikhuri 1991; Oli et al. 2015). Thus, the findings indicate that households located further away encroach the MNP to extract natural resources less due to high labor, time and transportation costs.

Fuelwood procured from home gardens

It appears logically that if multiple sources are used to obtain fuelwood, the amount of fuelwood supplied by each source decreases (Kegode et al. 2017). The higher the proportion of fuelwood harvested from home gardens was, the less likely it was for households to rely on fuelwood obtained from the MNP. Previous research found that the extent of private fuelwood supply can have a diminishing effect on fuelwood harvested from forests (Bugayong 2003; Heltberg et al. 2000; Iiyama et al. 2014; Ndayambaje & Mohren 2011; Webb & Dhakal 2011). Without taking the other significant variables into consideration, an increase in the proportion of fuelwood collected from home gardens by 10% would decrease the probability of households to enter the MNP to extract fuelwood by 4.8%. This indicates that, if local people would procure more fuelwood from home gardens, they could sustain their fuelwood demand without extracting fuelwood from the MNP.

Fuelwood contingent in home gardens

The proportion of fuelwood that was obtained from home gardens increased with their size. A reason for the size to play a vital role in the proportion of fuelwood collected from home gardens could be that the owners have more access to private fuelwood supplies. In the study area it is common, that property is subdivided between heirs, which might be the cause of relatively small landholding sizes. In times of land scarcity and rapid population growth it is crucial to adapt to these conditions to prevent further shifts of natural environments to land used for anthropogenic purposes (Andrews & Kannan 2016; Kumar & Nair 2004).

With the size of home gardens, the stock of fuelwood augmented (Heltberg et al. 2000; Webb & Dhakal 2011). If the fuelwood abundance would be increased by 10 trees, the amount of fuelwood possibly obtained by people from home gardens would increase by 3%. The finding that the amount of fuelwood obtained from home gardens increased with the abundance of fuelwood trees in home gardens goes in line with previous research (Bugayong 2003; Heltberg et al. 2000; Kegode et al. 2017; Oli et al. 2015). However, some home gardens of relatively small size, had a below average abundance of trees (Figure 5), yet the respective households had an above average demand of fuelwood (Figure A2), which was still obtained exclusively from home gardens. This could indicate that other households that harvest fuelwood from the MNP, with similar conditions did not make use of fuelwood available in their home gardens to the full extent. This supports the findings of Wangchuk et al. (2014) that the stock of trees in home gardens might be sufficient to cover the households fuelwood demand, yet it is not used to its full extent. Harvesting fuelwood from the MNP spares the trees in home gardens, which could be the cause for people to use the resources from their own property thrifty. In the present study there are home gardens that are also of small size, yet have a high abundance of trees, this indicates that the number of trees could potentially be increased in home gardens that currently have a low abundance of trees.

The density of trees decreased with the size of home gardens, which demonstrates that home gardens , especially larger gardens, might provide the space to grow more trees. An increase of trees in home gardens could raise the probability that more fuelwood is harvested from home gardens, which would reduce the pressure on the MNP.

Nair (1995) stated that people usually don’t plant trees simply for the purpose to harvest fuelwood. The diversity of tree species found in home gardens, which are common to be used as fuelwood, did not affect the extent of fuelwood which was extracted from home gardens. This indicates that trees were not particularly grown to function as fuelwood, although local people favored certain species to use as fuelwood. Multipurpose trees usually grow naturally in home gardens and it could be proposed to specifically plant native trees that are valuable and favored as fuelwood trees to increase the amount of fuelwood harvested from home gardens and therefore reduce the pressure on the MNP (Bhatt et al. 2016; Kegode et al. 2017; Webb & Dhakal 2011). As multipurpose trees have the potential to provide natural resources like fruits and timber, which might bring additional income (Tiwari et al. 2017), it should further be investigated which species function well as fuelwood, are favored by local people and could increase the income.

