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Using local ecological knowledge to determine status and threats of the Critically Endangered Chinese pangolin (*Manis pentadactyla*) in Hainan, China

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ABSTRACT

The use of robust ecological data to make evidence-based management decisions for highly threatened species is often limited by data availability, and local ecological knowledge (LEK) is increasingly seen as an important source of information for conservation. Pangolins are now the most heavily trafficked mammals in illegal wildlife trade, and Chinese pangolins (*Manis pentadactyla*) are Critically Endangered, with no recent baseline data available to assess status of pangolin populations in China. We conducted community-based interviews across seven protected areas in Hainan, China, to investigate whether LEK can provide novel insights for pangolin conservation. LEK of pangolins remains high in Hainan (90% of respondents recognize pangolins and can provide supporting information), and pangolins are likely to survive in all protected areas that were surveyed, as evidenced by recent sightings dating from 2013 to 2015. However, all populations have declined and are now perceived to be of very low abundance (only 34% of respondents consider pangolins to remain locally present, and these respondents all regard pangolins as rare). Illegal hunting continues across this region, with pangolin body parts used locally and sold to outsiders. Pangolins are likely to soon become extirpated across Hainan unless effective conservation management plans can be initiated. Methods to monitor and assess pangolin status and threats are urgently required across all range states, and we demonstrate that large-scale LEK surveys can strengthen the evidence-base for informing robust conservation action and management plans for these species.

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1. Introduction

The importance of using evidence-based conservation to inform effective management decisions is increasingly recognized by conservation researchers and practitioners (Sutherland et al., 2004; Segan et al., 2010). Developing a robust evidence-base for conservation planning using rigorous, objective data is particularly important for ecosystems in eastern and southeast Asia, which are experiencing extreme levels of anthropogenic pressure and contain the world's highest proportion of threatened vertebrate and plant species (Schipper et al., 2008; Sodhi et al., 2010). However, highly threatened species can be challenging to study due to low population density or detectability, and robust data on key parameters (e.g., population status, threats) may be difficult or impossible to collect using standard field techniques. Relevant information about such species may also be available in the form of local ecological knowledge (LEK) held by untrained local people using the same environments (Berkes et al., 2000; Anadón et al., 2009; Newing, 2011). LEK is increasingly seen as an important alternative source of conservation data, especially for "charismatic" large-bodied vertebrates (van der Hoeven et al., 2004; Meijaard et al., 2011; Parry and Perez, 2015; Turvey et al., 2015a). However, smaller-bodied species, including mammals, are more likely to be unreported or misidentified by respondents in interview surveys (Turvey et al., 2014). Assessing the effectiveness of LEK for providing robust baselines for such "non-charismatic" (cf. Entwistle and Stephenson, 2000) species, particularly in Asia, has been the focus of relatively little investigation. Identifying tools to combat the Asian biodiversity crisis is imperative, and such research is an important conservation goal.

The Chinese pangolin (*Manis pentadactyla*) is an insectivorous scaly-bodied small mammal with a wide historical distribution across eastern, southern and southeast Asia, but populations across its range are now severely threatened by hunting and illegal wildlife trade (Corlett, 2007; Challender et al., 2014b). Pangolins are the most heavily trafficked mammals in illegal wildlife trade globally (Challender et al., 2015), with trade driven by demand for meat as a luxury food item, and skins and scales for traditional medicines (Wu and Ma, 2007; Pantel and Chin, 2009; Challender, 2011; Zhou et al., 2014). All pangolin species are globally threatened, and the Chinese pangolin is Critically Endangered (IUCN, 2015). Legislation exists to protect Chinese

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pangolins across their range (CITES, 1975; Jiang, 2014), with pangolins listed under Category II of 'Animals Under State Special Protection' in China (Li et al., 2000; Watters and Wang, 2002). However, legal hunting of pangolins was widespread in China until the 1980s (Li et al., 2000), and illegal hunting and trade of many wild animals in China remains a serious conservation problem (Liu et al., 2011; Liang et al., 2013; Li and Lu, 2014; Pan et al., 2015). Changing such illegal but entrenched behaviours is challenging (Wu et al., 2002b; Zhang et al., 2008; Fellowes et al., 2009; Challender et al., 2014a).

Developing an effective conservation management framework for Chinese pangolins is hindered by a lack of robust recent baseline data on status, distribution and population sizes across most of their range. Although field survey methods can provide ecological information about pangolins, such studies are often small-scale, impractical, or of limited use due to rarity and cryptic status of surviving populations (Wu et al., 2004b). Pangolins are unlikely to be detected through monitoring approaches that are effective for other mammals, and are often not well-covered in general wildlife surveys because of their different ecologies (Duckworth et al., 1999; Shek et al., 2007). Chinese pangolins are predominantly nocturnal ground-dwellers that excavate burrows (Wu et al., 2004c), and burrow counts have been used to estimate abundance and density (Wu et al., 2002a; Thapa et al., 2014), but these estimates are complicated by low and variable rates of burrow reutilization (Wu et al., 2004c).

