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BALANCING HUMAN ENERGY NEEDS AND
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By

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ABSTRACT

BALANCING HUMAN ENERGY NEEDS AND CONSERVATION OF PANDA HABITAT

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Resource extractive activities to meet the basic needs of humans have been the leading causes of habitat degradation and thus biodiversity loss. Complex human-nature interactions make it difficult to understand the impacts of human activities on wildlife habitat and to develop effective solutions for balancing human needs and wildlife conservation. Integrated with modern computer technology and systems modeling and simulation, decision support systems (DSSs) can ease this challenge. Such systems can provide a platform for a variety of stakeholders such as conservation scientists, policy analysts, and decision makers, to quantitatively and visually construct, analyze, and evaluate different solution options.

To demonstrate the functionality of such systems, a WebGIS-based DSS named WOW (Wolong Online WebGIS) has been developed. It was applied to Wolong Nature Reserve for giant pandas (*Ailuropoda melanoleuca*) in southwestern China. The WOW enables various geographically dispersed stakeholders to simulate long-term spatial and temporal dynamics of human population, human energy needs (fuelwood), human activities (fuelwood collection and consumption), and thus the impacts of these activities on panda habitat. This system incorporated the results from an analysis of the spatial and temporal trends of fuelwood collection in the past three decades in the 20th century. It also considers the effects of two conservation policies (Natural Forest Conservation

Program [NFCP] and Grain to Green Program [GTGP] implemented since 2000) on fuelwood consumption of rural households in the reserve.

As fuelwood is a key issue of natural resource conflict between people and pandas, one model was incorporated into the system to demonstrate the feasibility of thinning plantation forests for fuelwood. It showed that forest plantations in the reserve could sustainably provide rural households with enough fuelwood, if deliberate forest thinning plans and conservation policy regulation were applied. Furthermore, a multi-criteria decision making component was developed for stakeholders to synthesize and compare scenarios or solution options. Since the system was made public, 36 of 76 registered users evaluated four predefined scenarios. The preferred scenario is to thin plantation forests for fuelwood. Thus, we encourage reserve managers to consider this idea and incorporate it with the on-going conservation programs such as the NFCP and GTGP as soon as possible.

This dissertation made a novel effort to integrate traditional DSS technology and systems modeling with spatial analyses functionality, a key component of the issue under investigation in a web-based interactive system, which helps stakeholders search for options balancing household energy needs and panda conservation. Besides the practical implications of the results directly for balancing human (energy) needs and panda conservation in the reserve studied, this dissertation has broad methodological applications in developing Web-based decision analysis tools, assisting decision making processes, and integrating multiple sources of data and multiple-disciplines for many of other 2,531 natural reserves in China and many other coupled human-nature systems worldwide.

To people who have sacrificed

and are willing to sacrifice their own well-being

for the survival of Giant Pandas

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I wish that my work deserves a “WOW” when one looks at it.

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CHAPTER 1

INTRODUCTION

Energy is critical to meet the basic needs of human beings. Fuelwood collected in natural forests and other ecosystems is one of the major energy sources for numerous households worldwide, especially those in developing countries. Approximately three billion people, half of the world's population, are still using fuelwood for food preparation, space heating, and other basic human needs in their daily lives (Population Action International, 1999). However, as human populations and household numbers are rapidly increasing (Liu et al., 2003), fuelwood collection, together with other human activities, has led to reduction of various ecosystem services (Leach and Mearns, 1988; Vitousek et al., 1997; Liu et al., 2001a; Millennium Ecosystem Assessment, 2005). For example, fuelwood collection through cutting down trees can lead to fragmentation and degradation of wildlife habitat (Liu et al., 2001b), reduction of wildlife populations (Aigner et al., 1998; Hall and Farrell, 2001), and loss of biodiversity (Bhatt et al., 1994; Rosenstock, 1998; Bhatt and Sachan, 2004; Sagar and Singh, 2004). Such degradation and loss of ecosystem services due to these activities may eventually diminish the welfare of human beings themselves (Daily, 1997) and jeopardize the sustainable development of human society in the long term (Millennium Ecosystem Assessment, 2005; Daily and Matson, 2008). It is a challenge for stakeholders, such as research scientists, policy analysts, and decision makers to balance human energy needs and wildlife conservation and address both the needs of humans and wildlife.