Extent of areca palms in home gardens

Similarly to the abundance of trees, the abundance of areca palms increased with the size of home gardens. Das and Das (2005) found in a more southern district in Assam that home gardens were dominated by areca palms and that its commercialization might have negative consequences on naturally grown trees in the future. The proportion of areca palms per trees did not affect the amount of fuelwood procured from home gardens, although there was a trend that home gardens with higher proportion of areca palms per trees had a lower abundance of fuelwood trees. However, despite that some smaller gardens had a high abundance of areca palms, they still functioned as the exclusive fuelwood source for households. The density of areca palms also declined with the size of home gardens, suggesting that it should be further investigated whether the spaces in home gardens are used to their full extent. The results indicate that there is no need to decrease the areca palm abundance and density, in order to increase the amount of fuelwood obtained from home gardens. Therefore, the areca palms could still function as the main income while fuelwood trees may be planted in spare areas to increase the fuelwood supply by home gardens, thus reduce the pressure on the MNP.

Recommendations for conservation strategies

As the size of home gardens can hardly be increased, and the existing stock of fuelwood might have the potential to meet the fuelwood demands, it needs to be further investigated, why residents of fringe villages of the MNP prefer to collect fuelwood from the MNP, rather than from their home gardens. Conservation strategies like environmental education could not only provide knowledge for local people about their impact on and the importance of the MNP, but also demonstrate that home gardens may have the potential to meet fuelwood demands. Present actions like the establishment of nurseries by the MTCP could be extended with tree plantings in home gardens and with afforestation trainings for local people. This could increase the willingness to plant more trees and to make use of fuelwood stocks in home gardens (Meijer et al. 2016). Bugayong (2003), for example found that in the Philippines participants of a forestry program had a reduced dependency on natural forests, mainly due to their raised awareness about the importance of natural environments, as well as due to the utilization and increased fuelwood stocks in home gardens. As the size of home gardens is limited it could furthermore be recommended to more plant trees in common areas. Plantations in common areas, managed and used collective by villagers were found to have a decreasing effect on the collection of fuelwood from natural forests (Köhlin et al. 2001; van't Veld et al. 2006). Especially for households with smaller home gardens community plantations could additionally function as alternative fuelwood sources to the MNP. Afforesting spare land, no matter if in common areas or home gardens, with native trees can have various positive consequences. It may contribute to the reduction of anthropogenic pressure on natural forests, yet also create new ecosystems and provide habitat for other species and ecosystem functions for the environment (Horwich et al. 2010; Jose 2012; Syiem et al. 2018).

Conclusion

The present study has confirmed the potential of livelihoods and home gardens to be improved, in order to live more sustainable and therefore reduce the destructive anthropogenic pressure on the MNP. To decrease the dependence on fuelwood harvested from the MNP all households in the study area should be connected to an electric power source and be provided with an enhanced general education. The approach to use home gardens as compensating fuelwood sources to the MNP, could be successfully achieved by spreading knowledge of the importance of the MNP and by providing suggestions and support on increasing the harvests of fuelwood from home gardens. The implementation of these livelihood development and conservation strategies may halt the degradation of the MNP. And in the long term the flora and fauna, like the Bengal tiger population in the MNP could thrive, recover from human encroachments and therefore provide ecosystem functions to its full extent.

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Appendix

Appendix I:

Table A1: List of potential fuelwood species found in home gardens in the fringe of the Manas National Park.

