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ORIGINAL ARTICLE

Mixed-method study on medicinal herb collection in relation to wildlife conservation: the case of giant pandas in China

Yichao ZENG,[1] Jindong ZHANG[2] and Vanessa HULL[1]

[1]Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, Florida, USA and [2]Key Laboratory of Southwest China Wildlife Resources Conservation, China West Normal University, Ministry of Education, Nanchong, China

Abstract

Medicinal herb collection has historical and cultural roots in many rural communities in developing countries. Areas where herb collection occurs may overlap with biodiversity hotspots and crucial habitat of endangered and threatened species. However, impacts of such practices on wildlife are unknown and possibly underestimated, perhaps due to the elusive nature of such activities. We examined this phenomenon in Wolong Nature Reserve, China, a protected area in the South-Central China biodiversity hotspot that also supports a community of Tibetan, Qiang and Han people who use herb collection as a supplementary source of livelihood. We adopted a participatory approach in which we engaged local people in outlining spatial and temporal dynamics of medicinal herb collection practices. We found that the overall spatial extent of herb collection increased in the past two decades. We then overlaid herb collection maps with localities of giant panda (*Ailuropoda melanoleuca*) feces collected over two time points in the reserve. Using a Bayesian parameter estimation, we found evidence for declined giant panda occurrence in the areas most recently impacted by emerging medicinal herb collection. Our methodology demonstrates the potential power of integrating participatory approaches with quantitative methods for processes like herb collection that may be difficult to examine empirically. We discuss future directions for improving explanatory power and addressing uncertainty in this type of mixed-method, interdisciplinary research. This work has implications for future attempts to understand whether and how prevalent but subtle human activities may affect wildlife conservation.

Key words: Bayesian parameter estimation, medicinal herb collection, participatory mapping, wildlife conservation

Correspondence: Yichao Zeng, Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, USA.
Email: yichao.zeng@ufl.edu

INTRODUCTION

Understanding human knowledge and behavior is essential to biodiversity conservation (Sutherland *et al*. 2018). Effects of human disturbances have long been a major concern in wildlife conservation (Carney & Sydeman 1999; Gill *et al*. 2001; Beale & Monaghan 2004). Although behavioral responses of individuals do not always translate into population consequences (Gill *et al*. 2001), different types of human disturbances such as presence of pet dogs, hiking and tourism have been noted to negatively affect animals such as ungulates and bears in various ways (Miller *et al*. 2001; Taylor & Knight 2003; Rode *et al*. 2006). Medicinal herb collection is one type of human activity that potentially affects wildlife conservation, as it is a common practice in nature reserves in developing countries (Yang & Xu 2003; Chhatre & Saberwal 2005; Carter *et al.* 2014). Medicinal herbs are valued as important natural resources by people from some cultures (Principe 1991). They are, however, often prone to overharvesting and overexploitation (Schippmann *et al.* 2002). In many instances, collection practices may also conflict with wildlife conservation goals if they are improperly managed. For instance, collection of the herb *Smilax glabra* in Maolan Nature Reserve, Guizhou, China is postulated to be a major threat to the survival of the silver pheasant, *Lophura nycthemera* Linnaeus, 1758, as the plant is a major food source for the bird during wintertime (Xiong *et al.* 2003).

Practices of collecting medicinal herbs are especially prevalent in China. The use of herbal medicine has been woven into the fabric of the culture of this old civilization, and the importance of traditional medicine for the well-being and economy of the Chinese people is well established (Xu & Yang 2009). However, intersections between medicinal herb collection and wildlife conservation are less understood. Although Chinese law prohibits any collection of plants and animals without permission in core zones of its roughly 500 national nature reserves, herb collection by local people is often hard to managed in some reserves (as of 2018). This issue is particularly relevant for nature reserves in southwest China because they are located in a global biodiversity hotspot (Myers *et al.* 2000) and are also home to herbs with high value in traditional Chinese medicine markets. Many herbs in these reserves are subject to extensive exploitation to meet the needs of increasing domestic and international markets (Patwardhan *et al.* 2005).

