Influence of traditional ecological knowledge on conservation of the skywalker hoolock gibbon (*Hoolock tianxing*) outside nature reserves

Lu Zhang[1#], Zhenhua Guan[2#], Hanlan Fei[1#], Lu Yan[3], Samuel T. Turvey[4], Pengfei Fan[1*]

[1]School of Life Sciences, Sun Yat-sen University, Guangzhou, Guangdong, China

[2]Yunnan Academy of Biodiversity, Southwest Forestry University, Kunming, Yunnan, China

[3]Cloud Mountain Conservation, Dali, Yunnan, China

[4]Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK

[#]These authors contributed equally to this study.

*Correspondence: fanpf@mail.sysu.edu.cn; +86-20-84112950

Acknowledgements

This study was funded by the National Natural Science Foundation of China (#31770421, #31822049), the National Youth Talent Support Program of China, Yingjiang County Environmental Protection Bureau (#611712), Sun Yat-sen University, Southwest Forestry University, and Cloud Mountain Conservation. We thank the Forestry Bureau of Yingjiang County, Gaoligongshan NNR, and Tongbiguan Nature Reserve for their support in manpower and logistics. We are

grateful to numerous volunteers, field guides and interpreters from local communities for conducting field surveys, and students from Sun Yat-sen University for helping with fieldwork and data entry. We also thank Dr. M. Lawes for his help with editing this manuscript.

Influence of traditional ecological knowledge on conservation of the skywalker hoolock gibbon (*Hoolock tianxing*) outside nature reserves

Abstract

Although many species are threatened by hunting or resource extraction from indigenous human communities, traditional ecological knowledge (TEK) of local communities has the potential to support management and conservation of natural resources and wildlife. The newly described skywalker hoolock gibbon (*Hoolock tianxing*) is found on the border of China and Myanmar, and a large proportion of the remaining population in China occurs outside nature reserves. We surveyed this species across its range in China, and interviewed 622 people in 99 villages to evaluate the relationship between gibbon status and TEK of local communities. The total confirmed population was estimated to be less than 150 individuals. Gibbon subpopulations appear to have remained stable from 2009 to 2017 both within and outside nature reserves. Sociological and environmental correlates of gibbon survival outside the reserve were: (1) more Lisu than Han people present in villages; (2) greater forest cover; (3) greater distance from county towns; (4) existence of traditional taboos on hunting gibbons; and (5) higher dependency on forest resources by villagers. Interviewees living closer to surviving gibbon populations were more knowledgeable about gibbons, although interviewees living more than 25 km away also knew more about gibbons. Formal education level was also correlated with better knowledge of gibbons, and men were better informed about gibbons than women. TEK appears to limit poaching of gibbons, thus contributing to their survival. The persistence of gibbons outside nature reserves may depend on incorporating TEK within community-based conservation strategies.

Keywords: China, community-based conservation, Critically Endangered, hunting taboo, interview survey, population dynamics, TEK

1. Introduction

One of the primary drivers of biodiversity loss is hunting and/or resource extraction conducted by indigenous human communities that exist within the same landscapes, especially in east and southeast Asia (Schipper et al., 2008; Sodhi et al., 2004). However, traditional ecological knowledge (TEK) held by indigenous communities can also play an important role in biodiversity conservation, especially outside protected areas (Berkes et al., 2000; Hernández-Morcillo et al., 2014; Leiper et al., 2018). TEK is usually defined as a complex of knowledge, practice and belief regarding the relationship between humans and the environment in which they live, which is accumulated and passed down across generations (Berkes et al., 2000; Hernández-Morcillo et al., 2014). TEK has the potential to complement scientific knowledge and help to improve management of natural resources and threatened wildlife, by providing novel information on the distribution and population status of species of conservation concern (Ceríaco et al., 2011; Wilkinson and Duc, 2017), enhancing local awareness and support for conservation based on indigenous value systems (Shen et al., 2012), and providing models for sustainable management of natural resources (Phuthego and Chanda, 2004). However, the extent to which TEK actually contributes toward effective conservation and persistence of key species or natural resources, and the socio-cultural factors that might increase the effectiveness of TEK in promoting indigenous conservation, remain incompletely understood, especially in landscapes that contain global top-priority threatened species (Gagnon

and Berteaux, 2009; Gilchrist et al., 2005; Gratani et al., 2011).

Gibbons (family Hylobatidae) are among the most threatened mammal taxa. All 18 extant gibbon species are listed by IUCN as Vulnerable, Endangered or Critically Endangered due to hunting and habitat loss (Fan and Bartlett, 2017). Gibbons have been extirpated across most of their historical distribution in China (Fan, 2012; Turvey et al., 2015; Zhou and Zhang, 2013), and only four gibbon species survive today in small forest patches in remote areas of Yunnan, Guangxi and Hainan Provinces in southwestern China (Fan, 2017). Two additional gibbon species have been extirpated from China in recent decades (Fan, 2017; Fan et al., 2017), and several other endemic Chinese species may have become extinct during the past few centuries (Turvey et al., 2018). To protect remaining gibbon populations and their habitats, the Chinese government has established several nature reserves (the primary form of protected area in China), and all gibbon species have been listed as Class I Protected Animals since 1989. However, gibbon populations have continued to decline, even inside nature reserves (Fan, 2017; Ni and Ma, 2006); notably, the last Chinese population of lar gibbon (*Hylobates lar*) was extirpated from Nangunhe National Nature Reserve (NNR) by 2007 (Grueter et al., 2009), and the last Chinese population of northern white-cheeked gibbon (*Nomascus leucogenys*) disappeared from Xishuangbanna NNR in 2011 (Fan et al., 2014).

The skywalker hoolock gibbon (*Hoolock tianxing*) is a recently described species which occurs between the Irrawaddy River and the Salween River in Myanmar and China (Fan et al., 2017). The population status of skywalker hoolock gibbons in Myanmar is unknown, but this population is likely to be small and highly threatened because of political instability and associated habitat destruction and uncontrolled poaching. In China, fewer than 200 individuals were estimated to occur in Yunnan

Province in 2009, and this surviving population is threatened by poaching and by habitat loss and fragmentation caused by commercial logging and agricultural encroachment (Fan et al., 2011b). The new species has consequently been assessed as Critically Endangered by IUCN, and is listed in the World's 25 Most Endangered Primates of 2018-2020.

Although the overall conservation status of the species is poor, a large proportion of China's skywalker hoolock gibbon population (~50% of the total population) occurs outside any nature reserves (Fan et al., 2011b). Given that many national nature reserves in China have not been effective at conserving gibbon populations (e.g. Fan et al., 2014; Grueter et al., 2009; Turvey et al., 2017), the existence of multiple subpopulations of skywalker hoolock gibbons in unprotected landscapes offers a unique opportunity to investigate the influence of local human communities on gibbon survival.

Here we examine whether TEK (including knowledge, practice and belief) of local communities across the distribution of skywalker hoolock gibbons in Yunnan Province, China, has helped to maintain gibbon populations outside nature reserves by suppressing local hunting pressure on gibbons. We re-surveyed all known gibbon populations reported in the last survey (Fan et al., 2011b), and compared the status of subpopulations living in unprotected landscapes with those living inside a national nature reserve. We then conducted interviews in local communities within the known range of skywalker hoolock gibbons in China, as well as over the former range of this species, to investigate the relationship between TEK in local communities and gibbon survival. Our results provide important new insights into socio-cultural factors that can promote sustainability in social-ecological systems, as well as invaluable suggestions for future conservation planning for skywalker hoolock gibbons and other

gibbon populations outside protected areas in southeast Asia.

2. Materials and methods

2.1. Study area

Our study area is located in southwestern Yunnan Province close to the border with Myanmar, in Longyang District and Tengchong County (Baoshan Municipality), Yingjiang County (Dehong Autonomous Prefecture), and Lushui County (Nujiang Autonomous Prefecture), covering the entire known range of skywalker hoolock gibbons in China (Fig. 1). Local communities in this region include several ethnic groups, primarily comprising Han, Lisu, Jingpo and Dai ethnicities. These ethnic groups have very different traditions and cultures; most Lisu people were traditionally hunters and their livelihoods are still heavily dependent upon forest products (Ai, 1999; Meng and Lu, 2004), whereas most Han and Dai people are dependent on farming and trade (Yu, 2014), and Jingpo people utilize farm, trade and forest products. The majority of Han communities are not religious, whereas many Dai communities are Buddhist and many Jingpo and Lisu communities are Christian, and Dai, Jingpo, and Lisu communities also have their own traditional animist religions (Yang, 2002, 2017; Yu, 2010). Villages in this region have historically been inhabited by communities belonging to the same ethnic group; although population movement among villages has become more common, this general demographic pattern is still maintained across much of the region.

We divided the study area into four regions based on proximity to gibbon subpopulations and Gaoligongshan NNR, the only reserve in China which contains skywalker hoolock gibbons (Fig. 1): Region A, villages within 10 km of surviving gibbon subpopulations present outside Gaoligongshan NNR; Region B, villages

126 within 10 km of gibbons present inside Gaoligongshan NNR (villages themselves are
127 all outside the boundary of the nature reserve); Region C, villages over 10 km away
128 from surviving gibbon subpopulations and Gaoligongshan NNR (gibbons were
129 extirpated before the 1980s from this region); and Region D, villages over 10 km
130 away from surviving gibbon subpopulations but within 10 km of Gaoligongshan NNR
131 (gibbons were extirpated after the 1980s from this region) (Fan et al., 2011b; Lan et
132 al., 1995; Yang et al., 1985). Another nature reserve in our study area, Tongbiguan
133 Provincial Nature Reserve, extended its range in 2011 to include a small part of
134 forests in Region A where some gibbon subpopulations survive (Fig. 1). However,
135 regular patrol and conservation actions did not start until 2017 in this region, so
136 gibbon conservation was not affected by this reserve at the time when we conducted
137 this study.
138
139 *2.2. Gibbon population survey*
140 We conducted population surveys from 5–21 April and 23 May–7 June 2017 in four
141 townships: Sudian and Zhina (Yingjiang County), Lujiang (Longyang District), and
142 Houqiao (Tengchong County). We divided the survey area into 15 discrete sites based
143 on topography and distribution of gibbon subpopulations (three in Sudian, four in
144 Zhina, five in Lujiang, and one in Houqiao; more details in Appendix Table S1). Most
145 sites were more than 5 km apart, exceeding the distance that gibbons can hear each
146 other (Raemaekers et al., 1984). We did not survey Datang and Zizhi (Tengchong
147 County) in the northern section of Gaoligongshan NNR because the NGO Kadoorie
148 Conservation China had already surveyed these two sites in 2016 using the same
149 method (Chan et al., 2017). Due to logistical considerations, we incorporated their
150 data and did not re-survey these sites.