Scientific name	Family	Local/ Common name	Use	Income	Relative Species Abundance
Aegle marmelos	Rutaceae	Behel, Bel, Bael	Timber, Fuel wood, fruit Religious, medicinal	Timber: 200 INR/m³ Fruit: 10 INR/piece	0.002
Albizia procera	Leguminosae	Korai, Loha Siris, White Siris	Timber, Fuel wood, nitrogen fixer, shade tree	Timber: 700-1200 INR/m³	0.041
Alstonia scholaris	Apocynaceae	Sitona, Chatim, Devils Tree	Timber, Fuel wood, medicinal	Timber: 400 INR/m³	0.008
Anthocephalus cadamba or Neolamarckia cadambia	Rubiaceae	Khwdwm, Kadamba	Timber, Fuel wood, fruit, ornamental	Timber: 200-400 INR/m³	0.012
Aquilaria agallocha or A. malaccansis	Thymelacaceae	Agar, Eagle Wood	Coloring from inside timber, black -> industry; can get 50-70kg out of one tree, Fuel wood, fragrance oil, ornamental	Color: 3000 INR/kg	< 0.000
Artocapus chama / chaplasa	Moraceae	Dhaoli, Bogadhola	Timber, Fuel wood, fruit	Timber: 500-600 INR/m³	0.04
Artocarpus heterophyllus	Moraceae	Kanthal, Kaathal, Jackfruit	Fruit, Timber, Fuel wood, Fodder, Vegetable	Timber: 400-1200 INR/m³ Fruit: 100-60 INR/kg	0.047
Averrhoa carambola	Oxalidaceae	Kambrenga, Starfruit	Fuel, fruit		0.008
Azadirachta indica	Meliaceae	Neem	Timber, Fuel wood, Medicinal, Ornamental		0.001
Baccaurea ramiflora	Euphorbiaceae	Letuko, Bhubi	Fruit, Fuel wood	Fruit: 50 INR/80pieces; 500 INR/yield of one tree	0.027
Bauhinia sp	Leguminosae	Kanchan lakri	Timber, Fuel wood, Nitrogen fixer, Fencing		0.042

Table A1 (continued): List of potential fuelwood species found in home gardens in the fringe of the Manas National Park.

Bischofia javanica	Phyllanthaceae	Thaiso, Urium,Tiger marking tree	Timber, Fuel wood, Fruit, Seeds, Bark as red dye	Timber: 500-600/m³	0.004
Bombax ceiba	Malvaceae/ Bombaceae	Sumbli, Semul tula, Shimul, Silk cotton	Timber, Fuel wood, fibre for pillow inside etc. as cotton	Timber: 200-400 INR/m³ Fruit: 100-350 INR/kg	0.026
Cassia fistula	Fabaceae	Suralu, Sonalu, Golden Rain Tree	Timber, Fuel wood, Ornamental, Medicinal, leaves used for ripening banana fruit	Timber: 700-1000 INR/m³	0.014
Cinnamomum tamala	Lauraceae	Thejpat, Indian Cassia	Fuel wood, Spice		0.001
Citrus maxima	Rutaceae	Jumbra, Jambura, Pomelo	Fruit, Fuel wood	Fruit: 5 INR/3pieces	0.02
Dalberiga sissoo	Fabaceae	Sisu, Cicsu, Indian rosewood	Timber, Fuel wood, natural pesticide	Timber: 1000-1500 INR/m³	0.002
Dillenia indica	Dilleniaceae	Taigir, Elephant apple	Fruit, Fuel wood, Timber, Ornamental	Timber: 400-500 INR/m³ Fruit: 5-10 INR/piece	0.01
Ficus hispida	Moraceae	Adumbra, Dumbru, Dumur	Timber, Fuel wood, Fodder	Timber: 300 INR/m³	0.025
Gmelina arborea	Verbenaceae	Gambhar, Gambari	Timber, Fuel wood, Fodder	Timber: 700-1200 INR/m³	0.11
Lagerstroemia indica	Lythraceae	Aazar, Aojar, Crape myrtle	Timber, Fuel wood	Timber: 600-1200 INR/m³	0.054
Lagerstroemia parviflora	Lythraceae	Sida, Small flowered crape myrtle	Timber, Fuel wood	Timber: 1200-1500 INR/m³	< 0.000
Leea indica	Vitaceae	Koreng, Bandicoot berry	Fuel wood, Medicinal		0.001
Litchi chinensis	Sapindaceae	Lesu, Lechu, Litchi	Timber, Fruit, Fuel wood	Timber: 500 INR/m³ Fruit 10 INR/20 pieces	0.005
Litsea glutinosa	Lauraceae	Bagnal, Sundhi	Timber, Fuel wood	Timber: 500-800 INR/m³	0.014
Mallotus phillippensis	Euphorbiaceae	Sindur, Kamala or kumkum tree	Fuel wood, red dye, Medicinal		0.013
Mangifera indica	Anacardiaceae	Aam, Thaijwo, Mango	Timber, Fuel wood, Fruit, Ornamental	Timber: 300-400 INR/m³ Fruit: 10-50 INR/kg	0.095

Table A1 (continued): List of potential fuelwood species found in home gardens in the fringe of the Manas National Park.

