A Framework for Evaluating the Effects of Human Factors on Wildlife Habitat: the Case of Giant Pandas

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Abstract: *To address the complex interactions between humans and wildlife habitat, we developed a conceptual framework that links human factors with forested landscapes and wildlife habitat. All the components in the framework are integrated into systems models that analyze the effects of human factors and project how wildlife habitat would change under different policy scenarios. As a case study, we applied this framework to the Wolong Nature Reserve in Sichuan Province (southwestern China), the largest home of the giant panda (*Ailuropoda melanoleuca*). We collected ecological and socioeconomic data with a combination of various methods (field observations, aerial photographs, government documents and statistics, interviews, and household surveys) and employed geographic information systems and systems modeling to analyze and integrate the data sources. Human population size has increased by 66% and the number of households in the reserve has increased by 115% since 1975, when the reserve was established. During the same period, the quality and quantity of the giant panda habitat dramatically decreased because of increasing human activities such as fuelwood collection. Systems modeling predicted that under the status quo, human population in the reserve would continue to grow and cause more destruction of the remaining panda habitat, whereas reducing human birth rates and increasing human emigration rates would lower human population size and alleviate human impacts on the panda habitat. Furthermore, our simulations and surveys suggested that policies encouraging the emigration of young people would be more effective and feasible than relocating older people in reducing human population size and conserving giant panda habitat in the reserve.*

Marco para la Evaluación de los Efectos de Factores Humanos en el Hábitat de Vida Silvestre: Caso de Estudio de Pandas Gigantes

Resumen: *Para estimar las complejas interacciones entre humanos y el hábitat de la vida silvestre, desarrollamos un marco conceptual que vincula factores humanos con paisajes boscosos y hábitat de la vida silvestre. Todos los componentes en el marco fueron integrados en modelos de sistemas que analizaron los efectos de factores humanos y proyectaron como el hábitat de la vida silvestre puede cambiar bajo diferentes escenarios de políticas. Como un caso de estudio aplicamos este marco a la Reserva Natural Wolong en la provincia Sichuan (China Surocidental), el hogar mas grande del panda gigante (*Ailuropoda melanoleuca*). Colectamos datos ecológicos y socioeconómicos combinando varios métodos (observaciones de campo, fotografias aéreas, documentos y estadísticas gubernamentales, entrevistas y encuestas a lugareños) y empleamos sistemas de información geográfica y modelado de sistemas para analizar e integrar las fuentes de datos. La población humana y el número de habitantes en la reserva se ha duplicado desde 1975, cuando se estableció la reserva. Durante el mismo periodo de tiempo, la cantidad y calidad de hábitat del panda gigante disminuyó dramáticamente debido al incremento de actividades humanas como lo es la colecta de leña. El modelado de sistemas predijo que bajo este estatus, la población humana en la reserva continuará creciendo*

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Paper submitted August 18, 1998; revised manuscript accepted March 24, 1999.

y causará mayor destrucción a los remanentes del hábitat del panda, mientras que la disminución de la tasa de nacimientos de la población humana y el incremento en la emigración podría disminuir el tamaño de la población humana y aliviar impactos humanos en el hábitat del panda. Más aún, nuestras simulaciones y encuestas sugieren que las políticas para promover la emigración de gente joven podría ser mas efectiva y factible que el reubicar gente adulta en la disminución del tamaño de la población humana y conservar el hábitat del panda gigante en la reserva.

Introduction

The effects of humans on biodiversity and landscapes have been widely recognized (e.g., Wilson 1988; Lubchenco et al. 1991; Ehrlich 1995; McNeely et al. 1995; Forester & Machlis 1996; Vitousek et al. 1997). As the human population continues to increase, demands on natural resources grow larger; few places on Earth are unaffected by human activities. Even many nature reserves, or "protected areas" (Dompka 1996), are not well protected from human interference. Nature reserves are a traditional approach to biodiversity conservation, but their effectiveness is limited by increasing human pressures. The objective to protect wildlife and other species is often in serious conflict with the needs for socioeconomic development by local residents (McNeely & Ness 1996). Although increase in human population pressure has been recognized as a major threat to environmental protection and biodiversity conservation (Holdren & Ehrlich 1974; Ehrlich 1988), the mechanisms underlying complex interactions between population and environment or population and biodiversity are largely unknown (Dompka 1996).

To minimize or eliminate conflicts between wildlife conservation and socioeconomic development, we must understand how humans affect wildlife habitat. To comprehend the mechanisms, we must develop a framework that integrates ecological, socioeconomic, and demographic components.

