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Fuelwood Use and Availability in Bhutan: Implications for National Policy and Local Forest Management

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Abstract Fuelwood is the principal energy resource for millions of households around the world, yet its use, availability and management remain poorly understood in many areas. We document fuelwood consumption, growth/yield and standing biomass in a Bhutanese village and alpine area used seasonally by villagers where the government is concerned about harvesting in a recently designated national park. *Pinus wallichiana* was the only fuelwood used in the village and assessments suggest 52 ha could sustain local needs at current consumption levels (54 m3/household/yr). In contrast, *Rhododendron aeruginosum* was used in the alpine site and at current consumption rates all will be consumed by 2023. Our findings emphasize the need to manage fuelwood based on site-specific consumption, growth and standing biomass criteria rather than single, nation-wide regulations. We provide methods to develop sustainable fuelwood harvesting and forest management guidelines that are applicable to government and community-managed forests in Bhutan and elsewhere.

Keywords Community forestry · Household livelihood · Sustainable harvesting

Introduction

Fuelwood has provided humans with cooking, heating and related energy needs for thousands of years and remains an important source of energy throughout the world (Gregory *et al*. 1999; FAO 2008). Globally, fuelwood is the principal energy source for over 2 billion, primarily poor people (FAO 1997; Pattanayak *et al*. 2004) and fuelwood harvesting accounts for over 54 % of total annual wood removal from forests (Bhatt and Sachan 2003). Approximately 1.7 billion m^3 of fuelwood and charcoal were produced globally in 2004 (IEA 2006) and wood-based fuels comprise about 80 % of total household energy consumption (Sharma and Banskota 2005) and 35 % of total energy use in developing countries (Dovie *et al*. 2004). Low income countries account for about 90 % of global fuelwood consumption (Broadhead *et al*. 2001) and the number of people who depend on fuelwood is increasing with at least 1.7 billion expected to do so in Asia alone by 2030 (Arnold and Persson 2003; IEA 2006). Rural people are particularly dependent on fuelwood, but urban dwellers, industry and government offices also consume wood for cooking, heating and manufacturing (FAO 1997; Dovie *et al*. 2004).

Factors influencing fuelwood consumption include household income and size, site-specific ecological conditions (e.g., forest type, climate and soils), and cultural, economic, land tenure and religious factors (Bari *et al*. 1997; FAO 1997; Pandey, 2002; Palmer and Macgregor 2009). For example, households in temperate regions (i.e., high latitudes and elevation) consume more wood than those in the lowland tropics where fuelwood is generally used only for cooking (FAO 1997; CIFOR 2003; Rawat *et al*. 2009).

Low income households who cannot afford to purchase alternative energy (e.g., kerosene or gas) are particularly vulnerable to reductions in fuelwood supplies and are often compelled to spend more time collecting from distant locations as resources decline (Singh *et al*. 2009). Fuelwood harvesting is typically women's work (FAO 1997) and when supplies are limited, women allocate more time to gathering (Macht *et al*. 2007). For example, women in the Garhwal Himalayas of India spend 55 % of their total labor gathering fuelwood which reduced their ability to do other activities such as procuring food (Bhatt and Sachan 2003).

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Environmental effects associated with fuelwood harvesting have been addressed by conservation and development organizations who have often assumed that it causes forest conversion, soil erosion and land degradation, particularly in the Himalayas (Eckholm 1975; Singh and Sundriyal 2009). The assumption that fuelwood harvesting inevitably degrades forests is part of the general myth of Himalayan environmental degradation (Ives 2004). Unmanaged fuelwood harvesting has led to local shortages and forest degradation in some areas (Pattanayak *et al*. 2004; Bhatt *et al*. 2009; Ghilardi *et al*. 2009), but not in others (FAO 1997; Palmer and Macgregor 2009; Singh *et al*. 2009). Shortages and degradation tend to occur where demand is high, growth rates limited by climatic or soil conditions (e.g., high elevation and arid environments; Gregory *et al*. 1999, Rawat *et al*. 2009), and where demand is high or expanding, such as near growing urban areas (Ghilardi *et al*. 2009). Globally, demand for wood fuels is increasing as concerns over climate change mount and interest in renewable energy grows (FAO 2010).

Reliable assessments of fuelwood consumption, supplies, and growth and yield are limited in much of the world (Arnold and Persson 2003). In addition, many consumption estimates are based on per capita energy data that have not changed for decades (FAO 1997). Furthermore, since most fuelwood is gathered and consumed by households or traded informally, actual measured data are lacking (Pandey 2002; Arnold and Persson 2003; FAO 2008). Most fuelwood studies have focused only on consumption; much less is known about standing biomass or growth rates. Few studies have evaluated fuelwood harvesting in protected areas, but where they have, such as in the Wolong Nature Reserve in China, harvesting has resulted in forest degradation (Liu *et al*. 2001). The need for integrated studies of fuelwood availability, yield and consumption is imperative where people have a long history of resource use and management, as is the case in Bhutan and the Himalayas in general (Liu *et al*. 2007).

