Int J Primatol
DOI 10.1007/s10764-011-9535-6

How Human Household Size Affects the Habitat of Black-and-White Snub-Nosed Monkeys (*Rhinopithecus bieti*) in Hongla Snow Mountain Nature Reserve in Tibet, China

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Received: 9 October 2010 / Accepted: 9 May 2011

Abstract Human impacts on the environment at local or regional scales largely depend on intrinsic characteristics of the population, such as household size, household number, and human population growth. These demographic factors can vary considerably among ethnic groups sharing similar ecological landscapes, yet the role of traditional cultural practices in shaping local environmental impacts is not well known for many parts of the world. We here quantify land-cover changes and their relation to the habitat of the endangered *Rhinopithecus bieti* in Tibet, in 2 areas populated by different ethnic groups (polyandrous Tibetans and monogamous Naxi) from 1986 to 2006. Results indicate that habitat of the monkey decreased greatly within our study area over the 20-yr period. Polyandrous and monogamous ethnic communities differed in household size, household number, population growth, and per capita and per household land use. The practice of polyandry by ethnic Tibetan appears to have reduced per capita resource consumption by reducing the growth of overall household number and increasing household size, which can mitigate the

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Electronic supplementary material The online version of this article (doi:10.1007/s10764-011-9535-6) contains supplementary material, which is available to authorized users.

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Published online: 02 August 2011

negative effects of higher human density and population growth on the environment. Ethnic Tibetan may also reduce land impacts by adhering to Buddhist customs and alternative, more sustainable means of livelihood. Accordingly, the protection of traditional cultural resources, such as polyandry and Buddhist beliefs, could be an effective way to aid biodiversity and environmental conservation efforts in this key ecosystem.

Keywords Environmental degradation · Human polyandry · Land use · *Rhinopithecus bieti* · Traditional cultures

Introduction

The past decades have seen widespread natural and anthropogenic land-cover changes resulting in a strong threat to wildlife habitat and biodiversity (Brooks *et al.* 2002; Forester and Machlis 1996; Meyer and Turner 1994; Vitousek *et al.* 1997). Although some economic policies and opportunities are also associated with land-cover change (Lambin *et al.* 2001), in previous studies, researchers have often used population growth, density, and structure to analyze human–environment interactions (Carr 2004; Chen *et al.* 2009; Liu *et al.* 1999; Thompson and Jones 1999). However, the influence of traditionally polygamous cultures and the consequential relation to population dynamics are rarely considered. In a fraternal polyandrous society in Tibet, brothers in a household typically marry the same woman and live with their parents and grandparents instead of establishing new households (Goldstein 1971). Accordingly, many women remain unmarried, and reside with their families or enter Buddhist nunneries. Thus, the number of households increases more slowly than population size. Historically, this traditional polyandrous system was common throughout the Tibetan region (Editorial Group 1984; Goldstein 1971), and is recognized as an important social adaptation to limited arable land (Goldstein 1981). In recent years, increasing economic opportunities worked to undermine the traditional family structure: Some younger brothers left the traditional polyandrous family to seek nonfarm wage in towns or legally take a share of family land (Goldstein 1981; Goldstein *et al.* 2002; Suo 2009). However, little is known about how the traditional polyandrous Tibetan social structure affects land use and the conservation of wildlife habitat.

An aim of this study is to evaluate and compare patterns of land-cover change within a predominantly polyandrous ethnic Tibetan community and a monogamous Naxi community in Tibet. We studied land-cover changes of a black-and-white snub-nosed monkey (*Rhinopithecus bieti*) habitat in the Hongla Snow Mountain National Nature Reserve (HSMNNR) to determine the impacts of each settlement. We chose the habitat of black-and-white snub-nosed monkey in Tibet for 3 main reasons. First, the monkey is a flagship species that is endemic to the Trans-Himalayas, and categorized as Endangered (C1) on the IUCN Red List of 2010 (IUCN 2010), as the total population estimate for the species is fewer than 1700 individuals (Long and Wu 2006; Long *et al.* 1994; Xiao *et al.* 2003). Second, the monkey is one of a few truly temperate nonhuman primates (Bishop 1979; Oates 1987) with the highest elevation ranges in the world (Zhao *et al.* 1988). Secondary succession of the forest vegetation is slow; thus it is difficult to restore original habitat in this high temperate region once it is lost. Third, the monkeys in Tibet, the northernmost range of the species of *ca.* 300 individuals (Xiang *et al.* 2007a), comprise 1 of the 3 genetically independent subpopulations of this species (Liu *et al.* 2007). Therefore, its habitat in Tibet should be a very high conservation priority to avoid local extinction and preserve genetic diversity of the species.

Constrained by high altitude (>4000 m on average), Tibet (>1.2 million km^2) maintains the lowest human population density (2.2 persons/km^2) and productivity in China (Sa and Cao 2005). Commercial activity and industrialization in Tibet are also very limited. Most Tibetan daily activities and income are directly related to local natural resources, creating a strong relationship between human populations and their environment. In our study area, polyandrous Tibetans and monogamous Naxi live within critical habitat of the highly endangered black-and-white snub-nosed monkeys. We assessed local habitat dynamics of the monkeys in relation to the 2 ethnic groups. We expected the ethnic groups to impact surrounding habitat of the monkeys differently owing to culturally derived differences in population growth rate and associated number of households. In addition, the Tibetan majority in this region believe in the Buddhist creed that encourages respect for all living organisms. The Buddhist belief system has been shown to have a positive influence on environmental conservation elsewhere (Anderson *et al.* 2005; Liu *et al.* 2002; Salick *et al.* 2007).

