

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

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2 **skywalker hoolock gibbon (*Hoolock tianxing*) outside nature reserves**

3

4 **Abstract**

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

26

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

29

## 30 **1. Introduction**

31 One of the primary drivers of biodiversity loss is hunting and/or resource extraction  
32 conducted by indigenous human communities that exist within the same landscapes,  
33 especially in east and southeast Asia (Schipper et al., 2008; Sodhi et al., 2004).

34 However, traditional ecological knowledge (TEK) held by indigenous communities  
35 can also play an important role in biodiversity conservation, especially outside  
36 protected areas (Berkes et al., 2000; Hernández-Morcillo et al., 2014; Leiper et al.,  
37 2018). TEK is usually defined as a complex of knowledge, practice and belief  
38 regarding the relationship between humans and the environment in which they live,  
39 which is accumulated and passed down across generations (Berkes et al., 2000;  
40 Hernández-Morcillo et al., 2014). TEK has the potential to complement scientific  
41 knowledge and help to improve management of natural resources and threatened  
42 wildlife, by providing novel information on the distribution and population status of  
43 species of conservation concern (Ceríaco et al., 2011; Wilkinson and Duc, 2017),  
44 enhancing local awareness and support for conservation based on indigenous value  
45 systems (Shen et al., 2012), and providing models for sustainable management of  
46 natural resources (Phuthego and Chanda, 2004). However, the extent to which TEK  
47 actually contributes toward effective conservation and persistence of key species or  
48 natural resources, and the socio-cultural factors that might increase the effectiveness  
49 of TEK in promoting indigenous conservation, remain incompletely understood,  
50 especially in landscapes that contain global top-priority threatened species (Gagnon

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

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

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

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

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

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

101 gibbon populations outside protected areas in southeast Asia.

102

## 103 **2. Materials and methods**

### 104 *2.1. Study area*

105 Our study area is located in southwestern Yunnan Province close to the border with  
106 Myanmar, in Longyang District and Tengchong County (Baoshan Municipality),  
107 Yingjiang County (Dehong Autonomous Prefecture), and Lushui County (Nujiang  
108 Autonomous Prefecture), covering the entire known range of skywalker hoolock  
109 gibbons in China (Fig. 1). Local communities in this region include several ethnic  
110 groups, primarily comprising Han, Lisu, Jingpo and Dai ethnicities. These ethnic  
111 groups have very different traditions and cultures; most Lisu people were traditionally  
112 hunters and their livelihoods are still heavily dependent upon forest products (Ai,  
113 1999; Meng and Lu, 2004), whereas most Han and Dai people are dependent on  
114 farming and trade (Yu, 2014), and Jingpo people utilize farm, trade and forest  
115 products. The majority of Han communities are not religious, whereas many Dai  
116 communities are Buddhist and many Jingpo and Lisu communities are Christian, and  
117 Dai, Jingpo, and Lisu communities also have their own traditional animist religions  
118 (Yang, 2002, 2017; Yu, 2010). Villages in this region have historically been inhabited  
119 by communities belonging to the same ethnic group; although population movement  
120 among villages has become more common, this general demographic pattern is still  
121 maintained across much of the region.

122 We divided the study area into four regions based on proximity to gibbon  
123 subpopulations and Gaoligongshan NNR, the only reserve in China which contains  
124 skywalker hoolock gibbons (Fig. 1): Region A, villages within 10 km of surviving  
125 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.



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

157 Like other gibbon species, skywalker hoolock gibbons regularly produce loud  
158 distinctive calls, typically in the morning from sunrise until about five hours post-  
159 sunrise (Fan et al., 2011b; Yin et al., 2016). We determined the presence of gibbons  
160 by monitoring their vocalizations from listening posts using triangulation, a widely-  
161 used method in gibbon surveys (e.g., Brockelman and Srikosamatara, 1993; Fan et al.,  
162 2011b; Johnson et al., 2005). For each subpopulation, we chose several listening posts  
163 situated on ridge tops with good views of the landscape. Every morning from before  
164 dawn to noon, three or more survey groups each occupied a listening post, and  
165 recorded the direction and estimated the location of singing gibbons, the starting and  
166 stopping time of calling bouts, and when possible the number of singing individuals.  
167 Because gibbons are highly territorial and two neighboring groups of skywalker  
168 hoolock gibbons never sang at the same site according to our long-term behavior  
169 study, we distinguished groups according to singing time, singing location (direction),  
170 and number of singing individuals. We confirmed the presence of isolated gibbon  
171 groups living in small forest patches by one survey group, with no need to use  
172 triangulation. Because paired hoolock gibbons rarely produce solo songs (Yin et al.,  
173 2016), we distinguished solitary individuals from family groups by the number of  
174 singing individuals. When gibbon groups sang near the listening posts, we tried to  
175 find and observe them directly and record their group composition. Since gibbons do

