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Social and Ecological Consequences of Commercial Harvesting of Oak for Firewood in Bhutan

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*Oak (*Quercus *spp.) is an important commercially harvested firewood resource in Bhutan. An oak firewood shortage began in 2000–2009, when demand, spurred by urban domestic and institutional use, began to exceed supply, resulting in overcutting of oak-dominant forest, which affected tree species diversity. This study solicited urban and rural perceptions on oak firewood availability, alternative firewood sources, and whether harvest is consistent with oak conservation, and conducted an assessment of the consequences of commercial oak firewood harvest for species diversity and regeneration. Semistructured interviews and focus group discussions were conducted, and regeneration was sampled on unharvested and commercially harvested oak firewood stands. Urban and rural respondents reported that the oak firewood supply was diminishing. Rural respondents said that oak firewood, leaf litter, fodder, and wood for handles for agricultural implements were abundantly available in the past but that, with the increase in population, these products have become less available, a trend that is likely to continue in the future. Urban respondents overwhelmingly chose electricity as an oak firewood substitute because it was associated with clean energy, improved sanitation, and forest conservation. Electricity should be promoted as an oak firewood substitute in urban homes. Oak as a source of firewood, leaf litter, fodder, and handles for agricultural implements is indispensable for sustaining rural livelihoods, and harvest consistent with conservation needs to be practiced. Tree species diversity and regeneration were not significantly higher in unharvested stands compared to harvested stands, indicating that oak firewood harvest may not have impacted species diversity. The findings support banning commercial harvesting of green oak trees for firewood and promoting electricity as an alternative energy source as the most important oak conservation measures.*

Keywords: *Oak; commercial felling; oak firewood substitute; regeneration; tree species diversity; Bhutan.*

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Introduction

Fuelwood is one of the main sources of energy for 69% of the rural population in Bhutan (DoE 2009). In 2005, a total of 725 metric tons of fuelwood, constituting 58% of the total energy supply, was consumed in Bhutan—one of the highest per capita fuelwood consumption quantities in the world (DoE 2009). Oak (*Quercus* spp.) is a commercially important firewood tree species growing in warm broadleaf forests, evergreen oak forests, and cool mixed broadleaf forests at different altitudes in Bhutan. Oak species include *Quercus glauca*, *Q. thomsoniana*, *Q. lanata*, *Q. semiserrata*, *Q. leucotrichophora*, *Q. lamellosa*, *Q. griffithii*, *Q. semecarpifolia*, *Q. senescens*, *Q. oxyodon*, and *Q. acutissima* (Grierson and Long 1983). Oak firewood is commonly used for heating and cooking in urban and rural homes due to its high calorific value and accessibility (Baskota 1998; Moktan 2010). The commercial price at Thimphu increased from US\$9/m^3 in 1998 to US\$14/m^3 in 2001 (Moktan et al 2003). Its cracking, splitting, and sawing difficulties, however, lower its value in the domestic market. Oak fodder is also used as cattle feed, leaf litter is spread as ground bedding for cattle, and when the latter decomposes along with cow dung, it is then used as compost for fertilization in agriculture (Roder et al 2003). According to Norbu and Floyd (2004), oak leaf litter has a low carbon:nitrogen ratio, which leads to more rapid decomposition and release of nutrients (eg nitrogen) compared to conifer leaf litter. Owing to more rapid decomposition and soil fertility retention, farmers from the western Himalayas also use oak compost instead of inorganic fertilizers (Makino 2011).

In Bhutan, the oak firewood shortage dates to 2000–2009, when demand exceeded supply, primarily fueled by urban expansion and institutional use of oak firewood. Oak-dominant forests were overcut, resulting in a change in species diversity with oak gradually replaced by conifer species (Dhital and Wangchuk 1998; Tashi and Thinley 2008). Singh et al (1984) reported that oak forest, because of cutting and burning, was replaced in vast areas by pine forest, resulting in changes in tree species diversity in the

