

## Supplementary Materials

### Conservation policies and capacities on both sides of the border

Until recently, with the introduction of the Log Export Ban in 2014 and the designation of Mount Imawbum National Park (MINP) in 2020 (Lim et al., 2017; Meyer et al., 2017; Springate-Baginski et al., 2016; Williams, 2020), *Rhinopithecus strykeri* has received limited specific protection in Myanmar (Aung, 2007; Geissmann et al., 2011; Rao et al., 2002). In recent years, however, the Myanmar government has worked closely with the conservation community, e.g., Fauna & Flora International, to initiate local-scale conservation programs in villages around MINP (Meyer et al., 2017; Williams, 2020). These programs involve raising conservation awareness, creating non-hunting core zones, establishing local conservation groups, and providing small funding for livelihoods (Meyer et al., 2017; Williams, 2020). However, the current conservation capacity of MINP is limited (Williams, 2020) and insufficient resources, such as funding, staff, and infrastructure, remain considerable challenges for implementing effective conservation (Aung, 2007; Rao et al., 2002; Williams, 2020). In addition, deep poverty, economic stress, unstable political regimes, armed conflict, and the COVID-19 pandemic have also contributed to current protection concerns (Lim et al., 2017; Prescott et al., 2017; Springate-Baginski et al., 2016; Thang et al., 2014; United Nations, 2021). Therefore, all *R. strykeri* populations in Myanmar are presumed to be extremely vulnerable to the frequent human disturbances in their habitats (Aung et al., 2013; Geissmann et al., 2011; Nijman, 2015), such as hunting, logging, mining, infrastructure development, and forest fires (Biswas et al., 2015; LaJeunesse Connette et al., 2016; Meyer et al., 2017).

In China, *R. strykeri* is presently listed as a Class I National Key Protected Wildlife species (National Forestry and Grassland Administration, 2021). Currently, two *R. strykeri* groups are known to inhabit the Mt. Gaoligong National Nature Reserve (GNNR, established in 1983) (Long et al., 2012; Meyer et al., 2017). Human activities (e.g., hunting, logging, grazing, and harvesting) occasionally occur in the GNNR and surrounding areas but have gradually decreased in the past three decades with increased field patrols and law enforcement (Xue, 1995; Ma et al., 2014). *Rhinopithecus strykeri* is also protected by nationwide policies (Chapman, 2018), such as the Gun Ban in 1996, National Forest Protection Program in 1998, Grain-for-Green Program in 2000 (Ren et al., 2015; Wang et al., 2021), and Ecological Poverty Alleviation in 2018 (National Development and Reform Commission, 2018). These policies have successfully reduced poaching and deforestation (Ma et al., 2014; Ren et al., 2015; Wang et al., 2021), and sustainably increased local community livelihoods around GNNR, including Pianma (Government of Pianma, 2020). As an important part of the Ecological Poverty Alleviation program, recruiting and training local people as forest rangers has significantly strengthened conservation capabilities in GNNR. In the Pianma region, for example, recruitment has not only provided additional income and jobs, but has also increased the number of forest rangers from 20–30 (before 2015) to more than 205 (after 2018) (Government of Pianma, 2020). The local government in Nujiang has also initiated a series of publicity campaigns and conservation education programs regarding *R. strykeri* and biodiversity for local communities around GNNR (Nujiang Forestry and Grassland Administration, 2021), while also intensifying border control to combat illegal activities (Government of Pianma, 2020).

### Survey methods

We interviewed experienced forest rangers ( $\geq 5$  years patrol experience) or local people known to have knowledge of the forests and monkeys (Geissmann et al., 2011; Ma et al., 2014). We showed the interviewees 3D satellite images in Google Earth Pro (v7.3.3) and

asked them to indicate where they had seen monkeys in recent years (2016–2020). We recorded dates and locations of each reported sighting. Interviews in the Myanmar region were conducted by local forest rangers who had relatives or families in Pawaku village.