Many efforts have been practiced to overcome this challenge in the past. For example, from the demand side of fuelwood, improved cook-stoves were promoted in India and Ethiopia (Prasad et al., 2001; Amacher et al., 2004); agroforestry systems for mitigating the problems of fuelwood scarcity in the Montane/Savanna ecosystems were advocated in Nigeria (Bisong et al., 2007), various renewable energy sources and technologies such as biogas, and small hydropower and solar energy were discussed in China, India, Nepal, and Pakistan (Rijal, 1999; Prasad et al., 2001; Li et al., 2005). Previously scholars have focused extensively on fuel characteristics (Vodak et al., 1986; Nygard and Elfving, 2000; Shanavas and Kumar, 2003; Nygard et al., 2004), resource availability and diversity (Samant et al., 2000), consumption pattern (Bhatt et al., 1994; An et al., 2001; Mandondo, 2001; Tabuti et al., 2003; Top et al., 2004), and fuelwood management (Chomitz and Griffiths, 2001), which are essential in understanding the conflicts between human energy needs and wildlife conservation. Far fewer studies have focused on estimating supply than demand of fuelwood. Less local biomass availability decreases the probability of collecting fuelwood from common forests and increases the probability of producing fuelwood on private land in Indonesia and Vietnam (Linde-Rahr, 2003; Pattanayak et al., 2004). A recent review of the state of economic understanding about fuelwood in developing countries concludes that community forestry has the potential to address the gaps between household energy needs and fuelwood scarcity (Cooke et al., 2008). Some of those studies investigated the factors affecting fuelwood need while some focused on the variables controlling fuelwood supply in order to tackle fuelwood scarcity and reduce the negative impacts on wildlife habitat without significant sacrifice of human welfares. However, none of them had integratively considered both supply and demand sides of fuelwood consumption at the household level (although household is the basic unit of fuelwood consumption and collection) to balance human energy needs and their ecological, social and economic impacts on wildlife conservation.

The difficulty of finding a balanced solution lies primarily in the complexity of social-economic-ecological systems (Liu et al., 2007a; Liu et al., 2007b) in which humans and wildlife compete for natural resources through human activities such as fuelwood collection. To find a sustainable solution of both meeting household energy needs and minimizing the impacts on wildlife habitat, the following questions have to be simultaneously answered. What social-economic conditions determine fuelwood consumption of households? Where do households collect fuelwood and what are their impacts on wildlife habitat across space and time? How do households respond to policy interventions in terms of fuelwood collection and consumption behaviors? Are there any fuelwood source alternatives? What are the social, economic, and ecological impacts of alternative solutions (e.g., thinning plantation forests as a fuelwood source alternative) on human communities and wildlife habitat? Are there any user-friendly computer tools to assist stakeholders answer those questions and facilitate decision making processes?

