Pandas, Plants, and People

PANDAS, PLANTS, AND PEOPLE[1,2]   *Jianguo Liu*[3] *and Andrés Viña*[3]

ABSTRACT

Plants are essential for the survival and sustainability of both humans and wildlife species around the world. However, human activities have directly and indirectly affected almost all plants, which in turn have produced cascading effects on humans and wildlife through disruption of crucial ecosystem services and wildlife habitat. Understanding such complex interactions is crucial for developing better policies that reconcile the needs of an ever-growing human population with biodiversity conservation. Using the coupled human and natural systems (CHANS) framework, this article synthesizes research on the complex interactions of plant species, giant pandas, and people. The CHANS framework is particularly useful for uncovering key patterns and processes behind plant-animal interactions modified by human activities. Our synthesis shows that many human factors, including socioeconomic and demographic, together with other factors (e.g., projected global climate change), exhibit reciprocal interactions with pandas and the plant species that comprise their habitat. Although substantial efforts have been made to preserve plants and wildlife, much work still remains to be done, including the expansion and more effective management of protected areas, use of native plant species in reforestation/afforestation programs, and active participation of local residents in conservation actions.

Key words: Bamboo, China, coupled human and natural systems (CHANS), ecosystem services, endangered species, giant pandas, protected areas, wildlife.

Plants provide essential sources of food, fiber, medicine, and other important goods and services for humans (Díaz et al., 2006). They also constitute crucial components of wildlife habitats (Tuanmu et al., 2011), offering not only food to herbivorous wildlife species but also shelter to herbivorous and carnivorous wildlife species across many different ecosystems (Taylor et al., 2004; Nilsson & Wardle, 2005; Gilliam, 2007). However, human activities have converted much of the natural landscapes to human-dominated landscapes and have led to biodiversity loss worldwide (Vitousek et al., 1997; Sala et al., 2000; Pereira et al., 2004; Waltert et al., 2004; Lepczyk et al., 2008). This loss is usually expressed as species extinction at local, regional, and global scales and homogenization of regional and continental biotas. The rate of species extinction due to human activities is between 1000 and 10,000 times faster than background rates, i.e., those without human causes (Hilton-Taylor, 2000; Pimm & Raven, 2000; Ceballos et al., 2010). As a result, according to criteria of the International Union for Conservation of Nature (IUCN, 2001), estimates of the percentages of plant species worldwide that may be threatened with extinction range from ca. 22% to as many as 50% (Pitman & Jørgensen, 2002; Baillie et al., 2004). The loss of plant biodiversity poses enormous direct and indirect consequences for humans as well as wildlife species and, ultimately, the structure and function of ecosystems (Hooper et al., 2005). Therefore, the loss of plant biodiversity is of great concern not only for ethical and aesthetic reasons but also for its cascading effects on entire ecosystems and the goods and services they provide to humanity.

The loss of biodiversity has inspired many conservation actions, such as the establishment of protected areas and implementation of conservation policies. Protected areas are supposed to be areas where human activities are limited or controlled (DeFries et al., 2007). By 2011, there were over 130,700 protected areas, covering more than 24 million km^2 of surface area on the earth (IUCN, UNEP-WCMC, 2012). Although their creation constitutes a cornerstone of biodiversity conservation (Margules & Pressey, 2000), biodiversity inside these areas is not necessarily better protected than outside them (Liu et al., 2001; Caro, 2002; Parks & Harcourt, 2002; Meir et al., 2004; Viña et al., 2007), because

many people inside and outside the protected areas
still use them in a variety of ways, such as for
harvesting timber, agriculture, mining, and tourism
(Liu et al., 1999b). They are also exposed to the
potentially negative effects of human-induced climate
change (IPCC, 2007).

The world's biodiversity conservation challenge is
well represented by China. Due to its enormous
variation in climatic, topographic, and geologic
features, China is one of the world's 17 mega-diverse
countries (Mittermeier et al., 1997) and ranks third in
the world (after Brazil and Colombia) in the number
of known plant species (Liu et al., 2003b). China's
flora is extremely rich and diversified, with around
33,000 vascular plant species in more than 3000
different genera and ca. 334 families of angiosperms,
ca. 42 genera and 11 families of gymnosperms, 231
genera and 63 families of pteridophytes, and ca. 500
genera and 106 families of bryophytes (Lu, 2004;
Wang, 2004; Wu et al., 2004a; Wu et al., 2004b).
More than 10,000 higher plant species are endemic
to China (Fu, 1992; Pitman & Jørgensen, 2002), with
ca. 243 genera found only in China (Ying & Zhang,
1994). In addition, although not endemic, many plant
genera have been recorded predominantly in China,
including the 650 species of the genus *Rhododendron*
L. (of the 1025 distributed worldwide) (Wu et al.,
2003, 2004b). This high diversity is at high risk
mainly due to deforestation (e.g., for timber and fuel
wood), as well as the conversion of both forests and
grasslands into croplands and urban areas. While
China has been occupied by humans for millennia,
the tremendous loss and fragmentation of natural
ecosystems have been particularly drastic from the
1950s onward (Dinerstein & Wikramanayake, 1993;
Liu, 2010). The huge destruction of China's ecosys-
tems began to receive attention by government
authorities due, in part, to the occurrence of natural
disasters and the decrease in crop productivity
associated with soil erosion and desertification.
Therefore, starting in the 1970s, the government
began to implement a series of afforestation and
reforestation programs that have resulted in a
progressive increase of forest cover over the last 40
years (Liu et al., 2013b). Yet nearly all of these new
tree plantations, which are replacing previously
natural forests, have been mono-specific and often
consist of fast-growing exotic species (Viña et al.,
2013) that greatly diminish the biodiversity value of
the original forests (Xu & Wilkes, 2004). In addition,
the government has established many protected areas
at an impressive rate (Liu & Raven, 2010). By the
end of 2011, a total of 2640 nature reserves were
established covering ca. 14.9% of the land surface of
China (Ministry of Environmental Protection, Peo-
ple's Republic of China, 2011). Many endangered
and charismatic species, such as the giant panda
(*Ailuropoda melanoleuca* [David, 1869]), the South
China tiger (*Panthera tigris* subsp. *amoyensis*
[Hilzheimer, 1905]), and the Asian elephant (*Elaphas
maximus* [Linnaeus, 1758]), have been used as
surrogates for the establishment of these nature
reserves. The giant panda is particularly interesting
because it is considered an icon of biodiversity
conservation not only in China but in the whole world
(Mackinnon & De Wulf, 1994; Liu et al., 2001;
Loucks et al., 2001).

Almost all ecosystems, including protected areas,
constitute coupled human and natural systems
(CHANS) (Liu et al., 2007a, 2007b) in which humans
and natural components interact with each other
directly or indirectly. Thus, understanding and
conserving plants and wildlife require a new
approach that treats humans, plants, and wildlife as
parts of an integrated system. To illustrate the
CHANS approach (Liu et al., 2007a, 2007b), in this
article we focus on complex relationships among
giant pandas, plants (the tree and bamboo species
pandas depend on), and humans. We first outline a
conceptual framework of CHANS and then highlight
the major components and their interrelationships,
using results mainly from our research group and
collaborators.