Based on the interviews, we tracked *R. strykeri* using trace signals (e.g., broken branches, food litter, feces, and acoustics) along accessible tracks 2–5 times per week from 08:00 to 20:00 (China standard time, UCT+8) (Chen et al., 2015). Once the monkeys were observed, we followed them for as long as possible using a GPS receiver (South S720 or Canon GP-E2) to record the central position of the group or temporally separated sub-groups every 30 min and censused the group when they crossed open areas (Xiang et al., 2013).

Simultaneously, we monitored 58 camera trap sites (spacing 200–1 000 m apart) using infra-red cameras (Ltl-Acorn 6511MC & Ereagle E1B) at altitudes of 2 570–3 758 m a.s.l. (Figure 1A). We attached cameras to trees (DBH $\geq$ 20 cm) or thick bamboo at a height of 50 cm, facing animal trails, water resources, or resting sites (Chen et al., 2015, 2019). Images were retrieved from the cameras every 4–6 months. Independent detections (30 min interval between sightings) of the species were identified and cross-referenced with the camera coordinates (Chen et al., 2015, 2019).

## Data analysis

When mapping the multi-year home range of *R. strykeri*, we pooled all recorded geographic locations using the 100% minimum convex polygon approach in ArcGIS (v10.7). We adjusted the polygon to avoid areas unsuitable for the species (e.g., farmlands, roads, meadows, and alpine bamboo forests  $\geq$ 3 500 m a.s.l.) (Chen et al., 2015; Ren et al., 2017). The current home range in Myanmar was estimated based on the Pawaku village interviews, border observations, and satellite images in Google Earth Pro (v7.3.3). When mapping recorded human disturbance, particularly fire-affected areas and mining sites, we combined field observations at the border and satellite images in both Google Earth Pro (v7.3.3) and Global Fire Map (FIRMS, 2021).

Our earlier census data (2012–2014) obtained by direct observations (Li et al., 2014) and camera traps (Chen et al., 2015) were extracted from survey video footage and camera trap images. In previous analyses, we did not identify sub-adults due to insufficient experience distinguishing them from adults (Chen et al., 2015; Li et al., 2014) (Supplementary Table S2, S3; Supplementary Figure S1). Here, we reviewed all raw video footage and camera images used in our prior studies (Chen et al., 2015; Li et al., 2014) and revised the previous census data (Supplementary Table S2, S3; Supplementary Figure S1). We excluded indeterminate individuals from analyses. We used the Chi-squared and one-sample proportion tests (significance level:  $P < 0.05$ ) to detect composition differences in the three age-sex ratios between current and previous census data from the revised direct observation (Li et al., 2014) and camera trap results (Chen et al., 2015) in 2012–2014 (Supplementary Table S2). Statistical tests were carried out using R (v4.0.4) (R Core Team, 2021).

## Results

### Coordinates and population records

We interviewed 25 forest rangers and local people from four villages. Twelve people from Pianma, Gulang, and Gangfang villages provided 14 recent records (2016–2020) of *R. strykeri* within GNNR and adjacent forests. None of the interviewees encountered the species in Piansihe village.

During direct tracking and observations, we obtained 964 geographic coordinates (262 trace records, 702 direct observation records) (Figure 1A). Infra-red cameras also captured images at 24 locations, totaling 59 independent detections. Similar to the interview results, the species was only recorded in Pianma, Gulang, Gangfang, and Pawaku villages, with no records in Piansihe village (Figure 1A).

In addition to the census obtained on 18 November 2020, we also counted more than 120–130 individuals on 13 April 2019, 29 October 2019, and 11 April 2020 (distance *ca* 80–200 m) as they travelled across forest gaps. Due to dense vegetation and poor visibility, we could not reliably identify each individual's age-sex or their social affiliations on most encounter days, even when they formed large cohesive groups ( $\geq 100$  individuals). On 8 and 9 May 2020, we identified 20–23 distinct fecal patches at each of two sleeping sites, suggesting the presence of 20–23 social units.

### **Recorded transboundary activities of *R. strykeri***

At 14:25 on 7 March 2020, we observed one sub-group (*ca* 17 individuals) belonging to at least two OMUs feeding and traveling in forest far beyond GNNR, after which they moved along the border and entered Myanmar territory at 16:43 (Figure 1B). On 19 May 2020, after locating the large cohesive group at Gangfang village, many freshly broken branches and food litter were found at four distinct locations (30–60 m from each other) of the border. We only obtained acoustic records of *R. strykeri* on that day (15:45–16:02) based on activities and vocalizations on the Myanmar side (*ca* 200 m from the border) (Figure 1B).