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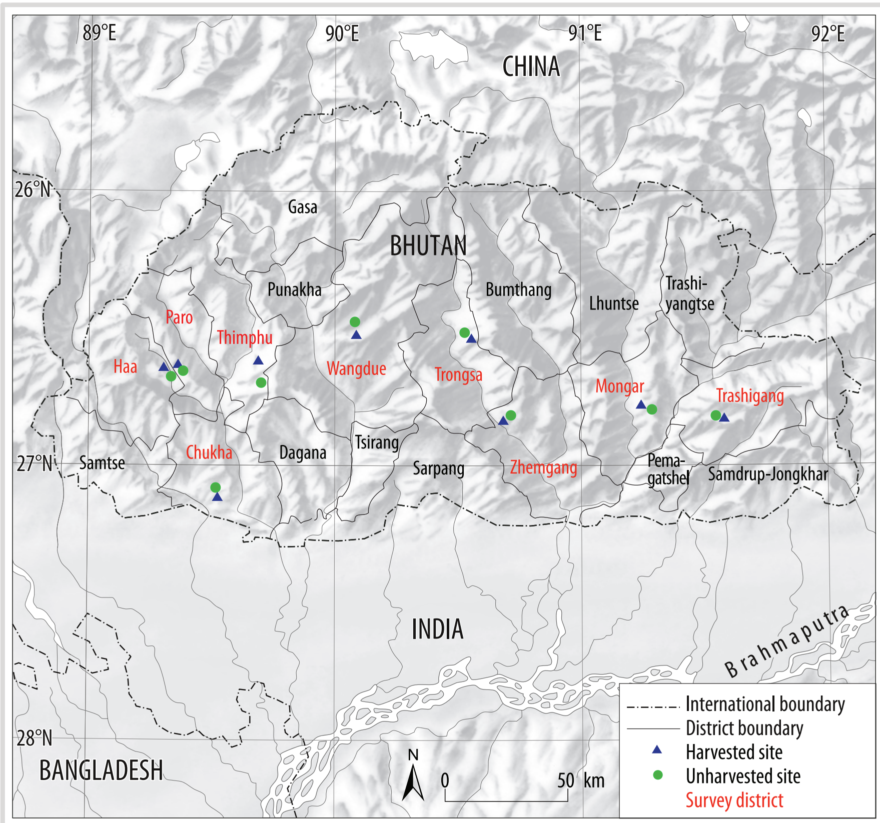
FIGURE 1 Location of the study areas in Bhutan. The urban centers and villages surveyed are all located near the sampled oak forest sites. (Map by Andreas Brodbeck [†] and Mani Ram Moktan)



central and western Himalaya. They also found that although replacement of oak by pine is common, the reverse has not been observed.

Forest grazing is widely considered to negatively affect the natural regeneration of broadleaf tree species in Bhutan (Norbu 2000). The uncontrolled and repeated grazing of oak seedlings by free-ranging cattle has caused regeneration failure in oak-dominant forest in eastern Bhutan (Davidson et al 1999), but positive effects of forest grazing have also been documented (Darabant et al 2007). Others have argued that timber harvesting and moderate grazing can be combined without any negative impact on broadleaf forest regeneration (Buffum et al 2008).

Driven by overharvesting of oak-dominant forest for commercial firewood use, the decline of oak forests has become obvious around urban centers in Bhutan. As a result, policymakers have become concerned about commercial harvesting of oak firewood, particularly for heating in urban homes and public institutions, and have asked forest managers and researchers to provide evidence for informed decision making. This study solicited urban and rural perceptions of the availability of oak products in the past, present, and future; oak firewood substitutes; and whether harvest is consistent with oak conservation. It also assessed the consequences of commercial oak firewood harvesting on regeneration and species diversity of oak forests in Bhutan.

Methods

Study area

Oak-dominant forest around urban centers in Chukha, Haa, Mongar, Paro, Thimphu, Trashigang, Trongsa, Wangdue, and Zhemgang Districts in Bhutan were identified as study sites in consultation with local forest offices (Figure 1; *Supplemental data*, Table S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00113.S1). These oak forests were commercially harvested to meet rising urban population demand from 2000–2009. The National Statistical Bureau of Bhutan reported a 2005 population of 634,982 and projected growth to 886,523 by 2030 (NSB 2012). This population is concentrated in major urban centers. Thimphu District had the highest population in 2005 (98,676), followed by Chukha (74,387), Trashigang (51,134), Mongar (37,069), Paro (36,433), and Wangdue (31,135). Estimated population growth rates (urban versus rural) are 1.4% versus 0.9% for Thimphu, 1.1% versus 0.9% for Chukha, 1.4% versus 1.2% for Trashigang, 1.6% versus 1.5% for Mongar, 1% each for Paro, 1.8% versus 1.2% for Wangdue, and 1.7% versus

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TABLE 1 Respondents by gender.