The major objectives of our study were to develop such an integrated framework that could guide systematic and explicit evaluations of human effects on wildlife habitat and to apply this framework to a case study assessing habitat changes of giant pandas (*Ailuropoda melanoleuca*) under influences of human activities in a nature reserve that reflects the typical conflicts between wildlife conservation and local people. Previous panda-related studies have focused mainly on the panda biology, such as reproduction and feeding behavior (e.g., Hu et al. 1980; Schaller et al. 1985; Schaller 1994). These biological studies are necessary but not sufficient for effective conservation. Although some researchers have suggested that human activities are important factors in the loss and fragmentation of panda habitat and, thus, the decline in panda population (Hu et al. 1980; Pan et al. 1988; Schaller 1994), no quantitative and systematic research has been undertaken to explicitly link destruction of panda habitat with human factors.

To achieve these objectives, we took a systems approach to designing a comprehensive conceptual framework, collected ecological and socioeconomic data combining various methods (field observations, aerial photos, government documents and statistics, interviews, and household surveys), and employed geographic information systems and systems modeling (e.g., Liu et al. 1995) to analyze and integrate the various data sources. As a result, we were able to assess how much panda habitat has been affected by humans and how giant panda habitat would change in the future under different policy scenarios regarding human demography and resource consumption patterns. Our hope is that the framework and methodologies developed for our case study site can be applied to the assessment of habitat quality, quantity, and dynamics in other giant panda nature reserves as well as to other wildlife species around the world. We also hope that the results will provide important insights into the effects of humans on wildlife habitat dynamics in general and will provide useful information for designing effective policies for balancing human needs and panda conservation in particular.

Methods

Conceptual Framework

Many wildlife species depend on forests as their habitat. We hypothesize that human factors are the primary drivers of change in forest systems and thereby alter wildlife habitat systems (Fig. 1). Human factors include population demography, household structure, human needs and wants, perceptions and attitudes toward wildlife conservation, and activities such as timber harvesting and fuelwood collection for cooking and heating. It is these various human factors that indirectly affect wildlife habitat. Forest ecosystems can be described by structure, function, integrity, and dynamics. Wildlife habitat attributes include habitat quantity, quality (suitability), timing (when a habitat is available), and location (e.g., spatial position in relation to surrounding landscape).

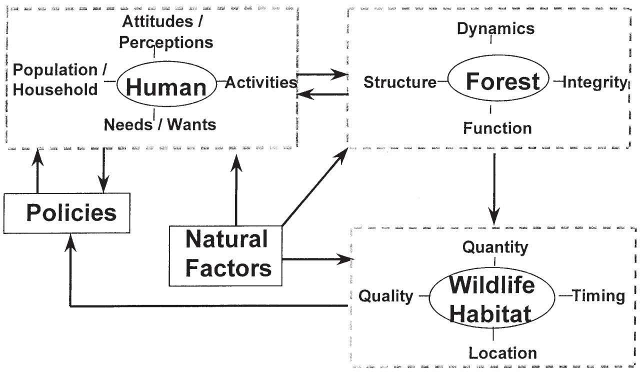


Figure 1. Conceptual framework of human effects on wildlife habitat.

Socioeconomic policies can significantly affect all aspects of human systems, and the policy-making process and effectiveness of policies are shaped by human systems and wildlife habitat conditions. For example, if wildlife habitat conditions are degraded and human attitudes toward wildlife conservation are positive, then socioeconomic policies may be favorable to conservation. Furthermore, human systems may be constrained by feedback from forest systems. For instance, after harvesting all trees in a forest, local residents must adopt an alternative lifestyle without timber and fuelwood. In addition, natural factors such as physical environment (e.g., elevation) are external variables directly affecting human and forest systems. For example, in areas with extremely high elevations (say 6000 m), humans cannot exist for long and no trees can live.

To test this conceptual framework (Fig. 1), we applied it in a case study assessing the effects of human factors on giant panda habitat in a nature reserve. All components in the framework were incorporated into a geographic information system as data layers and integrated into a systems model as driving variables, state variables, or parameters.

Biophysical and Administrative Characteristics of the Study Site

We chose Wolong Nature Reserve for giant pandas as our case study site because giant pandas are an important endangered species in China and because human activity has been encroaching on the panda habitat in the reserve. The reserve was established in 1962 with an area of 20,000 ha and expanded to its current size of 200,000 ha in 1975 (He et al. 1996). It is the largest among the 25 nature reserves in China designated for giant panda conservation (MacKinnon & DeWulf 1994; Wang 1997). Only 1050–1100 pandas are believed to exist in the wild, of which most inhabit the designated nature reserves (Giant Panda Expedition 1974; China's Ministry of Forestry & World Wildlife Fund 1989). Approximately 110 giant pandas, 10% of the total wild population, inhabit the Wolong reserve (Zhang et al. 1997).

Wolong Nature Reserve is located in Wenchuan County, Sichuan Province, southwestern China (lat 30°45′–31°25′ N, long 102°52′–103°24′ E). Wolong is situated between the Sichuan Basin and the Qinghai-Tibet Plateau and is characterized by high mountains and deep valleys. It encompasses several climatic zones, high habitat diversity (Schaller et al. 1985), and more than 2200 animal and insect species and nearly 4000 plant species (Tan et al. 1995). Besides the giant pandas, 12 other animal species and 47 plant species in the reserve are on China's national protection list.