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

177 We calculated the mean group size (including first and third quartiles) for gibbons  
178 based on data from our survey and previous studies (Chan et al., 2017; Fan et al.,  
179 2011b). We estimated population size of skywalker hoolock gibbons in China as the  
180 product of number of groups multiplied by mean group size (with first and third  
181 quartiles used to estimate error ranges), plus the number of solitary gibbons. We then  
182 compared the number of gibbon groups within each subpopulation between our  
183 survey and the previous census by Fan et al. (2011b) using non-parametric Wilcoxon  
184 signed rank tests for paired data.

185

### 186 *2.3. Human impact survey*

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

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

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

217 All variables were obtained from our interview survey except for forest cover data  
218 (for the year 2000), which we obtained from Global Forest Change 2000–2017  
219 ([https://earthenginepartners.appspot.com/science-2013-global-](https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html)  
220 [forest/download\\_v1.5.html](https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.5.html)). Preliminary analysis of interview data showed that 80%  
221 of interviewees (n = 197) reported that they conducted production activities within 5  
222 km of their village, and 93% conducted them within 10 km. To investigate spatial  
223 patterns of impact on forests by local people, we therefore created a 10 km buffer  
224 zone surrounding each village center in ArcMap (version 10.3.1), and calculated  
225 forest cover around each village as the average value of all 30 m×30 m grids within

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

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

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

251 from village to nearest gibbon group/solitary gibbon detected in our survey (Table 1).  
252 We included a quadratic term of distance to gibbons in modeling process since we  
253 hypothesized that the impact of distance may not be linear. Distances were calculated  
254 as Euclidean distances between two sites in ArcMap (version 10.3.1). We tested for  
255 collinearity between all numeric dependent variables; correlation coefficients were  $\leq$   
256 0.52, and so no variables were excluded.

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

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

267

## 268 **3. Results**

### 269 *3.1. Gibbon population dynamics*

270 We confirmed the presence of 26 gibbon groups and 11 solitary gibbons (Fig. 2 &  
271 Appendix Table S1). Combined with data from Chan et al. (2017), we estimated that  
272 the total known population of skywalker hoolock gibbons in China was 32 groups and  
273 11 solitary gibbons in 15 subpopulations. One additional group was reported by local  
274 people at Waku (Sudian Township, Yingjiang County) but vocalizations were not  
275 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  $3.6 \pm 0.2$  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 ( $6.3 \pm 0.2$  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

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

311

### 312 *3.3. Differences across the four regions*

313 The four defined regions in our study showed significant differences in demographic,  
314 cultural, and environmental patterns (Fig. 3, interviewee number = 163, 93, 87, and  
315 46, village number = 40, 23, 21, 15 for Regions A to D). Villages in Region A were  
316 further away from the closest county town (Fig. 3a) and tended to contain more Lisu  
317 people (58%) and fewer Han people (12.8%; Figs. 3b & 3c). Villages in Regions B  
318 and C were instead largely composed of Han people (80.4% and 82.7%), while  
319 villages in Region D were composed of both Lisu (44.3%) and Han people (48.6%;  
320 Figs. 3b & 3c). Villagers in Region A planted more cardamom (Fig. 3d) and  
321 conducted more production activities within the forest (Fig. 3e). Average income in  
322 Region A was similar to Regions B and C, but lower than in Region D (Fig. 3f).

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

326 100;  $W = 1158$ ,  $p < 0.001$ ). Forest loss during 2000-2017 in Region A was higher than  
327 Regions B and D ( $p < 0.001$ ), but was similar to that in Region C ( $p = 0.241$ ,  
328 Appendix Fig. S2).