Despite being small-bodied mammals, pangolins are morphologically distinctive with important economic and cultural value and are unlikely to be misidentified even by untrained respondents, and may therefore constitute useful target species for LEK-based research (Newton et al., 2008; Thapa et al., 2014). Small-scale LEK studies on pangolins, collected from hunters, market traders and forest workers, have previously been used to supplement ecological field surveys (Sodeinde and Adedipe, 1994; Duckworth et al., 1999; Newton et al., 2008). As data on key pangolin conservation parameters remain otherwise difficult to obtain, it is important to further investigate the efficacy of LEK-based surveys for clarifying regional population status, trends and threats in pangolins, and to conduct such studies at larger scales than before to generate robust baselines for regional conservation management.

Little recent pangolin field research has been conducted in China, the country most responsible for driving pangolin population declines across Asia and Africa (Challender et al., 2015), although local hunting pressure probably remains high (Wu et al., 2004a; Corlett, 2007; Zhang et al., 2008; IUCN, 2015). Targeted pangolin research has not been conducted at all on Hainan Island, China's southernmost province. Hainan is considered likely to retain remnant pangolin populations, recognized as a distinct endemic subspecies (*Manis pentadactyla pusilla*) by some authors (Allen, 1906; Zhang, 1997; IUCN, 2015). Most of Hainan's tropical and subtropical forests have been cleared for agriculture, timber and plantations, with nearly all remaining old-growth forest restricted to medium-high elevations within protected areas, and Hainan's biodiversity is under threat (Chan et al., 2005; Lau et al., 2010; Liang et al., 2013; Turvey et al., 2015b). Pangolins have been exploited heavily for food and medicine on Hainan since at least the early twentieth century (Allen, 1938; Liu, 1938; Xu et al., 1983). In a series of rapid biodiversity assessments in 1998–2001, local reports indicated probable pangolin presence in Bawangling, Diaoluoshan, Jianfengling, Jianling, Jiaxi, Nanweiling, Shangxi, Tongtieling, Wuzhishan and Yinggeling reserves on Hainan (Kadoorie Farm and Botanic Garden, 2001–2003). However, these reports only represent anecdotal presence/absence records, none of which date from within the past decade, and in most cases a status of "insecure" was ascribed to pangolins, meaning that populations were then considered highly threatened and likely to decline rapidly. Reports from other areas of Hainan are unavailable. It is therefore effectively impossible to infer current pangolin status on Hainan in the absence of new baseline data.

We conducted a large-scale community-based LEK survey in 2015 to assess the status of native mammals across seven protected areas on Hainan. In this study, we use this LEK dataset to provide the first detailed assessment of current regional status of Chinese pangolins across Hainan and between different protected areas on the island, to determine past and present pangolin abundance and threats and to understand local beliefs and attitudes about pangolins, all of which are essential for effective conservation management (Jim and Xu, 2002; Redford et al., 2011; Kelbessa, 2015; Weber et al., 2015). We also use these data to determine the extent to which LEK is able to provide novel insights into key pangolin conservation parameters, and we consider the potential strengths and limitations of an LEK-based survey approach for informing pangolin conservation (Olsson and Folke, 2001; Schulman, 2007; Haen et al., 2014).

2. Material and methods

2.1. Survey methods

Community-based surveys were conducted in Bawangling, Diaoluoshan, Jianfengling, Wuzhishan and Yinggeling National Nature Reserves and in Jiaxi and Limushan Provincial Nature Reserves, which together contain much of Hainan's remaining good-quality protected forest (Fig. 1, Table A1). People are not allowed to live inside the reserves, but numerous villages are situated close to the boundaries of each reserve, with local people utilizing animal and plant resources collected inside protected areas (Kadoorie Farm and Botanic Garden, 2001–2003; Chan et al., 2005; Turvey et al., 2015b). We obtained a full list of villages surrounding each reserve from each reserve management office, and randomly selected ten administrative villages per reserve in which to conduct interviews (Fig. 1); this random sampling strategy aimed to ensure that our data would be representative of wider patterns of local knowledge, awareness and attitudes for communities around each reserve. A target number of ≥10 interviews were conducted per village; this number complies with predicted response saturation levels (White et al., 2005; Guest, 2006), meaning that the total number of interviews per village should be sufficient to capture existing potential variation in responses for each question. As a detailed plan of households in each village was not available, our primary strategy for identifying respondents involved randomly selecting people to interview by walking through each village; each village was relatively small, and so this approach usually resulted in the entire village being traversed (cf. Pan et al., 2015). Local village heads sometimes also introduced us to respondents known to have good LEK through targeted "snowball sampling" (Newing, 2011). Children and teenagers below the age of 18 were not interviewed, and only one respondent was interviewed per household to ensure independence of responses; respondents of both genders and any reported occupation were interviewed.