CONCEPTUAL FRAMEWORK

The CHANS approach brings together theoretical
foundations (e.g., social norms, social networks,
ecological succession) and analytical techniques
(e.g., remote sensing, geographic information sys-
tems, systems modeling) from diverse disciplines,
including those from ecological and social sciences,
to understand complex systems (Liu, 2001; Liu et al.,
2007a; McConnell et al., 2011). The approach is,
therefore, well suited for understanding pandas, the
plants they depend on, and humans, which affect
both pandas and plants. In this article, we concep-
tualize the integrated system as consisting of four
main components: giant panda habitat, plants, local
residents, and policies, all of which, in turn, are
influenced by macroscale factors, including climate,
natural disasters (e.g., earthquakes, landslides), and
telecoupling processes that operate over distances
(Liu et al., 2013a; Liu, 2014) (Fig. 1).

Each of the components in our framework both
influences and is influenced by the other compo-
nents. For instance, the abundance, distribution, and
diversity of plants (i.e., tree and understory bamboo
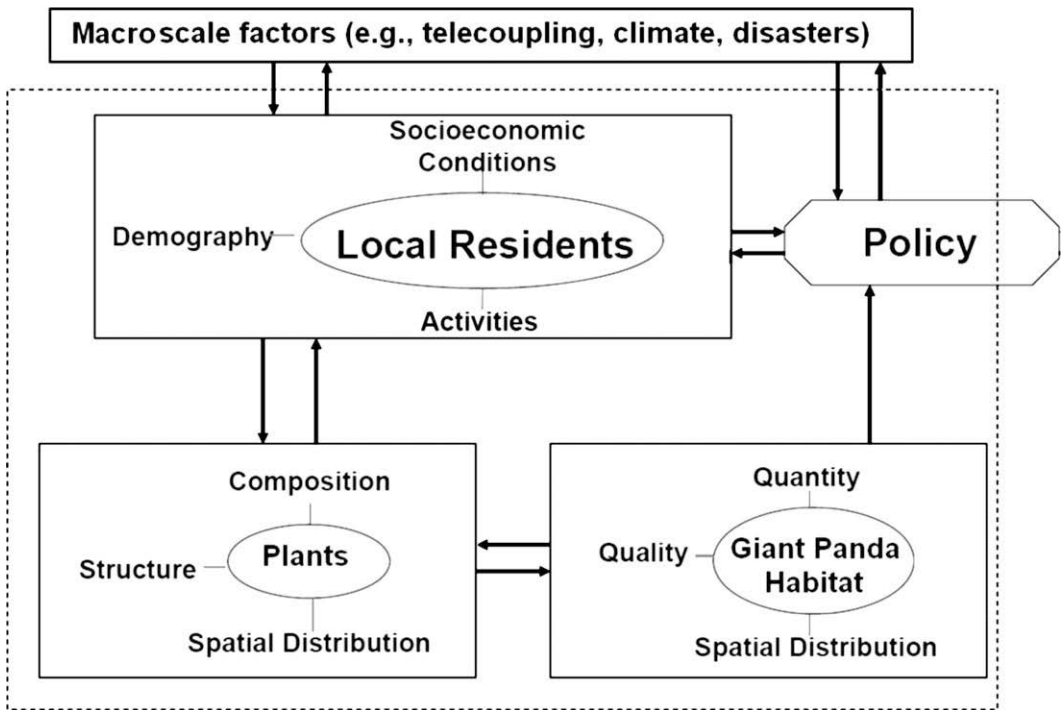species) are influenced by people (e.g., local

Figure 1. Conceptual framework of coupled human and natural systems (CHANS) for synthesizing information on the relationships among pandas, the tree and bamboo species they depend on, and humans (including conservation policies). Arrows represent the direction of influences among different system components, with those going in both directions representing feedbacks. The dotted line represents the permeable boundary of CHANS.

residents) through different activities such as farming, cutting trees for timber or fuel wood, collection of bamboo shoots, and tree and bamboo plantation (State Forestry Administration, 2006). All these activities modify the habitat suitability of pandas, thus affecting their abundance, distribution, and behavior. While hunting panda individuals is strictly prohibited and the sanctions imposed are drastic enough to discourage this practice, some illegal hunting still occurs, although it is mostly unintended (e.g., pandas may be inadvertently captured by wild boar snares; Lü & Kemf, 2001). Nevertheless, humans have other direct effects on the abundance, distribution, and behavior of pandas, since human settlements pose obstacles to dispersal not only within nature reserves, but also among nature reserves and mountain regions (Xu et al., 2006). Therefore, humans and their activities are at odds with the survival of pandas and of the tree and bamboo species they depend on (Liu et al., 2004).

In turn, the changes in the abundance and distribution of plants and pandas provide feedback to humans through changes in the accessibility to timber and non-timber forest products (e.g., bamboo shoots) and motivate the development and imple-

mentation of conservation policies that act both directly (e.g., preventing timber extraction and fuel wood collection; spurring tree planting) and indirectly (e.g., incentives to use alternatives to fuel wood, such as electricity). These policies constitute feedback mechanisms through which changes in the abundance and distribution of plants and pandas may be reduced. In short, policies influence human attitudes and activities, which in turn change panda habitat. Changes in panda habitat may prompt the government to develop and implement new policies. These interrelationships result in numerous feedback loops.

Finally, the relations and feedbacks among the four main components in the framework (Fig. 1) are influenced by macroscale factors. These include changes in climate (IPCC, 2007; Tuanmu et al., 2013), the impact of natural disasters such as earthquakes (Viña et al., 2011; Zhang et al., 2011), and telecoupling processes (Liu & Yang, 2013) such as labor migration and tourism, which in many cases have opposing effects.

GIANT PANDAS

The historical distribution of the species at one time covered an area of ca. 2.2 million km²
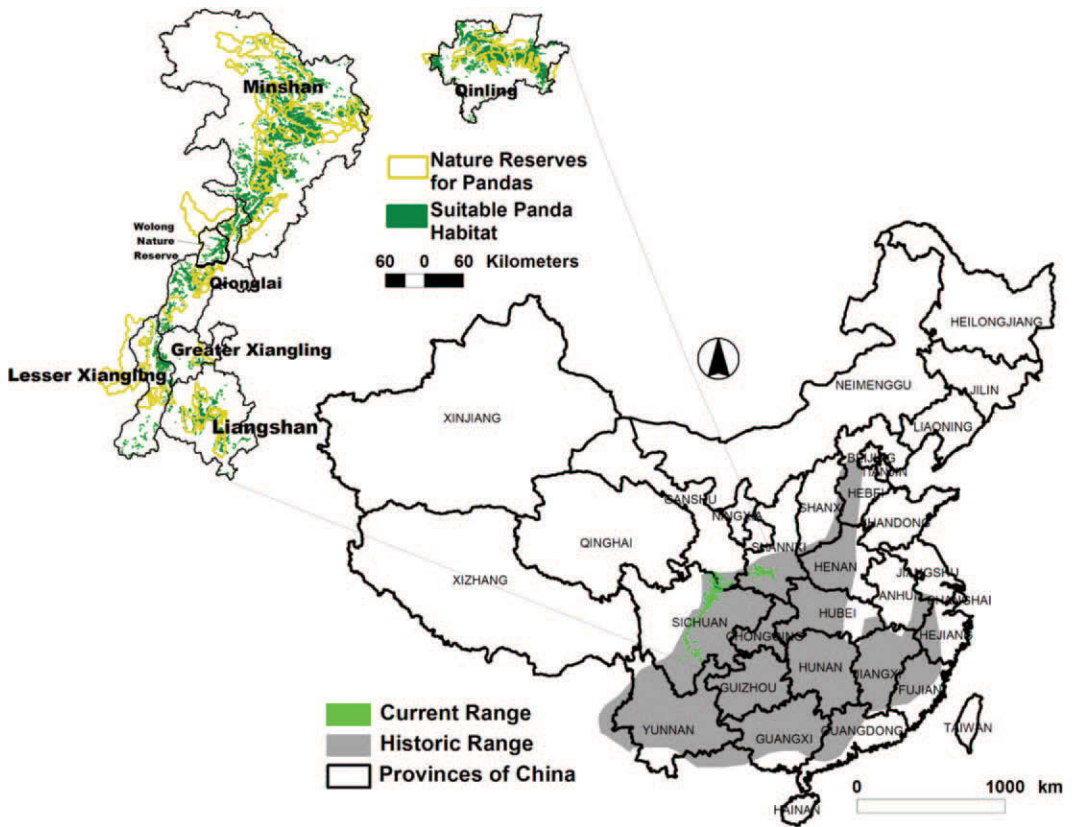
Figure 2.   Spatial distribution of the historical (gray) and current (green) geographic ranges of the giant panda (Mackinnon & De Wulf, 1994; Reid & Gong, 1999; Hu & Wei, 2004; State Forestry Administration, 2006; Viña et al., 2010). Also shown are the six mountain regions where pandas currently survive, as well as the 63 nature reserves (including the flagship Wolong Nature Reserve) established for the conservation of the pandas and their habitat.