Our survey team comprised researchers, graduate students, local governmental agency staff, volunteers, and field guides and interpreters from local communities, comprising a total of 86 people. The team was divided into 35 groups, each of which included at least one local field guide and one field worker with previous experience in surveying gibbons. Numbers of survey groups and group members varied in each township, ranging between 4-11 groups and 2-4 members per group.

Like other gibbon species, skywalker hoolock gibbons regularly produce loud distinctive calls, typically in the morning from sunrise until about five hours post-sunrise (Fan et al., 2011b; Yin et al., 2016). We determined the presence of gibbons by monitoring their vocalizations from listening posts using triangulation, a widely-used method in gibbon surveys (e.g., Brockelman and Srikosamatara, 1993; Fan et al., 2011b; Johnson et al., 2005). For each subpopulation, we chose several listening posts situated on ridge tops with good views of the landscape. Every morning from before dawn to noon, three or more survey groups each occupied a listening post, and recorded the direction and estimated the location of singing gibbons, the starting and stopping time of calling bouts, and when possible the number of singing individuals. Because gibbons are highly territorial and two neighboring groups of skywalker hoolock gibbons never sung at the same site according to our long-term behavior study, we distinguished groups according to singing time, singing location (direction), and number of singing individuals. We confirmed the presence of isolated gibbon groups living in small forest patches by one survey group, with no need to use triangulation. Because paired hoolock gibbons rarely produce solo songs (Yin et al., 2016), we distinguished solitary individuals from family groups by the number of singing individuals. When gibbon groups sang near the listening posts, we tried to find and observe them directly and record their group composition. Since gibbons do

not sing every day, we monitored their vocalizations on at least six consecutive days.

We calculated the mean group size (including first and third quartiles) for gibbons based on data from our survey and previous studies (Chan et al., 2017; Fan et al., 2011b). We estimated population size of skywalker hoolock gibbons in China as the product of number of groups multiplied by mean group size (with first and third quartiles used to estimate error ranges), plus the number of solitary gibbons. We then compared the number of gibbon groups within each subpopulation between our survey and the previous census by Fan et al. (2011b) using non-parametric Wilcoxon signed rank tests for paired data.

2.3. Human impact survey

We conducted semi-structured interviews in villages in Regions A and B from 5–21 April and 23 May–7 June 2017, and in villages in Regions C and D from 10–21 August 2018 (Fig. 1). We selected villages based on their distance to gibbons; we surveyed the closest villages to every known gibbon group or solitary individual, and selected additional villages situated further away while balancing sample sizes in all distance groups. As a result, we surveyed 41 villages within 5 km, 15 villages 5–10 km, 21 villages 10–20 km, and 22 villages >20 km from gibbons. We interviewed six households per village and one person per household, and selected interviewees opportunistically by walking through each village. We interviewed each household representative without other household members or villagers from other households present. We only interviewed people aged 18 years or above. Interviews were conducted with the help of local guides/interpreters who could speak Lisu, Jingpo or Dai languages, and with additional translation assistance provided by local villagers when necessary. In addition to basic personal/demographic information, we collected

information on livelihoods, knowledge of gibbons and nature reserves, and local wildlife conservation education, using a series of semi-structured questions (details in Appendix Table S2).

To investigate whether there are differences in local human activities and environmental characteristics between landscapes where gibbons survive and landscapes where they are locally extirpated, we compared 11 variables across the four regions (see details in Table 1). We used mixed ANOVAs with Tukey's all-pair comparisons and with village ID as a random effect for variables that differed between individual interviewees, and used non-parametric Kruskal-Wallis tests for variables that differed only between villages (Table 1). Our hypothesis was that gibbons survive in areas with more forest and lower human impacts; that villages in Regions A and B have higher forest cover and are further away from county towns (less influenced by outsiders); and that villagers in these regions conduct fewer activities within the forest, exert less hunting pressure on gibbons because of traditional hunting taboos or wildlife protection laws, and receive more wildlife conservation education.

All variables were obtained from our interview survey except for forest cover data (for the year 2000), which we obtained from Global Forest Change 2000–2017 (https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html). Preliminary analysis of interview data showed that 80% of interviewees (n = 197) reported that they conducted production activities within 5 km of their village, and 93% conducted them within 10 km. To investigate spatial patterns of impact on forests by local people, we therefore created a 10 km buffer zone surrounding each village center in ArcMap (version 10.3.1), and calculated forest cover around each village as the average value of all 30 m×30 m grids within

this buffer. Creating a 5 km buffer zone produced similar results (see Appendix Fig. S1). Since gibbons in Region B survive within Gaoligongshan NNR, we also compared forest cover within the reserve to villages in Region A, by selecting 100 random localities within the reserve and deriving forest cover for each locality using the same method as above, and then compared these values with data for villages in Region A using a Wilcoxon rank sum test. Since forest data were from the year 2000, we also compare forest loss during 2000-2017 among the four regions using a Kruskal-Wallis test.

We assessed local knowledge about gibbons by summarizing interviewees' binary responses (*Yes* – 1, *No* – 0) to the following five questions: 1) did they recognize a picture of a male gibbon; 2) did they recognize a picture of a female gibbon (this species exhibits sexual dimorphism, with black males and brown females); 3) did they know what gibbons were called in Mandarin or a local language, or know any gibbon behavioral characteristics; 4) did they know that gibbons are protected animals; and 5) did they know any cultural traditions or folktales about gibbons. Knowledge of nature reserves was determined by summarizing interviewees' responses to four questions: 1) knowledge of whether a nature reserve existed near the village; 2) knowledge of the reserve name; 3) knowledge of the location of the reserve boundary; and 4) knowledge of the purpose of nature reserves. Correct answers were scored as 1, and incorrect answers or "don't know" were scored as 0.

We used linear mixed effects models to explore variables that affect local people's knowledge of gibbons, with village ID again included as a random effect. Independent variables included gender, age, ethnicity, religion, educational background, knowledge of nature reserves, whether there had been any wildlife conservation education in the village, distance from village to nearest county town, and distance

from village to nearest gibbon group/solitary gibbon detected in our survey (Table 1). We included a quadratic term of distance to gibbons in modeling process since we hypothesized that the impact of distance may not be linear. Distances were calculated as Euclidean distances between two sites in ArcMap (version 10.3.1). We tested for collinearity between all numeric dependent variables; correlation coefficients were ≤ 0.52, and so no variables were excluded.

We developed 20 *a priori* models to explain patterns of interviewee knowledge about gibbons (Table 2 & Appendix Table S3). We determined the support for each model based on its AIC value; the model with the minimum AIC value was considered the best-fit model, and models with ≤ 2 ΔAIC were considered as having equivalent support (Burnham and Anderson, 2002). We calculated the Akaike weight (ω_i) for each candidate model and found that one model was superior to the others ($\omega_i > 0.9$), so that the best model was our final model.

We conducted all statistical analyses in R v3.3.3 (R Core Team, 2018), using the packages 'lme4' (Bates et al., 2015), 'multcomp' (Hothorn et al., 2008), 'usdm' (Naimi et al., 2014), 'PMCMR' (Pohlert, 2014), and 'MuMIn' (Bartoń, 2016).

3. Results

3.1. Gibbon population dynamics

We confirmed the presence of 26 gibbon groups and 11 solitary gibbons (Fig. 2 & Appendix Table S1). Combined with data from Chan et al. (2017), we estimated that the total known population of skywalker hoolock gibbons in China was 32 groups and 11 solitary gibbons in 15 subpopulations. One additional group was reported by local people at Waku (Sudian Township, Yingjiang County) but vocalizations were not detected during our survey, and another unconfirmed group was a possible double-

276 count at Zizhi (Mingguang Township, Tengchong County) noticed by Chan et al.
277 (2017).
278 We determined composition of eight groups during our surveys. Combining data
279 from previous surveys, mean family size of skywalker hoolock gibbons was
280 calculated as 3.6 ± 0.2 SE (n = 24; first quartile = 3, third quartile = 4) (more details in
281 Appendix Table S4). Total population size was estimated at 125 individuals (range:
282 106-138). Compared with the 2009 survey, which recorded 32-34 groups by the
283 survey team, the overall population remained stable and the number of subpopulations
284 did not change between 2009-2017; however, one subpopulation that contained only
285 one gibbon group disappeared at Qinglongshan (Lujiang Township, Longyang
286 District), while another group appeared at Xiangbozi, 9.5 km away from
287 Qinglongshan. We were unable to determine whether these events represent a local
288 extirpation, or movement of the same gibbon group. No other subpopulations were
289 extirpated between 2009-2017, although the number of gibbon groups/solitary
290 gibbons changed in some subpopulations (Appendix Table S1). Overall, the number
291 of groups in each subpopulation did not change significantly between 2009-2017,
292 either for all subpopulations ($V = 7$, $p = 1$, n = 15), those inside Gaoligongshan NNR
293 ($V = 6$, $p = 0.850$, n = 7), or those outside the reserve ($V = 0$, $p = 1$, n = 8).
294
295 *3.2. Interviewee sample*
296 We interviewed 622 people from 99 villages (6.3 ± 0.2 SE interviewees per village,
297 range: 1–13). Most interviewees were males (n = 536). The average age of
298 interviewees was 45.9 (range: 18–85), with most people aged between 30–60 (n =
299 440). Interviewees represented a range of ethnic groups, including 295 Han, 220 Lisu,
300 62 Jingpo, 19 Dai, and a small number of other groups (n = 26). Out of the 99

surveyed villages, 77 contained interviewees belonging to a single ethnic group (comprising 39 Han, 28 Lisu, eight Jingpo, and two Dai villages). Our interviewee sample included 119 Christians, 19 Buddhists, and four Taoists, with most interviewees reporting that they were not religious (n = 477); at the village level, 57 villages contained interviewees who were not religious, only five villages were entirely Christian, and the other 37 villages contained interviewees with multiple reported religious beliefs. Educational level across the region was low, with most interviewees only having finished elementary school (n = 281) or middle school (n = 188) education; only 54 interviewees had high school or higher degrees, and 99 had no formal education.

3.3. Differences across the four regions

The four defined regions in our study showed significant differences in demographic, cultural, and environmental patterns (Fig. 3, interviewee number = 163, 93, 87, and 46, village number = 40, 23, 21, 15 for Regions A to D). Villages in Region A were further away from the closest county town (Fig. 3a) and tended to contain more Lisu people (58%) and fewer Han people (12.8%; Figs. 3b & 3c). Villages in Regions B and C were instead largely composed of Han people (80.4% and 82.7%), while villages in Region D were composed of both Lisu (44.3%) and Han people (48.6%; Figs. 3b & 3c). Villagers in Region A planted more cardamom (Fig. 3d) and conducted more production activities within the forest (Fig. 3e). Average income in Region A was similar to Regions B and C, but lower than in Region D (Fig. 3f).