The reserve is part of the international Man and Biosphere Reserve Network (He et al. 1996) and is managed by the Wolong Administration Bureau. The bureau reports to both China's Ministry of Forestry and Sichuan Province. There are two township governments under the Administration Bureau, Wolong Township and Genda Township.

Human Factors

Wolong has more than 4000 local residents belonging to three minority ethnic groups (Tibetan, Chang, and Hui) and the Han majority ethnic group. Although the Han group is the vast majority in China, the three minority groups in the reserve comprised approximately 70% of the total population in 1996 (Liu et al., unpublished data). China's well-known policy of one child per couple does not generally apply to the reserve because minority ethnic groups are exempt from the population policy set by the Chinese central government. The majority of local residents are farmers, but there is a diversity of economic activities in the reserve, including agriculture (maize and vegetables are the major crops), fuelwood collection, timber harvesting, house building, transportation, collection of Chinese herbal medicine, and tourism. Other types of employment include road construction and maintenance and construction of small hydropower stations over rivers in the reserve.

We obtained data regarding the human population and households in the reserve from several sources, including annual population reports (Wolong Nature Reserve 1975–1996); population census (Wenchuan County 1983); records on birth, death, age, sex, immigration, and emigration (Genda Township 1986–1994; Wolong Township 1986–1994; Wolong Police Department 1992–1996; Wolong Department of Agriculture 1986–1994); and agricultural surveys of farm households (Wolong Nature Reserve 1996).

We conducted face-to-face interviews in a random sample of 49 households in May of 1997 to better understand (1) human needs and wants; (2) attitudes and perceptions toward giant panda and biodiversity conservation, re-

Table 1. Assessment of abiotic and biotic factors used to determine suitability of habitat for giant pandas.

	Degree of habitat suitability			
Factor	*highly suitable*	*suitable*	*marginally suitable*	*unsuitable*
Elevation (m)	>2250–≤2750	>1500–≤2250 >2750–≤3250	≤1500 >3250–≤3750	>3750
Slope (degree)	≤15	>15–≤30	>30–≤45	>45
Vegetation cover	mixed conifer and deciduous broadleaf forest	deciduous broadleaf forest, conifer forest	evergreen broadleaf forest, mixed evergreen and deciduous broadleaf forest	brush, meadow, or no vegetation
Types of bamboo	arrow bamboo and umbrella bamboo	arrow bamboo and umbrella bamboo	other bamboo species	no bamboo

source consumption, and human demography; and (3) economic activities and resource-use patterns. In some cases, only the heads of households were available for interviews; in other cases, we were able to survey household heads and other family members. Attitudes and perceptions were analyzed on the basis of individuals, whereas other data (e.g., fuelwood consumption) were examined with households as the unit of analysis. Additional data on economic activities from the two township governments and the Wolong Administration Bureau were also obtained.

Forest

The reserve contains several forest types along elevation gradients (Schaller et al. 1985): evergreen forests, mixed evergreen and deciduous broadleaf forests, mixed conifer and deciduous broadleaf forests, and conifer forests. We gathered information about the spatial distribution of different forest cover types and forest management history from the Wolong Administration Bureau. We digitized aerial maps of vegetation cover types and integrated them with historical data (e.g., forest harvest practices) into a geographic information system (Ouyang et al. 1995).

To measure forest structure and tree volume, we sampled 19 plots (20 × 25 m each) selected randomly within the panda habitat range. Smaller subplots inside a 20 × 25 m plot were selected for sampling shrubs (5 × 5 m, three in each plot) and herbaceous plants (1 × 1 m, five in each plot). In each sampling plot or subplot, we recorded canopy closure, species, and size of all vegetation (trees, shrubs, bamboo, herbaceous plants, mosses, etc.).

Panda Habitat

Panda habitat is the area that provides food and cover for daily activities and reproduction. Suitability of panda habitat depends on abiotic and biotic conditions (Table 1), as well as the degree of human impacts (Table 2). Slope and elevation are two major abiotic factors. Pandas prefer flat areas or gentle slopes for ease of movement. Elevation in the reserve ranges from 1200 m to 6250 m (Schaller et al. 1985). Pandas cannot tolerate the low temperatures and inadequate food and vegetative cover at an extremely high elevation. Important biotic factors in panda habitat include bamboo and vegetation cover types. In Wolong, giant pandas feed on two major bamboo species: arrow (*Bashania fangiana*) and umbrella (*Fargesia rebusta*). Conifer forests as well as mixed co-

Table 2. Assessment of the effects of human factors on giant panda habitat.