throughout 19 provinces of China, northern Vietnam, and northern Myanmar (Schaller et al., 1985; Pan et al., 2001) (Fig. 2). However, by the early 1800s this distribution was reduced to only five provinces in southwestern China comprising ca. 262,000 km², which was further reduced to ca. 124,000 km² by the early 1900s (Zhu & Long, 1983; Reid & Gong, 1999). The current distribution comprises only ca. 21,000 km² within six mountain regions (i.e., Qinling, Minshan, Qionglai, Greater Xiangling, Lesser Xiangling, and Liangshan) in three provinces (Gansu, Shaanxi, and Sichuan) of southwestern China (Mackinnon & De Wulf, 1994; Reid & Gong, 1999; Hu & Wei, 2004; State Forestry Administration, 2006; Viña et al., 2010) (Fig. 2).

In terms of the total number of pandas, no estimates before the 1970s (when range-wide censuses started to be performed) are available, although expert opinion suggests that the population could have been ca. 3000 individuals during the 1950s (Hu, 2001). The first census in the 1970s estimated

that ca. 2400 individuals survived in the wild, and the second census in the 1980s estimated a decline of more than 50%, to ca. 1100 (Hu, 2001). The third census (performed between 2001 and 2003) estimated the total number of giant panda individuals at around 1600 (State Forestry Administration, 2006). The increase in the number of pandas between the second and the third censuses has been attributed mostly to larger regions surveyed and better techniques used to assess the number of individuals living in a region during the latter census, rather than to an actual increase in the panda population, although such an increase cannot be completely rejected (State Forestry Administration, 2006).

Pandas are extreme dietary specialists; 99% of their diet is composed of understory bamboo species (Schaller et al., 1985). Adaptations to a strict bamboo diet include an enlarged wrist bone to allow for gripping bamboo stems and a large skull and jawbone for mastication of tough plant material (Schaller et al., 1985). However, the panda's short digestive tract

(characteristic of a carnivore) together with a lack of gut microflora suitable for breaking down the cellulose contained in their diet allows the pandas to digest less than 20% of their food intake (Schaller et al., 1985). To respond to these digestive constraints, the pandas have developed behavioral adaptations such as maintaining low energy expenditures (e.g., pandas prefer areas with gentle slopes for ease of movement) and selecting different bamboo species and plant parts with different nutritional characteristics that change along the year (Schaller et al., 1985). Because understory bamboo species in the forests of southwestern China are located at particular elevation ranges, the selection of different bamboo species along the year makes pandas elevation migrants (Linderman et al., 2004). Since the understory bamboo species require forest cover for shade, and pandas also depend on forest cover for shelter (Liu et al., 1999b, 2001), there is a tight relationship between pandas, understory bamboo, and tree species.

Plant Species in the Panda Geographic Range

The current geographic range of the giant panda is characterized by high mountains and deep valleys with elevations ranging from ca. 70 m to more than 6000 m. The drastic elevation gradient combined with complex terrain, geology, and soils is responsible for a high biological diversity, including more than 6000 species of plants in more than 1000 genera (IUCN, 2006). The region also features more than 100 species of mammals in 25 families, and ca. 400 species of birds in 45 families (Reid & Hu, 1991; Taylor & Qin, 1993b; IUCN, 2006). In fact, the region comprises one of the world's top 25 biodiversity hotspots (Myers et al., 2000; Mittermeier et al., 2004).

The vegetation is dominated by evergreen and deciduous broadleaf forests at intermediate and lower elevations and subalpine coniferous forests at higher elevations. Forests occupy around one third of the current panda range, with coniferous, broadleaf deciduous, and mixed coniferous/broadleaf deciduous forests accounting for ca. 48%, 32%, and 20% of the forest cover, respectively (Fig. 3). Tree species diversity in these forests is influenced by elevation and shows conspicuous declines in the number of tree species with an increase in elevation, particularly above 2500 m (Viña et al., 2012).

A total of 115 tree species were found in 104 field plots randomly distributed within an elevation range of 1000–3000 m in broadleaf deciduous, coniferous, and mixed forests across the Qinling Mountains region (Fig. 2) (Viña et al., 2012). Dominant tree

species (i.e., occurring in > 20% of the field plots) in this mountain region were *Quercus aliena* Blume, *Betula albosinensis* Burkill, *Prunus scopulorum* Koehne, *Toxicodendron vernicifluum* (Stokes) F. A. Barkley, and *Pinus armandii* Franch. (Viña et al., 2012). In a similar study in the Wolong Nature Reserve (the first and one of the largest giant panda nature reserves, established in 1975 and encompassing ca. 200,000 ha in Sichuan Province) located in the Qionglai Mountains region (Liu et al., 1999a) (Fig. 2), a total of 81 tree species were found in 62 field plots distributed along four transects ranging in elevation from 1500 to 3200 m (unpubl. data). Dominant tree species (i.e., occurring in > 20% of the field plots) in this region were *Acer laxiflorum* Pax, *Salix dolia* C. K. Schneid., *Prunus pilosiuscula* (C. K. Schneid.) Koehne, *B. albosinensis*, *Abies faxoniana* Rehder & E. H. Wilson, *Corylus ferox* Wall. var. *tibetica* (Batalin) Franch., and *Sorbaria arborea* C. K. Schneid.

Bamboo species are a particularly conspicuous feature in the understory of the forests of the panda geographic range. Although pandas can feed on more than 30 understory bamboo species found across their geographic range, they prefer only ca. 14 spatially dominant ones (Table 1). In the Qinling Mountains region the understory canopy is dominated by three bamboo species: *Fargesia qinlingensis* T. P. Yi & J. X. Shao, *Bashania fargesii* (E. G. Camus) Keng f. & T. P. Yi [= *Arundinaria fargesii* E. G. Camus], and *F. dracocephala* T. P. Yi (Viña et al., 2012), while in the Wolong Nature Reserve (Qionglai Mountains region), the dominant bamboo species are *F. nitida* (Mitford) Keng f. ex T. P. Yi, *F. robusta* T. P. Yi, and *B. faberi* (Rendle) T. P. Yi [= *A. faberi* Rendle] (Linderman et al., 2005b; Viña et al., 2008; Tuanmu et al., 2010). Because there is usually only one dominant understory bamboo species at a given location (Johnson et al., 1988; Reid et al., 1989; Linderman et al., 2005b, 2006; Viña et al., 2008; Tuanmu et al., 2010; Viña et al., 2012), changes in their abundance and spatial distribution (e.g., through bamboo harvesting; bamboo die-offs as a result of mass flowering occurring at time intervals from 16- to 90-year cycles depending on the species; cf. Table 1) could cause food shortages for the pandas (Schaller, 1987; Reid et al., 1989).