Given current and growing use of fuelwood, it is important to understand consumption trends, resource availability, growth and yield, and effects associated with harvesting, including both immediate impacts on resource availability and indirect effects on vegetation productivity and future growth and yield (Heltberg *et al*. 2000). It is surprising how little is known about fuelwood supplies, harvesting, trade, consumption and management given the importance of the resource, particularly among poor and vulnerable populations, and effects associated with unmanaged harvesting (Koopmans 2004). Site-specific documentation of fuelwood resource availability, growth/yield, and consumption are also essential to the identification and development of locally appropriate and sustainable forest management practices.

Bhutan is a small country in the eastern Himalayas (38,394 km^2) with a population of 671,000 (NSB 2009). The country ranges in elevation from 150 msl in the south to 7000 msl in the north and encompasses three broad ecological zones (sub-tropical, temperate and alpine) with widely divergent tree species and biomass growth rates (MoA 2009a). Fuelwood is the primary energy source for most rural and urban Bhutanese and comprises approximately 70 % of total national energy use (MoA 2009b). Per capita fuelwood consumption in Bhutan is estimated to be 1.2 metric tons/yr (MoA 2009a), one of the highest in the world, and is increasing (Dhital n.d.). Households account for 95 % of total fuelwood consumption, while the government, commercial sector and industry consume the balance (Uddin *et al*. 2006). Over 128,000 metric tons of fuelwood was consumed in 2007–08 (NSB 2009), but this underestimates actual consumption because it reflects only that recorded by forestry officials.

Fuelwood harvesting in Bhutan is regulated by the Government's Forest and Nature Conservation Rules of Bhutan 2006 (MoA 2006), henceforth referred to as the "Rule", which specifies that government-designated Forest Management Units are the main source of fuelwood (not including 1 % of forest land in community forests) and that domestic (i.e., household) fuelwood needs are to be met before industrial and commercial interests. The Rule specifies that households are allowed 16 m^3 of fuelwood/yr if they lack electricity or 8 m^3/yr if they have electricity, irrespective of household size, need, forest type, availability, or growth rates. Enforcing the Rule has proved to be difficult due to the number of fuelwood users, large area, challenging terrain, and limited number of forestry personnel. At present, little is known about fuelwood consumption, availability, growth rates or effects associated with harvesting throughout Bhutan and the issue has received little attention from government officials (Uddin *et al*. 2006), even in community forests where residents benefit from fuelwood sales (Chettri *et al*. 2009). Where residential consumption surveys have been conducted, fuelwood is considered the most important forest product (Katel and Schmidt-Vogt 2011). Gaining secure and ready access to fuelwood are key reasons residents report for participating in Bhutan's increasingly popular community forest program (Phuntsho *et al*. 2011).

To address the above issues, we document: 1) the amount of fuelwood consumed annually by a Bhutanese community in both the village and in an alpine area used seasonally by residents, and 2) whether locally available forest resources can meet fuelwood needs on a sustainable basis in these two sites. Specifically, we document fuelwood consumption, availability (i.e., standing biomass), growth (i.e., annual increment), and local perceptions of fuelwood resources in one permanent settlement (a village and adjacent hamlets) and an alpine site used seasonally by those residents for livestock grazing and collecting medicinal plants. The two study sites are adjacent to or within Wangchuck Centennial Park, Bhutan's largest protected area, respectively, but differ in terms of vegetation types and growth rates. Based on observed consumption rates and resource availability, we recommend policy and management changes in Government of Bhutan regulations (Rule) and community forest management policies. The research methods and general findings are applicable throughout Bhutan and could inform fuelwood and forest management practices in the Himalaya region and elsewhere.

Research Sites and Methods

Research Sites

This study was conducted in Nasiphel and neighboring hamlets of Sangsangma, Dhokrong and Shabjeythang, in the upper Bumthang Valley and in Chajeyna, an alpine area which is a three days walk from the village where households from these communities historically grazed yak during summer months and now also gather Cordyceps (*Ophiocordyceps sinensis*), a valuable medicinal fungus found in alpine areas throughout the Himalayas (Fig. 1). Both sites are within Bumthang District (Dzongkhag) in central Bhutan and resource access and use are managed by officials of Wangchuck Centennial Park.

Nasiphel (30 households, 341 individuals), Sangsangma (16 households, 181 individuals), Dhokrong (5 households, 44 individuals), and Shabjeythang (4 households and 55 individuals) are agricultural communities (2900 m, 9514 ft msl) where residents historically practiced swidden farming of buckwheat, wheat, barley, radish, turnips and potatoes in nearby fields and grazed yaks for butter and cheese in alpine areas during the summer and in fields near the village in the winter. Swidden farming was banned throughout Bhutan in 1997 and at about the same time road and market access were provided which led farmers to switch to intensive cultivation of potatoes as a cash crop in permanent fields (Siebert *et al*. 2014). In 2010, three households from Nasiphel tended yaks in Chajeyna and one to three individuals from every household in the community were issued permits to collect Cordyceps for 1 month (mid-May to mid-June) in Chajeyna and adjoining alpine areas.