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

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

348

#### 349 *3.4. Factors that affect interviewees' knowledge of gibbons*

350 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

376 that forest in Region A was retained better than in other regions, subpopulations of  
377 gibbons in Region A had remained stable between 2009 and 2017, similar to the  
378 dynamics of gibbons living within Gaoligongshan NNR in Region B (Fan et al.,  
379 2011b; this study). As a result of living closer to gibbons, local people in Region A  
380 know more about gibbons. Knowledge of gibbons was part of their TEK and may in  
381 turn reinforce their beliefs and practices regarding gibbon protection.

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

398 The fact that Lisu people in Region A do not hunt gibbons contributed to the  
399 survival of gibbons in this region. Although most Lisu people traditionally were  
400 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

451 knew more about them, a common pattern also shown for other threatened species  
452 (e.g., Turvey et al., 2017). Interestingly, this relationship was not linear in our study  
453 area, with people's knowledge of gibbons increasing again with distance above 25  
454 km. This U-shape relationship suggests that people may acquire knowledge of  
455 gibbons across the study area in different ways: people living close to gibbons may  
456 acquire knowledge of gibbons from either TEK or direct experience of encountering  
457 gibbons, whereas people living further away from gibbons (and often in less remote  
458 areas) may instead acquire knowledge from either formal education or media channels  
459 (e.g., television, newspapers/magazines, internet, social media). A similar pattern of  
460 conservation knowledge acquisition is seen in Tibetan villages (Shen et al., 2012). We  
461 found that education level was correlated with knowledge of gibbons, and that men  
462 were more knowledgeable about gibbons than women, a pattern of knowledge  
463 distribution that is also seen for other species (Kellert and Berry, 1987; Nyhus et al.,  
464 2003). Conversely, we found that ethnicity and age had no significant impact on local  
465 people's knowledge of gibbons, which differs from several previous studies (e.g.,  
466 Nyhus et al., 2003; Turvey et al., 2017, 2010). These differences may reflect the fact  
467 that Lisu people in Regions A and D have very different recent histories of forest use  
468 and gibbon-specific TEK retention, and that younger people can acquire knowledge  
469 about gibbons through formal education or media sources instead of requiring  
470 knowledge transfer through TEK.

471 We found that even though Region A represents an important stronghold for  
472 skywalker hoolock gibbons, awareness of legal protection of gibbons and the  
473 existence of a nearby nature reserve was lower here than in regions closer to  
474 Gaoligongshan NNR. We argue that publicity of wildlife conservation and nature  
475 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

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651

652

653 **Tables**

654 Table 1. Variables used in mixed ANOVAs and Kruskal-Wallis tests to compare among the four regions, and in linear mixed effect models to  
 655 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;<br>e) others | Mixed ANOVA<br>& LMM    |
| FOR           | Forest cover rate within 10 km buffer zone<br>surrounding villages  | Percentage (1-100)  | Kruskal-Wallis          |
| TOW           | Euclidean distance from village to closest county town  | Continuous (km)   | Kruskal-Wallis<br>& LMM |
| PRO           | Number of production activities conducted by<br>interviewee in forest (including hunting, logging,<br>firewood collection, understory plantation, herding,<br>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 |

656

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

| Hypothesis   | Model structure                   | $K$ | AIC    | $\Delta AIC$ | $\omega_i$ |
|--|-----------------------------------|-----|--------|--------------|------------|
| Negative influence of a middle-range of distance to gibbons, and positive influence of education, distance to county town, and male gender | DIS+DIS <sup>2</sup> +EDU+TOW+GEN | 8   | 1438.2 | 0            | 0.988      |
| Negative influence of a middle-range of distance to  | DIS+DIS <sup>2</sup> +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 <sup>2</sup> +EDU+TOW | 7 | 1453.0 | 14.8 | 0.001 |
|---|-------------------------------|---|--------|------|-------|