A standard questionnaire was used for all interviews, which took up to 1 h to complete, and which comprised a series of contrast, structured and open-ended questions (Supplementary Material Text-Files A1–A2). We obtained verbal consent before starting interviews, and all responses were anonymous. Prior to being asked questions, respondents were informed that they could stop interviews at any time. Interviews were mainly conducted in Mandarin or Hainanese, and recorded in Chinese, by pairs of volunteers recruited from universities or NGOs in Hainan; most local people could understand and communicate in these languages, although other local ethnic minority languages (Li, Miao/Hmong) were also relatively widely spoken in target communities. Pilot studies were conducted in villages around Bawangling in August 2014 and January 2015, following which the questionnaire was modified to enable more effective data collection. Interviews were conducted in Bawangling, Jiaxi and Yinggeling in January 2015, and in Diaoluoshan, Limushan, Jianfengling and Wuzhishan in April 2015; the four-person team of interviewers changed between these periods except for one team member, who led the second survey period to ensure consistency in interview methods. Local reserve staff were also present during

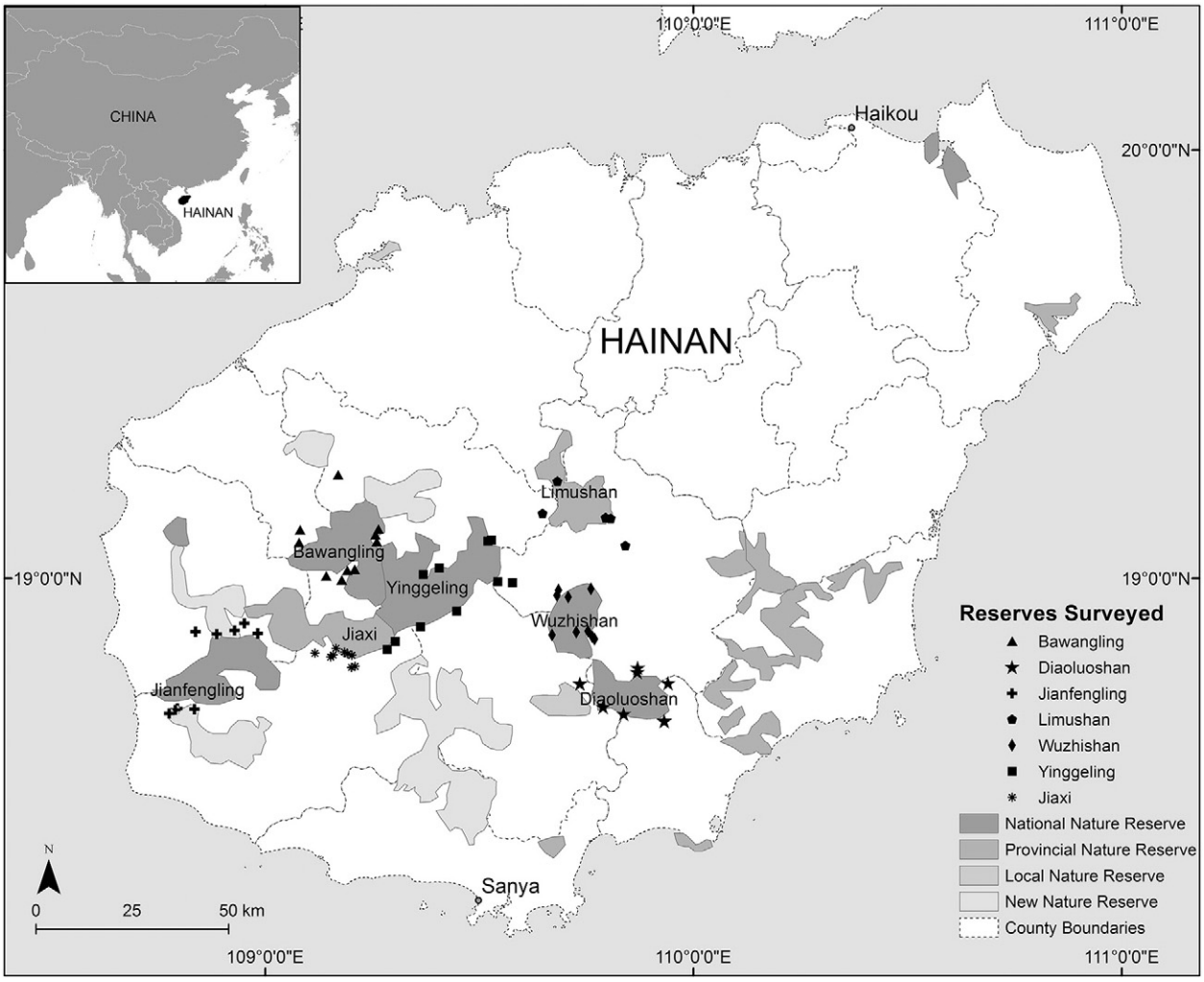

Fig. 1. Locations of 70 villages surveyed across seven protected areas in Hainan. Map produced in ArcGIS v.10.1; GPS coordinates collected on-site using handheld GPS units. Some surveyed villages were close together and are not differentiated by separate symbols.