In addition, we also assessed the effectiveness of HSMNNR (established in 1993 to protect snub-nosed monkeys and their environment, and which delineates our study area) on habitat conservation because the reserves are usually presumed to save biodiversity from human threats (Rodrigues *et al.* 2004; Scott *et al.* 2001). However, few reserves in China have been evaluated after establishment (Xu and Melick 2007). To accomplish these objectives we: 1) assessed changes in population and household size in Tibetan and Naxi villages within the monkeys' range, and explored their relationships to land-cover alteration; and 2) quantified land-cover changes in periods before and after HSMNNR establishment.

Methods

Study Area

The study area measures 75,700 ha within the HSMNNR in southeastern Tibet, located in one of the 34 biodiversity conservation hotspots of the world. The area is in the northwest of the Mountains of Southwest China Hotspot; it lies to the north of the Indo-Burma Hotspot and to the immediate east of the Himalaya Hotspot (Ebert 2005; Mittermeier *et al.* 2005; Fig. 1). The HSMNNR ranges from 2200 m to 5100 ma.s.l. elevation, characterized by extremely complex topography and climate. Dominant vegetation types in the reserve are coniferous forests, evergreen broad-leaf forests, and some deciduous broad-leaf forests and shrubs (Tibet Forestry Survey and Planning Institute 2000).

The Chinese national highway 214 intersects the HSMNNR and serves as a boundary between two human communities: the Xiaochangdu community, where

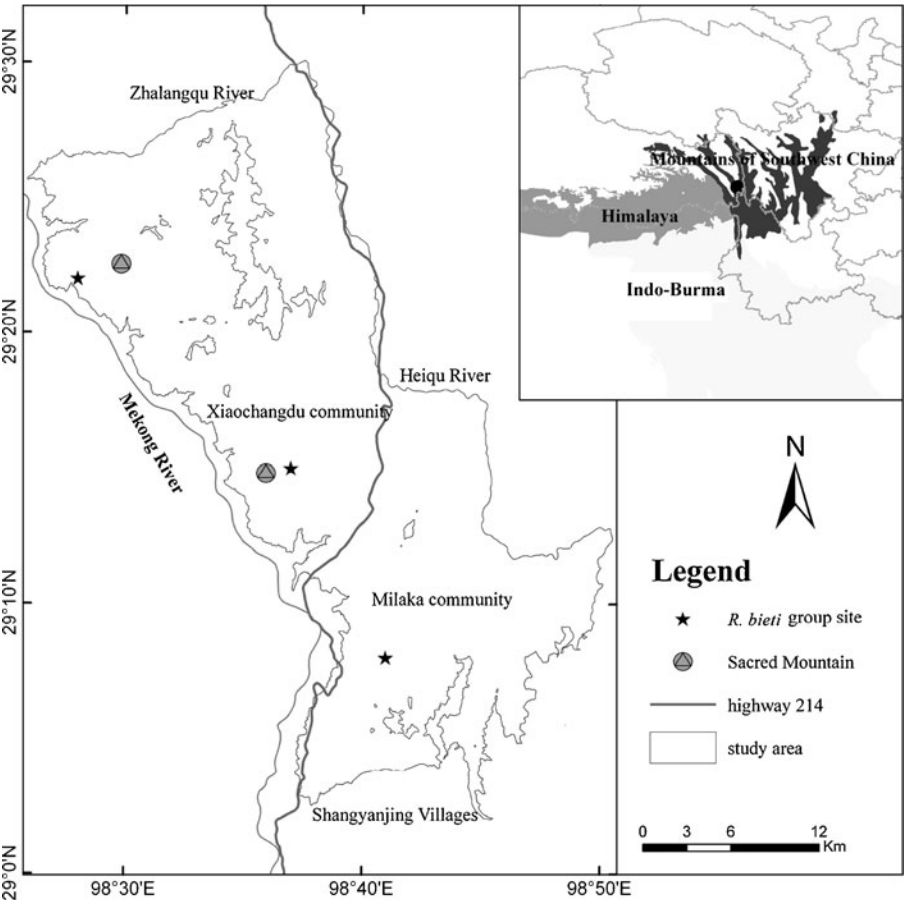

Fig. 1 The study area and its location in relation to 3 world biodiversity hotspots: the Mountains of Southwest China, Indo-Burma, and Himalaya.

residents are ethnic Tibetan and tend toward polyandry; and the Milaka community, where 60% of the residents are Naxi and 40% of the residents are Tibetan, and both groups tend toward monogamy. Two sacred mountains are located to the northwest of the Xiaochangdu settlement, where human impact on the environment is minimized because of religious customs (Fig. 1). Both Xiaochangdu and Milaka communities have permanent settlements up to 4000 ma.s.l. in elevation. The main sources of subsistence are agropastoral systems including cultivation of hulless barley (*Hordeum vulgare* var. *trifurcatum*), grazing of yak and sheep, and collection of caterpillar fungus (*Cordyceps sinensis*). Recently, locals have also begun to trade firewood in a small market that has developed as a result of improved roads.