The spatial distribution of understory bamboo species is influenced by many factors, including panda utilization and interactions with other plant species. Regarding the former, Pleistocene fossil records (Zhu & Li, 1980) indicate that the giant panda and the bamboo species composing their diet had plenty of time to develop co-evolutionary traits
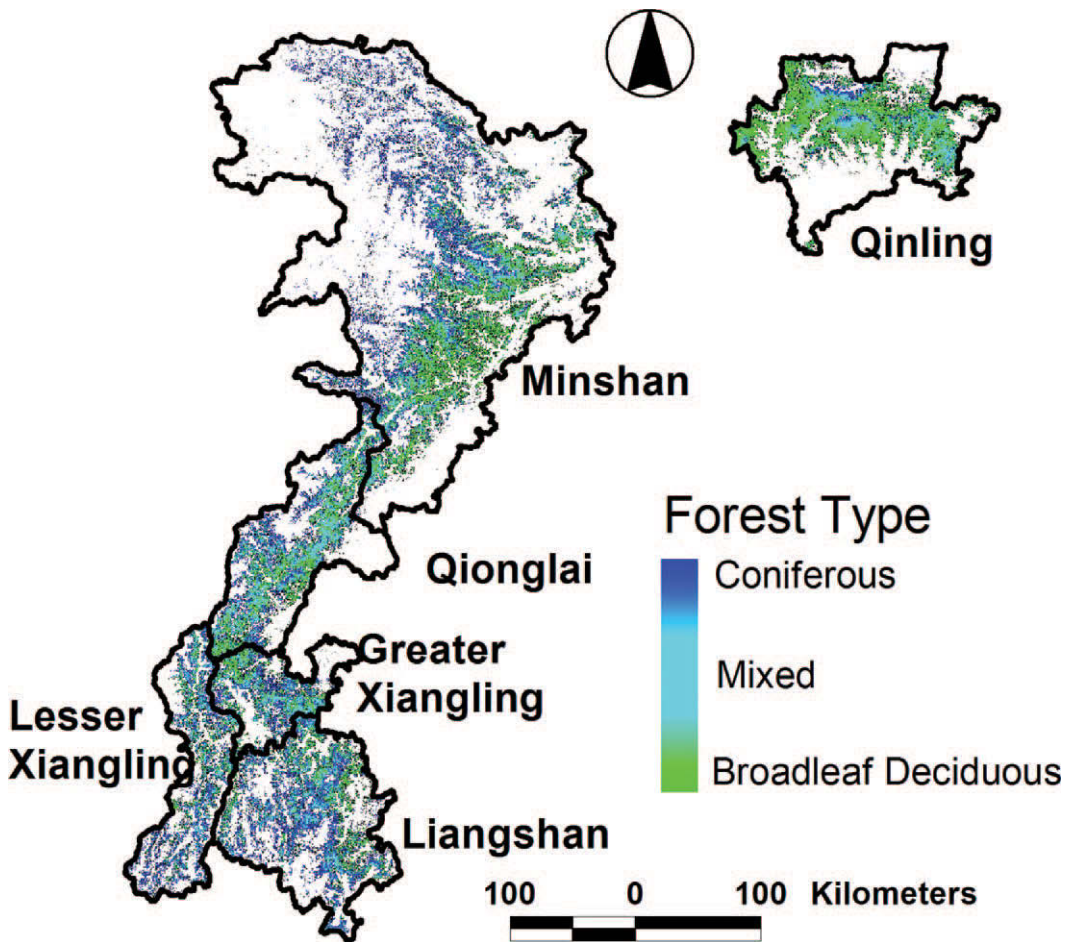
Figure 3. Distribution of coniferous, broadleaf deciduous, and mixed coniferous/deciduous forests in the mountain regions (in 2007) comprising the geographic range of the giant panda. Coniferous forests occur mostly at higher elevations, while mixed coniferous/deciduous forests and broadleaf deciduous forests occur more so at intermediate and lower elevations, respectively. Some coniferous forests also occur at intermediate elevations but are usually planted assemblages.

that ensured their survival, e.g., by reducing potentially negative effects of overgrazing. Nevertheless, under the current drastically reduced areas of suitable habitat, the degree to which bamboo over-utilization potentially results in a decline in both quality of bamboo stands and viability of the panda populations needs to be assessed. Studies conducted in Wolong Nature Reserve have found that *Fargesia robusta* had a low yearly recruitment rate, reflecting poor shoot production and survival rates (Taylor & Qin, 1993a). This was in part due to the intensive utilization of this species by pandas, particularly between May and June when adult individuals were found to consume as much as 35 kg of bamboo per day (Schaller et al., 1985). Since panda habitat areas located at lower elevations are becoming increasingly fragmented and degraded over time due to human

activities (Liu et al., 2001; Xu et al., 2006; Viña et al., 2007), there is potential for localized panda populations to over-utilize stands of *F. robusta* in isolated areas (Hull et al., 2010). However, much more work on this regard needs to be conducted. Regarding the interactions between bamboo and other plant species, the occurrence of overstory tree species influences the occurrence of understory bamboo (Taylor et al., 2004, 2006). Multivariate statistical analyses can be used to identify overstory tree species associated with understory bamboo species. Using the Jaccard similarity index (Jaccard, 1908) combined with hierarchical cluster analyses (i.e., average linkage method), we determined the tree species most likely associated with the six dominant bamboo species in the two field study sites (i.e., three bamboo species in the Qinling Mountains region and

Table 1. Dominant understory bamboo species occurring in the different mountain regions across the entire giant panda range. Mountain regions are indicated in the second column as (1) Qinling; (2) Minshan; (3) Qionglai; (4) Xiangling (both the Greater and Lesser Xiangling); and (5) Liangshan. These bamboo species also constitute the preferred food consumed by pandas. Also shown in the third column are their reported reproductive cycles (i.e., periods between mass flowering events). Names noted in bracketed equivalencies reflect a differing taxonomic usage in the *Flora of China* (Wu et al., 2006).