All heating and cooking needs in Nasiphel and Chajeyna have been historically met through locally collected fuelwood. Blue pine (*Pinus wallichiana*) is the only fuelwood species used in Nasiphel and it established dense stands following the cessation of swidden farming (Siebert *et al*. 2014). Residents use Chajeyna as a seasonal campsite near timberline (4650 m, 15,255 ft) where the dominant woody vegetation is *Rhododendron aeruginosum*, with scattered dwarf *Juniperus sp.* and *Salix sp*.; Rhododendron is the primary fuelwood species.

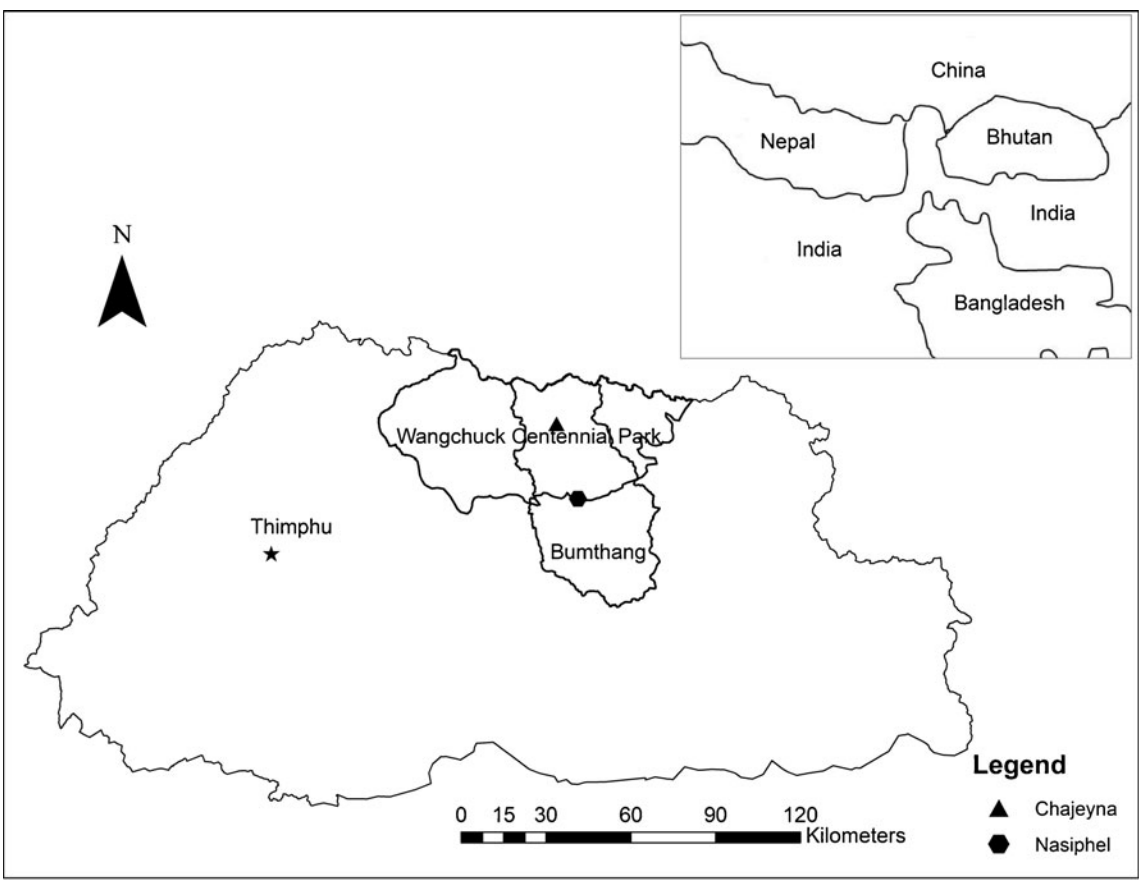

Fig. 1 Location of Nasiphel and Chajeyna research sites, Bumthang District, Bhutan

Chajeyna and other higher elevation areas in Bhutan attract large numbers of people from Bhutan and Tibet from mid-May through mid-June each year to gather Cordyceps. Cordyceps collectors and yak herders camp at Chajeyna because it provides the highest available source of fuelwood.

Methods

Fuelwood consumption by residents of Nasiphel was estimated by monitoring daily use among 15 randomly selected households (50 % of village households) for 15 consecutive days in August 2010 and in January 2011. Daily consumption was estimated using the weight-survey method (Bhatt and Sachan, 2003; Ali and Benjaminsen 2004) where each day a stack of fuelwood sufficient to meet all cooking and heating needs was weighed in each of the 15 houses using a spring balance and left in the kitchen with instructions to burn only that wood. The following day any remaining wood was weighed, the weight consumed during the previous 24 h recorded and the process repeated. The number of individuals in each household was noted and daily per capita consumption rates estimated for August and January. Assuming that the summer month of August and winter month of January reflect the range of fuelwood use, we estimated total annual per capita consumption (in kg) by averaging the two rates. We estimated total annual consumption by all residents of Nasiphel and adjacent hamlets by multiplying mean per capita consumption by the number of individuals in the area based on 2010 census data. Lastly, we measured the volume of wood in 20, 30, 40, 50 and 60 kg piles ten times in ten different homes (i.e., 100 times) and averaged the results to establish weight:volume relationships which we used to estimate the volume (m^3) of fuelwood harvested.