interviews, as required by our research permits. To minimize bias in results, these staff did not usually participate in interviews, although it was sometimes necessary for them to act as translators for ethnic minority languages; however, even when reserve staff acted as translators, the indirect style of questioning and anonymity in the survey was seen to facilitate responses even to potentially sensitive subjects.

Following initial questions to collect background demographic information, respondents were shown colour photographs of nine mammals (wild pig, *Sus scrofa*; rhesus macaque, *Macaca mulatta*; Hainan gibbon, *Nomascus hainanus*; clouded leopard, *Neofelis nebulosa*; Asian black bear, *Ursus thibetanus*; Chinese pangolin, *Manis pentadactyla*; binturong, *Arctictis binturong*; sambar deer, *Rusa unicolor*; giant anteater, *Myrmecophaga tridactyla*) to establish if they recognized each species. Photographs were sourced from Arkive (www.arkive.org) and the Zoological Society of London, and were shown in the same order in all interviews. Seven of these species are known to occur on Hainan; binturongs are suspected to occur on Hainan but their regional presence is not confirmed (Lau et al., 2010); and giant anteaters, native to Central and South America, were a negative control to check response accuracy (cf. Turvey et al., 2014). Data from interviews in which respondents reportedly recognized anteaters as occurring locally were discarded, although this only occurred twice. We expected most respondents to recognize wild pigs, which are reportedly common across Hainan (Kadoorie Farm and Botanic Garden, 2001–2003), so this species was included as a positive control (White et al., 2005; Turvey et al., 2015a). Incorporation of a wide range of species in interviews was intended to obscure the potential importance to interviewers of any specific target species, and therefore to increase the likelihood of respondents reporting potentially sensitive information about these species (Pan et al., 2015; Turvey et al., 2015a).

After being shown photographs of each species, respondents were asked to provide further ecological and morphological details to confirm accurate recognition. If they did not recognize species from photographs, standard Mandarin names were used to prompt recall (wild pig: *shanzhu*; macaque: *houzi*/*mihou*; gibbon: *changbiyuan*; clouded leopard: *yunbao*; bear: *xiong*; pangolin: *chuanshanjia*; binturong: *xiongli*; sambar: *shuilu*; giant anteater: *juxingshiyishou*). We asked respondents if they had heard of or seen animals in the photographs, and if so how frequently and recently, as well as additional questions about LEK associated with each species. Open questions about special characteristics of each species were also included to provide an opportunity for respondents to discuss personal beliefs, attitudes and opinions on the species (cf. White et al., 2005; Haen et al., 2014; Kelbessa, 2015). Regional conservation status of pangolins was further investigated by including specific questions about patterns of exploitation. We did not ask respondents directly about their own behaviour (cf. Jones et al., 2008; Golden et al., 2013); instead we asked questions about pangolin exploitation indirectly, in terms of the general regional nature, pattern and temporal trends of pangolin hunting. Finally, we asked further questions about respondent awareness and attitudes about wider species population trends and abundance in the local environment, and respondent patterns of local forest use.

Research was authorized by the Hainan Forestry Bureau and by the management office of each protected area where fieldwork was conducted. Project design was approved by the ZSL Ethics Committee and the Institutional Review Board of the National University of Singapore. Data collected for other mammals included in this study will be published elsewhere.

2.2. Analytical methods

Interview data were translated into English in May 2015 by at least two people fluent in both languages. Some respondents volunteered more than one category of answer, so that response totals per question were sometimes higher than the total number of respondents. Data were analysed using R version 3.0.2 (R Development Core Team, 2015).

Differences in responses between protected areas were investigated using X^2 tests. Factors affecting likelihood of respondents recognizing or having seen pangolins, or reporting on pangolin abundances or hunting, were further investigated using generalized linear mixed effects models (GLMERs) because response variables are binary. GLMERs were fit by maximum likelihood (Laplace Approximation) and carried out using the R package "lme4" (R Development Core Team, 2015). Main effects models were fitted first, including protected area, ethnicity, gender and age as fixed effects, and interviewer and village as random effects. For last-sightings data (i.e., count data), a generalized linear model (GLM) was used with Poisson error structure, with fixed effects including protected area and year. Residual deviance was compared with degrees of freedom to check data dispersion. For both GLMER and GLM analyses, insignificant interacting terms or factors were removed sequentially, and lowest Akaike information criterion (AIC) was used to select the minimal adequate model (R Development Core Team, 2015).