However, herb collection has seldom been considered as a predictor in ecological models for animals (e.g. species distribution models). This is due to either an underestimation of its impacts on wildlife or a lack of available data. Compared to other human activities, herb collection is difficult to detect because collectors generally leave minimal marks behind at collection sites. Yet this may not always mean that the impacts are negligible. There is an urgent need for ecologists and conservation managers to better understand the nature and effects of such practices.

While medicinal herb collection is difficult to detect empirically, participatory methods may be especially useful in such detections. In participatory methods, scientific or local experts provide information on a given aspect of a study system based on their knowledge or experiences. Such methods have been used in studies of natural resources to draw qualitative and quantitative inference on various topics ranging from human behavior to wildlife population and habitat (Yamada *et al.* 2003; Smith 2008; Murray *et al.* 2009; Kahler *et al.* 2013; Hamilton *et al.* 2015; Ramirez-Gomez *et al.* 2016).

Here we took a mixed-method approach to drawing both qualitative and quantitative inferences on medicinal herb collection in Wolong Nature Reserve, Sichuan, China, a coupled human and natural system that is home to the threatened giant panda (*Ailuropoda melanoleuca* David, 1869) (Liu *et al.* 2007; Carter *et al.* 2014). We engaged in participatory mapping coupled with semi-structured interviews with local villagers to understand changes in the nature and spatial extent of medicinal herb collection over time in Wolong. We presented a qualitative account of the nature and dynamics of herb collection based on our data and conducted a Bayesian parameter estimation to show how the occurrence of giant pandas related to the spatial extent of medicinal herb collection. Our study serves as an early step towards a better understanding of how prevalent but subtle human activities such as herb collection in China's nature reserves may influence wildlife conservation.

MATERIALS AND METHODS

Study area

Wolong Nature Reserve, Sichuan, China is in the South-Central China biodiversity hotspot (Myers *et al.* 2000). The reserve was initially established for the conservation of the giant panda by the Chinese Government in 1963. The elevation of Wolong Nature Reserve ranges roughly from 1200 to 6000 m (Fig. 1). The total area of the reserve is around 2000 km^2. Two towns, Wolong and Gengda, lie within the reserve and are home to around 5000 people (Zhang *et al.* 2018). Sanjiang, another town just outside the reserve, also has a population of around 4000 people, some of whom frequently go into the reserve. The population of Wolong, Gengda and Sanjiang consists primarily of the Tibetan, Qiang and Han people. Most of the population lives in the lowlands and on lower mountains (around 1200–1900 m). There are 3 villages in Wolong Town, 3 villages in Gengda Town and 2 villages in Sanjiang Town. Industries are limited in and around the reserve, and villagers live a lifestyle that relies heavily on natural resources. Villagers have long-standing traditions of collecting herbs to complement their income from other sources such as crops and livestock (Wolong Nature Reserve 2005).

Participatory mapping

We conducted participatory mapping in May 2018. A local villager with wide connections in the local community guided us to households of local people with good knowledge of community-wide herb collection practices. Villagers mapped in groups of one to three people and were allowed to discuss the activity among one another. A total of 11 groups (consisting of a total of 21 individuals) participated in the mapping. Groups were selected from all 8 villages comprising the 3 towns of Wolong, Gengda and Sanjiang, with 5 groups in Gengda, 4 groups in Wolong and 2 groups in Sanjiang (Fig. 1).