Species	Mountain region	Reproductive cycle (yrs.)	References
Bashania fargesii (E. G. Camus) Keng f. & T. P. Yi [= *Arundinaria fargesii* E. G. Camus]	1, 2, 3	23	Schaller et al., 1989; Wang, 1989; Tian, 1990; Pan & Lu, 1993; Zhou & Pan, 1997; State Forestry Administration, 2006; Viña et al., 2012
B. faberi (Rendle) T. P. Yi [= *A. faberi* Rendle]	2, 3, 4, 5	45	Campbell & Qin, 1983; Campbell, 1984; Johnson et al., 1988; Reid et al., 1989; Wang, 1989; Tian, 1990; Reid & Hu, 1991; Reid et al., 1991; Taylor & Qin, 1993a; State Forestry Administration, 2006
Chimonobambusa pachystachys Hsueh & T. P. Yi	2, 3, 4	16	Campbell & Qin, 1983; Wang, 1989; State Forestry Administration, 2006
Fargesia scabrida T. P. Yi	2, 3	50	Campbell, 1984; Schaller et al., 1985; Wang, 1989; State Forestry Administration, 2006
F. denudata T. P. Yi	2	40	Schaller et al., 1989; Wang, 1989; State Forestry Administration, 2006
F. dracocephala T. P. Yi	1, 2	n/a	State Forestry Administration, 2006; Li et al., 2007; Viña et al., 2012
F. ferax (Keng) T. P. Yi	4, 5	40	Wang, 1989; State Forestry Administration, 2006
F. nitida (Mitford) Keng f. ex T. P. Yi	1, 2, 3	90	Wang, 1989; Tian, 1990; State Forestry Administration, 2006
F. qinlingensis T. P. Yi & J. X. Shao	1	50	Tian, 1987; State Forestry Administration, 2006; Wang et al., 2007; Viña et al., 2012
F. robusta T. P. Yi	1, 2, 3	37	Campbell & Qin, 1983; Campbell, 1984; Johnson et al., 1988; Reid et al., 1989; Wang, 1989; Tian, 1990; Reid & Hu, 1991; Reid et al., 1991; Pan & Lu, 1993; Zhou & Pan, 1997; State Forestry Administration, 2006
F. rufa T. P. Yi	2	15	Wang, 1989; State Forestry Administration, 2006
Qiongzhuea opienensis (J. R. Xue & T. P. Yi) D. Z. Li & J. R. Xue [= *Chimonobambusa opienensis* (J. R. Xue & T. P. Yi) T. H. Wen & Ohrnberger]	4, 5	20	Wang, 1989; State Forestry Administration, 2006
Yushania chungii (Keng) Z. P. Wang & G. H. Ye [= *Y. brevipaniculata* (Hand.-Mazz.) T. P. Yi]	1, 2, 3	20	Campbell & Qin, 1983; Campbell, 1984; Wang, 1989; State Forestry Administration, 2006
Y. confusa (McClure) Z. P. Wang & G. H. Ye	4, 5	22	Wang, 1989; State Forestry Administration, 2006

three in the Wolong Nature Reserve in the Qionglai Mountains region) (Fig. 4). In both of these regions the species *Betula albosinensis*, a dominant tree species in the giant panda geographic range, was associated with at least three dominant understory bamboo species (Fig. 4). Other species of the genus *Betula* L. (e.g., *B. utilis* D. Don, *B. platyphylla* Sukaczev, *B. luminifera* H. J. P. Winkl.) were also associated with some of the dominant bamboo species (Fig. 4). The occurrence of these species associations can be explained by the interactions between tree species life histories and bamboo life cycles which influence both tree and bamboo regeneration and, thus, contribute to structuring the species composition in the forests of the panda geographic range (Taylor et al., 2004).

PEOPLE

The pattern of decline of both the distribution and number of pandas has been largely associated with the loss of tree and understory bamboo species, which, in turn, have been attributed to climate fluctuations over many centuries (Schaller et al., 1985; Reid & Gong, 1999; Pan et al., 2001). However, the most recent loss has been attributed to an ever increasing growth of human population and activities (e.g., agricultural expansion, timber harvesting, road construction, livestock grazing, tourism, bamboo harvesting, mining) (Schaller et al., 1985; Reid & Gong, 1999; Pan et al., 2001), together with a drastic increase in the number of households. For example, from 1975 to 2000, the number of local residents in Wolong Nature Reserve increased by 72.4% (from 2560 to 4413) while the number of households jumped by 129.9% (from 421 to 968) (An et al., 2011). The increase in the number of households may have even more drastic negative effects than population growth alone (Liu et al., 2003a), because the proliferation of smaller households (e.g., as a result of divorces and kids moving out of parental homes [An et al., 2003]) translates into more households and less efficient use of natural resources on a per-capita basis (Yu & Liu, 2007).
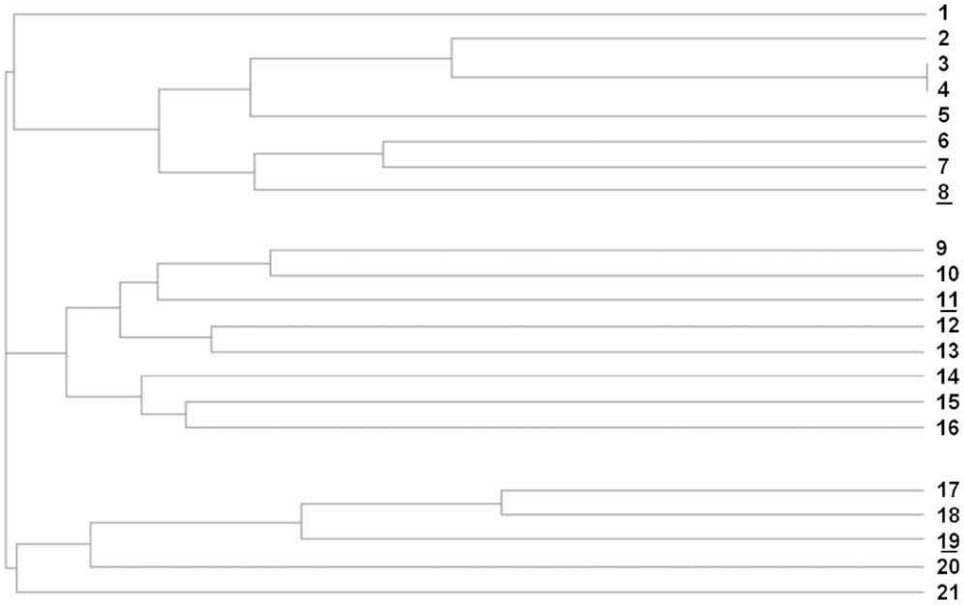
Human activities vary across space and over time. For example, while cultivation has occurred in the panda geographic range for centuries, it mostly occurred at low elevations which were more accessible to humans (Pan et al., 2001; Loucks et al., 2003). However, in recent decades, cultivation has extended to higher elevations, thus, induced forest clearings where core panda habitat was previously located (Schaller et al., 1985; Wang, 2008). In addition, the extensive timber harvesting and fuel wood collection observed in the panda region

between the 1960s and the 1990s were identified to be the most important threats to pandas (Liu et al., 2001; State Forestry Administration, 2006), particularly because clear-cut areas are characterized by two extremes that prevent the occurrence of panda individuals: complete lack of bamboo or extremely dense patches of non-nutritious bamboo without an overstory of trees (Schaller et al., 1985; Bearer et al., 2008).

In addition to changes in the distribution and composition of tree and bamboo species, timber harvesting and fuel wood collection have many other effects that generate feedbacks which ultimately affect local residents. For example, inside Wolong Nature Reserve, timber harvesting occurred along a spatially defined deforestation front in which forests were exploited near households during the 1970s (He et al., 2009). As forests near households depleted, the local residents were forced to cut trees farther away (He et al., 2009). The spatial expansion of timber-extraction activities was also driven by improved accessibility due to the development of road networks. For instance, a project by the United Nations' World Food Programme in the early 1980s designed to mitigate human impacts on panda habitat in the Reserve resulted in a road expansion. This road expansion facilitated the access to a forested area rarely visited during the 1970s, which was subsequently deforested (Wolong Administration Bureau, 2004; He et al., 2009).