Land-cover Mapping

The main habitat range for black-and-white snub-nosed monkeys in Tibet is between 3400 m snd 4400 ma.s.l. (determined from previous and present surveys). Therefore, we did not consider drier and warmer valleys <3200 m or alpine and snow-covered areas above timberline (4500 m). We categorized land cover of the study area into 4 types: 1) fir forest (FF), composed mainly of *Picea likiangensis* and *Abies squamata*; 2) evergreen subalpine oak, e.g., *Quercus aquifolioides* and fir-mixed forest (OMF); 3) summer grazing land (SGL); and 4) farmland. Near villages, twigs and leaves of oak trees are routinely collected as fodder for livestock in winter, and OMF was usually cleared by fire to produce pure oak shrubs (see Electronic Supplementary Material Fig. S1), which included more fodder (leaves and twigs) compared with OMF. As far as the monkey habitat is concerned, fir forest (FF) is considered highly suitable and OMF is suitable, whereas SGL and farmland are unsuitable (Ding and Zhao 2004; Kirkpatrick *et al.* 1998; Xiang *et al.* 2007b, 2009).

We used a chronosequence of Landsat images (Path 133, Row 40, 30 m resolution) to characterize land-cover dynamics over a 20-yr period. We chose all Landsat images acquired in the winters of 1986, 1992, 1997, 2001, and 2006 (the image of 2001 is ETM+, and other years' are TM) to map land cover. We use winter images because it is the best season to obtain cloud-free images; summer months in the HSMNNR are characterized by heavy clouds and fog. We geo-referenced all the images to Gauss Kruger coordinates with a root mean square (RMS) <30 m. All of the 4 land-cover categories we defined could be readily identified from winter images. First, we produced 30 spectral clusters using the interactive self-organizing data analysis technique (ISODATA) under Erdas Imagine 9.0 (Leica Geosystems Geospatial Imaging LLC, 2005). Then, we labeled each cluster as FF, OMF, SGL, farmland, or mixed with the aid of field survey data. We labeled a few clusters at the marginal area of FF or OMF, which contained >2 land-cover types due to spectral confusion, as mixed. We reclassified these mixed clusters again using a maximum likelihood classifier or through visual interpretation on the base of field survey data or reliable historical vegetation information in the 1:100,000 relief maps. Lastly, we generated land-cover maps for the years 1986, 1992, 1997, 2001, and 2006.

During our field surveys between 2005 and 2008, we collected suitable samples of ground-truth data, which labeled as different land-cover types in the false color image (band 7, 4, 2 of Landsat TM image in 2006 as RGB) with the aid of handheld GPS. Referencing to the suitable samples, we visually interpreted a stratified sample according to elevation and slope aspect as ground truth data to assess the accuracy of land-cover maps.

Data Analysis

Using FRAGSTATS 3.3 (McGarigal *et al.* 2002), we calculated the following variables of each land-cover type from each of the 5 land-cover maps developed above: 1) total area of each land-cover types (total size) and patch numbers; 2) mean patch area; and 3) largest patch index, calculated by $\mathrm{Max}(a_1, a_2 \ldots, a_n)/A \times 100\%$: a_i is the area of patch i; A is total area of certain land-cover type. We further calculated changes of these variables to measure habitat changes over 4 periods (1986–1992, 1992–1997, 1997–2001, and 2001–2006, separated by the time of each satellite image obtained). We expressed changes as annual change to allow comparisons among these periods. We selected data of 1986–1992 to represent habitat conditions immediately preceding the establishment of the nature reserve (1993), to compare land cover during pre- and postestablishment periods.

We obtained demographic data from the Statistical Bureau of Mangkang County (where HSMNNR is located) for 1983–2003, which provided the closest available overlap with our land-cover data. Our 2 field assistants estimated the proportion of polyandry in each community in 2006 based on their accumulated empirical knowledge and discussion with some elders (who are familiar with the family structure in their communities): about 60% of households in Xiaochangdu, and fewer than 20% of households in Milaka were polyandrous. This method was necessary because we were not permitted to conduct direct surveys, and those data were not available from material prepared by the Statistical Bureau of Mangkang County. Surveys (Suo 2009) from adjacent regions imply that our estimation is acceptable. We calculated growth: $\text{human population}(hp) = (hp_{2003} - hp_{1983})/hp_{1983}$; $\text{household number}(hn) = (hn_{2003} - hn_{1983})/hn_{1983}$, both in Xiaochangdu and Milaka communities, and compared land-cover change between communities. The area of SGLs and farmlands per capita and per household for each community represent measures of community contributions to habitat loss because we converted those areas from intact forest.

We calculated Spearman correlation coefficients (r) to test relationships between land-cover change and demographic data (local population, household number). We further used Wilcoxon matched-pairs signed ranks tests to compare growth rate between human population and household number, and land-cover change rate between 2 communities. We calculated data on per-capita and per-household possession of farmland and SGL by dividing farmland and SGL area by the number of households and population size in each community.