	Degree of effect			
Factor	*strong*	*moderate*	*weak*	*none*
Time from timber harvest or fuelwood collection (years)	≤20	>20–≤50	>50–≤80	>80 or primary forest
Distance from main road (m)	≤60	>61–≤210	>210–≤720	>720
Distance from small road (m)	n/a	n/a	≤30	>30
Distance from residential area (m)	≤900	>900–≤1410	>1410–≤1920	>1920
Distance from cropland (m)	≤90	>90–≤240	>240–≤750	>750
Distance from area of timber harvesting and fuelwood collection (m)	≤30	>30–≤60	n/a	>60
Location of herbal collection (elevation, m)	n/a	n/a	>1750–≤3600	n/a

nifer and broadleaf forests provide the most suitable cover types for giant pandas (Schaller et al. 1985).

We analyzed the suitability of the giant panda habitat by assessing abiotic and biotic factors and the effects of human factors on habitat.

We carried out the spatial analysis of panda habitat according to the degrees of habitat suitability and human impact (Table 1) using EPPL7, a geographic information system (Minnesota Department of Natural Resources 1992). We represented the environmental heterogeneity of the reserve with a grid of cells. Each cell was 900 m^2 in size (30 × 30 m, the same resolution as thematic mapper imagery). We divided giant panda habitat suitability for each environmental factor into four categories: highly suitable, suitable, marginally suitable, and unsuitable (Table 1). The classification was based on surveys of panda distribution and previous studies of panda requirements for reproduction, feeding, and cover (e.g., Schaller et al. 1985).

Potential habitat would degrade in quality and potentially decrease in quantity under human influences, which were divided into four categories: strong, moderate, weak, and no effect (Table 2). When estimating the effects of timber harvesting and fuelwood collection on panda habitat, we converted the amount of timber and fuelwood consumed into the area of timber harvesting and fuelwood collection according to our field measurement of wood volume per unit area. Our field observations indicated that after timber harvesting and fuelwood collection, vegetation in the affected area took about 80 years to recover. We assumed that an affected area exhibited strong effects for 20 years after timber harvesting or fuelwood collection, moderate effects between 20 and 50 years, weak effects between 50 and 80 years, and no effects after 80 years. The assumption was based on the extent of recovery found in our field studies which included data on bamboo biomass, average tree diameter at breast height (dbh), maximum dbh, and tree height. For example, areas in early stages of secondary succession had only small trees (poor cover for pandas). Some of these areas had no or little bamboo, whereas the remaining areas had bamboo and brushes that were too dense for pandas to move into. On average, bamboo biomass, tree height, average tree dbh, and maximum tree dbh in areas logged 30 years ago were two-thirds, one-half, one-third, and one-fifth of those in nonlogged areas, respectively. Because timber harvesting and fuelwood collection often cause damage to nearby forests, we also assumed that such activities affected an adjacent region of 60 m (width of two grid cells) according to the average height of felled trees and the average extent of influencing zones when the felled trees were taken out of the forest. For the effects of roads, residential areas, and agriculture (Table 2), we assumed that they decreased with the distance from human activity zones (Table 2) because the frequency and intensity of human activities decreased with distance. Our assumptions were estimations; more rigorous and extensive studies (field observations and remote sensing data analysis) are underway to obtain a more accurate assessment. By incorporating human effects into potential habitat estimations, we obtained the realized habitat for the giant pandas (Table 3). For example, highly suitable, suitable, or marginally suitable habitats became unsuitable under strong human influence (Table 3).

Policy Scenarios

In addition to understanding how human activities changed giant panda habitat in the past, we were also interested in projecting how panda habitat would change under various policy scenarios related to human population, household, and resource consumption. To evaluate the long-term effects of different policies on panda habitat (Table 4), we used systems modeling. First, we projected how human population would change by extending a deterministic demographic model developed by Song and Yu (1988) so that emigration of specific age groups could be simulated. The output of the modified demographic model fit well with an independent set of Wolong population data from 1982 to 1990. We repeated the process at 50-year intervals to simulate 50 years into the future. Along with the effects from human activities, we incorporated the results of the systems modeling into realized giant panda habitat (Table 3).

We considered six policy scenarios that differed in the value of one or more of three possible factors related to human population (birth rate, emigration rate, and family size) and fuelwood consumption (Table 4). We assumed that the values of all other factors (e.g., immigration rate and death rate) remained the same as those in 1996 for all simulations. The six scenarios and the rationales behind them follow.

Scenario 1. The first is the status-quo scenario in which all human population growth, household, and

Table 3. Realized giant panda habitat resulting from a combination of potential habitat[a] and human effects on habitat.[b]

Quality of potential giant panda habitat	*Human effect*			
	strong	*moderate*	*weak*	*none*
Highly suitable	unsuitable	marginally suitable	suitable	highly suitable
Suitable	unsuitable	marginally suitable	marginally suitable	suitable
Marginally suitable	unsuitable	unsuitable	marginally suitable	marginally suitable
Unsuitable	unsuitable	unsuitable	unsuitable	unsuitable

[a] *Based on biotic and abiotic habitat characteristics (Table 1).*
[b] *Table 2.*

Table 4. Policy scenarios and their effects on human population and panda habitat.