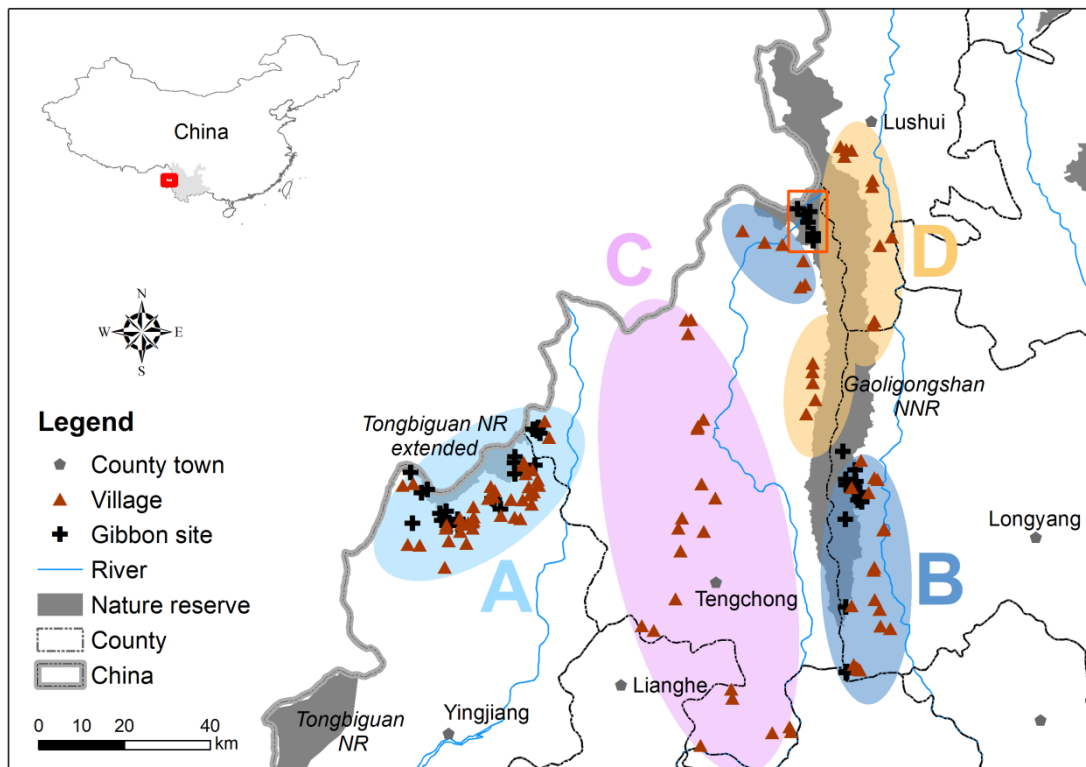
|  |                           |   |        |      |       |
|--|---------------------------|---|--------|------|-------|
| Negative influence of a middle-range of distance to gibbons, and positive influence of male gender | DIS+DIS <sup>2</sup> +GEN | 6 | 1455.7 | 17.5 | 0.000 |
|--|---------------------------|---|--------|------|-------|

|   |                 |   |        |      |       |
|---|-----------------|---|--------|------|-------|
| 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 |
|---|-----------------|---|--------|------|-------|

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 <sup>2</sup> | 0.003       | 0.001 |
| EDU              | 0.209       | 0.059 |
| TOW              | 0.019       | 0.006 |
| GEN-male         | 0.623       | 0.151 |