3. Results

A total of 714 interviews were carried out during the survey. Most respondents described themselves as belonging to a recognized Chinese ethnic minority group: Li (84%, n = 601), Miao (12%, n = 81), Zhuang (<1%, n = 2) and Dai (<1%, n = 1), with only a small number of respondents identifying as Han Chinese (4%, n = 27). More men than women were interviewed (82%, n = 588 versus 18%, n = 126). All 70 communities surveyed were agrarian; reported respondent occupations included farming (85%, n = 607), reserve rangers (6%, n = 46), rubber tapping (2%, n = 11), construction work (1%, n = 8), politics (1%, n = 7), and unemployed (1%, n = 9). Most respondents had lived in the same village for their entire lives, except some women who had moved after marriage (mean time living in village = 48 years, SD = 16.9, n = 705). Most respondents also reported that they frequently entered the local protected area (mean = 95 visits per year, SD = 144.7, n = 706).

Almost all respondents were able to recognize (90%, n = 641), name (87%, n = 619), and provide supporting ecological or morphological descriptions when shown a photograph of a pangolin. Most respondents volunteered the standard Mandarin name for pangolin (72%, n = 513); '*muan*' in Li was the second most widely reported name (14%, n = 100), and alternative names were also sometimes used, e.g., '*lili*' in Li (<1%, n = 5), '*yai*' in Miao (<1%, n = 1). Pangolins were also specifically named as talismans against evil spirits by some respondents (<1%, n = 5). GLMER analysis showed that significantly more respondents recognized pangolins in Yinggeling relative to other reserves (effect size = 2.31, SE = 0.80, p = 0.004) and that age and gender influenced recognition, with likelihood of recognition increasing with age (p = 0.004) and male gender (p < 0.001), although these effect sizes were very small (Tables A2–A3).

Most respondents claimed to have seen a pangolin (81%, n = 579). GLMER analysis showed that significantly more respondents had seen pangolins in Diaoluoshan and Yinggeling relative to other reserves (Diaoluoshan effect size = 1.13, SE = 0.49, p = 0.02; Yinggeling effect size = 1.14, SE = 0.47, p = 0.01). Age and gender again influenced results, with the likelihood of having seen a pangolin increasing with age (p < 0.001) and male gender (p < 0.001), although these effect sizes were again very small (Tables A4–A5). Respondents who claimed to have seen a pangolin also provided further details about sighting location and usually also an associated sighting date (n = 537, 75.2%); almost all sighting locations were specific local mountains, ridges and other landmarks within the adjacent protected area. Sighting dates expressed in numbers of months or years before the date of the interview were converted into calendar years for comparison; dates prior to 1975 were grouped together in one category. In all reserves except Limushan, pangolin sightings were reported until 2014–2015, i.e., within the approximate twelve-month period immediately before interviews were conducted; the last reported sighting in Limushan was in 2013 (Fig. A1). From 2010 to 2014, there were significantly more sightings of pangolins in Diaoluoshan, Jianfengling and Jiaxi relative to other reserves (GLM with Poisson errors; Diaoluoshan effect size = 2.40, SE = 1.04, p = 0.02; Jianfengling effect size = 2.71, SE = 1.03, p = 0.01; Jiaxi effect size = 2.40, SE = 1.04, p = 0.02) (Tables A6–A7). We found neither overdispersion nor underdispersion in the GLMs (Table A6).

From a scale of 'none' (*mei you*), 'rare' (*hen shao*), 'not many' (*bu duo*), or 'many' (*hen duo*), almost all respondents considered that the current local status of pangolins was either 'none' (65%, n = 420) or 'rare' (34%, n = 220) (Fig. 2A); no respondents reported 'many' pangolins in their local region, and only two respondents described local pangolin status as 'not many' (0.3%, n = 2). For analysis and in Fig. 2A we included the two 'not many' responses within the 'rare' category. GLMER found no significant difference in reported pangolin status between reserves, except for Yinggeling and Limushan (Tables A8–A9), where respondents reported a greater proportion of 'none' responses relative to other reserves (Yinggeling: effect size = −1.97, SE = 0.54, p < 0.001; Limushan effect size = −1.86, SE = 0.73, p = 0.01). The likelihood of reported pangolin abundance was not predicted by respondent age, gender, or ethnicity.