	Scenario parameters				Effects				
					Human population in year 2047[a]			Panda habitat in year 2047[b]	
Scenario number	birth rate (children woman)	annual emigration rate (%)	family size (persons/ household)	annual fuelwood consumption (m^3/household)	size (persons)	change rate (%)	Number of emigrants (1997–2047)	amount (ha)	rate of change (%)
1	2.5	0.5[c]	4.86	10.86	5960	+37.55	1370	36484	−36.66
2	2.5	0.5[c]	4.86	0[d]	5960	+37.55	1370	40212	−30.18
3	2.5	0.5[c]	4.0	0[d]	5960	+37.55	1370	39961	−30.61
4	2.5	3.0[c]	4.0	0[d]	1671	−61.44	4553	61557	+6.43
5	1.5	3.0[c]	4.0	0[d]	1019	−76.48	3831	61791	+7.28
6	2.5	22[e]	4.0	0[d]	762	−82.41	2189	61839	+7.36

[a]*Human population at the beginning of simulation, 4333.*
[b]*Giant panda habitat at the beginning of simulation, 57,597 ha.*
[c]*Emigration rate of local people across all age groups (household emigration).*
[d]*Reduction from 10.86 m^3/household/year to 0 in 5 years.*
[e]*Emigration rate of local people 17–25 years old only (youth emigration).*

fuelwood consumption parameters were equal to their values in 1996 and remained the same in all simulations.

Scenario 2. Our surveys showed that per capita consumption of fuelwood had a negative relationship with household size. In other words, small households caused more fuelwood consumption per capita than large households. Total amount of fuelwood consumption in the reserve has been rapidly increasing due to an increase in total population size and an increase in the number of smaller households. Our surveys indicated that local residents would prefer to use electricity because of the difficulty in collecting fuelwood in the mountains. If the price were affordable and if a sufficient amount of electricity were provided to local residents, fuelwood could be replaced by electricity. Therefore, for Scenario 2 and all subsequent scenarios, we phased out fuelwood consumption over a 5-year period and assumed that the conditions for replacing fuelwood with electricity were met.

Scenario 3. A traditional Chinese household consists of several generations (usually grandparents, parents, children, and grandchildren). Our socioeconomic surveys found that many young people in Wolong now prefer to live separately from their parents and grandparents after they are married. This kind of social change would further reduce household size. To reflect the reduction in household size, we limited average family size to four persons per household in scenarios 3–6.

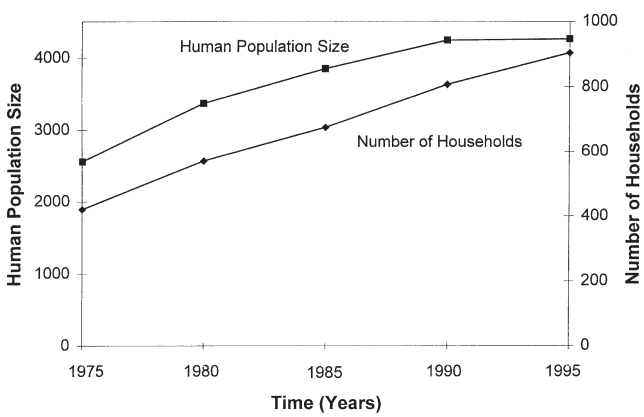


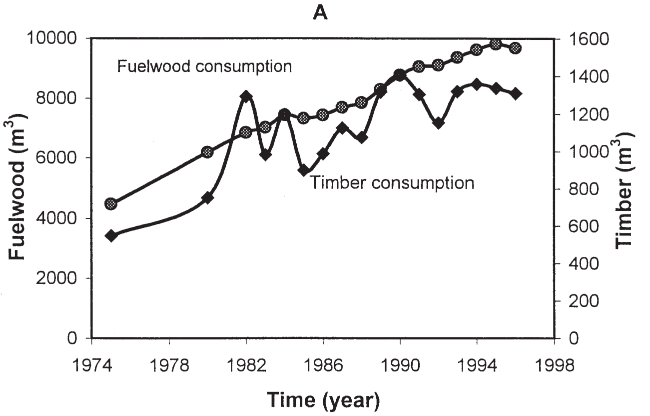
Figure 2. Human population and household dynamics in Wolong Nature Reserve, 1975–1996.

Scenarios 4–6. To reduce human population size in the reserve, birth rates and emigration rates are the most important feasible policy variables to alter because immigration has already been under strict government control. In the 1980s and early 1990s the government attempted to move entire households out of the reserve or core area of the reserve, but this approach had limited success (Wolong Department of Agriculture 1986–1994). For example, in the early 1980s the World Food Program and the Chinese government built a large apartment complex in an area where panda habitat would be minimally affected. Even though the apartment complex is within the reserve, no local residents relocated to occupy the apartments due to a lack of nearby farmland.