During a mapping session, we laid a printed map with local place names on the floor in front of the local people and instructed them to use woolen yarn to map areas where herb collection had been conducted by residents of their town: (a) at present (2018); and (b) 20 years ago (around 1998). Considering the illegality of herb collection, we asked the villagers about the collection of herbs in this region in general (i.e. "where people collect herbs") instead of their individual behaviors (i.e. "where you collect herbs") to minimize dishonesty in participants' responses. Semi-structured interviews were also conducted with participants during the mapping process, in which we asked participants if they knew any other information about herb collection that could not be reflected in their mapping. In a pilot study, villagers reported that herbs at higher elevations (i.e. usually above ~3500 m) require considerably more resources (e.g. labor, time and food) to collect compared to those at lower elevations because collectors generally need to walk for more than one day and camp on the mountains. In contrast, a collection practice at lower elevations usually takes collectors less than one day and is sometimes done on a nearly daily basis. In this work, we define lower-elevation medicinal herb collection based on such cultural and customary distinctiveness, consistent with the villager's definition. In our participatory mapping, we only focused on lower-elevation medicinal herb collection for two reasons: (i) there is little overlap between panda distribution and herb collection at high elevations, due to pandas' selection of elevation lower than ~3600 m; and (ii) maps of collection at high elevations were usu-

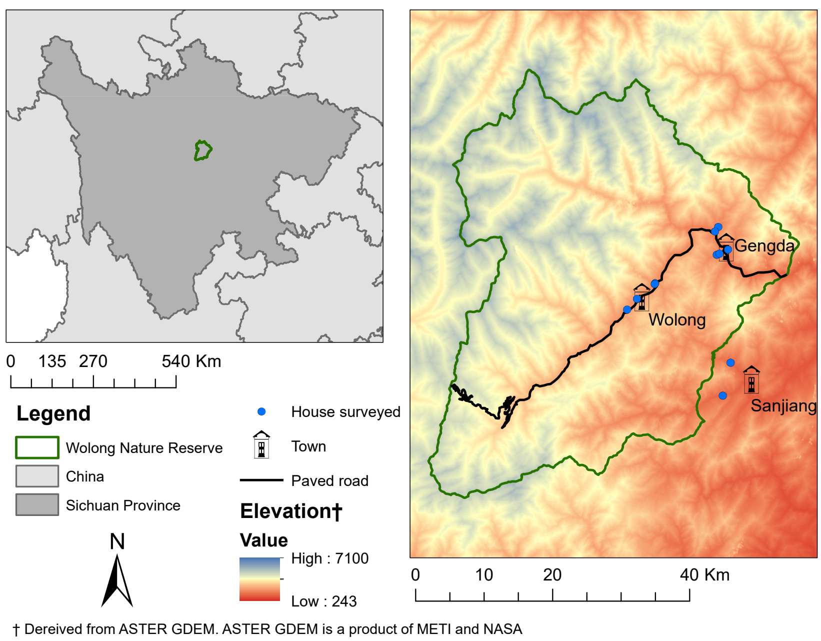

Figure 1 Wolong Nature Reserve in Sichuan Province, China. All 8 villages from the 3 towns of Wolong, Gengda and Sanjiang were visited to recruit participants for the participatory mapping exercise conducted in this study.

ally vague and failed to give adequate spatial information. Participation of human subjects in this study was approved by the Institutional Review Board of the University of Florida (IRB201800497).

Maps were later digitized, georeferenced and converted to shapefiles. We then merged shapefiles from each village to obtain a single layer representing the spatial extent of medicinal herb collection for each of the three towns. Then we divided the area reported with herb collection into four zones: areas experiencing no herb collection in either time period (no collection zone), areas experiencing medicinal herb collection in 1998 but not in 2018 (historic collection zone), areas experiencing medicinal herb collection in both 1998 and 2018 (sustained collection zone) and areas experiencing herb collection in 2018 but not in 1998 (emerging collection zone).

Species data and sampling

The giant panda is considered an icon for the conservation of endangered and threatened species globally (Swaisgood *et al*. 2010). A national survey of the species is carried out by the State Forestry Administration roughly every decade. Local researchers and reserve staff are hired in these surveys to look for and record panda feces in their natural habitat along transects systematically located throughout the entire giant panda range (State Forestry Administration 2006; Tang *et al.* 2015). The reserve was surveyed in 2001 during the 3rd national survey (Wen et al. 2006) and in 2014 during the 4th national survey. We used both surveys to represent panda occurrence at those two time points. We assumed uniform sampling intensity across all areas surveyed in the same national survey. However, we cannot assume that sampling intensity was the same across the two surveys partly because they were conducted by different coordinated groups of individuals. We divided the reserve into 400 m × 400 m grid cells (n = 12616) and summed the number of panda occurrence points in each cell for each panda survey year for further analyses.