	Men	Women	Total
Urban			
Chukha	4	1	5
Haa	7	3	10
Mongar	9	0	9
Paro	7	0	7
Thimphu	6	0	6
Trashigang	8	0	8
Trongsa	7	3	10
Wangdue	3	1	4
Zhemgang	5	3	8
Rural			
Barsong	13	0	13
Bjena	9	1	10
Bongo	4	5	9
Chamgang	9	4	13
Chelela	9	1	10
Dorjigonpa	9	3	12
Gempong	9	1	10
Kilikhar	2	8	10
Lamjokatsho	9	3	12
Total	129	37	166

1.3% for Trongsa; the national average is 1.3% (NSB 2012). Urban populations continue to grow more quickly than rural populations, placing pressure on the nearby forests. People living in the study areas belong to the Drukpa and Sharchop ethnic groups.

Within these study districts, temperate evergreen oak forest occurs at elevations ranging from 1800–2600 meters above sea level (masl), and composition varies according to climate and rainfall. With increasing dryness, xerophytic oak (*Q. lanata*, *Q. griffithii*, and *Q. semecarpifolia*) appears; *Q. lamellosa* is found in moist temperate forests at higher elevations (Grierson and Long 1983). These oak species have been commercially harvested for firewood.

In the urban areas, the economy is semicommercial, while in rural areas, it is predominantly based on subsistence agriculture. Major land uses are forest, wetland, dryland, orchard, grazing land, and farm land; agricultural crops include paddy rice, maize, potato, wheat, and buckwheat; livestock include cattle, pigs, and poultry.

Most climate stations are located in valleys. The valleys are drier than the uphill forested slopes (Schweinfurth and Schweinfurth-Marby 1975). For example, at Bumthang, in central Bhutan, the annual precipitation in the valley was 795 mm/y at 2600 masl and 1164 mm/y at 2940 masl (Chhetri and Dorji 2000). As weather stations are installed in valleys and not on higher slopes, a similar valley slope gradient was assumed for the study sites, based on Schweinfurth and Schweinfurth-Marby (1975).

Participatory rural appraisal

Household interviews: Semistructured household questionnaires were administered to urban and rural interviewees by a multidisciplinary team consisting of foresters and farming system and extension personnel in July–December 2010. Respondents lived in the urban centers of Chukha, Haa, Mongar, Paro, Thimphu, Trashigang, Wangdue, Trongsa, and Zhemgang and the rural areas of Barsong, Bjena, Bongo, Chamgang, Chelela, Dorjigonpa, Gempong, Kilikhar, and Lamjokatsho in the corresponding districts. The urban centers are district headquarters, while the rural areas are small villages located at the outskirts of urban centers within the districts. Altogether, 166 respondents—129 men and 37 women—were interviewed (Table 1). The unbalanced gender distribution of the respondents was not purposive. The average age of respondents was 41 years for urban men, 20 years for urban women, 43 for rural men, and 36 for rural women. Household lists on file with the administrative heads of the study sites were used as a sampling frame, and households were chosen at random for interview. Heads of households who usually make decisions on behalf of family members were interviewed. Questionnaires were designed to solicit perceptions on oak firewood availability, oak firewood substitutes, and whether harvest is consistent with oak conservation.

Focus group discussions: Rural perceptions of oak product availability in the past, present, and future and of different oak firewood substitutes were solicited through focus group discussions using charts. The key informants were middle-aged to elderly men and women with historical knowledge of oak forest use. Oak firewood substitutes were ranked in the order of preference, with participants using stones to communicate their choices. In total, 9 focus groups, each with 7 participants, were consulted.