Our surveys indicated that many young people (17–25 years old) would settle outside the reserve because they want to attend college or find jobs in cities. To evaluate the effects of emigration, we designed three policy scenarios (Table 4): scenario 4 increased household emigration by relocating all household members; scenario 5 increased household emigration and decreased birth rate; and scenario 6 increased youth emigration by relocating only those 17–25 years old. The chosen emigration rates in scenarios 4–6 allowed for the same numbers of emigrants at the beginning of simulations.

Results

Human population size has increased by 66.41% and the number of households has increased by 114.73% in the Wolong Nature Reserve since 1975 (Fig. 2). Starting



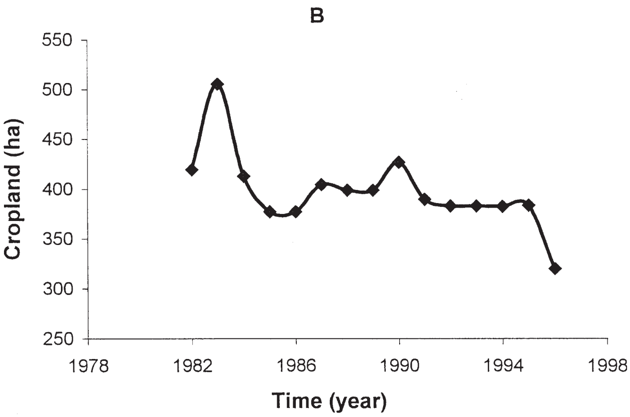


Figure 3. Dynamics of (a) timber and fuelwood consumption in 1975–1996 and (b) cropland in 1982–1996.

in 1990, the rate of population growth was lowered, but the number of households continued to increase rapidly.

Fuelwood consumption in the reserve continued to increase, doubling over the past two decades (Fig. 3a), whereas annual timber consumption increased dramatically in the early 1980s and then fluctuated around the 1982 level (Fig. 3a). Fuelwood consumption was about seven times higher than timber consumption in 1996. The area for planting crops was about 400 ha annually, although it fluctuated somewhat, with a high peak in 1983 (Fig. 3b).

About 41% of the reserve would be highly suitable, suitable, or marginally suitable to giant pandas (Fig. 4a) on the basis of abiotic and biotic conditions. When human influences were considered, giant panda habitat shrank significantly and became highly fragmented, and the quality of panda habitat in many areas became degraded (Fig. 4b). Approximately 17,000 ha (21%) of panda habitat was lost to human activities before 1975. The major change took place in the northeast section of the reserve and along a main road from the northeast to the southwest (Fig. 4). During the two decades after the reserve was established, the amount of giant panda habitat was further reduced by about approximately 8% (from about 62,369 ha to 57,597 ha; Fig. 5).

Under the status quo scenario (scenario 1), human population in the reserve would increase by 38% and giant panda habitat would decrease by 21,113 ha (37%) by the end of the next 50 years (Table 4). Compared to the status quo, eliminating fuelwood consumption in 5 years (scenario 2) would save 3728 ha of habitat. Limiting average household size to 4.0 persons and eliminating fuelwood collection (scenario 3), however, saved less habitat

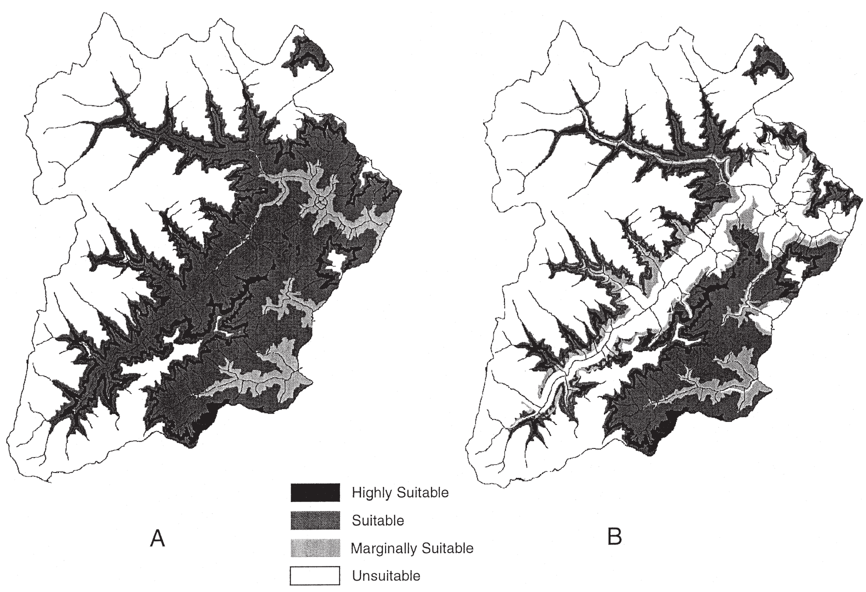


Figure 4. (a) Potential panda habitat and (b) realized habitat in 1996.