Although the forest in Region A was not formally protected, forest cover was higher than the other three regions (70.6 ± 0.8 SE, n = 40; Fig. 3g). Forest cover within Gaoligongshan NNR was slightly higher than in Region A (71.2 ± 2.4 SE, n =

100; $W = 1158$, $p < 0.001$). Forest loss during 2000-2017 in Region A was higher than Regions B and D ($p < 0.001$), but was similar to that in Region C ($p = 0.241$, Appendix Fig. S2).

In total, 102 interviewees reported that they did not hunt gibbons because of a hunting taboo. Of these, 96 interviewees (82 Lisu, 10 Jingpo, 3 Han, and 1 Bai) lived in Region A, 4 interviewees (1 Lisu, 2 Han, and 1 Bai) lived in Region B, and 2 interviewees (both Han) lived in Region D. As a result, the proportion of people knowing hunting taboos in Region A was significantly higher than in other regions (Fig 3h). Hunting taboos were associated with four different reasons (details in Appendix Table S5): it is a tradition passed down from the older generation (n = 66); gibbons are the ancestors of people (n = 13); gibbons are the gods of all primates because they can forecast weather or death through their singing behavior (n = 6); and killing a gibbon causes misfortune to the hunter's family or to the whole village (n = 14). In contrast, more people living in Region B were aware that gibbons are protected by Chinese wildlife conservation law (Fig. 3i). People in Region C had no traditional taboos on hunting gibbons, and few people knew that gibbons are protected (Fig. 3h and 3i).

People in Regions A and B, where gibbons still occur, had a better knowledge of gibbons (Fig. 3j), and people in Regions B and D, which are closer to Gaoligongshan NNR, had a better knowledge of nature reserves (Fig. 3k). Conservation education was also lowest in Region C, which is far away from both gibbons and the reserve (Fig. 3l).

3.4. Factors that affect interviewees' knowledge of gibbons

Excluding incomplete records, we built linear mixed effects models using data

351 collected from 475 interviewees. Based on our best-supported model, interviewees'
352 knowledge of gibbons was affected by the distance from their village to the nearest
353 gibbon group or solitary gibbon detected in our survey, their educational level, the
354 distance from their village to the nearest county town, and gender (Tables 2 and 3).
355 Interviewees' knowledge of gibbons declined with distance to gibbons. Interestingly,
356 this effect was quadratic, with interviewees' knowledge of gibbons increasing again
357 as distance from gibbons increased above ~25 km (Table 3). Greater knowledge about
358 gibbons was shown by people living further away from county towns, male
359 interviewees, and people with a higher educational level, whereas ethnicity, age,
360 religion, local wildlife conservation education, and nature reserve knowledge were not
361 correlated with knowledge of gibbons.
362

363 ## 4. Discussion

364 As a newly described and Critically Endangered species, the skywalker hoolock
365 gibbon is in urgent need of research attention and conservation efforts. This study
366 provided the first thorough survey of its population status and distribution in China
367 since its recognition as a new species. We found no evidence of regional gibbon
368 population decline over the past decade; however, although gibbons living within
369 Gaoligongshan NNR are legally protected, their population did not increase from
370 2009 to 2017. More widely, our study demonstrated that the TEK of indigenous
371 communities can support conservation of threatened wildlife (Ceríaco et al., 2011;
372 Drew, 2005). The TEK of Lisu people in Region A, including their hunting taboos on
373 gibbons (practice), which were induced by their beliefs that gibbons were ancestor of
374 human, gibbons were gods of primates, and/or killing a gibbon would bring bad luck
375 (belief), appeared to limit poaching of gibbons. Consequently, together with the fact

that forest in Region A was retained better than in other regions, subpopulations of gibbons in Region A had remained stable between 2009 and 2017, similar to the dynamics of gibbons living within Gaoligongshan NNR in Region B (Fan et al., 2011b; this study). As a result of living closer to gibbons, local people in Region A know more about gibbons. Knowledge of gibbons was part of their TEK and may in turn reinforce their beliefs and practices regarding gibbon protection.

Villages in Region A were the most remote and isolated (measured in terms of distance from county towns in this study), and the lifestyle of local inhabitants had not been strongly affected by outsiders (Meng and Lu, 2004). The Lisu people in this region still relied heavily on forests, that they conducted diverse production activities within the forest including cardamom planting and livestock herding. Probably due to this dependency, and the fact they lived most remotely, they had maintained extensive local forest cover even in the absence of formal protection, and forest cover in Region A was greater than in the other study regions outside Gaoligongshan NNR (Fig. 3). The considerable forest cover that remains overall in Region A supports local survival of gibbons, which require intact forest canopy habitat (Fan et al., 2011a; Phoonjampa et al., 2011; Zhang et al., 2010). However, forest loss during 2000-2017 in Region A was higher than in Regions B and D (but was similar to Region C), implying that the traditional way of forest use may be under some pressure, and nature reserves continue to play an important role in forest protection. To include forest in Region A into formal protection system, i.e., nature reserves, may also be necessary to conserve forests needed by gibbons.

The fact that Lisu people in Region A do not hunt gibbons contributed to the survival of gibbons in this region. Although most Lisu people traditionally were hunters (Ai, 1999), the Lisu people in this region never hunted gibbons because of a

401 series of traditional beliefs associated with the perceived similarity between gibbons
402 and people, and/or that hunting gibbons would bring bad luck to the hunter or the
403 entire village (Appendix Table S5). These cultural beliefs are similar to traditional
404 taboos which contribute to the conservation of animal species in other regions. For
405 example, the ursine black and white colobus (*Colobus vellerosus*) and Campbell's
406 monkey (*Cercopithecus campbelli lowei*) persist in the Boabeng-Fiema Monkey
407 Sanctuary in central Ghana because of local hunting taboos on these two species (Saj
408 et al., 2006), and local taboos against harvesting water monitor lizard (*Varanus*
409 *salvator*) and reticulated python (*Python reticulatus*) may help to preserve these
410 species on Tinjil Island, Indonesia, while populations have decreased elsewhere in the
411 absence of such taboos (Uyeda et al., 2016). Such species-specific taboos represent
412 one of a series of conservation-relevant taboos, also including habitat taboos that are
413 usually expressed through local recognition of sacred landscapes, and which can all
414 contribute to the conservation of wildlife and habitats (Colding and Folke, 2001; Shen
415 et al., 2016).
416 Not all Lisu people have traditional taboos on hunting gibbons. In Region D,
417 village populations were comprised of approximately half Lisu and half Han people.
418 Villagers in this region did not report any traditional taboos on hunting gibbons, forest
419 cover was lower here than in Region A, and although these villagers planted
420 cardamom, they conducted few other production activities within the forest. Villages
421 in Region D were less remote than in Region A, and people in this region had the
422 highest level of income across our study, so we inferred that these local communities
423 had shifted their livelihood to be less dependent upon forest resources. We considered
424 that a shift in subsistence economy away from sustainable forest-based resource use in
425 Region D is likely to have led to the loss of both forest cover and traditional hunting

426 taboos, and may therefore account for the extinction of gibbons in this region in the
427 1980s. It is likely that the Lisu people in this region could have then lost additional
428 amounts of their gibbon-specific TEK following local gibbon extinction (cf. Turvey et
429 al., 2010; 2018b), so that they now had significantly less knowledge of gibbons than
430 people in regions A and B, who live in closer proximity to extant gibbon groups.
431 Most people in villages in regions B and C were of Han ethnicity. Traditionally,
432 Han people were farmers and relied less on forest resources. Consequently,
433 unprotected forest in these regions has been extensively transformed to farmland, and
434 has experienced much greater habitat loss in comparison to Region A. However, in
435 Region B, forest cover within Gaoligongshan NNR was comparable to that in Region
436 A, thus retaining environmental conditions that support gibbon survival. Although
437 very few local people (n = 4) reported traditional gibbon hunting taboos, they still
438 appear not to hunt gibbons within the adjacent Gaoligongshan NNR because they
439 understand that gibbons are protected by law. Gibbons therefore appear to have
440 survived within Gaoligongshan NNR because they benefit both from protection of
441 forest inside the reserve, and from awareness of legislation protecting wildlife through
442 effective publicity and education in villages surrounding the reserve. Conversely,
443 Region C was not close to Gaoligongshan NNR, contained poor-quality forest, had
444 lost gibbons before the 1980s, and had received little wildlife conservation education.
445 People in this region consequently had the lowest levels of awareness across our study
446 area about both gibbons and nature reserves.
447 The framework of knowledge-attitudes-behaviors suggests that knowledge of
448 threatened species affects people's attitudes and behaviors towards those species
449 (Barney et al., 2005; Shen et al., 2012), which ultimately affects the effectiveness of
450 conservation efforts. We found that people living closer to skywalker hoolock gibbons

knew more about them, a common pattern also shown for other threatened species (e.g., Turvey et al., 2017). Interestingly, this relationship was not linear in our study area, with people's knowledge of gibbons increasing again with distance above 25 km. This U-shape relationship suggests that people may acquire knowledge of gibbons across the study area in different ways: people living close to gibbons may acquire knowledge of gibbons from either TEK or direct experience of encountering gibbons, whereas people living further away from gibbons (and often in less remote areas) may instead acquire knowledge from either formal education or media channels (e.g., television, newspapers/magazines, internet, social media). A similar pattern of conservation knowledge acquisition is seen in Tibetan villages (Shen et al., 2012). We found that education level was correlated with knowledge of gibbons, and that men were more knowledgeable about gibbons than women, a pattern of knowledge distribution that is also seen for other species (Kellert and Berry, 1987; Nyhus et al., 2003). Conversely, we found that ethnicity and age had no significant impact on local people's knowledge of gibbons, which differs from several previous studies (e.g., (Nyhus et al., 2003; Turvey et al., 2017, 2010). These differences may reflect the fact that Lisu people in Regions A and D have very different recent histories of forest use and gibbon-specific TEK retention, and that younger people can acquire knowledge about gibbons through formal education or media sources instead of requiring knowledge transfer through TEK.

We found that even though Region A represents an important stronghold for skywalker hoolock gibbons, awareness of legal protection of gibbons and the existence of a nearby nature reserve was lower here than in regions closer to Gaoligongshan NNR. We argue that publicity of wildlife conservation and nature reserves is insufficient in regions where gibbons survive in unprotected landscapes.