Regeneration sampling

The consequence of commercial oak firewood harvest on species composition and regeneration was examined in July–December 2010 by vegetation sampling, in different study sites, in 2 adjacent oak-dominant forest plots, one commercially harvested and one unharvested, in consultation with local forest offices. For this study, unharvested stands are defined as natural stands where no commercial or noncommercial timber harvest has

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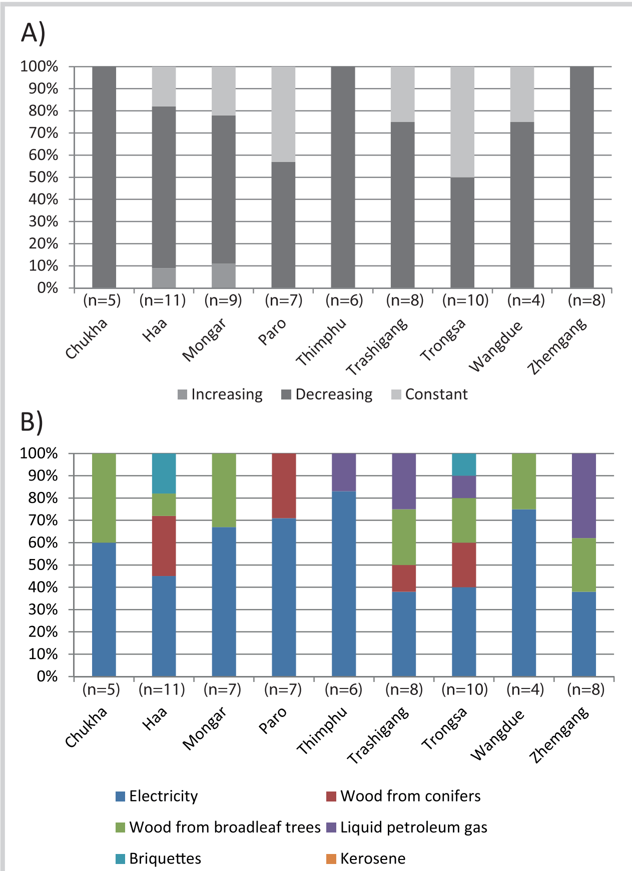
FIGURE 2 Urban perceptions of the availability of oak firewood (A) and of substitutes for oak firewood (B).



occurred, or forest stands preserved for ecological or educational purposes within and outside forest management units, or old-growth multicohort stands with canopy cover >75%. Harvested stands are defined as forest stands where commercial firewood harvest has occurred within the last 10 years and canopy cover is <10%. Within these plots, all naturally regenerating seedlings and saplings (>2.5–10 cm height) and trees (>10 cm diameter at breast height, ie 1.3 m) were enumerated by species in 10 × 10 m plots. Altogether, 18 plots (9 unharvested and 9 harvested) were sampled. The Shannon (1948) index was used to characterize tree species diversity using the formula

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

where H = index of species diversity and p_i = (number of individuals of one species/total number of individual species in the plot).

Data analysis

Frequencies and percentages were calculated from the responses of urban and rural participants to questions about their perceptions of oak firewood availability, oak firewood substitutes, and whether harvest is consistent with oak conservation. Seedling densities from 2 independent samples were compared using the nonparametric Mann–Whitney U test (Z) between unharvested and harvested stands and using SPSS 16.0 (SPSS 2004) for regeneration data analysis.

Results

Oak firewood availability and substitutes

Across the 9 urban centers, oak firewood availability was perceived as diminishing (Figure 2A). All respondents in Thimphu, Chukha, and Zhemgang and a majority in Paro (57%), Haa (73%), Wangdue (75%), Mongar (67%), and Trashigang (75%) reported a decrease in oak firewood supplies; respondents in Trongsa reported no change in supply. Urban respondents' perceptions of oak firewood substitutes are given in Figure 2B. At Thimphu, Paro, Haa, Chukha, Wangdue, and Mongar, the majority of respondents said they preferred electricity as a substitute for oak firewood. At Trongsa, Trashigang, and Zhemgang, a substantial minority of respondents chose broadleaf trees other than oak. In Paro and Haa, conifer firewood is also used as oak firewood substitute.

Table 2 presents focus group participants' perceptions of past, current, and likely future rural availability of oak for firewood, leaf litter, fodder, and handles for agricultural implements. (The "current" category refers to 2010–2011.) At Chamgang, Chelela, Lamjokatsho, Bjena, Bongo, Kilikhar, Barshong, and Gempong, oak products were said to be abundantly available in the past with a few exceptions (fodder in Chamgang, leaf litter in Lamjokatsho, leaf litter and fodder in Dorjigonpa). Presently, with some exceptions (fodder at Chamgang, leaf litter at Lamjokatsho, leaf litter and fodder at Dorjigonpa, leaf litter at Kilikher, and leaf litter and fodder at Gempong), participants reported that the availability of other products has declined. They predicted that oak firewood would decrease in the future but that future supplies would remain constant for leaf litter, fodder, and wood for tool handles at Chamgang; fodder and wood for tool handles at Chelela; leaf litter and fodder at Dorjigonpa; fodder at Kilikhar; and fodder and wood for tool handles at Gempong. Rural preferences among oak firewood substitutes and their selection criteria are given in Table 3.