Bayesian parameter estimation

We then performed a Bayesian random-effect parameter estimation to help visualize variation in panda occurrence across collection zones in each of the two surveys. The model structure was as follows:

$$Y_i \sim Poisson(\lambda_{sz} \times Z_i)$$

$$Z_i \sim Bernoulli(p_{sz}).$$

Y_i, the number of occurrences of pandas in the ith cell, is directly governed by a Poisson process where the mean is a product of λ_{sz} and Z_i. λ_{sz}, which is the relative mean of occurrence for each survey (denoted by the subscript s) and collection zone (denoted by the subscript z), is the random-effect parameter to be compared across collection zones. Z_i is a binary variable representing presence or absence of pandas in the ith cell and is governed by a Bernoulli process where p_{sz} is the probability of panda presence for each survey (denoted by the subscript s) and collection zone (denoted by the subscript z). We did not compare the p_{sz} parameter across collection zones but used it to account for processes that determine whether pandas are present in the ith cell. For example, two important processes are that some cells are not inhabitable for pandas due to unsuitable environmental factors (e.g. elevation, slope and vegetation) and that some cells were not visited in the surveys due to accessibility issues. This is a zero-inflated Poisson model, which is often used when presence and occurrence arise from different processes (Martin *et al.* 2005; Chiogna & Gaetan 2007; Wenger & Freeman 2008). We chose this model because each of the three zones contain excessive zeros that arise from processes other than a Poisson and may jeopardize the estimation of λ_{sz} if not modeled by separate parameter(s).

The analysis was performed with the software JAGS (Plummer 2003) using the R package "rjags" (Plummer 2016). We used uninformative prior distributions for both λ_{sz} and p_{sz} (i.e. Beta(1,3) for λ_{sz} and Gamma(0.5,1) for p_{sz}). The Markov Chain Monte Carlo was set to 3 chains, with 50 as the thinning interval, 15000 iterations in total, and 5000 iterations to discard as burn-in. We tested the validity of this model with simulated occurrence data before using observed data. After running the model, we checked the R-hat values to ensure successful convergence of the 3 chains.

RESULTS

Participants in our survey revealed that there were seven major herbs that are collected in the reserve (Table 1). Elevation at which these herbs of interest grow ranged from 1350 to 4300 m (Table 1). June and July appeared to be the months of the year in which the most herb collection (in terms of the number of herb kinds) occur, with an additional season apparent in the fall months from September to November (Table 1).

During the participatory mapping, 4 of the 11 groups reported an increase in total area of herb collection over the two decades (1998 to 2018), while another 6 groups reported an unchanged area, and 1 group a decreased area. Gengda and Sanjiang towns experienced an increase in the area of herb collection over the two decades, while the area for Wolong remained the same (Fig. 2). Overlapping areas where herb collection was conducted by villagers from more than one town also increased over the two time periods (Fig. 2). Across the four herb collection zones identified, the sustained collection zone had the largest area (Fig. 3). The emerging zone was divided into two discrete segments, one larger area close to the Sanjiang Town and one smaller region on the west side of Gengda Town. The collection of one herb, "*Chonglou*" (*Paris* spp.), has boomed since a dramatic increase in the market demand for this herb and a 25-time increase in its price (from approximately 40 to 1000 Chinese yuan per kilogram) over the past decade. The emerging herb collection zone in Gengda in Village 1 (*Yicun*) was directly associated with this herb. Villagers reported harvesting mature plants of this herb and collecting immature plants from the wild for cultivation and propagation in their own yards.