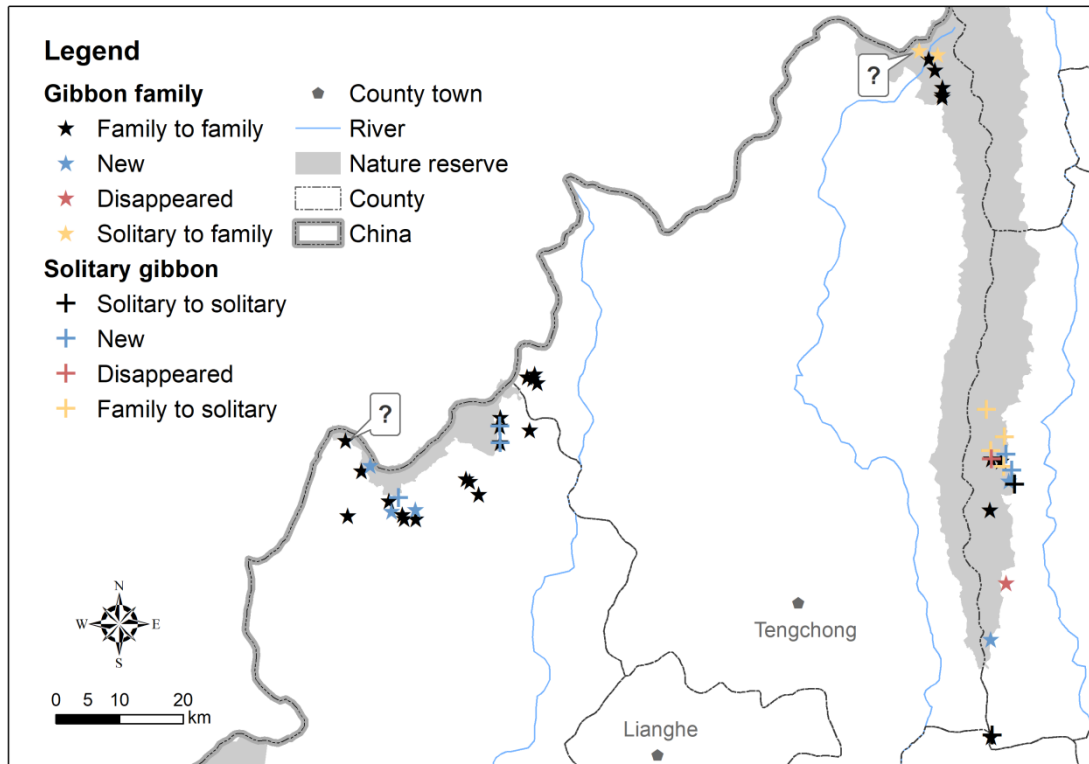
664  
665



667

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

676



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

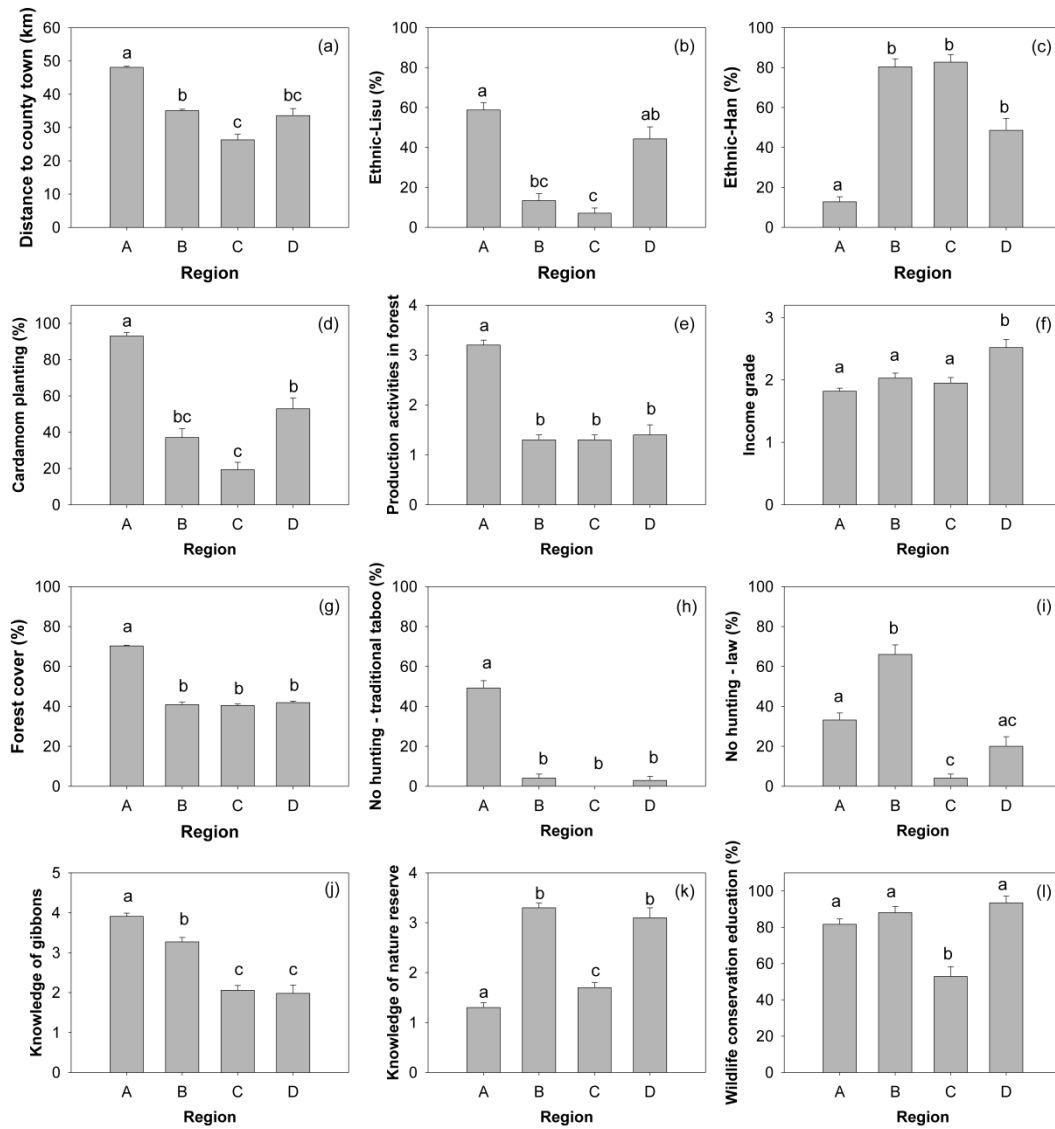
681 “family to solitary” means a gibbon family was found in 2009 while a solitary gibbon