Results

Total Land-cover Change

The overall accuracies of land-cover maps for 1986, 1992, 1997, 2001, and 2006 are 0.95, 0.95, 0.94, 0.97, and 0.95, respectively. These accuracies might be over-estimated because the “ground truth data” were typical representations of each land-cover type and we visually interpreted them.

Total forest area within our study area in 2006 was 56,200 ha, consisting of 30,500 ha of FF and 25,700 ha of OMF; the total area of nonforest was 19,500 ha, including 13,100 ha of SGL and 6400 ha of farmland. Over the 20 yr studied (1986–2006), the area of FF (highly suitable habitat for the monkey) decreased 14.6% (5200 ha) at 0.7% per year (258 ha/yr); the area of SGL and farmland increased 47.2% (4300 ha) and 14.3% (800 ha) in total at 2.4% per year (209 ha/yr) and 0.8% per year (44 ha/yr), respectively; and the area of OMF was relatively stable (Table I).

Highly suitable habitat for the monkeys decreased continuously even after the nature reserve was established in 1993 (Table I). The annual loss of FF was 0.9% (327 ha/yr) before the nature reserve was founded in 1993 (1986–1992), and decreased to 0.7% (223 ha/yr, 1992–1997) and 0.4% (124 ha/yr, 1997–2001) after the reserve establishment. Unfortunately, annual FF loss increased to 1.0% (318 ha/yr) between 2001 and 2006.

Table I Annual land-cover changes in the HSMNNR (established in 1993) from 1986 to 2006

Land cover	Annual change in area: ha (%)				
	1986–1992	1992–1997	1997–2001	2001–2006	1986–2006
FF	−327 (–0.9)	−223 (–0.7)	−124 (–0.4)	−318 (–1.0)	−258 (–0.7)
OMF	30 (0.1)	14 (0.0)	−22 (–0.1)	−13 (–0.0)	5 (0.0)
SGL	248 (2.8)	178 (1.7)	112 (1.0)	270 (2.3)	209 (2.4)
Farmland	49 (0.9)	30 (0.5)	34 (0.6)	61 (1.0)	44 (0.8)

FF = fir forest; OMF = oak- and fir-mixed forest; SGL = summer grazing land.

Habitat Fragmentation

Number of Patches From 1986 to 2006, the annual patch number of FF, OMF, and SGL increased 3.4% (from 2370 to 3990), 0.7% (from 5437 to 6226), and 2.3% (from 4022 to 5880) respectively. In contrast, the farmland patches decreased 1.3% annually (from 49 to 36).

Mean Patch Area From 1986 to 2006, the annual mean patch area of FF and OMF decreased 2.5% (from 15.1 ha to 7.6 ha) and 0.6% (from 4.7 ha to 4.1 ha), respectively. The mean patch area of SGL was relatively stable at about 2.2 ha. The annual patch area of farmland increased 2.9% (from 113.6 ha to 179.1 ha).

Largest Patch Index The largest patch index of FF decreased 2.7% annually; however, that of the OMF, SGL and farmland increased 0.5%, 1.7%, and 3.6% annually (respectively) over the 20 yr studied.

Demographic Data and Relation to Land Cover

The total human population and the number of households within the HSMNNR increased 1.4% and 0.4% annually (respectively) from 1983 to 2003. The population growth rate was higher than the growth rate of the number of households, although this difference was not statistically significant (Fig. 2; z=–1.83, p=0.07, n=4). Average household size increased from 5.7 to 6.8 persons from 1986 to 2001. The area of FF decreased with increasing human population and household number, and areas of SGL and farmland increased with increasing population and number of households (Table II).

Community-related Changes in Land Cover

Patterns of human population growth and increases in household number and size differed between the Xiaochangdu (Tibetan) and Milaka (Naxi dominated) communities. In Xiaochangdu, the annual population growth (1.7%) was higher than the annual growth of household number (0.4%) from 1986 to 2001, although this difference was not statistically significant (z=–1.86, p=0.07, n=4). In the Milaka community, there was little difference between the annual population growth (0.4%) and the household number growth (0.3%) from 1983 to 2003 (z=–0.368, p= 0.71, n=4).

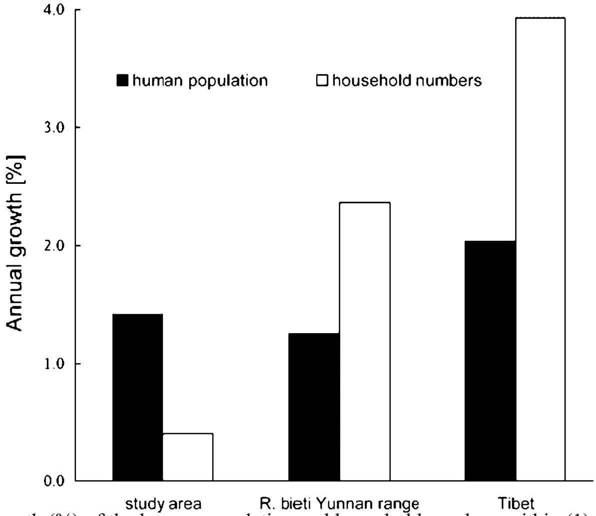

Fig. 2 Annual growth (%) of the human population and household numbers within (1) the study area, (2) the range of black-and-white snub-nosed monkeys in Yunnan, and (3) the whole of Tibet. Human population growth exceeds household number growth only within our study area. The demographic data in the range of the monkeys in Yunnan are cited from *Yunnan Statistical Yearbook* (Statistical Bureau of Yunnan Province 1999, 2007).