476 We consider that gibbon survival outside reserves is largely due to TEK, and if local
477 communities were to be moved or disrupted, as has happened in other areas of the
478 world (Hernández-Morcillo et al., 2014), gibbon survival could consequently be
479 threatened. Gibbon survival in southwest China should therefore be supported by
480 increased dissemination of TEK, and through associated educational activities in local
481 communities, including either formal education in schools, and/or informal education
482 programs conducted by governmental agencies, nature reserves and NGOs. The role
483 of TEK in conserving populations of skywalker hoolock gibbons and other threatened
484 species through forest protection and prohibition of hunting, especially in landscapes
485 lacking formal protection, should be recognized more widely. We hope our findings
486 will promote awareness of TEK as an essential component of the conservation
487 management toolkit, which should be incorporated into community-based initiatives
488 and other strategies that aim to maintain intact social-ecological systems and
489 biocultural diversity.
490

491 ## References

492 Ai, H., 1999. Hunting culture and biodiversity protection of Lisu nation in
493 Gaoligongshan Area. Yunnan Geogr. Environ. Res. 11, 75–80.
494 Barney, E.C., Mintzes, J.J., Yen, C.-F., 2005. Assessing knowledge, attitudes, and
495 behavior toward charismatic megafauna: the case of dolphins. J. Environ.
496 Educ. 36, 41–55.
497 Bartoń, K., 2016. MuMIn: Multi-Model Inference. R package version 1.42.1.
498 Available from https://CRAN.R-project.org/package=MuMIn.
499 Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects
500 models using lme4. J. Stat. Softw. 67, 1–48.

501 Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological
502 knowledge as adaptive management. Ecol. Appl. 10, 1251–1262.
503 Brockelman, W.Y., Srikosamatara, S., 1993. Estimation of density of gibbon groups
504 by use of loud songs. Am. J. Primatol. 29, 93–108.
505 Burnham, K.P., Anderson, D.R., 2002. Model selection and multimodel inference: a
506 practical information-theoretic approach, 2nd ed. Springer Verlag, New York,
507 New York, USA.
508 Ceríaco, L.M., Marques, M.P., Madeira, N.C., Vilaviçosa, C.M., Mendes, P., 2011.
509 Folklore and traditional ecological knowledge of geckos in Southern Portugal:
510 implications for conservation and science. J. Ethnobiol. Ethnomedicine 7, 26.
511 Chan, B.P.L., Mak, C.F., Yang, J., Huang, X., 2017. Population, distribution,
512 vocalization and conservation of the Gaoligong hoolock gibbon (*Hoolock*
513 *tianxing*) in the Tengchong section of the Gaoligongshan National Nature
514 Reserve, China. Primate Conserv. 31, 107–113.
515 Colding, J., Folke, C., 2001. Social taboos: “Invisible” systems of local resource
516 management and biological conservation. Ecol. Appl. 11, 584–600.
517 Drew, J.A., 2005. Use of traditional ecological knowledge in marine conservation.
518 Conserv. Biol. 19, 1286–1293.
519 Fan, P., 2017. The past, present, and future of gibbons in China. Biol. Conserv. 210,
520 29–39.
521 Fan, P., 2012. Taxonomy and conservation status of gibbons in China. Acta Theriol.
522 Sin. 32, 248–258.
523 Fan, P., Bartlett, T.Q., 2017. Overlooked small apes need more attention! Am. J.
524 Primatol. 79, e22658.
525 Fan, P., Fei, H., Luo, A., 2014. Ecological extinction of the Critically Endangered

526 northern white-cheeked gibbon *Nomascus leucogenys* in China. Oryx 48, 52–
527 55.
528 Fan, P., Fei, H., Scott, M.B., Zhang, W., Ma, C., 2011a. Habitat and food choice of
529 the critically endangered cao vit gibbon (*Nomascus nasutus*) in China:
530 implications for conservation. Biol. Conserv. 144, 2247–2254.
531 Fan, P., He, K., Chen, X., Ortiz, A., Zhang, B., Zhao, C., Li, Y.-Q., Zhang, H.-B.,
532 Kimock, C., Wang, W.-Z., 2017. Description of a new species of Hoolock
533 gibbon (Primates: Hylobatidae) based on integrative taxonomy. Am. J.
534 Primatol. 79, e22631.
535 Fan, P., Xiao, W., Huo, S., Ai, H., Wang, T., Lin, R., 2011b. Distribution and
536 conservation status of the vulnerable eastern hoolock gibbon Hoolock
537 leuconedys in China. Oryx 45, 129–134.
538 Gagnon, C.A., Berteaux, D., 2009. Integrating traditional ecological knowledge and
539 ecological science: a question of scale. Ecol. Soc. 14, 19.
540 Gilchrist, G., Mallory, M., Merkel, F., 2005. Can local ecological knowledge
541 contribute to wildlife management? Case studies of migratory birds. Ecol. Soc.
542 10, 20.
543 Gratani, M., Butler, J.R.A., Royee, F., Valentine, P., Burrows, D., Canendo, W.I.,
544 Anderson, A.S., 2011. Is validation of indigenous ecological knowledge a
545 disrespectful process? A case study of traditional fishing poisons and invasive
546 fish management from the Wet Tropics, Australia. Ecol. Soc. 16, 25.
547 Grueter, C.C., Jiang, X., Konrad, R., Fan, P., Guan, Z., Geissmann, T., 2009. Are
548 *Hylobates lar* extirpated from China? Int. J. Primatol. 30, 553–567.
549 Hernández-Morcillo, M., Hoberg, J., Oteros-Rozas, E., Plieninger, T., Gómez-
550 Baggethun, E., Reyes-García, V., 2014. Traditional ecological knowledge in

551 Europe: status quo and insights for the environmental policy agenda. Environ.
552 Sci. Policy Sustain. Dev. 56, 3–17.
553 Hothorn, T., Bretz, F., Westfall, P., 2008. Simultaneous inference in general
554 parametric models. Biom. J. 50, 346–363.
555 Johnson, A., Singh, S., Duangdala, M., Hedemark, M., 2005. The western black
556 crested gibbon *Nomascus concolor* in Laos: new records and conservation
557 status. Oryx 39, 311–317.
558 Kellert, S.R., Berry, J.K., 1987. Attitudes, knowledge, and behaviors toward wildlife
559 as affected by gender. Wildl. Soc. Bull. 15, 363–371.
560 Lan, D., Ma, S., Han, L., 1995. Distribution, population size and conservation of
561 Hoolock gibbons in West Yunnan, in: Studies on Mammal Biology in China.
562 China Forestry Press, Beijing, pp. 11–19.
563 Leiper, I., Zander, K.K., Robinson, C.J., Carwadine, J., Moggridge, B.J., Garnett,
564 S.T., 2018. Quantifying current and potential contributions of Australian
565 indigenous peoples to threatened species management. Conserv. Biol. 32,
566 1038–1047.
567 Meng, R., Lu, X., 2004. Lisu's eco-view and it's meaning of today. J. Yunnan Norm.
568 Univ. 36, 71–74.
569 Naimi, B., Hamm, N., Groen, T., Skidmore, A., Toxopeus, A., 2014. Where is
570 positional uncertainty a problem for species distribution modelling. Ecography
571 37, 191–203.
572 Ni, Q., Ma, S., 2006. Population and distribution of the black crested gibbons in
573 southern and southeastern Yunnan. Zool. Res. 27, 34–40.
574 Nyhus, P.J., Sumianto, Tilson, R., 2003. Wildlife knowledge among migrants in
575 southern Sumatra, Indonesia: implications for conservation. Environ. Conserv.

30, 192–199.

Phoonjampa, R., Brockelman, W.Y., 2008. Survey of pileated gibbon *Hylobates pileatus* in Thailand: populations threatened by hunting and habitat degradation. Oryx 42, 600–606.

Phoonjampa, R., Koenig, A., Brockelman, W.Y., Borries, C., Gale, G.A., Carroll, J.P., Savini, T., 2011. Pileated gibbon density in relation to habitat characteristics and post-logging forest recovery. Biotropica 43, 619–627.

Phuthego, T.C., Chanda, R., 2004. Traditional ecological knowledge and community-based natural resource management: lessons from a Botswana wildlife management area. Appl. Geogr. 24, 57–76.

Pohlert T., 2014. The Pairwise Multiple Comparison of Mean Ranks Package (PMCMR). R package version 4.3. Available from https://CRAN.R-project.org/package=PMCMR.

Raemaekers, J.J., Raemaekers, P.M., Haimoff, E.H., 1984. Loud calls of the gibbon (*Hylobates lar*): repertoire, organisation and context. Behaviour 91, 146–189.

Saj, T.L., Mather, C., Sicotte, P., 2006. Traditional taboos in biological conservation: the case of *Colobus vellerosus* at the Boabeng-Fiema Monkey Sanctuary, Central Ghana. Soc. Sci. Inf. 45, 285–310.

Schipper, J., Chanson, J.S., Chiozza, F., Cox, N.A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A.S., Stuart, S.N., Temple, H.J., 2008. The status of the world's land and marine mammals: diversity, threat, and knowledge. Science 322, 225–230.

Shen, X., Li, S., Wang, D., Lu, Z., 2016. Viable contribution of Tibetan sacred mountains in southwestern China to forest conservation. Conserv. Biol. 29, 1518–1526.

Shen, X., Li, Sheng, Chen, N., Li, Shengzhi, Mcshea, W.J., Lu, Z., 2012. Does science replace traditions? Correlates between traditional Tibetan culture and local bird diversity in Southwest China. Biol. Conserv. 145, 160–170.

Sodhi, N.S., Koh, L.P., Brook, B.W., Ng, P.K.L., 2004. Southeast Asian biodiversity: an impending disaster. Trends Ecol. Evol. 19, 654–660.

Turvey, S.T., Barrett, L.A., Hao, Y., Zhang, L., Zhang, X., Wang, X., Huang, Y., Zhou, K., Hart, T., Wang, D., 2010. Rapidly shifting baselines in Yangtze fishing communities and local memory of extinct species. Conserv. Biol. 24, 778–787.

Turvey, S.T., Bruun, K., Ortiz, A., Hansford, J., Hu, S., Ding, Y., Zhang, T., Chatterjee, H.J., 2018a. New genus of extinct Holocene gibbon associated with humans in Imperial China. Science 360, 1346–1349.

Turvey, S.T., Bryant, J.V., Duncan, C., Wong, M.H.G., Guan, Z., Fei, H., Ma, C., Hong, X., Nash, H.C., Chan, B.P.L., Xu, Y., Fan, P., 2017. How many remnant gibbon populations are left on Hainan? Testing the use of local ecological knowledge to detect cryptic threatened primates. Am. J. Primatol. 79, e22593.

Turvey, S.T., Bryant, J.V., McClune, K.A., 2018b. Differential loss of components of traditional ecological knowledge following a primate extinction event. R. Soc. Open Sci. 5, 172352.