No previous efforts have been made to address the aforementioned questions in a comprehensive fashion. A particularly well-suited site to address those questions is Wolong Nature Reserve, China, which was designated for conserving the endangered giant panda (*Ailuropoda melanoleuca*) (He et al., 1996) and where fuelwood collection by rural households has been a direct and important threat to panda habitat in the past decades (An et al., 2001; Liu et al., 2001b). The reserve, one of the largest panda reserves in China, is home to roughly 150 wild pandas (approximately 10% of the wild population) (State Forestry Administration, 2005). The pandas depend on the forests for shelter and understory bamboo for staple food (Schaller et al., 1985). The species is solitary but could not be alone, pushed into the high mountains and often disturbed by humans inhabiting the lower and flat bottomland. There are more than 4,500 local residents distributed in approximately 1,250 households in 2005 (Wolong Nature Reserve, 2005a). The majority of them are farmers, living a subsistence farming lifestyle. They have traditionally collected fuelwood from natural forests near their homes for a long time. Fuelwood is used by rural households for three purposes: cooking food for humans, cooking livestock fodder, and heating houses in winter (An et al., 2002; Wolong Nature Reserve, 2005a). From 1975 to 1998, the human population and the number of households increased by 69% and 124%, respectively, while fuelwood consumption in the reserve has doubled over the past two decades, consequently resulting in dramatic habitat degradation (Liu et al., 1999a; Liu et al., 2001a).

Meanwhile, the Chinese government has been implementing some conservation policies in order to directly change social and economic behaviors of humans (e.g., fuelwood and electricity consumption) and indirectly protect panda habitats and populations (Wolong Nature Reserve, 1998a; Sichuan Forestry Survey Institute and Wolong Nature Reserve, 2000a; Wolong Nature Reserve, 2005a). Some examples since 2000 are Grain-to-Green program (GTGP, which provides subsidies to farmers with grain and cash if they convert their cropland to forested land), Natural Forest Conservation Program (NFCP) provides subsidies to households for monitoring one or several forest parcels from illegal harvesting, and hydro-power plants (which provide electricity to local residents and help them to eliminate fuelwood use) (Wolong Nature Reserve, 2005a; Vina et al., 2007; Liu et al., 2008a). Due to GTGP, more than half of cropland of households has been converted into forested land. Almost all households participated in NFCP and are responsible for monitoring 37.5% of forests in the reserve to prevent illegal logging (the reserve staff monitor the remaining portion of forests) (Sichuan Forestry Survey Institute and Wolong Nature Reserve, 2000a). Under these programs, fuelwood collection has been explicitly forbidden. In the beginning of these programs (2000 – 2003) few illegal harvesting or branches collection were seen, partially because many households still had remaining fuelwood from previous years. As a result, it was also observed that 60~80% of the energy need for cooking human food and about 30~40% for heating houses in winter were switched from fuelwood to electricity. Since 2004, as the remaining fuelwood was used dead tree branches gathering has been seen and even allowed officially permitted (Chen et al, in review). When NFCP/GTGP programs officially stop, it is likely that rural households would return to their earlier practice of cutting natural forests for fuelwood (Uchida et al., 2005). Therefore, a sustainable fuelwood source is urgently needed in the long term to meet the energy needs of rural households and reduce the impact of fuelwood collection on panda habitat.

A number of studies on human energy consumption and panda habitat have been conducted in Wolong Nature Reserve. Some of them answered one or two questions aforementioned and none of them provided a decision analysis component for stakeholders. Using Stella 5.0 (a commercial modeling tool) and field data from household surveys conducted in 1998, An et al. (2001) developed a model to describe the dynamics of human population and households and then predict the fuelwood consumption of rural households for the three consumption purposes. They found that fuelwood consumption was the functions of the socio-economic conditions of households such as household size, with or without one or more senior members, and cropland for corn plantations. Using SELES (a high level programming language) Linderman et al. (2005) estimated the impacts of various levels of fuelwood consumption and household creation rates on the landscape characteristics of panda habitat for 1997-2030. An agent-based model was developed for Wolong Nature Reserve to explore the complexity of coupled human-nature systems (An et al., 2005). Similar to the study by Linderman et al. (2005), this work also focused on the ecological impacts of demographic factors of households on panda habitat. These models did not consider the impacts of conservation policies on fuelwood consumption and collection behaviors. Economic impacts of different scenarios in these models were not considered. Several researchers have proposed to use plantation forests for human needs (Ronnback et al., 2007; Bearer et al., 2008). For example, Bearer (2005) has studied the potential of harvesting plantation stands varied by age for three levels of fuelwood consumption of an average household and then predicted the amount of natural forests that could be saved. But he did not consider the dynamics of human population and households and did not measure the spatial and temporal impacts of fuelwood collection on panda habitat.