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 /<br>subpopulation | Gibbon ID            | Lon      | Lat      | Population<br>change <sup>a</sup> | Group<br>type <sup>b</sup> | NR  |
|----|-----------|--------------------------------|----------------------|----------|----------|-----------------------------------|----------------------------|-----|
| 1  | Sudian    | Waku                           | Zijiawaduo           | 97.85746 | 25.25117 | 1                                 | F <sup>c</sup>             | 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 <sup>d</sup> | 98.69481 | 25.79768 | 5                                 | F <sup>c</sup>             | in  |
| 42 | Mingguang | Zizhi                          | Zizhi-2 <sup>d</sup> | 98.66879 | 25.80339 | 5                                 | F                          | in  |
| 43 | Mingguang | Zizhi                          | Zizhi-3 <sup>d</sup> | 98.68231 | 25.79130 | 1                                 | F                          | in  |
| 44 | Mingguang | Zizhi                          | Zizhi-4 <sup>d</sup> | 98.69088 | 25.77557 | 1                                 | F                          | in  |

|    |        |        |                       |          |          |   |   |    |
|----|--------|--------|-----------------------|----------|----------|---|---|----|
| 45 | Jietou | Datang | Datang-1 <sup>d</sup> | 98.70136 | 25.74097 | 1 | F | in |
| 46 | Jietou | Datang | Datang-2 <sup>d</sup> | 98.70166 | 25.75097 | 1 | F | in |
| 47 | Jietou | Datang | Datang-3 <sup>d</sup> | 98.70112 | 25.73713 | 1 | F | in |

<sup>a</sup>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.

<sup>b</sup>Group type: F – family; S – solitary.

<sup>c</sup>Gibbon groups that reported by local people but could not be confirmed during surveys.

<sup>d</sup>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: _____ | <input type="checkbox"/> Increase | <input type="checkbox"/> Decrease | <input type="checkbox"/> Stable | <input type="checkbox"/> Don't Know |
| Name of species: _____ | <input type="checkbox"/> Increase | <input type="checkbox"/> Decrease | <input type="checkbox"/> Stable | <input type="checkbox"/> Don't Know |
| Name of species: _____ | <input type="checkbox"/> Increase | <input type="checkbox"/> Decrease | <input type="checkbox"/> Stable | <input type="checkbox"/> Don't Know |
| Name of species: _____ | <input type="checkbox"/> Increase | <input type="checkbox"/> Decrease | <input type="checkbox"/> Stable | <input type="checkbox"/> Don't Know |
| Name of species: _____ | <input type="checkbox"/> Increase | <input type="checkbox"/> Decrease | <input type="checkbox"/> Stable | <input type="checkbox"/> 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)