On 17 May 2020, one infra-red camera (PM39GF) located very close to the border (<40 m) captured images at 12:47 of an OMU (eight individuals) and two adult males belonging to an AMU, who were moving toward unprotected forest in Pawaku village (Myanmar) (Figure 1B). At 10:49 on 20 May 2020, the same infra-red camera captured images of another OMU (seven individuals) and one indeterminate individual (Figure 1B), moving in a direction that suggested recent crossing of the border from Myanmar to China.

Another infra-red camera (PM36GF) deployed close to the border (<500 m) recorded images of the species on 29 August 2020 and 17 January, 18 January, and 29 January 2021 (Figure 1B). The camera recorded 22 individuals (belonging to at least three OMUs) from 15:53 to 16:15 on 17 January 2021, and 19 individuals (belonging to at least one OMU and one AMU) from 09:07 to 09:24 on 29 January 2021. Their moving direction was toward the border (Figure 1B), but we could not confirm the exact dates and locations of their transboundary activities in the forthcoming days.

### **Composition differences in *R. strykeri* group between surveys**

The current ratio and composition of adults was similar to that of the two previous censuses (Supplementary Table S4), although skewed toward females ( $P=0.017$ ). The adult female-to-infant ratio was similar between the censuses (Supplementary Table S4), but the current group contains more infants ( $P=0.028$ ). However, the current adult-to-immature ratio was significantly different from previous direct observations ( $\chi^2=5.402$ ,  $P=0.020$ ) and camera trap results ( $\chi^2=4.192$ ,  $P=0.041$ ), with significantly more immature individuals than in 2012–2014 ( $P<0.000$ ) (Supplementary Table S4).

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**Supplementary Table S1.** Comparative data on population distribution status of Myanmar or black snub-nosed monkey (*Rhinopithecus strykeri*) in Pianma region (China) and adjacent Pawaku village (Myanmar). “Interview”, “Confirmed”, and year in parentheses under previous and current statuses indicate whether the group was only reported by local interviewees confirmed by direct evidence from field surveys, and last recorded year, respectively. Group names and previous records follow Ma et al. (2014) and Meyer et al. (2017).

Group	Group size (individuals)	Home range (km <sup>2</sup> )	Locations (villages)	Previous record status	Current status	References
C7	30	Unknown	Gangfang, Pawaku	Interview (1983)	Confirmed / sub-group of C8	Ma et al., 2014
C8	ca 100	22.90	Pianma, Gulang	Confirmed (2011–2015)	Confirmed / Transboundary	Chen et al., 2015; Li et al., 2014; Long et al., 2012; Ma et al., 2014;
C9	20	Unknown	Piansihe	Interview (2008)	Historical, may move to elsewhere	Ma et al., 2014
C10	10	Unknown	Pianma, Gulang	Interview (1980s)	Historical	Ma et al., 2014
M5	30–100	Unknown	Pawaku	Interview (2007–2010)	Unknown	Aung et al., 2013; Meyer et al., 2017
Pianma (C8+C7)	149 (155–160)	51.50–57.02	Pianma, Gulang, Gangfang, Pawaku	-	Confirmed / Transboundary	This survey

**Supplementary Table S2.** Comparative data on home range and population composition of free-ranging snub-nosed monkeys (*Rhinopithecus* spp.). Numbers in parentheses under population size indicate estimated numbers of a given population. Numbers outside and inside parentheses under each age-sex class represent revised and original records from previous censuses of *R. strykeri* in Pianma region, respectively.