Government forestry officials established two areas from which residents of Nasiphel and neighboring hamlets were permitted to harvest fuelwood in 2010: one adjacent to Nasiphel (site 1) and a second 5 km to the south along the village access road (site 2); both are even-aged blue pine stands. Government foresters marked trees available for harvesting based on the Rule which stipulates that households without electricity (all households in this study) are permitted 16 m^3/yr. Local residents, government foresters and personal observations revealed that fuelwood was harvested only from the two designated sites and by local residents only.

The areas of the harvesting sites were estimated by walking the perimeters and establishing polygons with a Garmin eTrek GPS and with Arc GIS 9.3.1 and Google Earth maps. To estimate the standing volume of fuelwood, we established 10 m radius sample plots at 50 m intervals along randomly established transects in each site (9 plots in site 1, 4 plots in site 2) and measured the diameter at breast height (dbh) and height of all trees in the plots (63 trees in site 1, 45 trees in site 2). We cored all trees in the plots with an increment borer and determined the mean annual growth increment using Measure J2X software (n =11 complete samples). Lastly, we estimated tree volumes using Bhutan Ministry of Agriculture volume tables developed specifically for blue pine (MoA n.d.).

We interviewed 32 households selected randomly in Nasiphel and adjacent hamlets to document fuelwood consumption patterns, perceptions of current availability, anticipated future needs, and changes observed over time, in addition to the number, ages and genders of all individuals in each household. This information supplemented insights gathered from the 15 monitored households and from five key informants considered by local residents to be knowledgeable about fuelwood issues.

Seasonal fuelwood consumption by Cordyceps collectors and yak herders in Chajeyna was estimated by monitoring daily use among 12 groups of Bhutanese collectors/yak herders (33 % of groups in the area) for 10 consecutive days in mid-June 2010. We selected 12 groups near one another to facilitate monitoring, recorded the number of individuals in each camp and estimated daily per capita consumption through the same weight-survey method (Bhatt and Sachan 2003; Ali and Benjaminsen 2004) described previously. Illegal Cordyceps collectors from Tibet were not surveyed, but they did not harvest fuelwood from the same rhododendron stands.

We interviewed one individual from each of the groups to determine the number of individuals in each group, whether they used any fuel other than wood, and to document perceptions of current fuelwood availability and changes observed over time. All the yak herders and Cordyceps collectors reported using only rhododendron for cooking and drying. Of the 97 collectors, 86 camped and 11 stayed in stone houses (i.e., yak herder huts).

The total amount of fuelwood available in Chajeyna (i.e., total above ground biomass) was estimated by mapping and calculating the area of all rhododendron stands in the area, recording the number and size of rhododendron plants found in randomly established belt transects in the two largest plots, and by developing diameter: weight relationships from a random sample of plants (n= 25). We mapped the area of all rhododendron stands (four) by walking the perimeter of each with a GPS Garmin eTrek and establishing polygons, and importing the data into Arc GIS 9.3.1. We randomly established nine 4 m wide belt transects across the two largest rhododendron stands (five in plot 1, four plot in 2) and recorded the number and diameter at the base of all rhododendrons encountered (1080 individuals in plot 1 and 795 individuals in plot 2). We measured diameters at the base of plants due to their heavy and low branching growth habit.

We estimated mean annual rhododendron growth rates (i.e., annual increment) by randomly selecting ten plants of various sizes, cutting them at their base, removing a cross sectional disc, and counting and measuring the number of

The density of rhododendron biomass in the two sampled stands averaged 1.20±0.22 kg/m^2 which when extrapolated to the total rhododendron area (92,470 m^2) indicates that there was approximately 111 metric tons of fuelwood (i.e., rhododendron standing biomass) in Chajeyna. We estimated the weight of rhododendron from their measured diameters by establishing weight: diameter relationships (Fig. 4; weight (kg)=0.742 × diameter $(cm)^{1.262}$). The variability of rhododendron weights increased with diameters over 7 cm due to the large and extensive branching typical of the plant as it grows and ages.

Rhododendron growth rates in Chajeyna are very low. Annual growth averaged approximately 0.6±0.04 mm/year or about 0.02 kg per plant/year (n= 10). Based on the observed density of rhododendrons in the sample plots, the annual growth increment was approximately 0.009± 0.0002 kg/m^2. When extrapolated across the collection area, the total rhododendron biomass increment in Chajeyna was approximately 809 kg/yr. Given the observed rate of fuelwood consumption, standing biomass and annual growth increment, we estimate (i.e., annual growth increment x rhododendron density x area of rhododendron stand ÷ annual consumption) that Chajeyna will be devoid of fuelwood (i.e., woody vegetation) by 2023.