Spatial overlap between herb collection and giant panda distribution was high (Fig. 3). Our model included all four identified herb collection zones except the historic herb collection zone because it contained no panda signs in either panda survey (Fig. 3). The 3rd and 4th national surveys did not have the same surveying intensity (State Forestry Administration 2006; Tang *et al.* 2015), so the relative mean occurrence λ_{sz} is not directly comparable between the two surveys because λ_{sz} depends partly on the surveying intensity. However, we can still make inferences based on the ranking of all three examined zones in terms of the parameter estimate average of λ_{sz} in each of the surveys. The emerging herb collection zone had the highest estimate average of λ_{sz} in all three zones in 2001, but the lowest in 2014 (Fig. 4).

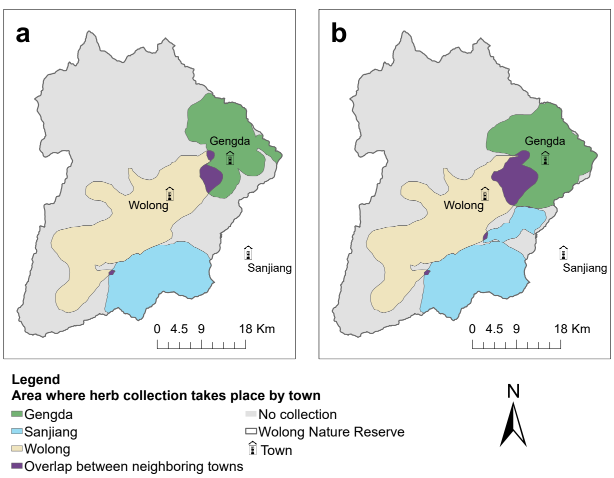

Figure 2 Polygons representing spatial extent of lower-elevation medicinal herb collection by town in Wolong Nature Reserve, China in (a) 1998 and (b) 2018. Polygons were derived through a participatory mapping exercise with groups of local residents residing in each of the towns (Gengda, Wolong and Sanjiang towns).

DISCUSSION

The emerging collection zone had the most drastic decline (i.e. from the highest to the lowest) in its ranking among all three examined zones in terms of the estimate average of relative mean occurrence. This decline suggests a negative relationship between medicinal herb collection expansion and giant panda occurrence. There are several possible mechanisms in which herb collection may deter pandas. Pandas are sensitive to both scent and noise and are known to avoid humans due to disturbances related to these stimuli (Schaller *et al.*

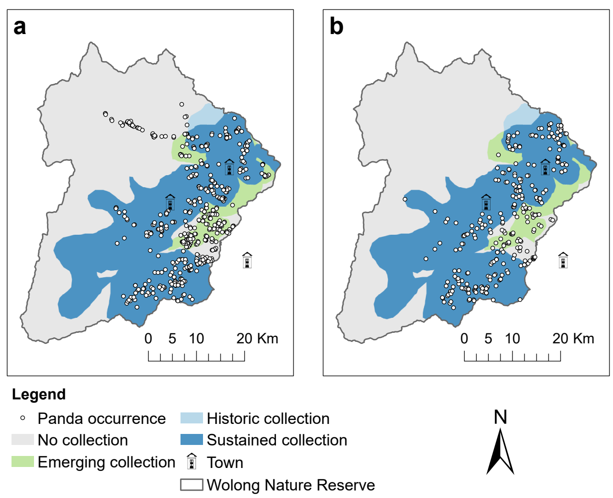

Figure 3 Overlap between the distribution of giant pandas in Wolong Nature Reserve and the spatial extent of medicinal herb collection. Giant panda distributions in (a) 2001 and (b) 2014 are derived from national surveys of the species (State Forestry Administration 2006; Tang *et al.* 2015). Herb collection areas were derived from participatory mapping exercises with local residents and divided into four zones: no collection; historical collection (occurring around 1998 but not 2018); sustained collection (occurring in both 1998 and 2018); and emerging collection (occurring in 2018 but not 1998).