Species	Group (Location)	Home range (km <sup>2</sup> )	Population size	Adult male	Adult female	Sub- adult	Juvenile	Infant	Indeterminate individual	Survey period	Reference
<i>R. strykeri</i>	Pianma (N26°02', E98°38')	51.50–57.02	149 (155–160)	21	58	23	29	18	-	2019–2021	This survey
		12	99 (100)	24 (22)	40 (47)	11	12 (18)	7 (10)	5	2012–2013	Li et al., 2014
		22.90	97 (100)	18 (31)	35 (29)	10	7 (7)	9 (7)	18 (16)	2013–2014	Chen et al., 2015
<i>R. bieti</i>	Xiaochangdu (N29°15', E98°37')	21.25	207	32	71	-	72	32	-	2003–2005	Xiang et al., 2013
		25.25–100	173 (175–200)	66	22	-	60	29	-	1992–1994	Kirkpatrick et al., 1998
		32.31–56.10	407	63	138	21	132	42	11	2005–2007	Grueter et al., 2008, 2017
<i>R. roxellana</i>	Yuhuangmiao E (N33°47', E108°16')	18.30	112	11	41	-	14	21	25	2002–2003	Tan et al., 2007
		22.50	236±38	106±12	77±18	-	35±10	18±5	-	2007–2008	Fan et al., 2019
		12.30–49.10	130	18	32	28	46	6	-	2013–2015	Fang et al., 2018
<i>R. brelichi</i>	Yangaoping (N27°55', E108°45')	35	228	30	75	-	97	26	-	1991–1992 2007–2008	Bleisch, 1995; Nie et al., 2009
<i>R. avunculus</i>	Tat Ke (N22°26', E105°26')	≥ 10	72 (80)	5	17	19	16	15	-	1993–1994	Boonratana & Le, 1998, 2013



**Supplementary Table S3.** Morphological traits used for identification of different age-sex categories of *R. strykeri*.

Trait	Adult male (≥ 7–8 years old)	Adult female (≥ 6 years old)	Sub-adult (4–6 years old)	Juvenile (2–4 years old)	Infant ( < 2 years old)
Body size	Largest	Large	Slightly large	Medium-small	Smallest
Limbs robustness	Most robust	Robust	Slightly robust	Medium	Slender
Tail robustness	Most robust	Robust	Slightly robust	Medium	Slender
Erect tuft on head	Very noticeable	Noticeable	Slightly noticeable	None	None
White fur around perineum	Very noticeable	Noticeable	Noticeable	Slightly noticeable	Unnoticeable
Overall coloration	Black	Black	Black	Black-dark grey	Light dark grey
Coloration on face	Pale pink	Pale pink	Pale pink	Partial pale pink	Light grey-slightly pale pink
Sexual characteristic	Testes, noticeable	Nipples and labia, noticeable	Testes or labia, less noticeable	Unnoticeable	Almost invisible

**Supplementary Table S4.** Statistical results of current age-sex-ratio and composition (2019–2021) compared with two previous surveys in 2012–2014. First three rows present three age-sex ratios and Chi-squared statistics. Last four rows show composition of each age-sex class and one-sample proportion statistics. Asterisk (\*) represents significant difference ( $P < 0.05$ ).

Category	Current census	Li et al., 2014 (Direct observation)			Chen et al., 2015 (Infra-red camera trapping)		
		Ratio/Individual	$\chi^2$	<i>P</i>	Ratio/Individual	$\chi^2$	<i>P</i>
Adult male : adult female	1 : 2.76	1 : 1.67	1.954	0.162	1 : 1.94	0.830	0.362
Adult female : infant	3.22 : 1	5.71 : 1	1.386	0.239	3.89 : 1	0.167	0.683
Adult : immature	1.13 : 1	2.13 : 1	5.402	0.020*	2.04 : 1	4.192	0.041*
Adult male	21	24	-	0.655	18	-	0.631
Adult female	58	40	-	0.069	35	-	0.017*

Immature	70	30	-	< 0.000*	26	-	< 0.000*
Infant	18	7	-	0.028*	9	-	0.083

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**Supplementary Figure S1. Photos of different age/sex classes of *R. strykeri*. Photos taken by Yi-Xin Chen and Pu Liu.**

**A:** Incomplete OMU containing adult male (back), sub-adult female (left), and adult female (right).

**B:** Sub-adult male (left) and adult male (right).

**C:** Two juveniles.

**D:** Juvenile and adult male.

**E:** Adult female carrying infant (left) and sub-adult female.

**F:** Adult female and infant.