From 1983 to 2003, the human density in the Xiaochangdu and Milaka communities increased 33.3% and 7.5% respectively (Table III). The mean household size in the Xiaochangdu community increased 25.0%, whereas it was stable in Milaka community from 1983 to 2003.

In 1986, 40.9% of the total farmland and SGL was within Milaka community in our study area, which increased to 42.1% in 2006, whereas the proportion of total farmland and SGL in Xiaochangdu community decreased from 59.1% in 1986 to 57.9% in 2006. Mean person and household resource consumption (area of farmland and SGL possessed by each person and household) differed in Xiaochangdu and Milaka communities. In 1986 and 2001, the mean area of SGL and farmland possessed by each household (person) in the Xiaochangdu community was 7.9 (1.2) ha and 3.3 (0.5) ha, respectively, significantly less than the average 18.6 (3.1) ha of SGL and 13.9 (2.3) ha of farmland for each household (person) in the Milaka community over the 15-yr period (average household, SGL: $z=-2.02$, $p=0.04$, $n=4$;

Table II Spearman correlation (r) of local human population and household numbers with 4 land-cover types from 1986 to 2006 ($n=5$, 2-tailed)

Land-cover type	Local human population	Household number
FF	−1.00 ($p<0.001$)	−1.00 ($p<0.001$)
OMF	0.10 ($p=0.873$)	0.10 ($p=0.873$)
SGL	1.00 ($p<0.001$)	1.00 ($p<0.001$)
Farmland	1.00 ($p<0.001$)	1.00 ($p<0.001$)

For abbreviations see footnote to Table I.

Table III Dynamics of population density and mean household size in Xiaochangdu and Milaka communities (1983–2003)

Community	Human density (persons/km^2)			Mean household size		
	1983	2003	Δ (%)	1983	2003	Δ (%)
Xiaochangdu	11.1	14.8	33.3	5.6	7.0	25.0
Milaka	4.0	4.3	7.5	6.1	6.1	0.0

farmland: z=–2.02, p=0.04, n=4; average person, SGL: t=–2.02, p=0.04, n=4; farmland: t=–2.06, p=0.04, n=4).

Discussion

The habitat area of black-and-white snub-nosed monkeys within the HSMNNR in Tibet was continuously reduced and fragmented over the 20-yr study period despite low human density and remoteness from large human settlements. The area of FF (highly suitable habitat of the monkey) decreased by 14.6% (5200 ha), and was replaced by OMF, SGL, and farmland. Local transformation of FF to OMF, SGL, and farmland is achieved by burning the forest in the dry winter (see Electronic Supplementary Material, Fig. S1), and then cutting down residual stumps of the burned forest to ultimately form SGL or farmland. Close to the timberline (4300–4400 ma.s.l.), the loss of FF was usually replaced by SGL. Newly produced SGL merged with surrounding SGL, forming larger patches. A similar pattern occurred in lower elevations (<3800 ma.s.l.), where FF was replaced by farmland, and new farmland merged with neighboring farmland to form larger patches. The expanding farmland resulted in a reduction in total number of farmland patches (26.5%), and an increase in mean patch area (57.7%) and largest patch index (71.4%).

Although our study is within a national nature reserve, the success or failure of many Chinese nature reserves for ecosystem conservation is typically not well monitored or recognized (Liu *et al.* 2001; Xu and Melick 2007). In our study area, the decreasing rates of FF loss immediately after the reserve was established indicate that the reserve was positively affecting FF conservation over that period. Unfortunately, annual FF loss returned dramatically and unexpectedly to a level similar to the period preceding reserve establishment. It appears that conservation-related regulations were enforced or obeyed in the early years, and compliance weakened later on. Some regulations may fail to meet the needs of the local community; thus the effects of policies aimed for nature conservation are not likely to be sustained without conflict (Ervin 2003; Harkness 1998; Xu and Melick 2007).