Turvey, S.T., Crees, J.J., Di Fonzo, M.M.I., 2015. Historical data as a baseline for conservation: reconstructing long-term faunal extinction dynamics in Late Imperial–modern China. Proc. R. Soc. B Biol. Sci. 282, 1–9.

Uyeda, L.T., Iskandar, E., Purbatrapsila, A., Pamungkas, J., Wirsing, A., Kyes, R.C., 2016. The role of traditional beliefs in conservation of herpetofauna in Banten,

626 Indonesia. Oryx 50, 296–301.
627 Wilkinson, N.M., Duc, L., 2017. Rank aggregation of local expert knowledge for
628 conservation planning of the critically endangered saola. Conserv. Biol. 31,
629 625–634.
630 Yang, D., Zhang, J., Li, C., 1985. A survey on the population and distribution of
631 gibbons in Yunnan province. Med. Biol. Res. 3, 22–27.
632 Yang, G., 2002. A cultural interpretation of the Dai religious rites in Dehong. J.
633 Yunnan Univ. Natl. 19, 72–76.
634 Yang, L., 2017. A historical account of Christianity in the Jingpo inhabited
635 mountainous area in Yingjiang County of Yunnan. J. Dianxi Sci. Technol.
636 Norm. Univ. 26, 1–7.
637 Yin, L., Fei, H., Chen, G., Li, J., Cui, L., Fan, P., 2016. Effects of group density,
638 hunting, and temperature on the singing patterns of eastern hoolock gibbons
639 (*Hoolock leuconedys*) in Gaoligongshan, southwest China. Am. J. Primatol.
640 78, 861–871.
641 Yu, D., 2010. Traditional beliefs and taboos of Lisu nationality. J. South-Cent. Univ.
642 Natl. Humanit. Soc. Sci. 30, 79–82.
643 Yu, Y., 2014. Study on the tea and cultural change of Dai society (M.S. Thesis).
644 Yunnan University, Kunming, Yunnan.
645 Zhang, M., Fellowes, J.R., Jiang, X., Wang, W., Chan, B.P.L., Ren, G., Zhu, J., 2010.
646 Degradation of tropical forest in Hainan, China, 1991–2008: conservation
647 implications for Hainan Gibbon (*Nomascus hainanus*). Biol. Conserv. 143,
648 1397–1404.
649 Zhou, Y., Zhang, P., 2013. Distribution and vicissitude of gibbons (Hylobatidae) in
650 China during the last 500 years. Acta Theriol. Sin. 33, 258–266.

651

652

Tables

Table 1. Variables used in mixed ANOVAs and Kruskal-Wallis tests to compare among the four regions, and in linear mixed effect models to determine factors that affect local people's knowledge of gibbons.

Variable code	Description	Data type	Analyses
ETH	Ethnicity of interviewee	Categorical: a) Han; b) Lisu; c) Jingpo; d) Dai; e) others	Mixed ANOVA & LMM
FOR	Forest cover rate within 10 km buffer zone surrounding villages	Percentage (1-100)	Kruskal-Wallis
TOW	Euclidean distance from village to closest county town	Continuous (km)	Kruskal-Wallis & LMM
PRO	Number of production activities conducted by interviewee in forest (including hunting, logging, firewood collection, understory plantation, herding, non-timber products collection, and slash-and-burn)	Integer (0-7)	Mixed ANOVA

CAR	Whether interviewee planted cardamom in forest	Binomial: a) yes; b) no	Mixed ANOVA
INC	Annual total family income	Categorical: a) <10k; b) 10k-50k; c) 60k-100k; d) > 100k (CNY)	Mixed ANOVA
NRK	Interviewee knowledge of nature reserves (sum of correct answers to four questions)	Integer (0-4)	Mixed ANOVA & LMM
WCE	Whether wildlife conservation education has taken place in village	Binomial: a) yes; b) no	Mixed ANOVA & LMM
HUT	Interviewees do not hunt gibbons because of local hunting taboo	Binomial: a) yes; b) no	Mixed ANOVA
HUL	Interviewees do not hunt gibbons because of wildlife protection law	Binomial: a) yes; b) no	Mixed ANOVA
GIB	Interviewee knowledge of gibbons (sum of correct answers to five questions)	Integer (0-5)	Mixed ANOVA
AGE	Interviewee age	Integer (18-85)	LMM
GEN	Interviewee gender	Categorical: a) male; b) female	LMM

REL	Interviewee religion	Categorical: a) no religion; b) Christian; c) Buddhist; d) Taoist	LMM
EDU	Interviewee educational background	Integer: 1- no education; 2- primary school; 3- middle school; 4- high school; 5- higher degree	LMM
DIS	Euclidean distance from village to closest gibbon group/solitary gibbon detected in our gibbon survey	Continuous (km)	LMM

Table 2. The top five *a priori* linear mixed effects models explaining interviewees' knowledge of skywalker hoolock gibbons, ranked by Akaike's Information Criterion (AIC). The complete list of models can be found in Appendix Table S3. Codes listed under Model structure are given in Table 1. *K*, number of parameters; ΔAIC, difference in AIC values between each model and the best model; ω_i, Akaike weight.

Hypothesis	Model structure	*K*	AIC	ΔAIC	ω_i
Negative influence of a middle-range of distance to gibbons, and positive influence of education, distance to county town, and male gender	DIS+DIS^2+EDU+TOW+GEN	8	1438.2	0	0.988
Negative influence of a middle-range of distance to	DIS+DIS^2+EDU+GEN	7	1447.1	8.9	0.012

gibbons, and positive influence of education and male gender					
Negative influence of a middle-range of distance to gibbons, and positive influence of education and distance to county towns	$DIS+DIS^2+EDU+TOW$	7	1453.0	14.8	0.001
Negative influence of a middle-range of distance to gibbons, and positive influence of male gender	$DIS+DIS^2+GEN$	6	1455.7	17.5	0.000
Negative influence of distance to gibbons, and positive influence of education, distance to county towns, and male gender	DIS+EDU+TOW+GEN	7	1462.4	24.2	0.000

660

661 Table 3. Coefficients (+SE) for each variable from the best-supported linear mixed
662 effects model analyzing variables that affect interviewees' knowledge of gibbons.
663 Codes listed under Variables are given in Table 1.

Variables	Coefficient	SE
(Intercept)	2.362	0.340
DIS	-0.165	0.022
DIS^2	0.003	0.001
EDU	0.209	0.059
TOW	0.019	0.006
GEN-male	0.623	0.151

664
665

Figures

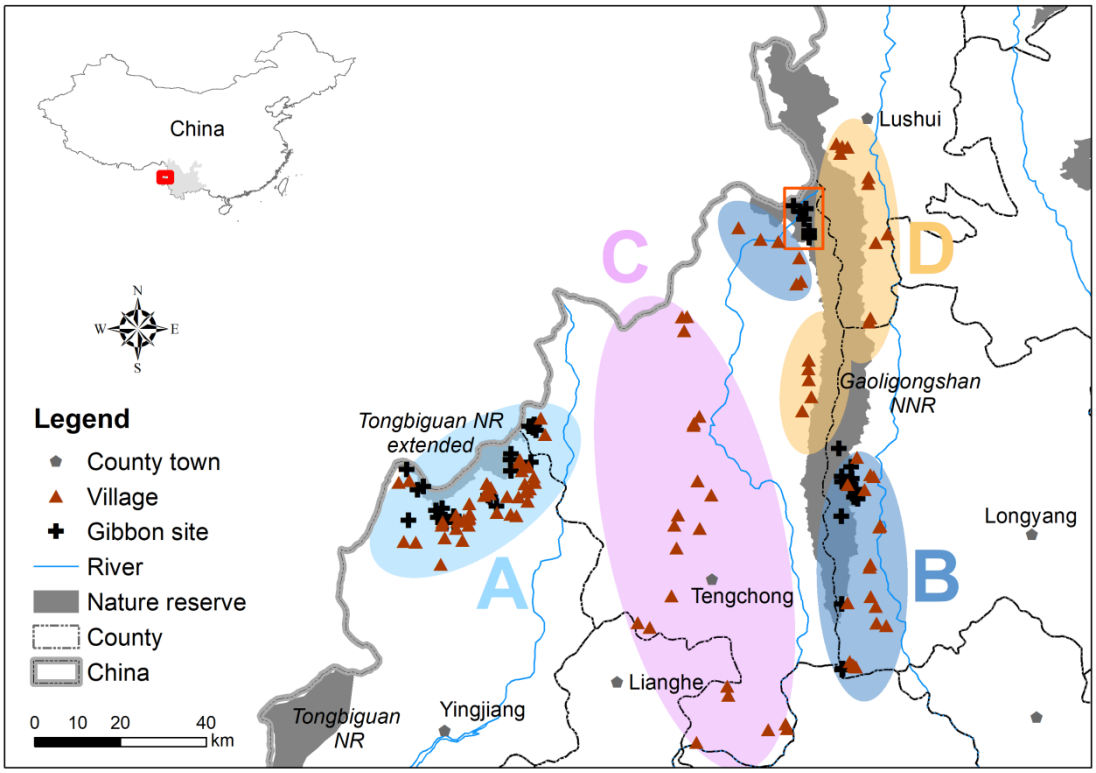
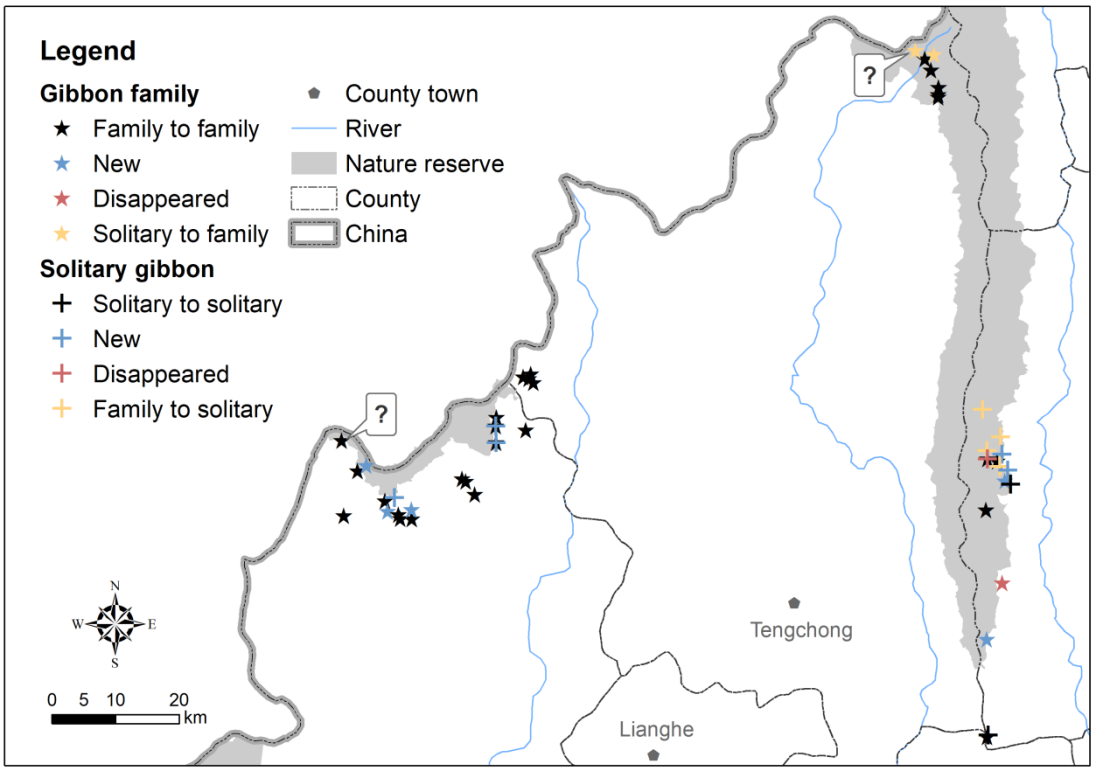