Sustainable oak firewood harvest consistent with conservation

Urban and rural perceptions on whether commercial oak harvest is consistent with conservation are given in Figure 3A. Urban respondents in favor of ending commercial harvesting of green oak trees for firewood were from Thimphu (67%), Paro (86%), Haa (55%), Chukha (60%), Trongsa (70%), Mongar (56%), and Trashigang (50%). At Wangdue and Zhemgang, urban respondents supported sustainable harvesting, that is,

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TABLE 2 Statements during rural focus group discussions on availability of oak for firewood and other uses.

	Barsh-ong	Bjena	Bongo	Cham-gang	Chelela	Dorji-gonpa	Gemp-ong	Kili-kher	Lamjo-katsho
Past (2000–2009)									
Firewood	+	+	+	+	+	+	+	+	+
Leaf litter	+	+	+	+	+	=	+	+	=
Fodder	+	+	+	=	+	=	+	+	+
Tool handles	+	+	+	+	+	+	+	+	+
Current (2010–2011)									
Firewood	–	–	–	–	–	–	–	–	–
Leaf litter	–	–	–	–	–	=	=	=	=
Fodder	–	–	–	=	–	=	=	–	–
Tool handles	–	–	–	–	–	–	–	–	–
Future (2012–2021)									
Firewood	–	–	–	–	–	–	–	–	–
Leaf litter	–	–	–	=	–	=	–	–	–
Fodder	–	–	–	=	=	=	=	=	–
Tool handles	–	–	–	=	=	–	=	–	–

cutting dry and dead oak trees only, whereas in rural areas, Chamgang (77%), Bongo (78%), Bjena (60%), Barsong (92%), Gempong (80%), Dorjigonpa (80%), and Kilikher (60%), respondents suggested sustainable harvesting measures for firewood, fodder, and leaf litter (Figure 3B).

Species diversity and regeneration

Tree species diversity ($Z = -1.585$, $p = 0.113$) and evenness ($Z = -0.527$, $p = 0.598$) were not significantly different (*Supplemental data*, Figure S1; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00113.S1). No significant difference between unharvested and harvested oak stands ($Z = -1.265$, $p = 0.206$) in the number of pooled seedlings per hectare was detected (*Supplemental data*, Table S2; http://dx.doi.org/10.1659/MRD-JOURNAL-D-12-00113.S1). The unharvested stands, however, tended to harbor more seedlings per hectare than harvested stands, with the exception of Dorjigonpa and Barshong.

Discussion

The diminishing oak firewood supply is attributed to increased demand driven by the wood's high calorific value, needed to combat cold winters in urban centers such as Thimphu, which has an annual minimum temperature of −3.3°C (Dhital and Wangchuk 1998). In an oak-abundant district like Trongsa, there was no shortage of firewood. Urban respondents clearly preferred electricity as an oak firewood substitute because of the clean energy it provides for cooking, the improvement it offers to household sanitation, and its cost-effectiveness (FAO 1991). Thus, electricity should be promoted as energy for all purposes in urban centers. The use of conifer firewood as a substitute for oak firewood should continue during cold winters in conifer-abundant districts.

Rural respondents recollected that oak products were abundantly available in the past due to the lack of passable roads and the smaller population. At present, however, the availability of many oak products has diminished because of the increase in population and accessibility, and the shortage of oak firewood is expected to continue in the future. Shortage of leaf litter arises due to collection for animal bedding and fertilizer use (Roder et al 2003), particularly in apple orchards and on dryland in valleys (Moktan 2010). At Dorjigonpa, leaf litter and

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TABLE 3 Rural preferences and selection criteria for oak firewood substitutes.