Timber harvesting and fuel wood collection not only affect current panda habitat, but also generate legacy effects on future panda habitat (An et al., 2005, 2006; Linderman et al., 2005a) through their conspicuous effects on plant species. For instance, in Wolong Nature Reserve, wood constitutes the main material for traditional house construction. In addition, a significant amount of fuel wood is consumed for cooking, heating, and stewing pig fodder, since pigs are the main animal protein source for local residents (An et al., 2001; Liu et al., 2004). Deciduous tree species such as *Betula albosinensis* and *B. utilis* are preferred for fuel wood, while species such as *Abies faxoniana* are preferred for construction. As mentioned above, these deciduous and evergreen tree species are dominant overstory canopy components in the forests that are suitable for the pandas, but currently they are rarely found in areas near local households, due to excessive harvesting through selective logging. As these species promote the regeneration of understory bamboo suitable for the giant panda (Taylor et al., 2004, 2006), the absence of these species in some areas reduces the likelihood of suitable panda habitat regeneration.
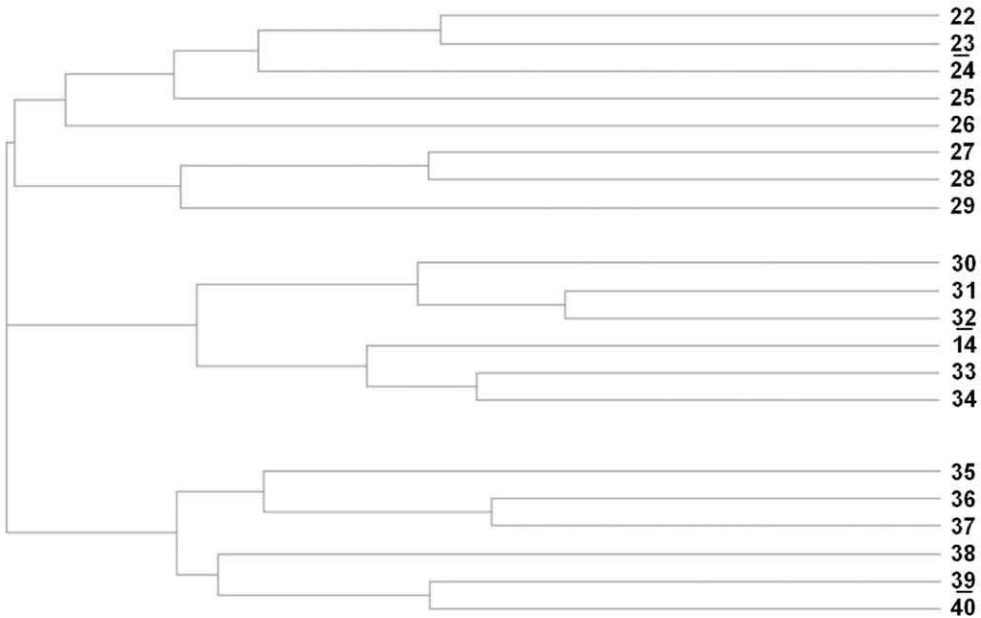
Figure 4.   Cluster analysis showing tree and bamboo species associations of six dominant bamboo species (underlined), three of which are located in the Qinling Mountains region and three in the Wolong Nature Reserve located within the Qionglai Mountains region (see Fig. 2 for location). Numbers in the figure correspond to: (1) *Betula platyphylla* Sukaczev; (2) *Quercus spinosa* David ex Franch.; (3) *Ulmus parvifolia* Jacq.; (4) *Pyrus betulifolia* Bunge; (5) *Cornus controversa* Hemsl.; (6) *Quercus liaotungensis* Koidz.; (7) *Betula luminifera* H. J. P. Winkl.; (8) *Fargesia qinlingensis* T. P. Yi & J. X. Shao; (9) *Juglans cathayensis* Dode; (10) *Toxicodendron vernicifluum* (Stokes) F. A. Barkley; (11) *Fargesia dracocephala* T. P. Yi; (12) *Pinus*

Current emerging threats from human activities on pandas and their habitat include the extensive investment in infrastructure (e.g., dams, highways, airports, roads, railroads, tourism facilities) under the West China Development Program. Between 2001 and 2006 alone, this program invested more than U.S. $125 billion for development projects with the main goal of attracting businesses and migrants to western China (Lu, 2009). This construction boom may exacerbate the degradation and fragmentation of giant panda habitat not only in the present but also in the years to come.

An additional threat comes in the form of livestock grazing (Hull et al., 2011). The third panda census reported that livestock grazing is the second most commonly encountered human-driven disturbance, after deforestation (State Forestry Administration, 2006). In the Minshan Mountain region (see its location in Fig. 1), disturbances due to livestock grazing were found in 19% of over 1600 sample plots (Wang, 2008). Despite the recorded prevalence of livestock grazing across the panda geographic range, research on its direct and indirect effects on pandas and their habitat is limited to a handful of case studies (Ran, 2003, 2004; Ran et al., 2003; Kang et al., 2011). These studies mostly reinforced the findings about the prevalence of livestock disturbance in panda habitat areas, hinting that there is some degree of overlap in the habitat selection of pandas and livestock. Therefore, many questions still remain unanswered, particularly regarding whether livestock could threaten the long-term sustainability of understory bamboo, which prior to the increase in livestock grazing was not believed to be threatened by any animal competing with the pandas (Schaller et al., 1985).

POLICIES

The impacts of human activities on pandas have prompted the Chinese government to develop a series of policies, including the establishment of panda nature reserves (protected areas specifically designed to conserve the panda). A total of 63 nature reserves (by 2007) have been designated to conserve the habitat for the panda. While these panda reserves contain about 40% of the current panda habitat (Viña et al., 2010), they tend to be isolated (Viña et al., 2007, 2010), which means that there is still a significant amount of panda habitat outside the nature reserve system. However, nature reserves have not been immune to human threats, as the panda habitat contained within their boundaries also experienced a steady decrease (Liu et al., 2001; Viña et al., 2007). This has occurred despite the fact that these reserves have imposed restrictions on resource use (e.g., fuel wood) (He et al., 2009) and are required to establish zoning designations to spatially contain human activities (Hull et al., 2011). In many cases these designations are ineffectual because the boundaries of zoning designations are displaced in response to development pressures (e.g., construction of tourism facilities) (Jim & Xu, 2004; Liu & Li, 2008; Hull et al., 2011). In addition, panda reserves often lack sufficient funding for their operations (Liu et al., 2003b) and, thus, do not properly enforce conservation activities (Lü & Kemf, 2001).

In addition, since the late 1990s the Chinese government has been implementing two of the largest ecological conservation programs in the world: (1) The Natural Forest Conservation Program (NFCP), which bans logging in natural forests in order to prevent illegal harvesting (Yang et al., 2013b), and (2) the Grain-to-Green Program (GTGP; also referred to as the Sloping Land Conversion Program), which encourages farmers to return steep cropland to forest or grassland (Uchida et al., 2005; Liu et al., 2008). Both of these policies have global implications, as they fulfill part of China's commitment to international biodiversity conservation treaties (Liu et al., 2008). These policies seem to have been producing overall positive effects on forests, including those in panda habitat regions (Li et al., 2013), by preventing further deforestation and promoting forest recovery (Viña et al., 2007, 2011; Liu et al., 2008, 2013). The implementation of the NFCP has started to also exhibit a significant positive effect on panda habitat, particularly when local people are actively involved in forest monitoring activities (Tuanmu, 2012). This is because timber harvesting has been curbed since