Figure 1. Study area in western Yunnan Province, China, close to the border with Myanmar, showing distribution of subpopulations of skywalker hoolock gibbons and subdivision of regions for community surveys: **A**, villages within 10 km of surviving gibbon subpopulations outside Gaoligongshan NNR; **B**, villages within 10 km of gibbons inside Gaoligongshan NNR; **C**, villages over 10 km away from surviving gibbon subpopulations and Gaoligongshan NNR; **D**, villages over 10 km away from surviving gibbon subpopulations but within 10 km of Gaoligongshan NNR. Gibbon groups within the orange box were surveyed prior to this study by Chan et al. (2017).



677

678 Figure 2. Population change of skywalker hoolock gibbons from 2009 to 2017.

679 Different colors of stars and crosses show different changes; for example, "family to

680 family" means a gibbon family was recorded at a site in both 2009 and 2017, while

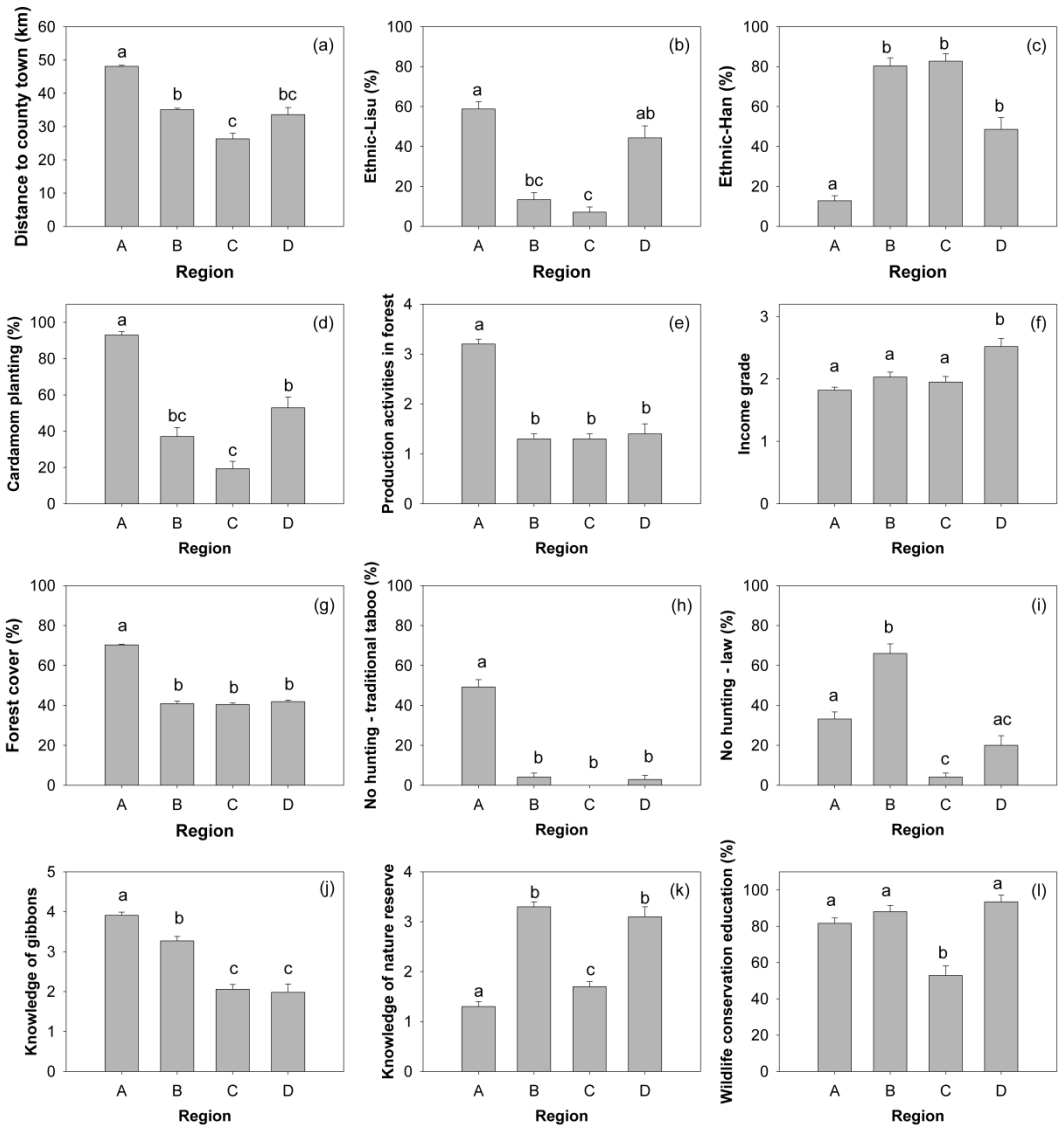
681 "family to solitary" means a gibbon family was found in 2009 while a solitary gibbon

682 was found at the same site in 2017. Gibbon families indicated with a question mark

683 were not confirmed during our 2017 survey or during the survey conducted by Chan

684 et al. (2017).

685



686

687 Figure 3. Differences in demographic, cultural, geographical, and environmental

688 variables among the four study regions (A-D). Details of each variable were listed in

689 Table 1. Bars and whiskers represent means and SEs. Different lowercase letters

690 indicate significant differences at $P < 0.05$.

691

692

We declare that we have no conflict of interest.

Supporting Information

Table S1. Distribution and status of gibbon groups/solitary gibbons.

ID	Township	Survey site / subpopulation	Gibbon ID	Lon	Lat	Population change[a]	Group type[b]	NR
1	Sudian	Waku	Zijiawaduo	97.85746	25.25117	1	F[c]	out
2	Sudian	Waku	Chengqiangyakou	97.88002	25.20863	1	F	out
3	Sudian	Waku	Dakuhetou	97.89229	25.21610	2	F	out
4	Sudian	Jiganzhai	Jiganzhai	97.86100	25.14500	1	F	out
5	Sudian	Lamahe	Lamahe-northwest	97.91901	25.16586	1	F	out
6	Sudian	Lamahe	Lamahe-west	97.92263	25.15117	2	F	out
7	Sudian	Lamahe	Lamahe-east	97.93793	25.14650	1	F	out
8	Sudian	Lamahe	Lamahe-northeast	97.93234	25.17027	2	S	out
9	Sudian	Lamahe	Lamahe-southeast	97.94053	25.14067	1	F	out
10	Sudian	Lamahe	Lishu	97.95713	25.14033	1	F	out
11	Sudian	Lamahe	Xiangdelong	97.95647	25.15368	2	F	out
12	Zhina	Zhongling	Zhongling	98.04584	25.17501	1	F	out
13	Zhina	Xiangbai	Xiangbai-1	98.02827	25.19700	1	F	out
14	Zhina	Xiangbai	Xiangbai-2	98.03314	25.19351	1	F	out
15	Zhina	Baiyan	Zhongshanba-1	98.07602	25.24809	1	F	out
16	Zhina	Baiyan	Zhongshanba-2	98.07602	25.24809	2	S	out
17	Zhina	Baiyan	Baiyan-old	98.07668	25.28427	1	F	out
18	Zhina	Baiyan	Baiyan-new-1	98.07548	25.27175	1	F	out
19	Zhina	Baiyan	Baiyan-new-2	98.07548	25.27175	2	S	out
20	Zhina	Dazhupeng	Dazhupeng	98.11789	25.26637	1	F	out
21	Houqiao	Heinitang	Heinitang	98.12521	25.34531	1	F	out
22	Houqiao	Heinitang	Dengcaoba-1	98.11457	25.34160	1	F	out
23	Houqiao	Heinitang	Dengcaoba-2	98.12229	25.33884	1	F	out
24	Houqiao	Heinitang	Dengcaoba-3	98.12905	25.33320	1	F	out
25	Lujiang	Baihualin	Mangganghe	98.78935	25.25654	4	S	in
26	Lujiang	Baihualin	Mazhudi	98.76335	25.29556	4	S	in
27	Lujiang	Baihualin	Malutang	98.79122	25.23215	2	S	in
28	Lujiang	Baihualin	Changdonghe	98.76946	25.23723	4	S	in
29	Lujiang	Baihualin	Wanshanhe	98.80323	25.18967	1	S	in
30	Lujiang	Baihualin	Chayeling	98.78821	25.21434	4	S	in
31	Lujiang	Baihualin	Yingwuyan	98.79924	25.20934	2	S	in
32	Lujiang	Baihualin	Cizhuping	98.79524	25.19390	2	F	in
33	Lujiang	Baihualin	Hengcaozi	98.78461	25.22228	1	F	in
34	Lujiang	Baihualin	Yangchashu	98.77076	25.22539	1	F	in
35	Lujiang	Baihualin	Yangchashu	98.77076	25.22539	3	S	in
36	Lujiang	Bailaotang	Bailaotang	98.76884	25.15324	1	F	in
37	Lujiang	Xiangbozi	Xiangbozi	98.76986	24.96989	2	F	in
38	Lujiang	Qinglongshan	Qinglongshan	98.79194	25.05000	3	F	in
39	Lujiang	Nankang	Nankang-1	98.77020	24.83206	1	F	in
40	Lujiang	Nankang	Nankang-2	98.77200	24.83438	1	S	in
41	Mingguang	Zizhi	Zizhi-1[d]	98.69481	25.79768	5	F[c]	in
42	Mingguang	Zizhi	Zizhi-2[d]	98.66879	25.80339	5	F	in
43	Mingguang	Zizhi	Zizhi-3[d]	98.68231	25.79130	1	F	in
44	Mingguang	Zizhi	Zizhi-4[d]	98.69088	25.77557	1	F	in

45	Jietou	Datang	Datang-1[d]	98.70136	25.74097	1	F	in
46	Jietou	Datang	Datang-2[d]	98.70166	25.75097	1	F	in
47	Jietou	Datang	Datang-3[d]	98.70112	25.73713	1	F	in

[a]Population change during 2009-2017: 1 – family to family/solitary to solitary; 2 – newly formed; 3 – disappeared; 4 – family to solitary; 5 – solitary to family.
[b]Group type: F – family; S – solitary.
[c]Gibbon groups that reported by local people but could not be confirmed during surveys.
[d]Gibbon groups surveyed by Kadoorie Conservation China (KCC).