Melia azedarach	Meliaceae	Mistang, Bukam, Persian lilac	Timber, Fuel wood, Fodder	Timber: 300-500/m³	0.036
Moringa oleifera	Moringaceae	Sarjona, Sajna, Drumstick tree	Fuel wood, Fruit, Fencing, Vegetable, Medicinal	Leaves as vegetable: 60 INR/kg	0.003
Murraya koeinigi	Rutaceae	Nerswn, Curry leaf tree	Fuel wood, Vegetable, Medicinal, Ornamental		0.001
Oroxylum indicum	Bignoniaceae	Karokandai, Nauka lakri	Timber, Fuel wood, Flower	Timber: 300-400 INR/m³	0.012
Phyllantus emblica or Emblica officinalis	Euphorbiaceae	Amlai, Indian gooseberry	Timber, Fuel wood, Fruit, Medicinal		0.002
Psidium guajava	Myrtaceae	Sumpram, Sophre, Guava	Fuel wood, Fruit	Fruit 5 INR/10pieces	0.016
Semecarpus anacardium		Bhwemel	Fruit, Fuel wood	Fruit: 5 INR/5-6 pieces; 2 INR/3pieces	0.002
Shorea robusta		Daowa/Sal tree	Timber, Fuel wood	Timber: 200-500/1200 INR/m³	0.007
Spondias mangifera	Anacardiaceae	Taisuri, Wild Mango	Flower for curry, Fruit, Timber, Fuel wood	Timber: 300 INR/m³	0.001
Streblus asper	Moraceae	Seora, Kaora	Fuel wood, Ornamental, Medicinal		0.018
Syzygium cuminii	Myrtaceae	Jambu, Jhum, Jaam, Jamun, Java plum	Timber, Fuel wood, Fruit, Fodder	Timber: 500-1000 INR/m³ Fruit: 5-30 INR/kg	0.054
Tectona grandis	Verbenaceae	Sigun, Shegun, Teek	Timber, Fuel wood	Timber: 200-1500 INR/m³	0.002
Terminalia arjung	Combretaceae	Arjun	Fuel wood, Ornamental, Medicinal		0.006
Terminalia bellirica	Combretaceae	Bhumsum	Timber, Fuel wood, Fodder, Seeds as biodiesel, Medicinal	Timber: 2000 INR/m³	0.004
Terminalia chebula	Combretaceae	Silika, Hurtuki, Chebulic	Timber, Fruit, Fuel wood, Medicinal, Ornamental	Timber: 70-600 INR/m³ Fruit: 5-10 INR/kg	0.008

Table A1 (continued): List of potential fuelwood species found in home gardens in the fringe of the Manas National Park.

Toona ciliata	Meliaceae	Bogi Poma, Jiya, Kuma	Timber, Fuel wood, Fodder	Timber: 200-1200 INR/m³	0.135
Ziziphus mauritiana	Rhamnaceae	Bwigri, Bogori, Boroi, Indian jujube	Timber, Fuel wood, Fruit	Timber: 400-500 INR/m³	0.006
unknown	unknown	Saola	Timber, Fuel wood	Timber: 300-800 INR/m³; 800-900 INR/whole tree	0.012
unknown	unknown	Kojo	Timber, Fuel wood	Timber: 400-500 INR/m³	0.032
unknown	unknown	Khwisi	Timber, Fuel wood, Fruit	Timber: 700-1000 INR/m³	0.001
unknown	unknown	Jabarsi	Fuel wood		0.002
unknown	unknown	Larubandaru, Morolia	Fuel wood		0.007
unknown	unknown	Mandar	Fuel wood		0.003
unknown	unknown	Rotopul	Fuel wood		0.003