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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;  $\Delta AIC$ , difference in AIC values between each model and the best model;  $\omega_i$ , Akaike weight.

| Hypothesis  | Model structure                   | $K$ | LogLik | AIC    | $\Delta AIC$ | $\omega_i$ |
|---|-----------------------------------|-----|--------|--------|--------------|------------|
| 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 <sup>2</sup> +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 <sup>2</sup> +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 <sup>2</sup> +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 <sup>2</sup> +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 <sup>2</sup> +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 <sup>2</sup> +TOW | 6 | -728.0 | 1468.0 | 29.8 | 0.000 |
| Negative influence of a middle-range of distance to gibbons   | DIS+DIS <sup>2</sup>      | 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 |

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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,<br>and conservation education |
| 90  | 0.478 | lisu   | yes | a | bb | misfortune   |
| 91  | 0.534 | lisu   | yes | a | ba | Tradition without specific reason,<br>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<br>singing, tradition                  |
| 107 | 0.534 | lisu   | yes | a | ba | No crop raiding  |
| 108 | 0.534 | lisu   | yes | a | ba | Tradition, good fortune,<br>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  |

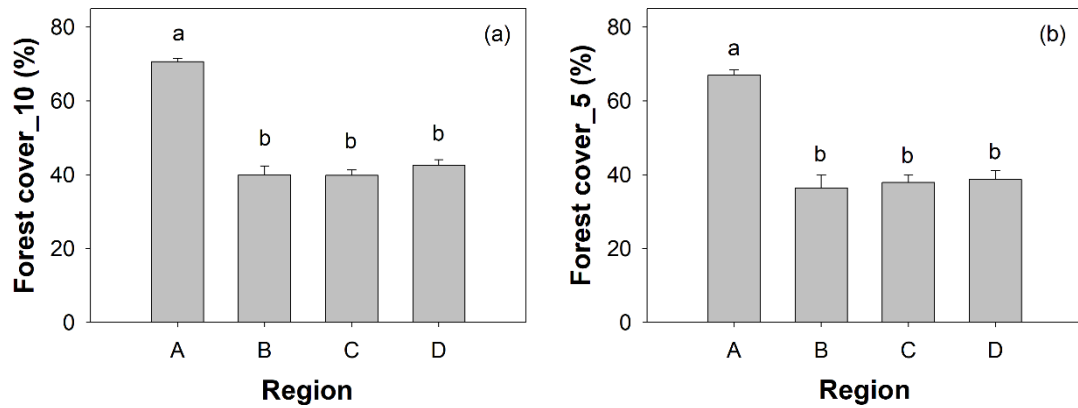


Fig. S1. Forest cover in the year 2000 in a 10 km buffer zone surrounding each village (a), and in a 5 km buffer zone (b). Different lowercase letters on bars indicate significant differences at  $P < 0.05$ .

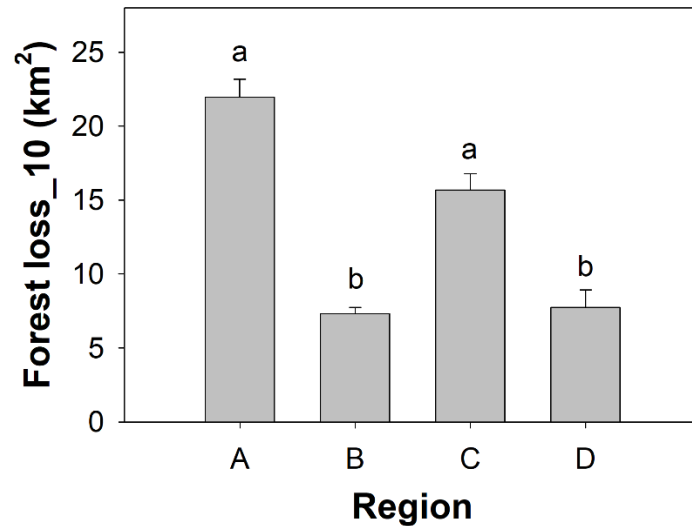


Fig. S2. Forest loss during 2000-2017 in a 10 km buffer zone surrounding each village. Different lowercase letters on bars indicate significant differences at  $P < 0.05$ .