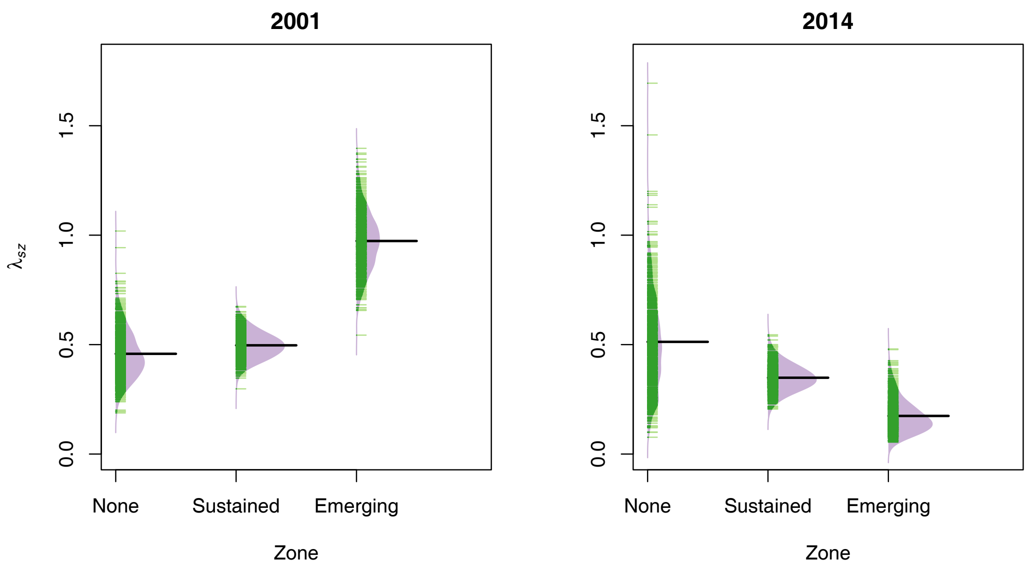

Figure 4 Bean plots showing posterior distribution of relative mean panda occurrence (λ_{sz}) across herb collection zones in Wolong Nature Reserve over two time periods, 2001 and 2014. Green lines are estimated values of λ_{sz}. Black lines are bean averages. Parameter estimation was performed via Bayesian modeling using a zero-inflated Poisson model on giant panda occurrence data obtained in surveys conducted during the two periods. The three zones represent areas of no herb collection, sustained herb collection (occurring in 1998 and 2018) and emerging herb collection (occurring in 2018 but not 1998).

1985). There have been observations that herb collectors make loud sounds when communicating with one another in the forest (T. Connor, personal communication). We have also observed other disturbances that occur during collection, such as littering, fire, and cigarette smoke, that may also cause pandas to avoid these areas. Therefore, we hypothesize that herb collection can negatively affect panda occurrence.

Several confounding factors need to be taken into consideration when testing this hypothesis. Much of the emerging collection zone, the zone with the most drastic decline, is in an area to the north of Sanjiang town that may also have been impacted by other human disturbances due to development in Sanjiang. In addition, the 2008 Wenchuan Earthquake that occurred between the two national surveys might also have contributed to the changes in panda occurrence that we observed because it may have promoted an overall increase in activities such as livestock grazing and hunting after an economic collapse (Zhang *et al*. 2011). A species distribution, abundance or occurrence model that includes herb collection and other environmental (e.g. elevation, slope, aspect and forest cover) and social factors (e.g. distances to paved roads or villages) will help better quantify the relative influence of herb collection on panda occurrence.

The temporal pattern of herb collection potentially overlaps with that of giant panda migration (Table 1; Hull *et al*. 2015; Liu *et al*. 2015). Arguably, the most important time for pandas is the mating season, which occurs from March to May (Schaller *et al.* 1985; Zhang *et al.* 2015, 2017). This time frame intersects with the collection period for *Chonglou*, the herb that was named by villagers as having the greatest increase in collection in recent years. Another key period for pandas in this reserve that overlaps with the mating season is the low-elevation umbrella bamboo (*Fargesia spathacea*) growing season from April to June, when pandas descend from higher (above ~2600m) to lower elevations to feed on succulent bamboo shoots sprouting up at this time of the year (Schaller *et al.* 1985). This elevational pattern overlaps with the one that herb collectors generally take, with lower-elevation herbs like *Tianma* and *Xixin* being selected during June and mid-elevation and higher-elevation herbs like *Dahuang* and *Qianghuo* being selected in the fall (Table 1).