←
armandii Franch.; (13) *Quercus aliena* Blume; (14) *Betula albosinensis* Burkill; (15) *Prunus* L. sp.; (16) *Acer davidii* Franch.; (17) *Betula albosinensis* var. *septantrionalis* C. K. Schneid.; (18) *Abies fargesii* Franch.; (19) *Bashania fargesii* (E. G. Camus) Keng f. & T. P. Yi [= *Arundinaria fargesii* E. G. Camus]; (20) *Larix chinensis* Beissn.; (21) *Euonymus phellomanus* Loes.; (22) *Abies faxoniana* Rehder & E. H. Wilson; (23) *Fargesia nitida* (Mitford) Keng f. ex T. P. Yi; (24) *Betula utilis* D. Don; (25) *Prunus dielsiana* (C. K. Schneid.) Koehne; (26) *Quercus aquifolioides* Rehder & E. H. Wilson; (27) *Salix dissa* C. K. Schneid.; (28) *Salix phanera* C. K. Schneid.; (29) *Tilia intonsa* E. H. Wilson; (30) *Acer laxiflorum* Pax; (31) *Corylus ferox* Wall. var. *thibetica* (Batalin) Franch.; (32) *Fargesia robusta* T. P. Yi; (33) *Rhododendron pachytrichum* Franch.; (34) *Tsuga chinensis* (Franch.) E. Pritz.; (35) *Cotoneaster moupinensis* Franch.; (36) *Sorbaria arborea* C. K. Schneid.; (37) *Salix dolia* C. K. Schneid.; (38) *Syringa* L. sp.; (39) *Bashania faberi* (Rendle) T. P. Yi [= *Arundinaria faberi* Rendle]; (40) *Prunus pilosiuscula* (C. K. Schneid.) Koehne.

the late 1990s due, in part, to the national logging ban implemented through the NFCP (State Forestry Administration, 2006; Viña et al., 2007, 2011; Li et al., 2013). This ban has brought not only a reduction in the rate of loss of natural forests, but also forest regeneration in previously clear-cut areas (Viña et al., 2011; Li et al., 2013). Such forest regeneration brings some hope for panda conservation, since pandas have been observed to use secondary forests that are 30+ years old if adequate understory bamboo is present (Viña et al., 2007; Bearer et al., 2008).

Nationwide, the GTGP has converted 8.8 million ha of cropland into forest or grassland (Liu et al., 2013b). In the Qionglai Mountains region, this program provides seedlings for ca. 48 tree species, many of which are exotic (Viña et al., 2013) and do not constitute suitable tree species that promote bamboo regeneration, nor giant panda habitat recovery. Among the species planted under the GTGP, *Cunninghamia lanceolata* (Lamb.) Hook., *Magnolia officinalis* Rehder & E. H. Wilson, *Ligustrum lucidum* W. T. Aiton, *Cryptomeria japonica* (Thunb. ex L. f.) D. Don, *Eucommia ulmoides* Oliv., and *Alnus cremastogyne* Burkill are the species used more often (Viña et al., 2013). The Wolong Nature Reserve has, in addition to the GTGP (Chen et al., 2009a, 2009b, 2010, 2012b), a local Grain-to-Green/ Bamboo Program (GTGB) in which farmers are compensated for actively planting the species *Fargesia robusta* in previous cropland areas (Yang et al., 2013a, 2013b). The planted bamboo is harvested particularly to provide fodder for the captive pandas in the breeding center of the Reserve. As these monospecific bamboo plantations generally lack overstory trees, they could not be considered suitable habitat areas for the pandas, either now or in the foreseeable future. Thus, promoting the re-growth of tree species that characterize suitable panda habitat should be one of the priorities in the panda conservation toolbox.

MACROSCALE FACTORS

Plants and pandas are not only affected by local factors, but also by large-scale factors such as migration, tourism, natural disasters, and climate change. Since China has been the fastest-growing economy in the world over the past three decades (Liu & Diamond, 2008), there has been an increase in job opportunities in cities; thus, more rural people are engaging in labor migration. This has the effect of reducing deforestation (e.g., through a reduction in fuel wood demands) while enhancing the natural regeneration of forests, particularly in giant panda regions (Chen et al., 2012a). In addition, many nature reserves in China are exhibiting a rapid increase in the influx of tourists from around the world (Han, 2000; Liu et al., 2003a). The increase in tourism is supported by rapid development of tourism facilities (e.g., hotels, restaurants), together with expansions in the road network, all of which influence the abundance and distribution of plants and pandas. For example, the number of tourists visiting Wolong Nature Reserve increased dramatically, from ca. 20,000 in 1995 to ca. 100,000 in 2000 (Lindberg et al., 2003) and to more than 200,000 in 2006 (He et al., 2008). During this time period, the number of households participating in tourism activities also increased, yet households with more livelihood assets (e.g., income, education, social capital) were more likely to participate than less affluent households (Liu et al., 2012).

Another macroscale factor is represented by natural disasters. As in most mountain regions around the world, landslides are the most common natural disaster in the panda geographic range (Brabb & Harrod, 1989; Lee, 2005; Pradhan et al., 2006). More than 70% of catastrophic landslides are related to land use change (Reid et al., 2006; Huang, 2007; Rindfuss et al., 2008) and are triggered by severe rainfall events during the summer months (Li, 1989), and by a high seismic activity, with four earthquakes larger than 7.0 on the Richter scale occurring in the region during the last hundred years (Wang et al., 2008). The last such earthquake was the 7.9 M_w (8.0 Richter scale) 12 May 2008 earthquake, the epicenter of which was located in Wenchuan County, Sichuan Province. Earthquake-induced landslides not only affect many forest areas (Viña et al., 2011) and giant panda habitat (Wang et al., 2008; Xu et al., 2009) (Fig. 5), but also induce significant losses to tree and shrub species richness (Zhang et al., 2011). Earthquake-induced landslides are so severe in many areas that they offset the gains in forest cover obtained through the implementation of conservation policies such as the NFCP (Viña et al., 2011).

A final macroscale factor potentially affecting plants and pandas is human-induced climate change. While deforestation and forest degradation are threatening the survival of about half of all bamboo species worldwide (Bystriakova & Kapos, 2006), climate change may present an additional significant threat. Many bamboo species are vulnerable to climate change because their unusual extended sexual reproduction intervals (from 10 to 120 years) (Janzen, 1976) and limited seed dispersal ability (Taylor et al., 1991) render them less capable of adjusting their distributions to the rapidly changing climate projected to occur within this century (IPCC,
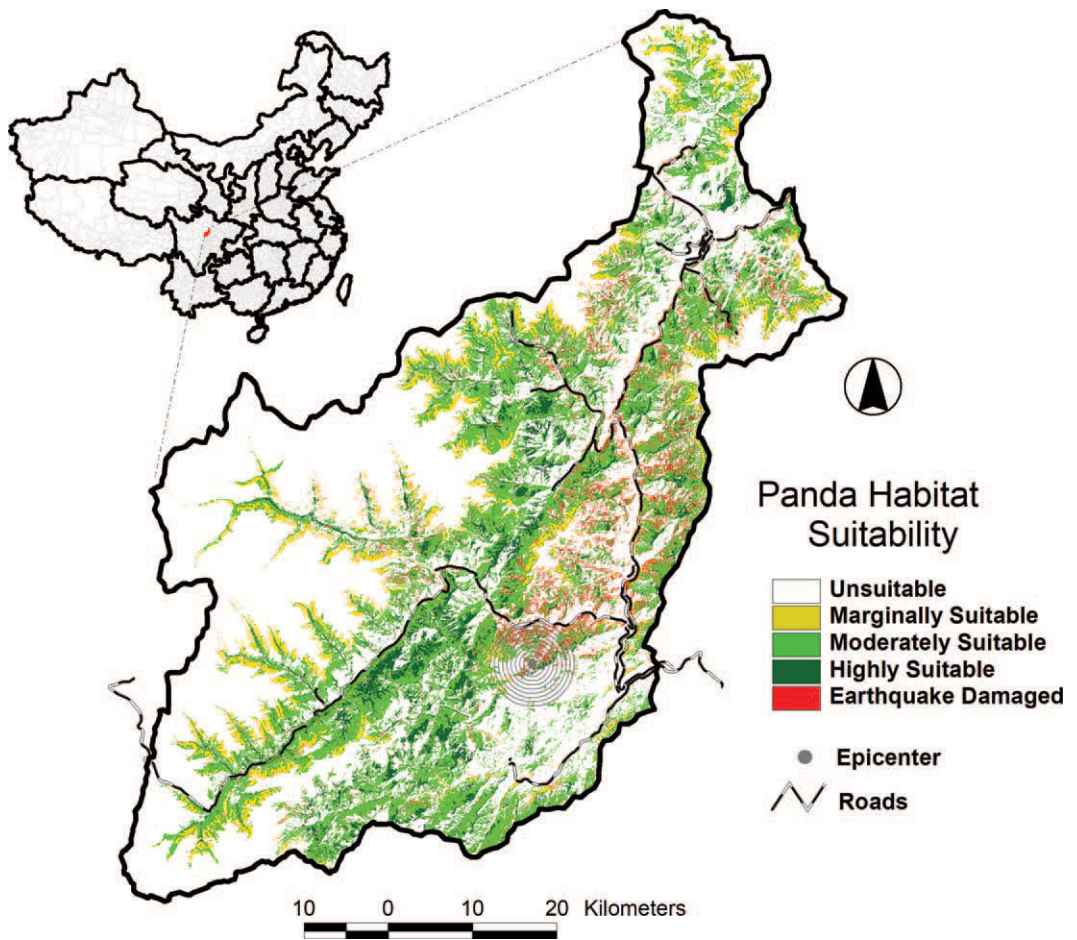
Figure 5. Spatial distribution of panda habitat areas (modified from Liu et al., 2001; Viña et al., 2007) in Wenchuan County damaged by the 12 May 2008, Wenchuan Earthquake. Wolong and Caopo nature reserves are located entirely within Wenchuan County.