Another common characteristic of these studies is lack of a decision making component for stakeholders to construct, simulate and evaluate the social, economic, and ecological impacts of simulated scenarios. Traditionally, decision support systems (DSSs) have been widely prescribed as an analysis tool (Carlsson and Turban, 2002; Engel et al., 2003; Phua and Minowa, 2005; Rauscher et al., 2005). However, those systems are little accessible to stakeholders, primarily because of complicated user interfaces targeting mainly professionals/experts (Tang et al., 2004; Mysiak et al., 2005; Paassen et al., 2007), high costs to deploy usually due to expensive specialized software (Kearns et al., 2003; Adinarayana et al., 2006; Paassen et al., 2007), lower degree of reuse and share of data and knowledge (Poch et al., 2004; Wong et al., 2007), and without persistence storage of simulation results and decision options allowing re-access of users. The recent advancement in internet technology makes a web-based DSS possible, which may address most of the disadvantages of the traditional desktop-based DSSs.

Based on several previous studies on household population dynamics (Liu et al., 1999c; An et al., 2001), fuelwood consumption by households (2001), and habitat impact assessment , this dissertation aimed to analyze fuelwood collection practices of households, study the effects of the implementation of conservation policies on fuelwood consumption, and build a web-based decision support system to assist decision makers simulating the economic, ecological, and social impacts of policy scenarios of balancing household energy consumption and panda conservation in their natural habitat. There are four chapters in my dissertation besides this Introduction chapter and a brief chapter of Synthesis and Conclusions. Chapter two analyzes the temporal and spatial patterns of fuelwood collection in the last three decades (1970s, 1980s, and 1990s) of the 20th century in Wolong Nature Reserve using household survey data collected in 2002. These findings were then incorporated into Chapter four to predict the locations of fuelwood collection. In Chapter three, the impacts of NFCP and GTGP programs on the three purposes of fuelwood consumption of rural households were investigated. The results were used in Chapter four to adjust the fuelwood consumption models developed by An et al. (2001)

Chapter four describes the system design of a web-based DSS called **W**olong **O**nline **W**ebGIS (**WOW**), which targets stakeholders such as research scientists, policy analysts and decision makers to simulate the dynamics of rural human population inside the reserve, household fuelwood demand, the spatial distribution of fuelwood collection, the economic impacts of reducing fuelwood collection on households, and the ecological impacts of fuelwood collection on panda habitat. In WOW, I also created a multi-criteria decision making tool, which allows stakeholders to integratively assess ecological, economic, and social impacts and to compare and choose the balanced scenarios which enable trade-offs between panda habitat conservation and human energy needs.

Chapter five illustrates an application of the system to search for a sustainable natural resource use schema that balances household fuelwood need and panda conservation in the reserve. Because the primary resource conflict between people and pandas takes place in the forests of the reserve, I used the WOW to explore possible strategies for achieving this balance. As such, the system helped me to develop a proposal to thin plantation forests for fuelwood in the afforested areas under GTGP and other existing reforested areas that previously experienced timber harvesting. Simulations with a length of 30 years from 1997 to 2026 using WOW were conducted to evaluate this feasibility. Three consumption options (more fuelwood, status quo, and less fuelwood) each defined by the switch rates from the three fuelwood consumption purposes to electricity were considered. Fuelwood production under different thinning scenarios (e.g., start time, cycle, and intensity) against these three consumption options was simulated and the extents of reducing the impacts of fuelwood collection on panda habitat were evaluated.