Resident Perceptions of Fuelwood Resources

Residents of Nasiphel and surrounding hamlets (n= 32 individuals sampled) reported having few concerns about the overall availability of fuelwood resources. However, 78 % of respondents noted supplies are decreasing in the designated harvest units, while 13 % said they were unchanged and 9 % that they were increasing. Reliance upon fuelwood for cooking varied among the households surveyed: 41 % of respondents reported preparing all meals on wood stoves year-round, while 59 % prepared lunches using LPG stoves when the weather was warm. Respondents who used only wood reported doing so due to the cost and inconvenience of filling LPG tanks. Survey respondents noted when electricity becomes available (scheduled for 2013) and the use of electric rice cookers becomes possible, they would likely use less fuelwood.

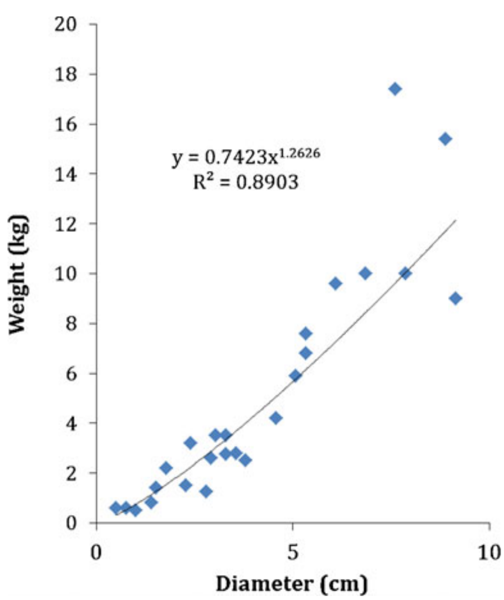

Fig. 4 Weight:diameter relationships of *Rhododendron aeruginosum* in Chajeyna, Bhutan

Seasonal Cordyceps collectors and yak herders in Chajeyna (n= 36) reported serious and growing fuelwood supply problems; 67 % of respondents reported difficulty gathering sufficient fuelwood which they attributed to increasing numbers of Cordyceps collectors. Half of those interviewed stated that fuelwood supplies had not changed in recent years, while the other half reported that supplies have decreased. The differing perceptions appear to reflect familiarity with and length of time in the area, with those noting declines having worked in the area longer. For example, 80 % of the yak herders interviewed reported fuelwood supplies had decreased substantially in recent years. This is noteworthy because yak herders have pastured livestock in Chajeyna for centuries, while most Cordyceps collectors have been coming for only 4–5 years. Respondents stated that they expect to continue burning fuelwood given the lack of alternatives.

Cordyceps collectors and yak herders rely entirely on rhododendron for all cooking, drying and heating needs. Seven groups brought small amounts of kerosene to Chajeyna, but only one had a kerosene stove which they reported using only to cook breakfast. The groups with kerosene used it to help start fires in the cold, wet weather (the Cordyceps collecting period coincides with the onset of the wet monsoon). Wangchuck Centennial Park officials reported (pers. com.) that they encourage collectors to use kerosene or other fuels. However, collectors stated that kerosene and gas are expensive and would require pack animals to transport the amount needed for an entire month (collectors now transport all food and supplies on foot).

Discussion

Fuelwood is the primary energy source for residents of Nasiphel and is likely to remain important even after electricity becomes available because it is essential for heating. Current fuelwood consumption in Nasiphel and adjoining hamlets (54 m^3/household/yr) is over three times the amount allowed by the nation-wide Rule (16 m^3/household/yr) and evidence of illegal harvesting was evident in the designated harvesting sites and confirmed by local residents. However, locally available blue pine resources are more than sufficient to meet fuelwood needs on a sustainable basis. The even-aged blue pine averaged about 1 cm diameter growth/yr and occurs in dense stands around the village which suggests that tree growth and vigor could be enhanced by silvicultural treatments (i.e., thinning). In addition, elderly residents noted that Nasiphel is much more heavily forested now than it has been for centuries due to the cessation of swidden cultivation. A recent assessment of 25 km^2 surrounding the village found that over 54 ha of former swidden fields (2.17 % of the total area) transitioned to closed blue pine forest between 1989 and 2010 (Siebert *et al*. 2014). Based on the observed standing biomass and annual increment data, 52 ha could sustainably meet local fuelwood needs at current consumption levels and consumption is likely to decline with the introduction of electricity.

In alpine Chajeyna, slow growing (0.6 mm/yr diameter increment) rhododendron stands are used for fuel by both Cordyceps collectors and yak herders and current harvesting rates are destructive and unsustainable. Biomass accumulation rates are simply too slow near timberline (i.e., above 4500 msl) to sustain fuelwood harvesting in alpine Bhutan and other high elevation areas in the Himalayas. On the other hand, collectors and herders stated that it is not feasible to camp at lower elevations, where fuelwood is abundant and growth rates higher, due to the distance and time required to return each day to alpine areas. *Rhododendron* spp. is widely used for fuelwood throughout the Himalayas due to its high caloric value (i.e., heating potential) (Chettri and Sharma 2009). While managed livestock grazing and fuelwood harvesting has occurred in Chajeyna and other alpine areas of Bhutan for centuries, elderly yak herders stated that excessive rhododendron harvesting began only after the arrival of large numbers of Cordyceps collectors (pers. com., June 2010).