A wide range of responses (n = 871) was provided by respondents when asked about pangolin characteristics, including information on pangolin diet, ecology, morphology, cultural beliefs, hunting, and medicinal uses (Tables A10–A11). Reported local cultural beliefs concerning pangolins are varied. Some respondents believed pangolin products, especially scales, to be talismans against evil spirits, with five reports that pangolins in general are lucky, and five further reports that scales in particular are lucky and can ward off evil. Conversely, 44 respondents considered that pangolins were unlucky, particularly if encountered during daytime, with 11 respondents stating that worship or other ritual activities must be carried out for protection if pangolins are seen during the day, and other respondents reporting that pangolins must be killed if encountered during the day. A relatively large number of respondents (n = 55) also reported that pangolin skin could be used as leather.

Only 20 responses (2%) related to medicinal uses of pangolins. There were 17 references to pangolin scales; three respondents suggested that scales increased lactation, and two reported that they were good for sore throats. One respondent described how to mix pangolin blood with rice to cure urticaria in children. Another respondent mentioned that pangolin skin can be used to make medicinal drugs. One other respondent reported that the whole pangolin has medicinal value, although without elaborating further.

Although we did not specifically ask about hunting in our pangolin characteristics question, this was raised by several respondents (6%, n = 64), with reported local hunting practices including digging pangolins out of burrows, using dogs, and opportunistically collecting them when they are encountered in the forest. There were significant differences in reported levels of pangolin hunting between reserves

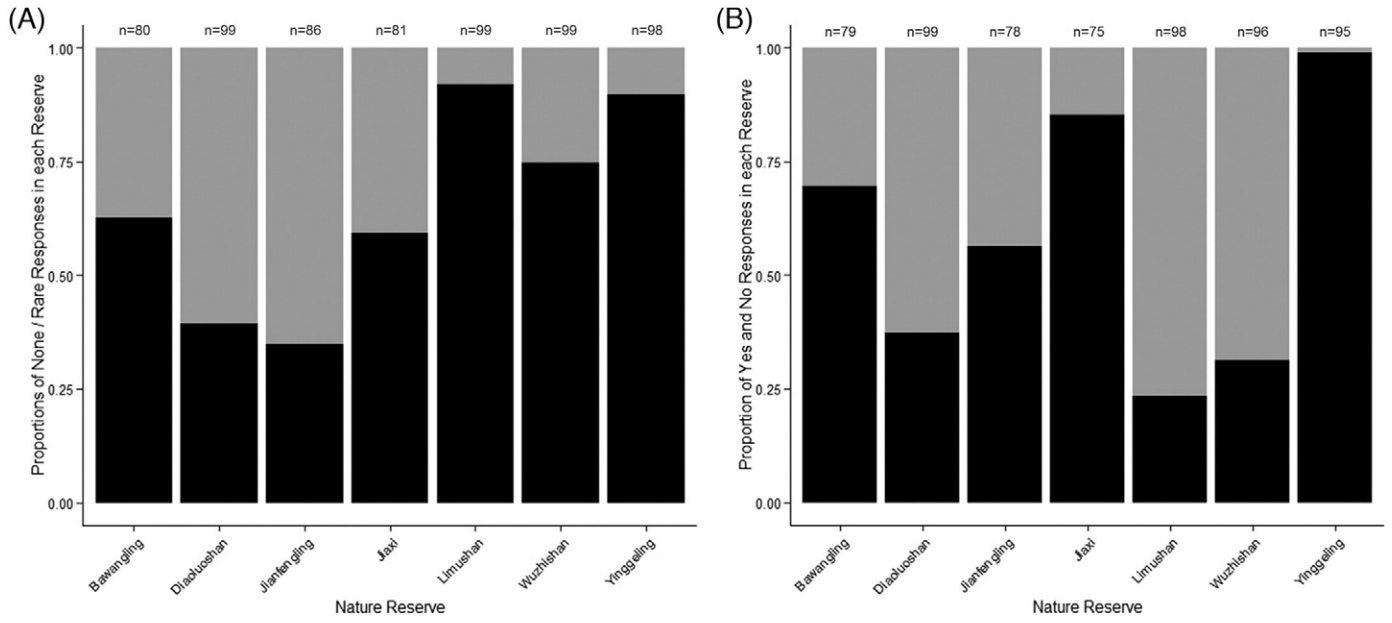

Fig. 2. A, Reported pangolin abundance across seven protected areas in Hainan (N = 642). Abundances in Yinggeling and Limushan are significantly lower relative to other protected areas ($p < 0.001$ and $p = 0.01$ respectively). Key: black, 'none'; grey, 'rare'. B, Proportions of reported pangolin hunting across seven protected areas in Hainan (N = 620). Hunting is significantly higher in Jiaxi ($p = 0.007$) and Yinggeling ($p < 0.001$), and significantly lower in Diaoluoshan ($p = 0.03$), Limushan ($p < 0.001$) and Wuzhishan ($p = 0.006$); there is no significant difference between Bawangling and Jianfengling. Key: black = reported hunting; grey = no reported hunting.