Differences in land use changes between the Xiaochangdu and Milaka communities observed in this study strongly support the results of Liu *et al.* (1999, 2003), who found that larger household sizes reduce the negative environmental impacts of high human density and lessens demand on natural resources by decreasing their per capita consumption. This conclusion can be illustrated by estimating how much FF would have been preserved if the average household size in the Milaka community had grown at the same rate as in the Xiaochangdu community (25%): there would be 7.6 persons per household in Milaka in 2003 (in fact there were 6.1 persons per household). The same increase in household size would result in 19.3% fewer households in Milaka in 2003. Assuming the per capita nonforest land remained constant over the 20 yr studied (as it did in Xiaochangdu), roughly 1606 ha (or 31.2% of the total FF area lost in the Milaka community over the 20 yr) could have remained as highly suitable habitat of black-and-white snub-nosed monkeys. However, human-related land-cover changes are often complex (Cincotta *et al.* 2000; Holdren and Ehrlich 1974; Thompson and Jones 1999; Veech 2003). Other factors such us migration, tourism, and exploitation of nontimber forest products (NTFPs) also affect land-use decisions and nature conservation (Liu *et al.* 1999; Xiang *et al.* 2007a). In our study area, significant migration, outside investment, and tourism have not obviously affected either community owing to their remoteness and controlled access (both by government policy and local custom), but we did not assess the economic and environmental impacts of NTFP collection, and these could influence land-use decisions within each community. The role of NTFPs in shaping land-use patterns in Tibet should be considered in the future.

Globally, the growth rate of household number is more rapid than that of the population, and this pattern has led to additional concerns for nations containing global hotspots of biodiversity (Liu *et al.* 2003). However, the Xiaochangdu portion of our study site contradicts the global pattern, and growth of household size (rather than number) with population can be attributed to polyandry. As previously mentioned, in polyandrous Tibetan society a portion of women do not marry and spend their lives with their parents or in nunneries, which also reduces population and household growth. Historically, polyandry has been common and generally affirmed and praised by Tibetans; thus the proportion of polyandrous families is higher than that of monogamous families in some areas (Editorial Group 1984). It is widely believed by Tibetans that several brothers marrying 1 wife can create thriving and prosperous families, because the relationship ensures that possessions are not dispersed, labor is consolidated, land is not partitioned among many households, and shared income within the household is higher (Goldstein 1971, 1981). For the environment, this traditional polyandrous custom has served as an effective way to maintain the balance between economic development and sustainable use of natural resources because per capita resource consumption remains low in large polyandrous households. Although men who marry polyandrously may not necessarily lower their individual fitness greatly (Crook and Crook 1988), to maintain a polyandrous family is becoming more difficult, because improved economic conditions and China’s monogamy policy encourage younger males to fission from the polyandrous family (Suo 2009).

Finally, it is of interest that the average amount of land resources possessed by large households in the Xiaochangdu community was significantly less than that of the small households in the Milaka community. This may be linked in part to the sacred mountain beliefs in Xiaochangdu, where natural landscapes and old trees become sanctified; thus all human activities such as enlarging SGL and farmland by burning the FF and poaching wildlife are taboo (Anderson *et al.* 2005; Salick *et al.* 2007). Higher land possession by numerous smaller households in Milaka could also be related to differences in livelihood. Most people in the Milaka community live at a higher elevation (>4000 ma.s.l.), where more income can be obtained from grazing, and farming is likely less productive, increasing the need for more land resources per capita and household.

Conservation Implications

The entire range of the Mountains of Southwest China biodiversity hotspot and nearly half of the Himalaya hotspot are located within the pan-Tibetan region of China (including Tibet and neighboring areas of Gansu, Qinhai, Sichuan, and Yunnan provinces; Fig. 1). To protect the biologically rich yet vulnerable ecosystems in this alpine region, the related regions and countries (the related part of China, Pakistan, India, and Myanmar, and the whole Nepal and Bhutan) have established many nature reserves, covering 126,612 km^2 (an area similar to that of Greece). Despite these efforts, forest cover in the region has unexpectedly undergone rapid degradation during recent years (Wang *et al.* 2008; Xiao *et al.* 2003). Obviously, nature reserves are not necessarily effective for ecosystem conservation (Liu *et al.* 2001; this study; Singh 1996; Thampy 1996), and new alternative measures or policies are needed, such as reviving sacred sites and traditional cultures (Xu and Melick 2007). Our study is perhaps the first to demonstrate that larger households of ethnic Tibetan, as a result of polyandry, may mitigate the negative impacts of humans on their environment, and help conserve the habitat of a critically endangered species. The results presented here support the assertions made by Xu and Melick (2007), who suggest that cultural preservation is likely to be more effective than the establishment of “paper parks” for sustainable habitat conservation. However, some traditional cultures, such as the traditional fraternal polyandrous families, are decreasing with increasing economic activities throughout Tibet (Suo 2009; Zhang 2008). Preserving and reviving traditional culture coupled with sustainable economic development may provide the impetus to protect biodiversity in both the Mountains of Southwest China and Himalaya biodiversity hotspots because the majority of the population in both regions is Tibetan.

Acknowledgments The study was supported by funding of National Nature Science Foundation of China (grant no. 30770308), Committee for Research & Exploration, National Geographic Society of US (grant no. 7962-05), The Nature Conservancy, and the Chinese Academy of Sciences (INFO-115-C01-SDB3-06-02). We thank the Forestry Department of Tibet Autonomous Region, Hongla Snow Mountain Nature Reserve for their enthusiastic support; GLCF for offering remote sense images; and Professor Chen Jin of Xishuangbanna Tropical Botanical Garden, Mr. Wang Lin of Kunming Institute of Zoology, and Dr Xiao Wen of University of Dali for providing important suggestions and technical support. We thank the 2 anonymous reviewers and associate editor, Dr. Oliver Schülke, for their detailed and valuable comments. We also appreciate the extensive assistance of our local guiders, Mr. Ciren, and Duoji, during field surveys.