The multidisciplinary study incorporates ecology, wildlife biology, human demography, systems simulation and modeling, and web-based DSS for wildlife conservation decision making which balances household energy needs and panda conservation. The resulting WOW could serve as a communicational tool for stakeholders because it enables users to view scenarios proposed by others and as an educational tool since it helps understand the complexity of coupled human-nature systems. Thus, the decision making process would be more open and democratic, which may increase the efficiency of decision making and help facilitate the implementation of future policies. The system could facilitate a more comprehensive understanding of complex issues, accelerate knowledge dissemination, increase conservation awareness of the general public, and search for sustainable natural resource uses. The methodology developed in this dissertation has broad applications in searching for solutions balancing human needs and wildlife habitat conservation in tightly coupled human-nature systems.

CHAPTER 2

SPATIAL AND TEMPORAL PATTERNS OF FUELWOOD COLLECTION IN WOLONG NATURE RESERVE: IMPLICATIONS FOR PANDA CONSERVATION

ABSTRACT

Approximately three billion people, half of the world's population, are still using fuelwood in their daily lives. Fuelwood collection has been recognized as an important factor in habitat fragmentation and degradation and biodiversity loss, especially in developing countries. Understanding spatial and temporal patterns of fuelwood collection is fundamental to understanding human-environment interactions and designing effective conservation policies. Using Wolong Nature Reserve for giant pandas (*Ailuropoda melanoleuca*) in China as an example, my research group surveyed 200 rural households for the locations of their fuelwood collection sites in the past three decades (1970s, 1980s, and 1990s) and other ecological, economic, social, and demographic data. We found that fuelwood collection sites were becoming higher in elevation, more remote, and closer to highly suitable panda habitat from the 1970s to the 1990s. Consequently, fuelwood collectors were traveling longer distances to physically challenging areas, in our case, to areas of high-quality panda habitat. These spatial and temporal patterns of fuelwood collection suggest that future conservation policies for giant pandas, and other species worldwide, should also consider the needs of local communities.

KEYWORDS: fuelwood collection, spatiotemporal distribution, conservation policy, panda habitat, Wolong Nature Reserve, China

INTRODUCTION

Approximately three billion people, half of the world's population, are still using fuelwood in their daily lives (Population Action International, 1999). The collection of fuelwood has become important in ecological degradation worldwide, especially in developing countries, where in many rural areas fuelwood is the sole or primary energy source for cooking and heating (Chomitz and Griffiths, 2001; An et al., 2002). Fuelwood collection through cutting down trees can lead to fragmentation and degradation of wildlife habitat (Liu et al., 2001b), reduction of wildlife populations (Aigner et al., 1998; Hall and Farrell, 2001), and loss of biodiversity (Rosenstock, 1998; Sagar and Singh, 2004).

Even many protected areas (e.g., nature reserves) in countries such as China are not exempt from impacts of human activities such as fuelwood collection (Liu et al., 2003). In order to conserve its diverse natural resources for sustainable development, China had established 2,531 nature reserves by the end of 2007, covering more than 15% of its territory (China.com.cn, 2007). However, many of these reserves are located in remote areas with poor economies and high human population pressures, and various types of resource extraction are inevitable. Wolong Nature Reserve, one of the largest reserves for protecting giant pandas (*Ailuropoda melanoleuca*), is a good example. Fuelwood collection is common inside the reserve and fluctuated around 7,000–9,400 m^3/year until recently (Liu et al., 1999c). Bearer et al. (2008) showed that panda activities in forests is reduced for several decades after timber harvesting and fuelwood collection in this reserve. An et al. (2005) found that fuelwood collection could lead up to a 1.23 km^2/year loss of habitat, depending on different scenarios of socioeconomic factors. Considering the distribution of bamboo and its periodic flowering, Linderman et al. (2005) demonstrated that over the next

30 years fuelwood collection would result in the loss of up to 30% of the habitat in the event of bamboo die-offs. If spatial arrangement and configuration of habitat had been incorporated into such an analysis, there would have been much higher impacts, as larger areas have been fragmented from a landscape ecology perspective.