Appendix II: Household survey

Date:
Village:
Household Code:
Name of Interviewee:
GPS:

1. What gender has the head of this household? ☐ male ☐ female

2. How many family members live in this household and to which of the following age categories do they belong?

Age	< 6	6-14	14-18	18-32	32- 60	> 60
Family members						

3. How many members of the households that are above the age of 14 are literate?

4. Which level of education have the members of this household that are above the age of 18 reached?

Level	Illiterate	Primary	High School	Degree
Family members				

5. How many earning members over the age of 14 live in this household?

6. To which ethnicity do the members of the household belong? ☐ Bodo ☐ Assamese

7. To which of the following facilities do you have access?

Traditional Cooking Stove	Improved Cooking Stove	Electricity	LPG

8. How many bundles of fuelwood do you use per day during the monsoon season?

9. How many bundles of fuelwood do you use per day during the non-monsoon season?

10. How many months per year does your home garden supply you with fuelwood?

11. Where do you get additional fuelwood from and for how many months per year?

	Market	Manas National Park	Other
Months/year			

Appendix III:

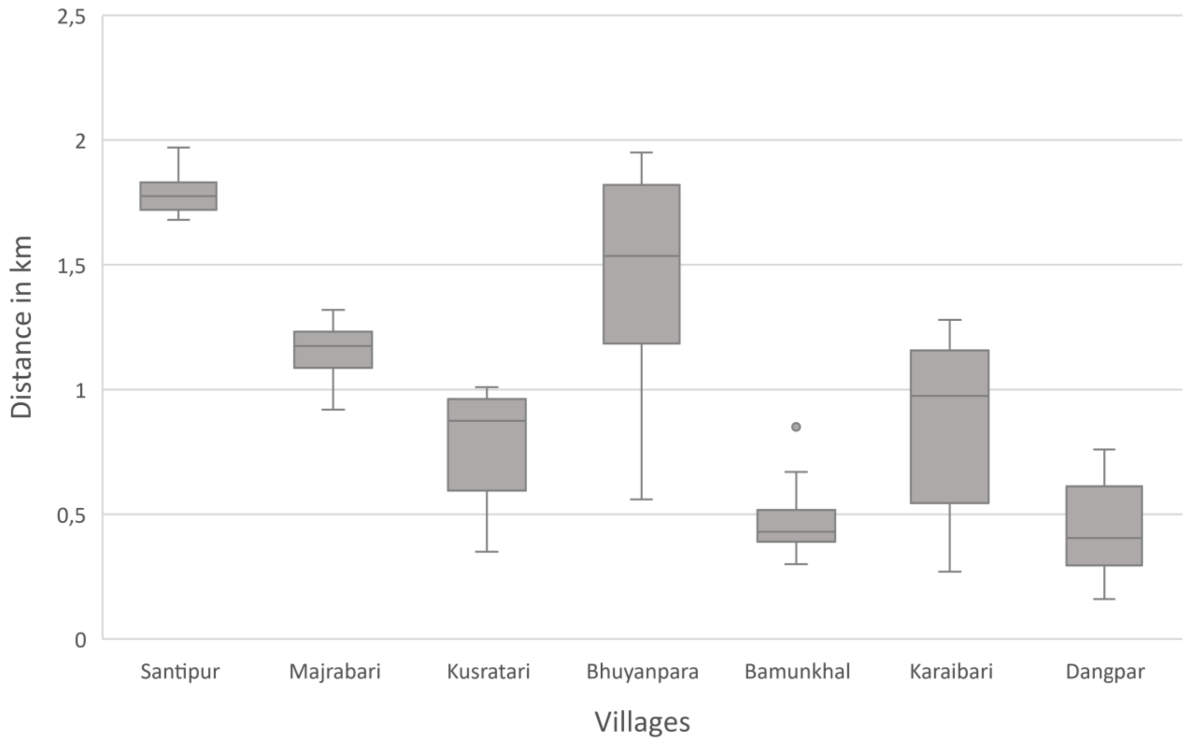
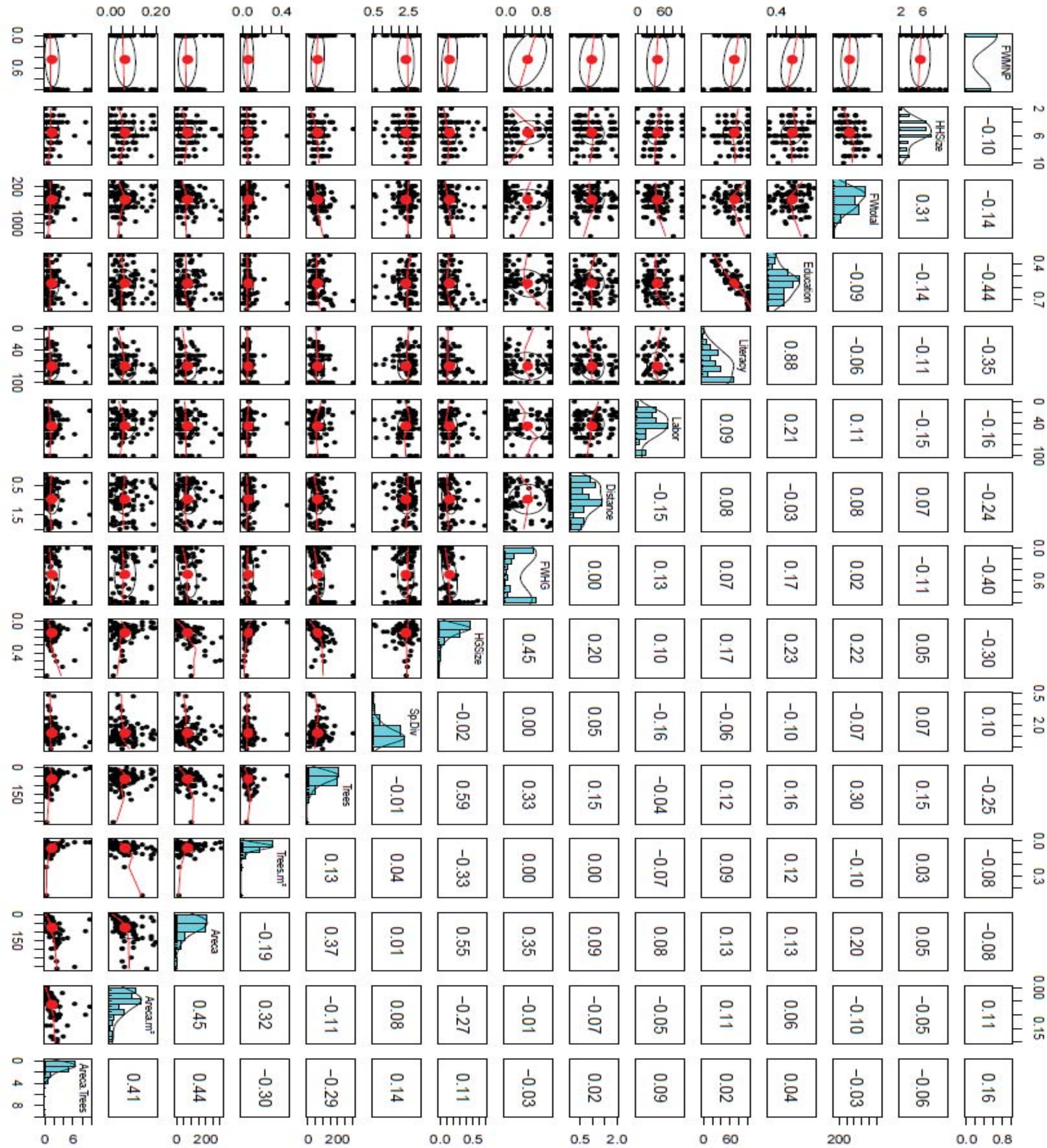


Figure A1: Median (± SE) distance between villages and the nearest entry of the Manas National Park in km.