References

Anderson, D. M., Salick, J., Moseley, R. K., & Ou, X. K. (2005). Conserving the sacred medicine mountains: a vegetation analysis of Tibetan sacred sites in Northwest Yunnan. *Biodiversity and Conservation, 14*(13), 3065–3091.

Bishop, N. H. (1979). Himalayan langurs: temperate colobines. *Journal of Human Evolution, 8*, 251–281.

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., Rylands, A. B., Konstant, W. R., *et al.* (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology, 16*(4), 909–923.
Carr, D. L. (2004). Proximate population factors and deforestation in tropical agricultural frontiers. *Population and Environment, 25*(6), 585–612.
Chen, X. D., Lupi, F., He, G. M., & Liu, J. G. (2009). Linking social norms to efficient conservation investment in payments for ecosystem services. *Proceedings of the National Academy of Sciences of the USA, 106*(28), 11812–11817.
Cincotta, R. P., Wisnewski, J., & Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature, 404*(6781), 990–992.
Crook, J. H., & Crook, S. J. (1988). Tibetan polyandry: Problems of adaptation and fitness. In L. Betzig, M. B. Mulder, & P. Turke (Eds.), *Human reproductive behavior* (pp. 97–114). New York: Cambridge University Press.
Ding, W., & Zhao, Q. K. (2004). *Rhinopithecus bieti* at Tacheng, Yunnan: diet and daytime activities. *International Journal of Primatology, 25*(3), 583–598.
Ebert, J. (2005). Nine more crisis areas for biodiversity. *Nature News*. doi:10.1038/news050131-10.
Editorial Group (Ed.) (1984). *Overview of Tibet Autonomous Region*. Lasa: People's Press of Tibet (in Chinese).
Ervin, J. (2003). Rapid assessment of protected area management effectiveness in four countries. *Bioscience, 53*(9), 833–841.
Forester, D. J., & Machlis, G. E. (1996). Modeling human factors that affect the loss of biodiversity. *Conservation Biology, 10*(4), 1253–1263.
Goldstein, M. C. (1971). Stratification, polyandry, and family structure in central Tibet. *Southwestern Journal of Anthropology, 27*(1), 64–74.
Goldstein, M. C. (1981). High-altitude tibetan populations in the remote Himalaya: social transformation and its demographic, economic, and ecological consequences. *Mountain Research and Development, 1*(1), 5–18.
Goldstein, M., Jiao, B., Beall, C., & Tsering, P. (2002). Fertility and family planning in rural Tibet. *The China Journal*, 19–39.
Harkness, J. (1998). Recent trends in forestry and conservation of biodiversity in China. *The China Quarterly, 156*, 911–934.
Holdren, J. P., & Ehrlich, P. R. (1974). Human population and the global environment. *American Scientist, 62*(3), 282–292.
IUCN. (2010). IUCN red list of threatened species. Version 2010.4. Retrieved 27 January, 2011, from www.iucnredlist.org.
Kirkpatrick, R. C., Long, Y. C., Zhong, T., & Xiao, L. (1998). Social organization and range use in the Yunnan snub-nosed monkey *Rhinopithecus bieti*. *International Journal of Primatology, 19*(1), 13–51.
Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., *et al.* (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change-Human and Policy Dimensions, 11*(4), 261–269.
Liu, J., Ouyang, Z., Taylor, W. W., Groop, R., Tan, K., & Zhang, H. (1999). A framework for evaluating the effects of human factors on wildlife habitat: the case of Giant pandas. *Conservation Biology, 13*(6), 1360–1370.
Liu, J., Linderman, M., Ouyang, Z., An, L., Yang, J., & Zhang, H. (2001). Ecological degradation in protected areas: the case of Wolong Nature Reserve for Giant pandas. *Science, 292*(5514), 98–101.
Liu, H. M., Xu, Z. F., Xu, Y. K., & Wang, J. X. (2002). Practice of conserving plant diversity through traditional beliefs: a case study in Xishuangbanna, southwest China. *Biodiversity and Conservation, 11*(4), 705–713.
Liu, J., Daily, G. C., Ehrlich, P. R., & Luck, G. W. (2003). Effects of household dynamics on resource consumption and biodiversity. *Nature, 421*(6922), 530–533.
Liu, Z., Ren, B., Wei, F., Long, Y., Hao, Y., & Li, M. (2007). Phylogeography and population structure of the Yunnan snub-nosed monkey (*Rhinopithecus bieti*) inferred from mitochondrial control region DNA sequence analysis. *Molecular Ecology, 16*(16), 3334–3349.
Long, Y., & Wu, R. (2006). Population, home range, conservation status of the Yunnan snub-nosed monkey (*Rhinopithecus bieti*). Paper presented at the China Fusui International Primatological Symposium, 2006.
Long, Y. C., Kirkpatrick, C. R., Zhong, T., & Xiao, L. (1994). Report on the distribution, population, and ecology of the Yunnan snub-nosed monkey (*Rhinopithecus bieti*). *Primates, 35*(2), 241–250.
McGarigal, K., Cushman, S. A., Neel, M. C., & Ene, E. (2002). FRAGSTATS: Spatial pattern analysis program for categorical maps. Retrieved September 2009, from www.umass.edu/landeco/research/fragstats/fragstats.html.