(Fig. 2B). The minimum adequate GLMER showed no significant difference in reported hunting between Bawangling and Jianfengling (Tables A12–A13), but significantly more reported hunting in Jiaxi (effect size = 1.22, SE = 0.45, p = 0.007) and Yinggeling (effect size = 4.12, SE = 1.05, $p < 0.001$), and significantly less reported hunting in Diaoluoshan (effect size = −1.98, SE = 0.916, p = 0.03), Limushan (effect size = −3.16, SE = 0.93, p = <0.001) and Wuzhishan (effect size = −2.54, SE = 0.93, p = 0.006). Age also had a small but significant influence on these results, with older people more likely to report hunting (effect size = 0.02, SE = 0.008, p = 0.02). A potential relationship between reported hunting and pangolin abundance was investigated with GLMER to determine whether these responses were correlated (i.e., lower pangolin abundance means that there are fewer pangolins to hunt, and vice versa); however, there was no significant relationship between reported hunting and reported pangolin abundance, with variation in reported hunting better explained by reserve (Tables A12–A13).

Most respondents (72%, n = 514) reported that they did not know whether pangolin hunters were locals or outsiders; 24% (n = 168) reported that hunting was conducted by locals, and only 2% (n = 18) reported hunting was conducted solely by outsiders, although hunting by outsiders was reported from all reserves. The majority of respondents (52%, n = 375) also reported that they did not know if hunting was for local use or export; 23% (n = 168) said both, 18% (n = 126) said for local use, and 3% (n = 21) said for sales to outsiders, with sales to outsiders again reported from all reserves. A further 2% (n = 14) said that pangolin meat was eaten locally but scales were sold.

The majority of respondents reported that they were unaware if levels of pangolin hunting had changed over time (73%, n = 520). Only 4% of respondents (n = 30) thought that hunting had stopped, and 1% (n = 9) reported that they had been allowed to hunt in the past but not anymore. Most respondents also reportedly did not know when (74.8%, n = 534) or why (68%, n = 512) pangolin hunting had changed, although 21% (n = 120) considered that it was because pangolins were now rare and too hard to find, with 20% (n = 142) also considering that pangolins were rare because too many had been hunted. A further 10% (n = 37) reported that hunting levels had changed due to strengthened reserve protection, including increased enforcement of anti-hunting laws, increased education about why not to hunt pangolins, restricted access to mountain areas inside reserves, and patrolling by reserve staff. However, four respondents also reported that no-one had ever been arrested for hunting pangolins, and one respondent considered that pangolins were now almost extinct because as fast as people were arrested for pangolin poaching, more people learnt how to hunt them. Age was a significant predictor of likelihood of hunting, with younger people less likely to participate (effect size = 0.018, SE = 0.008, p = 0.021) (Tables A12–A13).

4. Discussion

Our study represents the first large-scale conservation research investigation to use LEK for informing assessments of status and persistence of Chinese pangolin populations. This approach also permitted extensive data to be collected on past and present pangolin abundance and threats and local beliefs about pangolins, which are all essential to consider for effective conservation management (Challender et al., 2014a, 2014b; Pietersen et al., 2014; Turvey et al., 2015a).

Most importantly, our survey demonstrates the probable continued survival of pangolins in all seven reserves that were investigated, across a wide area of Hainan's protected forest landscapes, with sightings reported by local forest users in all reserves from the previous 1–2 years. Before our survey was conducted, international concerns had been raised that pangolins may have already been driven to extinction across much or all of China through massive-scale overexploitation (Challender et al., 2015), and no recent baseline data on regional pangolin status were available to critically evaluate this possibility. The likely persistence of pangolins in multiple localities across our survey region provides an important and encouraging note of hope that it is not yet too late to develop effective methods to protect pangolin populations in China. We therefore strongly encourage the use of similar large-scale LEK-based surveys to assess the status of pangolins, both across other regions of China and more widely across Asia and Africa. However, almost all respondents across all reserves investigated on Hainan considered that pangolins were very rare if they survived at all. Although this may reflect known low detectability/encounter rates for pangolins (Wu et al., 2002a), these reported abundance levels are concerning

and suggest that only tiny remnant populations may still survive, presenting major challenges to their effective protection.

In addition to revealing the continued survival of pangolins on Hainan, our large-scale LEK dataset also demonstrates differences in reported pangolin abundance, sightings and hunting pressure between different reserves across the island. These landscape-level findings are an essential baseline for prioritizing different regions for pangolin conservation. Based on reported sighting frequencies, assessments of local abundance, and levels of hunting in different reserves, we suggest that Diaoluoshan and possibly Jianfengling may represent top-priority protected areas for pangolins on Hainan, as respondents around these reserves reported the highest numbers of pangolin sightings, "least worst" levels of relative pangolin abundance, and lowest levels of hunting (at least for Diaoluoshan) compared to other reserves that we surveyed. Using these criteria, Jiaxi might additionally be considered to represent an important protected area for pangolins if local hunting pressure can be effectively reduced. However, significant work is still needed to prevent poaching and maximize education about pangolins across all of Hainan's protected areas.