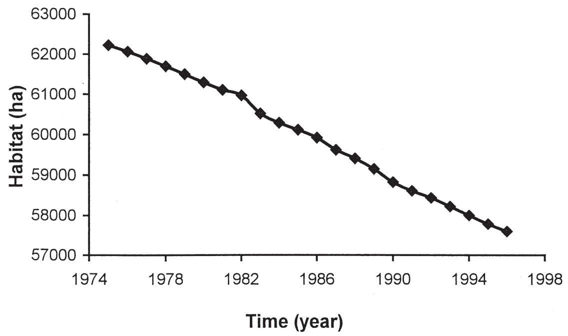


Figure 5. Panda habitat loss between 1975 and 1996.

because of higher per-capita consumption of fuelwood in small households during the initial 5 simulated years and because more land and timber would be needed for constructing houses for new households.

Reducing birth rates and/or increasing emigration rates would lower population size. A five-fold increase in the household emigration rate would reduce population size by 61% (scenario 4). Increasing the household emigration rate and lowering the birth rate simultaneously could reduce human population by 76% (scenario 5). Twenty-two percent of youth-only emigration (17–25 years old only) would lower human population size by 82% (scenario 6), indicating that youth emigration alone would be more effective in reducing population size than increasing household emigration by itself or in conjunction with lowering birth rates. Furthermore, the cumulative number of emigrants under youth-only emigration was less than half that of household emigration (scenario 6 vs. scenario 4, Table 4). Under scenarios with lower birth rates and higher emigration rates, panda habitat would gradually recover and exceed the amount in 1997 by approximately 7% after 50 years. Youth-only emigration would restore more giant panda habitat than household emigration (Table 4).

Discussion

Giant panda habitat in the Wolong Nature Reserve was significantly lost or degraded as a result of increasing human population and activities since 1975, when the reserve was established at its current size. Human population increased largely due to the high birth rates in the reserve. The number of households increased because of an increase in total population and a decrease in household size (the average household size decreased from 6.21 persons in 1975 to 4.86 persons in 1996). If the household size had been held constant, there would have been only 689 households in 1996 (total population in 1996 divided by the household size in 1975), but in fact there were 892 households in 1996. The disproportionate increase in the number of households has been caused mainly by changes in family structure, with more young people preferring to live separately from their parents and grandparents after they are married.

As long as the human population continues to grow and fuelwood remains a major means of energy for cooking and heating in the reserve, the amount of panda habitat will continue to decrease and habitat quality will continue to decline. Reducing the human population and eliminating fuelwood consumption would restore some of the previously lost or degraded panda habitat in the reserve. In our simulations we considered only natural recovery processes and did not take restoration efforts (e.g., bamboo plantations) into account.

In the 50-year simulations, we focused on the amount of panda habitat but did not consider the effects of habitat fragmentation (Harris 1984) or exact locations of forest destruction. In this sense, our estimate of human effects on panda habitat might be conservative because habitat suitability depends on the spatial arrangement of habitats and surrounding conditions (Liu et al. 1994, 1995; Forman 1995). Also, as in many other nature reserves around the world (e.g., Munasinghe & McNeely 1994), tourism is a major human activity in Wolong. Every year, thousands of tourists from all over the world visit Wolong to see the giant pandas in the breeding facility, view scenic sites, and watch birds. We did not explicitly analyze the effects of tourists because such data were not available and cause-and-effect linkages between tourism activities and their effects on panda habitat have yet to be scientifically established. Furthermore, errors in evaluation of habitats and of human effects on habitats may exist in our case study because some of our assumptions regarding panda habitat suitability and human effects need to be refined using more empirical data. In this sense, our study so far can be regarded as a "rapid assessment." We are currently conducting more in-depth studies on panda habitats under human influences in the Wolong reserve. It is necessary, however, to conduct rapid assessments of panda habitats and human effects in the 25 panda reserves because shortages of human and financial resources make it impossible to do in-depth research on each and every panda reserve. Our modeling approach provides a good basis for comparing the discrepancies between in-depth case studies and rapid assessments. Once the accuracy of detailed and rapid studies in the Wolong reserve is assessed, the discrepancies can be taken into consideration when habitat conditions and human effects are evaluated in other locations.

In the past, emigration practices in Wolong focused on full households where all members in a household, regardless of age, would be moved out of the reserve. Moving older people out of the reserve, however, was costly and socially difficult (Wolong Department of Agriculture 1986–1994). Our simulation results show that