The knowledge of spatial and temporal distribution of fuelwood collection at the landscape level is central to understanding the impacts of fuelwood collection on forests (Franklin et al., 2000; Pinzon et al., 2003) and panda habitat, including understory bamboo in the case of the giant panda (Reid et al., 1991; Taylor and Qin, 1993). It can aid in evaluating habitat suitability where human activities occur and providing insights to make informed conservation decisions (e.g., identifying priority areas for monitoring and altering human activities). Assessing the effectiveness of previously implemented policies related to fuelwood collection (Wolong Nature Reserve, 1998b, 2000b) could also help improve several on-going conservation programs in China (Loucks et al., 2001; Zhu and Feng, 2003; Liu et al., 2008b), including the Natural Forest Conservation Program (NFCP) and the Grain-to-Green Program at Wolong. However, little has been done on gaining such knowledge.

Therefore, this chapter aims to: (1) characterize spatial and temporal distribution patterns of fuelwood collection in Wolong Nature Reserve; (2) analyze the spatial and temporal trends of the impacts of fuelwood collection on panda habitat; (3) discuss some policy implications for panda conservation; and (4) assess the general relevance of the case study for fuelwood collection management in protected areas.

DATA AND METHODS

Study Area

Wolong Nature Reserve was designated in 1975 to help conserve the giant panda (MacKinnon and DeWulf, 1994). It is located in Wenchuan County, Sichuan Province, southwestern China (Latitude 30°45'-31°25'N, Longitude 103°52'-103°24'E) (Figure 2.1 at the end of this chapter). The Wolong Administration Bureau is responsible for both panda conservation and the well-being of local residents (Lü et al., 2003). It reports directly to the Department of Forestry in Sichuan Province and China's State Forestry Administration in Beijing (Wolong Nature Reserve, 2005b).

Approximately 110 giant pandas, representing about 10% of the total wild population, inhabit the reserve (China's Ministry of Forestry and WWF, 1989; Zhang et al., 1997). The vegetation of the reserve includes evergreen broadleaf, deciduous, and sub-alpine coniferous forests, and alpine meadows within an elevation range of 1,250 m to 6,525 m above sea level (Schaller et al., 1985). Forests covered 36.3% of the reserve in 2001 (Vina et al., 2007), less than 1% of the land is for agricultural use, and the remainder is shrubs, meadows, permanent snow, exposed rocks, roads, buildings, and water (Wolong Nature Reserve, 1998b, 2005b). Pandas depend on the forests for cover and shelter and use the understory bamboo (mainly *Bashania fangiana and Fargesia robusta*) as staple food (Schaller et al., 1985). They prefer slopes less than 30°, elevations between 1,500 and 3,250 m, and interior, old-growth forests (Schaller et al., 1985; Bearer et al., 2008). Panda habitat is determined by biotic features (e.g., forests), abiotic features (elevations and slopes), and human activities (e.g., roads) (see Liu et al., 2001b, for details on habitat classification). Approximately 4.4% of the reserve was marginally suitable, 25.6% was moderately suitable, and 5.8% was highly suitable, and the rest was unsuitable for pandas in 2001 (Vina et al., 2007).