Location	First choice	Second choice	Third choice	Fourth choice	Fifth choice
Chamgang	*Electricity* • Saves forest • Clean energy • Easy to heat with	*Picea spinulosa* • Hard conifer • More heat • Accessible	*Pinus wallichiana* • Easy to split • Easy to light • Accessible	*Abies densa* • Less smoke • Easy to split • Easy to light	*Tsuga dumosa* • Hard conifer • Less smoke • Accessible
Chelela	*Tsuga dumosa* • Hard conifer • Accessible • Less smoke	*Abies densa* • Easy to split • No sparks • Less smoke	*Picea spinulosa* • Easy to split • Less smoke • Fewer sparks	*Pinus wallichiana* • Easy to split • Accessible • Easy to light	*Electricity* • Fluctuates • Easy to heat with • Less affordable
Lamjokatsho	*Electricity* • Clean energy • Low cost • Eases housework	*Tsuga dumosa* • More heat • Less smoke • Easy to split	*Picea spinulosa* • More heat • Easy to split	*Pyrus* sp. • Less smoke • More heat • Easy to collect	*Castanopsis hystrix* • Hard wood • Less smoke • Easy to collect
Bongo	*Electricity* • Easy to heat • Clean energy • Saves forest	*Schima wallichii* • Hard wood • Less smoke • Accessible	*Castanopsis hystrix* • Hard wood • Easy to split • Fast growing	*Pinus wallichiana* • Fast growing • Hard wood • Less smoke	*Alnus nepalensis* • Coppices • Hard wood • Easy to split
Bjena	*Castanopsis hystrix* • Hard wood • Abundant • Easy to split	*Pinus wallichiana* • Light wood • Abundant • Easy to split	*Alnus nepalensis* • Fast growing • Accessible • Light	*Electricity* • Fluctuates • Clean energy • Powers machines	*Liquid petroleum gas* • Smokeless • Clean energy • Eases housework
Dorjigonpa	*Lyonia ovalifolia* • Hard wood • Accessible • Dries quickly	*Castanopsis hystrix* • Straight fiber • Easy to split • More heat	*Salix babylonica* • Coppices • Dries quickly • Accessible	*Alnus nepalensis* • Easy to cut • Light wood • Less smoke	*Symplocos lucida* • Easy to cut • Easy to light • Light wood
Kilikher	*Carpinus* sp. • More heat • Good firewood • Abundant	*Persea* sp. • Hard wood • More heat • Abundant	*Castanopsis hystrix* • Accessible • Easy to split	*Pinus roxburghii* • Accessible • Easy to split • Easy to light	*Canarium strictum* • Hard wood • Accessible • Good firewood
Barshong	*Schima wallichii* • Accessible • Coppices • Fast growing	*Castanopsis hystrix* • Dries quickly • Coppices • Easy to light	*Symplocos lucida* • Coppices • More biomass • Easy to split	*Lyonia ovalifolia* • Good firewood • Good charcoal • Fast growing	*Salix babylonica* • Easy to split • Dries quickly • More biomass
Gempong	*Myrica esculanta* • Hard wood • Dries quickly • More biomass	*Castanopsis indica* • Straight fiber • Easy to split • Light weight	*Lithocarpus elegans* • Easy to split • Bark can be used as firewood • Straight bole	*Castanopsis hystrix* • Hard wood • Easy to light • Less smoke	*Beilschmiedia gammieana* • Inaccessible • Frequent insect damage • Soft and quick burning

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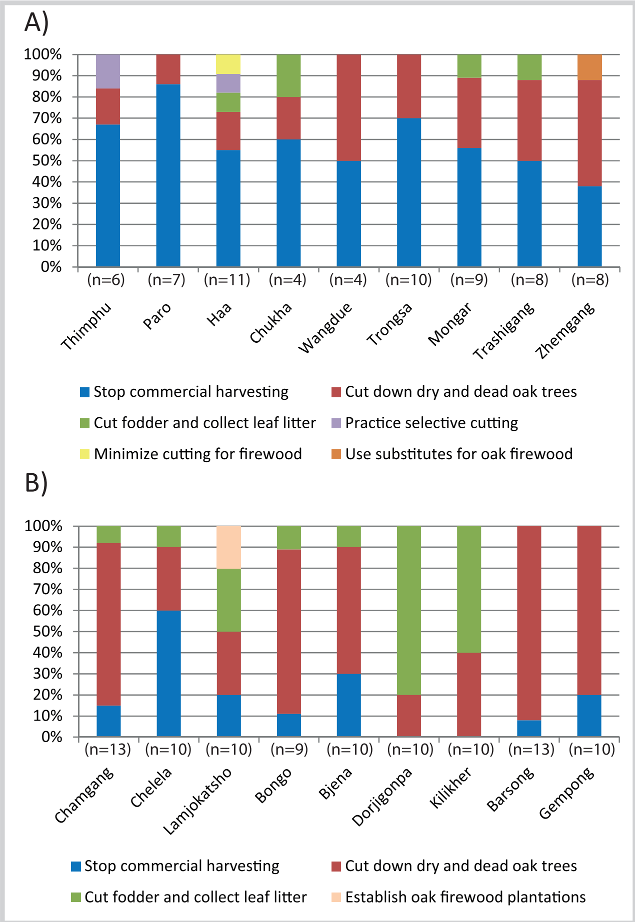
FIGURE 3 Urban (A) and rural (B) perceptions of sustainable oak harvest practices consistent with conservation.