2007). In addition, bamboo species have limited vegetative dispersal ability (e.g., ca. 0.2–0.35 m/year for *Bashania fargesii* and *Fargesia robusta*) (Tian, 1989; Taylor & Qin, 1993a). Yet, despite this vulnerability of bamboo species to climate change, few studies have evaluated the potential effects of climate change on bamboo distribution and how these will cascade to pandas. A recent ensemble of bamboo distribution projections associated with multiple climate change projections and bamboo dispersal scenarios indicates that a substantial reduction in the distributional ranges of the three dominant bamboo species in the Qinling Mountains of China may occur by the end of the 21st century, with potentially drastic effects in the distribution of suitable giant panda habitat (Tuanmu et al., 2013). For instance, two contrasting climate change projections derived from two general circulation models (one developed by the Commonwealth Scientific and Industrial Research Organisation, Australia [CSIRO-Mk2] and the other from a coupled model developed by the Center for Climate System Research and the National Institute for Environmental Studies, Japan [CCSR/ NIES]) under the conservative B2 greenhouse gas emission scenario (which emphasizes local solutions to economic, social, and environmental sustainability) (IPCC, 2007), project reductions and distributional shifts of climatically suitable areas (CSA) of the three bamboo species by the end of the century (i.e., 2070– 2099). Under the CSIRO-Mk2, there is a conspicuous projected shift of the CSA of the three species toward higher latitudes as compared with current conditions (Tuanmu et al., 2013) (Fig. 6). Under the CCSR/ NIES, the CSA of *F. qinlingensis* is projected to disappear, as this species currently occurs at higher elevations, while the CSA of *B. fargesii* and *F.*
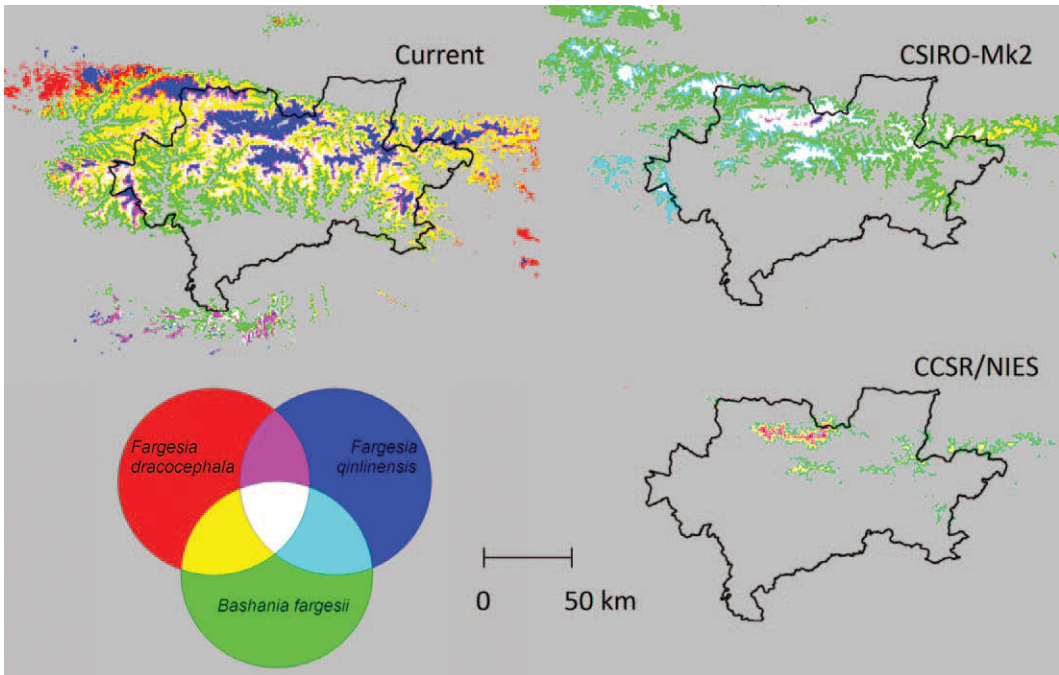
Figure 6.   Current and projected (2070–2099) distributions of climatically suitable areas for the three dominant bamboo species in the Qinling Mountains region of China (after Tuanmu et al., 2013): *Fargesia dracocephala* (red), *F. qinlingensis* (blue), and *Bashania fargesii* (green). Their co-occurrences are indicated by the overlapping colors of the three species circles. The climate projections were derived from two global circulation models (one developed by the Commonwealth Scientific and Industrial Research Organisation, Australia [CSIRO-Mk2], and the other a coupled model developed by the Center for Climate System Research and the National Institute for Environmental Studies, Japan [CCSR/NIES]) under the B2 scenario of the IPCC Special Report on Emission Scenarios (IPCC-SRES). The black line corresponds to the political boundary of the Qinling Mountains region in Shaanxi Province, China. For its location within the panda geographic range, see Figure 2.

dracocephala are projected to experience a substantial reduction (Tuanmu et al., 2013) (Fig. 6). However, irrespective of the global circulation model used, the projected location of the CSA is distant from current bamboo distribution ranges, which may hinder potential range shifts of bamboo species (as well as pandas) in response to the projected change in the global climate (Tuanmu et al., 2013). This is particularly exacerbated by the long history of human activities surrounding the Qinling Mountains, which are not projected to substantially reduce in the foreseeable future.

CONCLUSIONS

The current pace of biodiversity loss worldwide is intensifying the need for conservation actions that address not only species of conservation interest, but also their interactions with multiple other species, as well as with humans. Using the CHANS framework, this article has illustrated the complex relationships among pandas, plants (tree and bamboo species), and

humans. Our synthesis indicates that many human factors, including socioeconomic and demographic, exhibit reciprocal interactions with pandas and the plant species that comprise their habitat. The framework is particularly useful for uncovering key patterns and processes behind plant–animal interactions modified by human activities. Understanding of such patterns and processes is crucial for developing and evaluating policies that better reconcile the needs of an ever-growing human population with biodiversity conservation.

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