Meyer, W., & Turner, B. (1994). *Changes in land use and land cover: A global perspective*. New York: Cambridge University Press.
Mittermeier, R. A., Gil, P. R., Hoffman, M., Pilgrim, J., Brooks, T., Mittermeier, C. G., *et al.* (2005). *Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions*. Chicago: The University of Chicago Press.
Oates, J. F. (1987). Food distribution and foraging behavior. In B. B. Smuts, D. L. Cheney, R. M. Seyfarth, R. W. Wrangham, & T. T. Struhsaker (Eds.), *Primate societies* (pp. 197–209). Chicago: University of Chicago Press.
Rodrigues, A. S. L., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., *et al.* (2004). Effectiveness of the global protected area network in representing species diversity. *Nature, 428*(6983), 640–643.
Sa, R. L., & Cao, R. X. (2005). Probing into the population economy development in Tibet. *China Tibetology, 1*, 10–17 (in Chinese).
Salick, J., Amend, A., Anderson, D., Hoffmeister, K., Gunn, B., & Fang, Z. D. (2007). Tibetan sacred sites conserve old growth trees and cover in the eastern Himalayas. *Biodiversity and Conservation, 16*(3), 693–706.
Scott, J. M., Davis, F. W., McGhie, R. G., Wright, R. G., Groves, C., & Estes, J. (2001). Nature reserves: do they capture the full range of America's biological diversity? *Ecological Applications, 11*(4), 999–1007.
Singh, S. (1996). Case studies: India. In V. Dompka (Ed.), *Human population, biodiversity and protected areas: Science and policy issues* (pp. 97–126). Washington: American Association for the Advancement of Science.
Statistical Bureau of Yunnan Province (Ed.) (1999). *Yunnan statistical yearbook 1999*. Beijing: China Statistics Press (in Chinese).
Statistical Bureau of Yunnan Province (Ed.) (2007). *Yunnan statistical yearbook 2007*. Beijing: China Statistics Press (in Chinese).
Suo, Z. (2009). *The polyandrous marriage system in Tibet.* Master's thesis, University of Political Science and Law, Beijing (in Chinese).
Thampy, R. J. (1996). Case studies: Kenya. In V. Dompka (Ed.), *Human population, biodiversity and protected areas: Science and policy issues* (pp. 127–134). Washington: American Association for the Advancement of Science.
Thompson, K., & Jones, A. (1999). Human population density and prediction of local plant extinction in Britain. *Conservation Biology, 13*(1), 185–189.
Tibet Forestry Survey and Planning Institute. (2000). *The comprehensive programming to Hongla Snow Mountain National Nature Reserve of Mangkang County.* Lasa: Tibet Forestry Survey and Planning Institute [in Chinese].
Veech, J. A. (2003). Incorporating socioeconomic factors into the analysis of biodiversity hotspots. *Applied Geography, 23*(1), 73–88.
Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of earth's ecosystems. *Science, 277*(5325), 494–499.
Wang, W., Ren, G. P., He, Y. H., & Zhu, J. G. (2008). Habitat degradation and conservation status assessment of gallinaceous birds in the Trans-Himalayas, China. *Journal of Wildlife Management, 72* (6), 1335–1341.
Xiang, Z. F., Huo, S., Wang, L., Cui, L. W., Xiao, W., Quan, R. C., *et al.* (2007). Distribution, status and conservation of the black-and-white snub-nosed monkey *Rhinopithecus bieti* in Tibet. *Oryx, 41*(4), 525–531.
Xiang, Z. F., Huo, S., Xiao, W., Quan, R. C., & Grueter, C. C. (2007). Diet and feeding behavior of *Rhinopithecus bieti* at Xiaochangdu, Tibet: Adaptations to a marginal environment. *American Journal of Primatology, 69*(10), 1141–1158.
Xiang, Z. F., Huo, S., Xiao, W., Quan, R., & Grueter, C. C. (2009). Terrestrial behavior and use of forest strata in a group of black-and-white snub-nosed monkeys *Rhinopithecus bieti* at Xiaochangdu, Tibet. *Current Zoology, 55*(3), 180–187.
Xiao, W., Ding, W., Cui, L. W., Zhou, R. L., & Zhao, Q. K. (2003). Habitat degradation of *Rhinopithecus bieti* in Yunnan, China. *International Journal of Primatology, 24*(2), 389–398.
Xu, J. C., & Melick, D. R. (2007). Rethinking the effectiveness of public protected areas in southwestern China. *Conservation Biology, 21*(2), 318–328.
Zhang, L. M. (2008). *Educational demand of pastoral family in Tibet.* Master's thesis, Southwest University, Chongqing (in Chinese with English abstract).
Zhao, Q. K., He, S. J., Wu, B. Q., & Nash, L. T. (1988). Excrement distribution and habitat use in *Rhinopithecus bieti* in winter. *American Journal of Primatology, 16*(3), 275–284.