Appendix IV:

Table A2: Pearson Correlation and plots of all continuous variables FWMNP = Fuelwood MNP, HHSize = Household Size, FWtotal= Fuelwood total, Education = Education Index, Literacy = Literacy Rate, Labor = Labor Force Rate, FWHG = Fuelwood HG, HGSize= Size of home gardens, Sp.Div = Species Diversity, Trees = Counts of Trees, Trees.m² = Trees/m², Areca = Counts of areca palms, Areca.m² = Areca palms/m², Areca.Trees = Areca palms/Trees.



Appendix V:

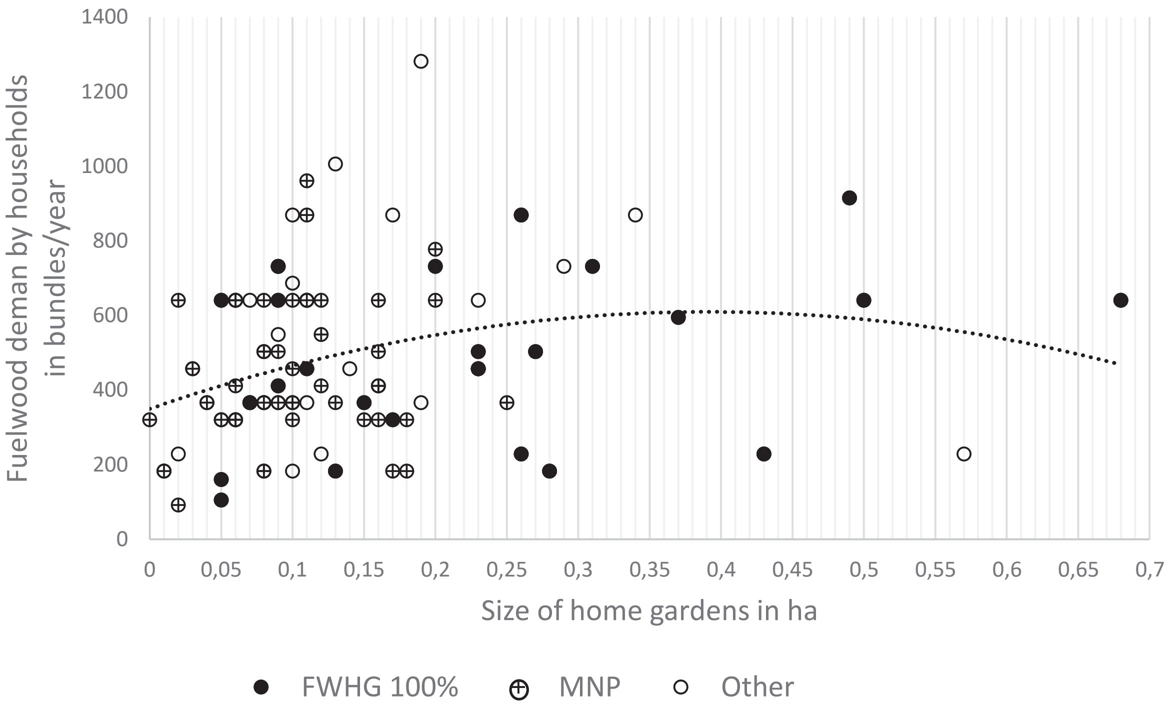


Figure A2: Relationship between the size of home gardens and the demand of fuelwood by households. Other are households that obtained fuelwood from markets or other sources and less than 100% from home gardens, FWHG 100% are households that obtained fuelwood exclusively from home gardens, MNP are households that depended on the Manas National Park as a fuelwood source (not necessarily 100%).

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