Managing fuelwood harvesting in Chajeyna and other alpine areas will be difficult; the area is large and rugged, the number of forest guards is inadequate, and hundreds of Tibetans illegally harvested Cordyceps in 2010 and were believed to do so more intensively and for a longer period of time than Bhutanese (park officials and Bhutanese collectors, pers. com., June, 2010). However, the number of Tibetan collectors appears to have recently declined; none were observed in Chajenya in 2013 (forest guards, pers. com, May, 2013).

Controlling fuelwood harvesting and conserving alpine rhododendron vegetation will require a combination of policy reforms and increased enforcement, including: 1) reducing the number of Cordyceps harvesting permits granted each year to Bhutanese, 2) identifying and enforcing the use of alternative fuels, and 3) eliminating illegal harvesting by Tibetans. The Government of Bhutan currently allows three Cordyceps collecting permits/household and granted 534 permits in Chokor Gewog (which includes Chajeyna) in 2010 alone (Wangchuck Centennial Park officials, pers. com.). Bhutanese Cordyceps regulations have been revised numerous times. Until 2003, collection was permitted only in the Lunana region of Bhutan, northwest of Chajeyna. Harvesting rights were expanded to traditional yak herders throughout the country in 2004, to one individual/household for all those living in Cordyceps collecting administrative districts in 2008 (Cannon *et al*. 2009), and to three individuals/household in 2009. We recommend returning to the 2008 regulations that limit harvesting to, at most, one individual/household among residents in administrative districts where Cordyceps is found.

Individuals interviewed in this study noted the difficulty and cost associated with using non-wood fuels. Kerosene, gas and stoves are expensive and would have to be transported to Chajeyna for the month long collecting period. However, Cordyceps harvesting is extremely lucrative and unless alternative fuels are adopted, collectors will need to find alternatives by about 2023 when all rhododendron biomass will likely have been consumed. We suggest the government evaluate alternative fuels and consider subsidizing the cost on the basis of household financial need (e.g., 30 % of the collectors interviewed reported that Cordyceps represents 80–100 % of their household's total annual income) and support the design and use of more efficient wood stoves. To address harvesting by Tibetans, we recommend the government post army personnel near international border passes and reduce illegal entry. Unless the Government adopts and enforces prohibitions against wood burning and reduces the number of collectors, fuelwood consumption can be expected to continue until the resource is exhausted.

The Forest and Nature Conservation Rules (MoA 2006) specifying fuelwood harvesting at 16 m^3 and 8 m^3/household/yr for those without and with electricity, respectively, encompasses all of Bhutan. The Rule is not based on empirical assessments and does not meet consumption needs in temperate regions, such as Nasiphel, and is unsustainable in alpine areas such as Chajeyna. Available fuelwood resources and annual biomass accumulation rates vary tremendously in Bhutan. Annual diameter growth rates averaged almost 1 cm/yr in temperate Nasiphel, but only 0.6 mm/yr in alpine Chajeyna. Even more pronounced differences are likely if subtropical and temperate broadleaf forests are considered. The present nation-wide fuelwood harvesting Rule has no ecological basis and should be revised. We recommend the Government stratify the country on the basis of ecological/climatic criteria and develop site-specific fuelwood harvesting regulations based on community and forest specific assessments of standing biomass, annual growth rates, and local needs. It appears that fuelwood harvesting could be increased throughout much of Bhutan as total forest cover increased from 72 % in 1995 to 81 % in 2010 (NSSC & PPD 2011).

The development of community and forest specific fuelwood harvesting regulations could benefit Bhutan's community forestry program. The Government of Bhutan is increasingly devolving management of forests around villages to designated user groups; the number of community forests increased from 8 in 1990 to over 500 in 2012, and procuring fuelwood is the principal management objective of most community forests (Phuntsho *et al*. 2011). However, at present many community forests are too small to meet household fuelwood needs on a sustainable basis (Siebert and Belsky 2013). We recommend designating community forest areas based on household fuelwood needs and site-specific assessments of standing biomass and annual growth rates.

Conclusion

Ecologically sustainable and socially acceptable management is based upon understanding biophysical and socioeconomic attributes of resources, particularly where there is a long history of resource use; what is sometimes referred to as coupled human—natural systems (Liu *et al*. 2007). This is certainly the case with regard to fuelwood harvesting in Bhutan and the Himalayas (Webb and Dhakal 2010). As a general policy, we recommend increased use of fuelwood in Nasiphel and other Bhutanese communities where assessments indicate standing stocks and growth rates are sufficient to meet local demands, and complete cessation of fuelwood harvesting in alpine and other ecologically limited areas.