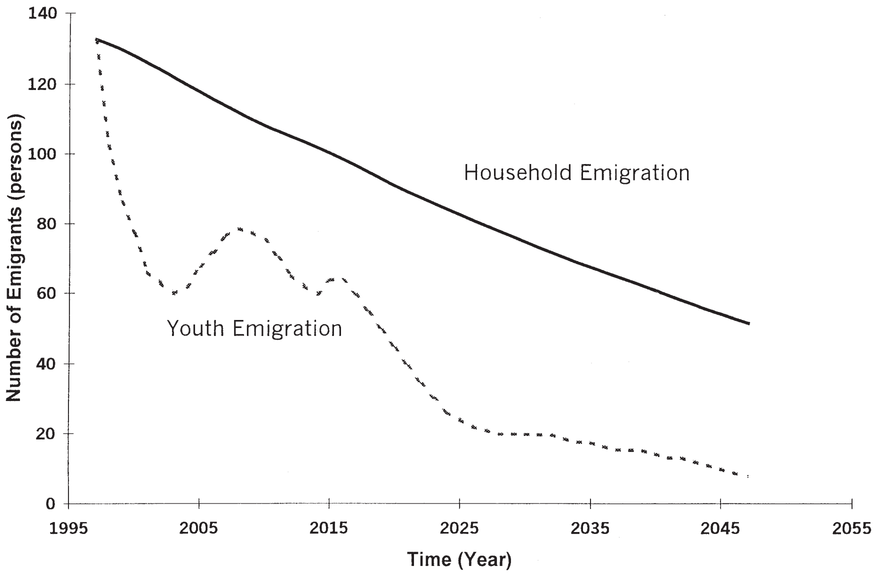


Figure 6. Simulated dynamics of emigrants under household emigration and under youth-only emigration from 1997 to 2047.

youth-only emigration would more effectively reduce total human population and human effects on panda habitat than would household emigration (Table 4). At the beginning of the simulations, the numbers of emigrants were the same under household emigration and under youth emigration, but as the simulation progressed (up to 50 years), household emigration always involved a much larger number of emigrants than youth emigration (Fig. 6). In other words, under youth-only emigration, the number of emigrants was lower although the percentage of young people moving out of the reserve was higher than that under household emigration because young emigrants would establish families outside the reserve and thus reduce the total births in the reserve. Because youth-only emigration relocates people who are entering or in their prime child-bearing years, from the long-term point of view moving one young person out of the reserve is equivalent to emigrating a number of people from other age groups; however, relocating an older person with lower or no reproductive potential does not have such lasting effects.

Higher numbers of emigrants would require higher compensation costs, implying that household emigration would be less economically desirable than youth emigration. Furthermore, our survey results indicated that young people were more willing to move out of the reserve, especially if they could receive higher education elsewhere. Providing more high-quality educational opportunities to the children of local residents would help local youth go to college and thus increase the emigration rates of younger groups. Although old people are not willing to relocate themselves, parents and grandparents take great pride in their children and grandchildren going to college. Thus, youth emigration has strong family support. Our socioeconomic surveys also indicated that a higher quality of life and nonfarming job opportunities in the reserve might discourage some young people from moving out of the reserve because those young people and their parents might be satisfied with local life. Nevertheless, even moving as few as 22% of young people out of the reserve would lower population size by 82% at year 2047 (Table 4). Thus, the youth emigration approach exhibits promising potential to lower human population size in the reserve and reduce human effects on panda habitat.

The conceptual framework proposed in our study provides an integrated approach to addressing human effects on wildlife habitat change. It is much more comprehensive than traditional population-environment frameworks (e.g., Holdren & Ehrlich 1974; Zaba & Clarke 1994; Clarke & Tabah 1995) or population-biodiversity frameworks (Ehrlich 1988; Dompka 1996), which focused mainly on the effects of human population size. As demonstrated in our study, human population size was just one of the many human factors that affected panda habitat. In this sense, population-environment and population-biodiversity studies should be expanded to include other human factors, such as human perceptions, attitudes, and activities of different age groups.

Understanding the underlying mechanisms and interrelationships of various human activities is critical to designing and implementing feasible policies for balancing human needs and wildlife conservation. It is also necessary to project the long-term consequences of human factors so that decision-makers can choose desirable management alternatives for achieving both ecological and socioeconomic goals. Our conceptual framework and systems approach provide a good foundation for more comprehensive studies on the effects of humans, including the interactive effects of different human factors, in Wolong and other nature reserves or protected areas around the world that face similar challenges of balancing development and conservation (Heinen & Kattel 1992; Dompka 1996; Batisse 1997).

Acknowledgments

We thank C. Chung, C. Lentz, C. Lepczyk, D. Rutledge, and J. Xie for their assistance in preparing this paper. We are grateful to L. Hunter, E. Main, G. Meffe, R. Muth, G. Schaller, and two anonymous reviewers for their helpful comments and suggestions on an earlier version of this paper. We also thank the logistic support of the Wolong Nature Reserve and field assistance from J. Huang, H. Xiao, J. Yang, Z. Yang, and S. Zhou. We gratefully acknowledge financial support from the National Science Foundation (CAREER Award, formerly Presidential Young Investigator Award), American Association for Advancement of Sciences/The John D. and Katherine T. MacArthur Foundation, Michigan State University (All-University Research Initiation Grant, Global Competence Fund, Institute for International Agriculture), the National Natural Science Foundation of China, the Chinese Academy of Sciences, and China Bridges International (North America).

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