fodder availability have neither increased nor decreased due to the smaller population. Rural households also use oak for the handles of agricultural implements, and they say that wood from other species is not a viable substitute. Makino (2011) reported that fresh green oak foliage as cattle fodder is essential for sustaining agricultural livelihoods in rural communities in Garhwal, India. This clearly indicates that oak products are indispensable for rural livelihoods. In rural areas without electricity, use of conifer and broadleaf trees continues due to their accessibility, ease of splitting, and cost-effectiveness (FAO 1991). For heating rural homes, however, electricity may be expensive, and a price reduction according to consumers' purchasing power is desirable. Until rural households are electrified, cutting of dead trees and collection of dry branches and twigs need to be allowed and monitored carefully.

The fact that there were no significant differences in species diversity and regeneration between unharvested and harvested stands may be due to the natural process of small gaps created by natural tree fall, allowing sunlight to reach the forest floor, thereby creating microsites conducive to regeneration, mortality, and regrowth (Davidson et al 1999; Davidson 2000). According to findings by Moktan et al (2009), commercial harvest has no significant impact on tree species diversity in the mixed conifer with broadleaved forests of Bhutan. Similarly, Tashi and Thinley (2008) reported that canopy opening from firewood harvest may not reduce regeneration of light-intolerant *Q. semecarpifolia* seedlings in Gidakom forests. After clear-cut logging, however, oak stands were found to be colonized by commercially less important, nonpalatable pioneer tree species and shrubs in moist sites only in eastern Bhutan (Davidson 2000). This study's findings suggest that oak firewood harvest for commercial use may not have reduced species diversity. However, owing to the limited number of sample plots and the fact that no significant regeneration difference was found, further studies are warranted.

However, oak forests in neighboring Nepal and India have also been reportedly degraded due to various anthropogenic disturbances (Shrestha 2003; Måren and Vetaas 2007; Singh and Rawat 2010). Considering that oak forests are intricately associated with the agroecosystem and life-support system of the inhabitants of Bhutan, harvest and regeneration should be consistent with conservation of oak forests in mountainous Himalayan countries, including parts of Nepal and India. Old-growth oak forests should be conserved as ecological reserves for research, education, and carbon sequestration. Young, healthy, and mature high-density oak stands should be managed under a sustainable harvest and regeneration system to produce firewood, leaf flitter, fodder, and wood to sustain rural livelihoods. In this context, our results may be transferable to other Himalayan countries for making informed decisions on oak forest conservation that promote sustainable harvest and sustainable management.

Conclusion

The study found a diminishing supply of oak firewood available for heating urban homes due to increased demand. Electricity is the preferred substitute fuel in urban homes because of clean energy, improved household sanitation, and forest conservation. For rural communities, oak firewood, leaf litter, fodder, and wood for handles for agricultural implements were abundantly available in the past; however, with the increase in population, shortages of these products have been experienced and are likely to continue in the future. Electricity should be subsidized to replace oak firewood gradually for cooking and heating in rural homes. Oak forests are indispensable for sustaining rural livelihoods, and harvest consistent with conservation should be continued. For adequate oak conservation measures, the findings support, first, banning commercial felling of green oak trees for urban firewood, and second, promoting electricity as an alternative energy.

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Supplemental data

TABLE S1 Selected oak-growing sites in Bhutan, with location and geophysical and climate characteristics.
TABLE S2 Number of seedlings per hectare in unharvested and harvested oak stands (mean ± sd).
FIGURE S1 Species diversity and evenness in unharvested and harvested oak stands.

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