Table S2. Questionnaire

Community questionnaire around habitat of Gaoligong hoolock gibbon (*Hoolock tianxing*)

Date _____ Interviewer _____ Village _____ Lat / Lon_____

We are researchers from Sun Yat-sen University. We want to know more about the village and environment around here, so I hope you can provide some information to help us better understand the local animals and any environmental changes that have taken place. The survey is anonymous and all the information you provide will only be used for research and analysis – we will not disclose any of your details to a third party.

1. Are you willing to participate in this survey? □ Yes □ Unwilling

2. Basic information of the interviewee
Age _____ Gender _____ Ethnicity _____ Religion _____ Education _____
Occupation _____ Retired? □ Yes □ No
Family composition _____
Any close relatives work for governmental agency? □ Yes □ No
Have you lived in this area for your entire life? □ Yes □ No
If NO, when did you move here, and from where? _____

3. Public transportation and communication
Can the village be accessed by vehicle? □ Yes □ No
Do you often go to the county town? □ Yes □ No How often?
_____
How do you go there? _____
How long does it take to go there? _____
If by a vehicle, how long does it take to get to the place to take the vehicle? _____
Are there many visitors in the village? □ Yes □ No □ Don't Know
What do they do here? (e.g. tourism, purchasing timber, purchasing land, doing business with local people)
_____
Are you happy with them? _____

4. Living style and income
What is your main income? e.g. as migrant worker (for how long per year), farming (what type of crops), doing business (what type), or others (details)
_____
_____
Total annual income of the family? _____ or: < 10K 10-50K 60-100K > 100K (RMB)

What is the main expense? _____
What do you usually do:
□ hunting □ timber harvesting □ fuelwood collection □ grazing
□ understory plantation □ collecting products in forests □ slash-and-burn
□ other (describe) _____
Main activity range (mark on the map) _____

5. Understory plantation
Do you plant any crop in the forest (e.g. amomum tsaoko)? □ Yes □ No
If YES, what: _____
Planting area _____ Location (mark on the map) _____
When did you start? _____
How do you manage? _____
How often do you go to the forest? _____
How long do you usually stay in the forest each time? _____
What is the profit from understory plantation? Or the proportion it makes up of your family income? _____

6. Livestock husbandry
Do you have any livestock? □ Yes □ No
If YES, what kind and how many?
_____
When did you start? _____
How do you raise them? _____
Do you let them graze in the forest? □ Yes □ No
If YES, where do they usually graze (mark on the map)? _____
How do you manage them? _____
What is the profit from livestock? Or the proportion it makes up of your family income?
_____

7. National policies of ecological compensation
Do you earn reimbursement based on national policies (e.g. Conversion of Degraded Farm Land into Forest and Grass Land, Non-commercial Forest)? □Yes □No
If you do, how much do you earn per year? _____
What is the area of the forest? _____
Do you think these are good policies? □Yes □No
Do you know why these policies are implemented? □Yes □No
If YES, describe why: _____
Do you know any other national policies (e.g. nature reserve, wildlife conservation, drug control)? □Yes □No
If YES, describe: _____

8. Knowledge of gibbons
(Gibbon photo-male) Do you know what this animal is? □Yes □No
(Gibbon photo-female) Do you know what this animal is? □Yes □No
If YES, describe local name / size / diet / appearance _____
If NO, do you know what "changbiyuan" is? Describe _____
If NO, do you know what "□□ (local name)" is? Describe _____
How do you know this animal? _____
Have you seen this animal? □Yes □No □ Don't Know
If YES, *when* was the most recent time that you have seen it? _____
If YES, *where* have you seen it? _____
If YES, *how often* have you seen it? _____
Do you know any stories (for example, legends or myths) about gibbons? □Yes □No
If YES, describe: _____
Can gibbons be used for anything? □Yes □No □ Don't Know
If YES, what? (describe) _____

Have you ever heard of gibbons being hunted? □Yes □No □ Don't Know

If YES - How often does this happen? _____
Does it still happen? _____
Where has it happened? _____
Do you know what the gibbons were hunted for? (e.g. food, medicine) _____
Were the gibbons hunted by people from around here, or by people who had come from somewhere else? (from where?) _____

If NO - Why do people not hunt gibbons? _____

Are there gibbons living close to the village? □Yes □No □ Don't Know

If YES - approximately how many gibbons? _____
what is the locality where they occur? (name the area, and show on map) _____
how did the gibbon population change?
□ Increase □ Decrease □ Stable □ Don't Know

If NO - were there gibbons around in this region in the past?
□ Yes □ No □ Don't Know
When did they disappear? _____
Why did they disappear? _____

Are there monkeys living close to the village? □Yes □No □ Don't Know

If YES – What kind? _____
approximately how many monkeys? _____
what is the locality where they occur? (name the area, and show on map) _____
how did the monkey population change?
□ Increase □ Decrease □ Stable □ Don't Know

If NO - were there monkeys around in this region in the past?
□ Yes □ No □ Don't Know
When did they disappear? _____
Why did they disappear? _____

9. Awareness of wildlife conservation

What sort of other animals also live close to the village, other than gibbons? _____
How did these animal populations change?

Name of species: _____ □ Increase □ Decrease □ Stable □ Don't Know
Name of species: _____ □ Increase □ Decrease □ Stable □ Don't Know
Name of species: _____ □ Increase □ Decrease □ Stable □ Don't Know
Name of species: _____ □ Increase □ Decrease □ Stable □ Don't Know
Name of species: _____ □ Increase □ Decrease □ Stable □ Don't Know

Do you hope that gibbons continue to survive close to the village?
□Yes □No □ Don't Know

Do you hope that other animals continue to survive close to the village?
□Yes □No □ Don't Know

Do people in this local area still hunt wildlife?
□ Yes □ No □ Don't Know
How do they hunt? _____
What kind of animals are hunted? _____

If no hunting exists now, when did hunting stop? _____
For what reasons did it stop? _____

10. Publicity and education

Have any people come to promote wildlife conservation publicity or education in the past 3 years?
□Yes □No □ Don't Know

From what agency? (e.g. Nature reserves, Forestry Bureau, or other organizations)
_____

Are gibbons protected animals under national laws? □Yes □No □ Don't Know
Do you know what animals are under protection except for gibbons? _____
Why we should protect wildlife? _____

11. Nature reserve

Are there nature reserves close to the village? □Yes □No □ Don't Know

If yes, what is/are the name(s) of the reserve(s)? _____

Do you know the boundary of the reserves? □Yes □No

Why we should build nature reserves? _____

Have you ever entered reserves? □Yes □No

If YES, how regularly do you enter the reserve? _____

If YES, when is the most recent time that you entered the reserve? _____

If YES, for what reason do you enter the reserve? _____

Do you think it is necessary to build nature reserves? □Yes □No

Are there any benefits or disadvantages from building nature reserves? (please describe)

_____

Thanks for your help.

Table S3. The complete list of *a priori* linear regression models explaining local people's knowledge of *Hoolock tianxing* (n = 475). Codes listed under Model structure are given in Table 1. K, number of parameters; ΔAIC, difference in AIC values between each model and the best model; ω_i, Akaike weight.

Hypothesis	Model structure	K	LogLik	AIC	ΔAIC	ω_i
Negative influence of a middle-range of distance to gibbons, and positive influence of education, distance to county town, and men over women	DIS+DIS^2+EDU+TOW+GEN	8	-711.1	1438.2	0	0.988
Negative influence of a middle-range of distance to gibbons, and positive influence of education and men over women	DIS+DIS^2+EDU+GEN	7	-716.5	1447.1	8.9	0.012
Negative influence of a middle-range of distance to gibbons, and positive influence of education and distance to county towns	DIS+DIS^2+EDU+TOW	7	-719.5	1453.0	14.8	0.001
Negative influence of a middle-range of distance to gibbons, and positive influence of men over women	DIS+DIS^2+GEN	6	-721.9	1455.7	17.5	0.000
Negative influence of distance to gibbons, and positive	DIS+EDU+TOW+GEN	7	-724.2	1462.4	24.2	0.000

influence of education, distance to county towns, and men over women						
Negative influence of a middle-range of distance to gibbons, and positive influence of education	$DIS+DIS^2+EDU$	6	-725.4	1462.8	24.6	0.000
Negative influence of a middle-range of distance to gibbons, and positive influence of distance to county towns	$DIS+DIS^2+TOW$	6	-728.0	1468.0	29.8	0.000
Negative influence of a middle-range of distance to gibbons	$DIS+DIS^2$	5	-733.0	1476.0	37.8	0.000
Negative influence of distance to gibbons, and positive influence of men over women	DIS+GEN	5	-737.3	1484.6	46.4	0.000
Negative influence of distance to gibbons, and positive influence of education	DIS+EDU	5	-739.9	1489.8	51.6	0.000
Negative influence of distance to gibbons, and positive influence of distance to county towns	DIS+TOW	5	-740.8	1491.6	53.4	0.000

Negative influence of distance to gibbons	DIS	4	-747.8	1503.5	65.3	0.000
Positive influence of distance to county towns	TOW	4	-756.5	1521.0	82.8	0.000
Positive influence of men over women	GEN	4	-765.2	1538.5	100.3	0.000
Positive influence of education	EDU	4	-769.6	1547.3	109.1	0.000
Different ethnic groups have different level of knowledge of gibbons	ETH	7	-765.5	1550.9	112.7	0.000
Positive influence of wildlife conservation education	WCE	5	-772.7	1555.4	117.2	0.000
Positive influence of nature reserve knowledge	NR	4	-774.3	1556.7	118.5	0.000
Positive influence of age	AGE	4	-775.8	1559.7	121.5	0.000
Different religions have different level of knowledge of gibbons	REL	6	-774.8	1561.6	123.4	0.000

Table S4. Composition of family groups from different sources used to calculate the mean family size of skywalker hoolock gibbons.