Fuelwood has been a valuable resource throughout the world for centuries and will remain important as interest in renewable energy grows (Hall and Scrase 1998; Richter *et al*. 2009). Fuelwood resources in Bhutan are abundant and expanding throughout much of the country and are less expensive than imported fossil fuels. In addition, managed harvesting could assist Bhutan achieve its goal of becoming carbon neutral by 2020. Advanced wood combustion technologies are increasingly providing heating, cooling, and electrical power generation, while simultaneously reducing greenhouse gas emissions in Europe (Richter *et al*. 2009). Bhutan's forest resources and growth rates are greater than Europe's and its population density lower which suggests that the country could meet much of its energy needs through wood. This study suggests that increased fuelwood harvesting is feasible and perhaps even desirable in some areas, pending site-specific assessments of biomass availability and growth/yield. In these situations, managed fuelwood harvesting could meet household energy needs, improve rural economic conditions, enhance tree growth and vigor, reduce the risk of forest fires, and contribute to conservation and carbon emission reduction objectives.

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References

Ali, J., and Benjaminsen, T.A. (2004). Fuelwood, Timber and Deforestation in the Himalayas: The case of Basho Valley, Baltistan Region, Pakistan. Mountain Research and Development 24: 312–318.

Arnold, M., and Persson, R. (2003). Reassessing the Fuelwood Situation in Developing Countries. International Forestry Review 5: 379–383.

Bari, M.N., Hall, D.O., Lucas, N.J.D., and Hossain, S.M.A. (1997). Biomass Energy use at the Household Level in two Villages of Bangladesh: Assessment of Field Methods. Biomass and Bioenergy 15: 171–180.

Bhatt, B.P., and Sachan, M.S. (2003). Firewood Consumption Along an Altitudinal Gradient in Mountain Villages of India. Biomass and Bioenergy 27: 69–75.

Bhatt, B.P., Sarang, S.K., and De, L.C. (2009). Fuelwood Characteristics of Some Firewood Trees and Shrubs of Eastern Himalaya, India. Energy Source, Part A: Recovery, Utilization, and Environmental Effects 32: 469–474.

Broadhead, J.S., Bahdon, J., and Whiteman, A. (2001). Past Trends and Future Prospects for the Utilization of Wood for Energy. Global Forest Products Outlook Study Working Paper No.5. FAO, Rome.

Cannon, P.F., Hywel-Jones, N.L., Maczey, N., Norbu, L., Samdrup, T., and Lhendup, P. (2009). Steps Towards Sustainable Harvest of *Ophiocordyceps sinensis* in Bhutan. Biodiversity Conservation 18: 2263–2281.

Chettri, N., and Sharma, E. (2009). A Scientific Assessment of Traditional Knowledge on Firewood and Fodder Values in Sikkim, India. Forest Ecology and Management 257: 2073–2078.

Chettri, B.B., Schmidt, K., and Gilmour, D. (2009). Community Forestry in Bhutan-Exploring Opportunities and Facing Challenges. Paper Presented in the Community Forestry International Workshop, Pokhara, Nepal, 15–18th September, 2009.

CIFOR (2003). Fuelwood Revisited: What has Changed in the Last Decade? CIFOR Infobrief No.6. Bogor, Indonesia.

Dhital, D.B. (n.d). National Forest Products Statistics-Bhutan. FRDD. Downloaded from http://www.fao.org/DOCREP/005/AC778E/AC778E08.htm#5913.

Dovie, D.B.K., Witkowski, E.T.F., and Shackleton, C.M. (2004). The Fuelwood Crisis in Southern Africa-Relating Fuelwood use to Livelihoods in a Rural Village. GeoJournal 60: 123–133.

Eckholm, E. (1975). The Deterioration of Mountain Environments. Science 189: 764–770.

FAO. (1997). Regional Study on Wood Energy Today and Tomorrow in Asia. Field Document No.50. Bangkok, Thailand.

FAO. (2008). Forests and Energy, Key Issues, FAO Forestry Paper 154, Rome.

FAO. (2010). Criteria and Indicators for Sustainable Woodfuels. FAO Forestry Paper 160, Rome.

Ghilardi, A., Guerrero, G., and Masera, O. (2009). A GIS-Based Methodology for Highlighting Fuelwood Supply/Demand Imbalances at the Local Level: A Case Study for Central Mexico. Biomass and Energy 33: 957–972.

Gregory, S.A., Hyde, W.F., and Kanel, K.R. (1999). Nepali Fuelwood Production and Consumption: Regional and Household Distinctions, Substitution and Successful Intervention. Journal Development Studies 35: 138–163.

Hall, D.O., and Scrase, J.I. (1998). Will Biomass be the Environmental Friendly Fuel of the Future? Biomass and Bioenergy 15: 357–367.

Heltberg, R., Arndt, T.C., and Sekhar, N.U. (2000). Fuelwood Consumption and Forest Degradation: A Household Model for Domestic Energy Substitution in Rural India. Land Economics 76: 213–232.

IEA. (2006). World Energy Outlook 2006. Paris.

Ives, J. (2004). Himalayan Perceptions. Routledge, London.