Table 1 Major herbs collected in Wolong Nature Reserve

Commercial name in Pinyin	Collection season	Scientific name	Elevation (m)
"*Beimu*"	June–July	*Fritillaria cirrhosa* D. Don	3900–4,300
		F. delavayi Franch.	4000–4300
		F. przewalskii Maxim. ex Batalin	3900–4200
		F. unibracteata Hsiao & K. C. Hsia	3800–4200
"*Dahuang*"	September–November	*Rheum officinale* Baill.	3700–4000
		R. palmatum L.	3500–4000
"*Qianghuo*"	September–November	*Notopterygium incisum* Ting ex H. T. Chang	2750–3700
"*Sanqi*"	August–September	*Panax pseudoginseng* var. *bipinnatifidus* (Seem.) H.L.Li	2400–2800
		P. bipinnatifidus Seem.	2800–3000
		P. japonicus (T. Nees) C. A. Mey.	1700–2400
"*Chonglou*"	March–July	*Paris polyphylla* Sm.	1350–1800
		P. polyphylla var. *chinensis* (Franch.) H. Hara	1900–2500
		P. polyphylla var. *stenophylla* Franch.	2100–2500
		P. thibetica Franch.	1900–2600
"*Tianma*"	June–July	*Gastrodia elata* Blume	1700–2700
"*Xixin*"	June–July	*Asarum himalaicum* Hook.f. & Thomson ex Klotzsch	1400–2600

Commercial names and collection seasons were recorded in semi-structured interviews with local people. Scientific names and elevational distribution of species were obtained based on a previous work on resource plants in the reserve (Hu *et al.* 1987). Scientific names were updated to match the PlantList (PlantList 2013) and the International Plant Names Index (IPNI 2012).

On-the-ground solutions to the issue of co-managing herb collection and wildlife conservation will be complex to navigate both logistically and ethically. In Wolong and similar protected areas in panda habitat, local people have experienced losses in income in recent years as other more extractive activities such as timber harvesting have been banned (Bearer *et al*. 2008). The reserve also still struggles to provide health care and education provisions for its residents (Liu *et al*. 2016). Medicinal herb collection is an important part of the ever-changing picture of livelihood generation in the reserve. Effective conservation practices in the reserve need to adequately consider livelihoods.

Our methodology demonstrated the utility of participatory mapping in understanding herb collection, a human activity that is often hidden. We showed that participatory maps can make powerful contributions to quantitative modeling. We suggest future models consider the uncertainties of the spatial information provided by local people. The flexibility of Bayesian hierarchical models makes them especially helpful in modeling this. One possible solution could be to account for false positive and false negative detections of human activities in the hierarchical modeling.

Our results highlight the temporal and spatial patterns of medicinal herb collection in a coupled human and natural system, a topic that has been understudied in relationship to wildlife conservation in this region. This work complements the existing literature on the effects of human disturbances on wildlife populations and reveals new challenges in this area. The most similar and comparable human disturbance to herb collection, in terms of the mechanism underlying the effects of human presence on wildlife, is probably recreational activities in protected areas (e.g. ecotourism and hiking). However, unlike tourists and hikers, herb collectors generally do not follow any fixed trails and instead behave in a complex, elusive and difficult-to-predict way like that of wild animals searching for resources (e.g. food) in their natural habitat. This type of human disturbances might be more common than previously thought, especially in rural communities in developing countries where people collect natural resources for livelihood. The difficulties in investigating this type of disturbance do not mean that such impacts are neglectable. We advocate for novel methodologies to tackle this complex issue in the future.

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