Family ID	Family size (individuals)	Survey year	Surveyor
DT1	3	2016	KCC (Chan et al., 2017)
DT2	3	2016	KCC (Chan et al., 2017)
DT3	3	2016	KCC (Chan et al., 2017)
ZZ1	2	2016	KCC (Chan et al., 2017)
ZZ2	4	2016	KCC (Chan et al., 2017)
ZZ3	3	2016	KCC (Chan et al., 2017)
ZZ4	2	2016	KCC (Chan et al., 2017)
NK	3	2009	Fan et al., 2011
DG	4	2009	Fan et al., 2011
BC	4	2009	Fan et al., 2011
DT1	4	2009	Fan et al., 2011
DT2	2	2009	Fan et al., 2011
HN	4	2009	Fan et al., 2011
XB	6	2009	Fan et al., 2011
LM	5	2009	Fan et al., 2011
JG	3	2009	Fan et al., 2011
BC1	4	2017	This study
BC2	2	2017	This study
NK	4	2017	This study
XB1	5	2017	This study
XB2	4	2017	This study
LS	3	2017	This study
BLT	4	2017	This study
HNT	5	2017	This study

Table S5. Traditional taboos on hunting gibbons in villages in our study area.

ID	Distance to gibbons	Ethnicity	Taboo	Region	Village ID	Taboo type
5	3.411	han	yes	a	ah	misfortune
22	3.482	jingpo	yes	a	ap	Tradition without specific reason
25	3.482	jingpo	yes	a	ap	Tradition without specific reason
29	3.049	jingpo	yes	a	ac	misfortune
31	3.049	jingpo	yes	a	ac	Tradition without specific reason
32	3.049	jingpo	yes	a	ac	Tradition without specific reason
37	5.143	jingpo	yes	a	o	Tradition without specific reason
40	2.746	lisu	yes	a	v	Tradition without specific reason
45	2.746	lisu	yes	a	v	ancestor, conservation education
46	1.861	lisu	yes	a	t	Tradition without specific reason
47	1.861	lisu	yes	a	t	ancestor
49	1.861	lisu	yes	a	t	ancestor
50	1.861	lisu	yes	a	t	ancestor
51	2.304	lisu	yes	a	bo	Tradition without specific reason

52	0.534	lisu	yes	a	ba	Tradition without specific reason
53	0.534	lisu	yes	a	ba	Tradition without specific reason
55	2.626	lisu	yes	a	aw	Tradition without specific reason
56	2.626	lisu	yes	a	aw	Tradition without specific reason
59	0.478	lisu	yes	a	bb	Tradition without specific reason
61	1.982	lisu	yes	a	a	weather forecast
62	1.982	lisu	yes	a	a	Tradition without specific reason
63	1.982	lisu	yes	a	a	weather forecast
64	1.982	lisu	yes	a	a	weather forecast
69	1.982	lisu	yes	a	a	Tradition without specific reason
71	1.982	lisu	yes	a	a	Tradition without specific reason
72	1.982	lisu	yes	a	a	weather forecast
73	1.982	lisu	yes	a	a	misfortune
81	1.473	lisu	yes	a	bh	Tradition without specific reason
84	0.478	lisu	yes	a	bb	Tradition without specific reason
86	0.534	lisu	yes	a	ba	Tradition without specific reason
87	0.534	lisu	yes	a	ba	Tradition without specific reason, and conservation education
90	0.478	lisu	yes	a	bb	misfortune
91	0.534	lisu	yes	a	ba	Tradition without specific reason, and conservation education
93	0.534	lisu	yes	a	ba	Tradition without specific reason
96	0.478	lisu	yes	a	bb	Tradition without specific reason
98	0.478	lisu	yes	a	bb	Tradition, good fortune
99	0.478	lisu	yes	a	bb	Tradition without specific reason
100	0.478	lisu	yes	a	bb	ancestor
103	2.116	lisu	yes	a	af	misfortune
104	2.116	lisu	yes	a	af	ecosystem indicator, nice singing, tradition
107	0.534	lisu	yes	a	ba	No crop raiding
108	0.534	lisu	yes	a	ba	Tradition, good fortune, protected animal
111	0.534	lisu	yes	a	ba	Tradition, good looking
150	6.699	dai	yes	a	bl	Tradition without specific reason
154	3.082	lisu	yes	a	y	misfortune
159	2.304	lisu	yes	a	bo	Tradition without specific reason
160	2.304	lisu	yes	a	bo	misfortune
161	3.562	jingpo	yes	a	d	Tradition, conservation education
166	5.611	jingpo	yes	a	az	Tradition without specific reason
172	4.212	lisu	yes	a	at	Tradition without specific reason
173	4.212	lisu	yes	a	at	misfortune
184	3.562	jingpo	yes	a	d	Tradition without specific reason
186	4.765	han	yes	a	e	misfortune
189	2.304	lisu	yes	a	bo	Tradition without specific reason
191	2.304	lisu	yes	a	bo	Tradition without specific reason
192	2.304	lisu	yes	a	bo	Tradition without specific reason
196	2.304	lisu	yes	a	bo	Tradition without specific reason
198	2.304	lisu	yes	a	bo	Tradition without specific reason
199	1.473	lisu	yes	a	bh	Tradition without specific reason

201	0.534	lisu	yes	a	ba	ancestor
202	0.534	lisu	yes	a	ba	misfortune
204	0.852	lisu	yes	a	r	Tradition without specific reason
205	0.852	lisu	yes	a	r	Tradition without specific reason
210	4.305	lisu	yes	a	x	ancestor
211	0.782	lisu	yes	a	ad	Tradition without specific reason, indicator species, conservation education
212	0.782	lisu	yes	a	ad	Tradition without specific reason
213	0.782	lisu	yes	a	ad	Tradition without specific reason
215	0.852	lisu	yes	a	r	Tradition without specific reason
216	0.852	lisu	yes	a	r	Tradition without specific reason
218	1.188	lisu	yes	a	aa	Tradition without specific reason
219	4.765	han	yes	a	e	ancestor
222	2.304	lisu	yes	a	bo	misfortune
223	0.782	lisu	yes	a	ad	Tradition without specific reason
224	1.188	lisu	yes	a	aa	Tradition without specific reason
225	0.766	lisu	yes	a	ab	Tradition without specific reason
226	2.304	lisu	yes	a	bo	misfortune
227	1.188	lisu	yes	a	aa	misfortune
228	1.188	lisu	yes	a	aa	nice singing
229	2.626	lisu	yes	a	aw	Tradition without specific reason
230	2.626	lisu	yes	a	aw	Tradition without specific reason
231	2.626	lisu	yes	a	aw	weather forecast
232	2.626	lisu	yes	a	aw	Tradition without specific reason
233	2.626	lisu	yes	a	aw	Tradition without specific reason
241	1.561	jingpo	yes	a	bm	Tradition without specific reason
243	1.982	lisu	yes	a	a	weather forecast
244	2.027	lisu	yes	a	s	Tradition without specific reason
245	2.027	lisu	yes	a	s	Tradition without specific reason
246	2.027	lisu	yes	a	s	Tradition without specific reason
247	2.027	lisu	yes	a	s	Tradition without specific reason
249	2.027	lisu	yes	a	s	weather forecast
250	2.027	lisu	yes	a	s	Tradition without specific reason
251	2.027	lisu	yes	a	s	Tradition without specific reason
252	2.027	lisu	yes	a	s	Tradition without specific reason
253	2.027	lisu	yes	a	s	Tradition without specific reason
258	13.258	han	yes	d	bi	ancestor
263	13.258	han	yes	d	bi	ancestor
285	2.151	han	yes	b	av	ancestor
328	3.997	Bai	yes	b	b	ancestor
358	3.997	Bai	yes	b	b	ancestor
379	7.947	lisu	yes	b	aq	misfortune
419	2.133	lisu	yes	a	j	Tradition without specific reason
425	2.133	lisu	yes	a	j	Tradition without specific reason

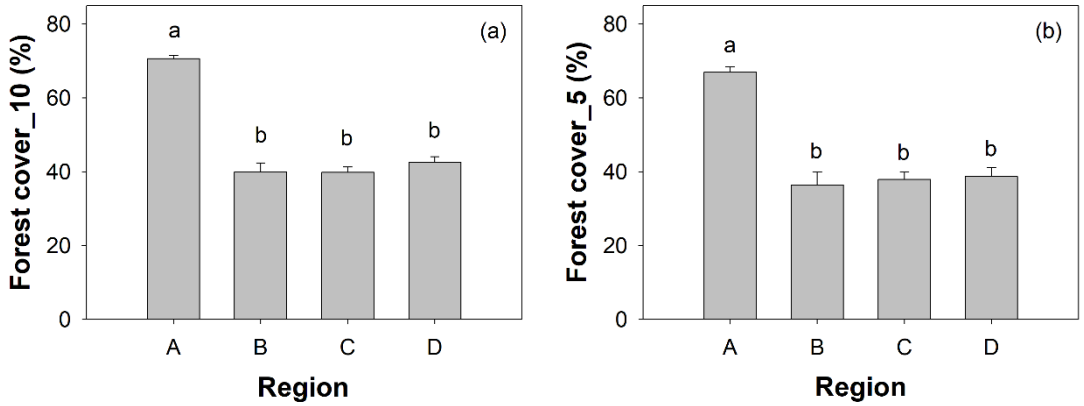


Fig. S1. Forest cover in the year 2000 in a 10 km buffer zone surrounding each village (a), and in a 5 km buffer zone (b). Different lowercase letters on bars indicate significant differences at $P < 0.05$.

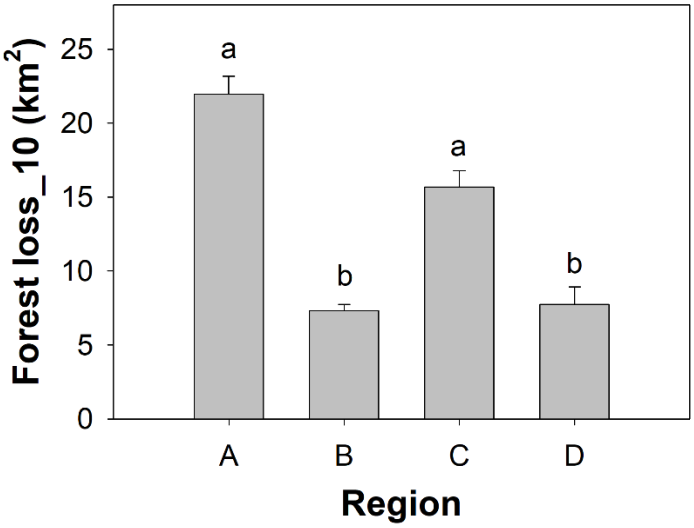


Fig. S2. Forest loss during 2000-2017 in a 10 km buffer zone surrounding each village. Different lowercase letters on bars indicate significant differences at $P < 0.05$.