Katel, O., and Schmidt-Vogt, D. (2011). Use of Forest Resources by Residents of Jigme Singye Wangchuck National Park, Bhutan. Mountain Research and Development 31: 325–333.

Koopmans, A. (2004). Biomass Energy Demand and Supply for South and South-East Asia-Assessing the Resource Base. Biomass and Bioenergy 28: 133–150.

Liu, J., Linderman, M., Ouyang, Z., An, L., Yang, J., and Zhang, H. (2001). Ecological Degradation in Protected Areas: The Case of Wolong Nature Reserve for Giant Pandas. Science 292: 98–101.

Liu, J., Dietz, T., Carpenter, S., Alberti, M., Folke, C., Moran, E., Pell, A., Deadman, P., Kratz, R., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C., Schneider, S., and Taylor, W. (2007). Complexity of Coupled Human and Natural Systems. Science 317: 1513–1516.

Macht, C., Axinn, W.G., and Ghimire, D. (2007). Household Energy Consumption: Community Context and the Fuelwood Transition. Population Studies Center, Report 07-629. University of Michigan, Institute for Social Research, Ann Arbor, Michigan.

MoA. (2006). Forest and Nature Conservation Rules of Bhutan, 2006. Ministry of Agriculture, Thimphu, Bhutan.

MoA. (2009a). RNR Sector Tenth Plan (2008–2013): Enabling Farming Communities to Overcome Poverty. Vol I. Main Document. Ministry of Agriculture, Thimphu, Bhutan.

MoA. (2009b). Bhutan Biodiversity Action Plan, 2009. NBC, Ministry of Agriculture, Thimphu, Bhutan.

MoA. (n.d.). Volume Tables for Blue Pine. Forest Resources and Management Division, Department of Forest and Park Services, Ministry of Agriculture. Thimphu, Bhutan.

NSB (National Statistics Bureau). (2009). Statistical Year Book of Bhutan, Royal Government of Bhutan, Thimphu, Bhutan.

NSSC and PPD. (2011). Bhutan Land Cover Assessment 2010 (LCMP-2010). Ministry of Agriculture and Forests. Thimphu, Bhutan.

Palmer, C., and Macgregor, J. (2009). Fuelwood Scarcity, Energy Substitution, and Rural Livelihoods in Namibia. Environment and Development Economics 14: 693–715.

Pandey, D. (2002). Fuelwood Studies in India: Myth and Reality. Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Pattanayak, S.K., Sills, E.O., and Kramer, R.A. (2004). Seeing the Forest for the Fuel. Environment and Development Economics 9: 155–179.

Phuntsho, S., Schmidt, K., Kuyakanon, R., and Temphel, K.J. (eds.) (2011). Community Forestry in Bhutan: Putting People at the Heart of Poverty Reduction. Ugyen Wangchuck Institute for Conservation and Environment and Social Forestry Division, Ministry of Agriculture, Royal Government of Bhutan. Thimphu, Bhutan.

Rawat, Y.S., Vishvakarma, S.C.R., and Todaria, N.P. (2009). Fuelwood Consumption Pattern of Tribal Communities in Cold Desert of Lahaul Valley, North-Western Himalaya, India. Biomass and Energy 33: 1547–1557.

Richter, D., Jenkins, D., Karakash, J., Knight, J., McCreery, L., and Nemestothy, K. (2009). Wood Energy in America. Science 323: 1432–1433.

Sharma, B., and Banskota, K. (2005). Women, Energy and Water in the Himalayas- Incorporating the Needs and Roles of Women in Water and Energy Management Project Learning. UNEP and ICIMOD, Kathmandu, Nepal.

Siebert, S. and Belsky, J. (2013). Household Fuelwood Security in Bhutan: Towards Energy Independence and Sustainable Livelihoods and Landscapes. Paper Presented At: International Symposium on Society and Resource Management, June 4–8, 2013, Estes Park, CO, USA.

Siebert, S., Belsky, J., Wangchuk, S., and Riddering, J. (2014). The end of Swidden in Bhutan: implications for forest cover and biodiversity. In Cairns, M. (ed.), Shifting Cultivation and Environmental Change: Indigenous People. Agriculture, and Forest Conversion, Earthscan, London.

Singh, N. and Sundriyal, R. (2009). Fuelwood, Fodder Consumption and Deficit Pattern in Central Himalayan Village. Nature and Society 7(4): 85–88.

Singh, G., Rawat, G.S., and Verma, D. (2009). Comparative Study of Fuelwood Consumption by Villagers and Seasonal Dhaba Owners in the Tourist Affected Regions of Garhwal Himalaya, India. Energy Policy 38: 1895–1899.

Uddin, S.N., Taplin, R., and Yu, X. (2006). Energy, Environment and Development in Bhutan. Renewable and Sustainable Energy Reviews 11: 2083–2103.

Webb, E.L., and Dhakal, A. (2010). Patterns and Drivers of Fuelwood Collection and Tree Planting in a Middle Hill Watershed of Nepal. Biomass and Energy 35: 121–132.