Our survey data also provide important insights into potential future conservation strategies for pangolins on Hainan, and for assessing further contributions that LEK could make towards local conservation. Respondent ability to recognize pangolins was high across our survey area, which might provide a good foundation for future conservation education projects. In particular, recognition of pangolins was significantly higher in Yinggeling than in other reserves, possibly as a result of greater levels of education and conservation awareness-raising that has been conducted at this reserve with support from external conservation organizations (Kadoorie Farm and Botanic Garden, 2015); it would be useful to explore whether these engagement activities could be organized more widely across Hainan to support pangolin conservation. That said, despite conservation efforts at Yinggeling, pangolins are very rare there, and we lack a clear-cut example of success for conserving wild pangolins in Hainan. Effect sizes of increased age and male gender on recognition of pangolins were significant but small, supporting other studies that have suggested LEK collected from respondents of both genders can provide valuable information for conservation management (Papworth and Rist, 2009). It is possible that our data reveal the beginning of a "shifting baseline" in LEK (Papworth and Rist, 2009; Turvey et al., 2010), with the cross-generational transmission of LEK starting to decline in response to pangolin population decrease, although again the effect size of increasing age on pangolin recognition was very small. Collective LEK about pangolins remains substantial across large parts of Hainan, possibly because sightings have continued to occur recently in each reserve, and so remain a useful tool for informing conservation management.

Open questioning about special characteristics of pangolins elicited insightful information on patterns of exploitation, supporting previous studies which have also demonstrated that LEK surveys can generate valuable results on conservation-relevant but sensitive subjects associated with illegal behaviours (Newton et al., 2008; Thapa et al., 2014). These data are of considerable usefulness for informing conservation actions, and raise questions about effectiveness of past and current enforcement of legislation aimed to protect pangolins. Interestingly, although respondents volunteered considerable information on reasons and methods for utilizing pangolins, the use of pangolins for traditional medicine does not now appear to be widespread on Hainan, helping to qualify our understanding of spatial patterns of use and demand for the species across China. However, we note that direct questioning of respondents about medicinal uses of target taxa may sometimes be required to elicit such information (Boakye et al., 2014). Our survey method aimed to avoid unintentionally suggesting any medical value in pangolin products to respondents; if further information on medicinal uses of pangolins on Hainan is required, then targeted surveys of local medical practitioners may be an appropriate alternative research strategy (Soewu and Ayodele, 2009; Boakye et al., 2014).

Our results support the current IUCN status of Chinese pangolin as Critically Endangered; although pangolins still appear to be present across several protected areas on Hainan, survival of all populations appears threatened by ongoing poaching, illegal wildlife trade, and ongoing use of scales and meat. Few respondents reported that the improved protection of pangolins explained perceived reduction in hunting, with more respondents considering that hunting had instead decreased due to low abundance of pangolins. However, levels of reported hunting did not relate to reported pangolin abundance in our dataset, in contrast to other studies in which hunting levels can act as an index of target species abundance (Sutherland, 2001; Kelbessa, 2015). These results are concerning, because they suggest that hunting may still continue even when pangolin abundance is extremely low, and that existing legislation and enforcement on Hainan needs to be improved. One potential note of optimism provided by our data is that younger people appear to be less likely to participate in pangolin hunting on Hainan, although this may simply reflect reduced pangolin availability in recent years. Much needs to be done to ensure continued survival of pangolins on Hainan, and pangolin conservation may require an integrated approach, potentially including simultaneous demand-reduction initiatives, incentives, local engagement, education, and behaviour change programmes (Challender et al., 2014a).

There is an urgent need to develop methods for assessing and monitoring pangolin status and threats at a global scale (Challender et al., 2014b). Our results suggest that large-scale systematic LEK surveys can contribute to this goal. LEK surveys can be inexpensive and relatively rapid to conduct over wide geographic areas in comparison to other methods employed to detect pangolins, and can collect data on sightings, population trends and patterns of exploitation through time rather than only providing an assessment of current conditions. Whilst LEK data must be collected and analysed critically using methods such as those we have employed, to try to minimize or control for potential response inaccuracy and/or biases (Jones et al., 2008; St John et al., 2012; Golden et al., 2013; Nuno et al., 2013), this first large-scale LEK survey of pangolins in China has produced landscape-level findings of major importance for prioritizing areas for future pangolin conservation; we recommend that further surveys are conducted regionally and internationally to help inform other regional pangolin conservation action plans. Whilst there is still an urgent need to develop and strengthen conservation management strategies for pangolins, showcasing pangolin survival and promoting conservation of these incredible animals on Hainan remains possible, and would set an important example at a global scale.

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