Timber harvesting, poaching, and agriculture were the main threats to panda habitat and conservation. Recently, fuelwood collection by local residents has emerged as an important threat. From 1975 to 1998, the human population and the number of households in the reserve increased by 69% and 124%, respectively, while fuelwood consumption in the reserve doubled (Liu et al., 1999b; Liu et al., 1999c). Traditionally, fuelwood is used for cooking food for humans and fodder for livestock, and for heating houses in winter (An et al., 2002). In 2000, there were more than 4,400 local rural residents in 970 households in two townships (Wolong and Gengda, see Figure 2.1 for their locations). Most human settlements were in the bottomland or on the relatively flat slopes of several valleys in the reserve. In rural China, there are three administrative units: groups, villages, and townships. Wolong Township has nine groups in three villages, and Gengda Township has 17 groups in three villages (Wolong Nature Reserve, 2000a). The annual amount of fuelwood consumed by each household ranged from 8 to 30 m^3, depending on household size, age structure, cropland area, and other socioeconomic conditions (An et al., 2001). Moreover, burgeoning tourism development now may be contributing to greater fuelwood collection by local residents, who can increase their cash income by selling local products, such as bacon, which requires fuelwood to cook pig fodder and smoke-dry the pork (He et al., in press).

The household is the basic unit of fuelwood consumption (Liu et al., 1999c), but fuelwood collection is often accomplished in winter by groups of 10–20 adult males each from several households to increase efficiency and minimize risks in the topographically challenging high mountains (Liu et al., 1999c). People usually walk or drive to the foothills close to the collection sites and climb up to those sites. They cut down trees with axes, then carry and slide logs to lower areas close to roads. Finally, logs are carried and loaded into vehicles, and transported home. Later, fuelwood logs are usually split into small pieces and piled near houses.

Local residents usually cut down large trees, partially removing forest canopy (An et al., 2001). Oak (*Cyclobalanopsis Oerst.*), maple (*Acer L.*), birch (*Betula L.*), spruce (*Picea Dietr.*), hemlock (*Tsuga Carr.*), larch (*Larix Mill.*), and pine (*Pinus L.*) are among the preferred tree species for fuelwood. Fuelwood collection changes the species composition in the overstory, thus stimulates denser understory bamboo stands with lower moisture content, and, consequently, discourages pandas from using the affected areas (Reid et al., 1991). Although selective cuts of a few trees for fuelwood at one time by one household may affect only a small area of habitat, collection of fuelwood by multiple households over a long time (e.g., decades) can eventually lead to the loss of a large amount of habitat (Bearer et al., 2008). Fuelwood collection started in the forests close to human settlements along the main road through the reserve but has expanded to other areas and caused a significant reduction in the quality and quantity of panda habitat (Liu et al., 2001b).

Data Collection

We used historical information on fuelwood collection over the past three decades (1970s, 1980s, and 1990s) as well as other ecological, economic, social, and demographic data to examine spatial and temporal patterns of fuelwood collection. One type of data is at the household level, such as household location (An et al., 2005), population (Wolong Nature Reserve, 2000a), fuelwood collection sites of the last three decades, attitudes toward fuelwood policies, and household economy of

2001. Another type of data is at the reserve level, which consists of digital elevation model (DEM), interpolated from digitalized 100 meter contours with a vertical accuracy of less than 50 meter root-mean-square error (RMSE)) (An et al., 2005), habitat suitability index (HSI) maps, including four categories of habitat – highly suitable, moderately suitable, marginally suitable, and unsuitable – of 1974 and 1997 (Liu et al., 1999c), and road network and construction records.

Household Survey

Intensive face-to-face household interviews were conducted in the summer of 2002. Two hundred households (about one–fifth of the total) were sampled based on a random sampling method stratified by villages and groups using the population census data of 2000. Of the 200 households interviewed, 12 established in the 1980s did not collect fuelwood in the 1970s, 8 did not collect in the 1990s, and 1 had not collected since the 1980s. Because of this, the degrees of freedom for tests of different time combinations may be different (e.g., 385 for the comparison of the 1970s versus the 1980s, and 388 for the comparison of the 1980s versus the 1990s). We recorded the most frequently visited fuelwood site for a household in each of the past three decades on a Wolong topographic map with a scale of 1:50 000. The site locations for all the surveyed households were then digitized and geometrically corrected to form a geographic information system (GIS) layer in ArcGIS.

We also simultaneously investigated the attitudes of the household heads, who usually know more about fuelwood collection activities than other household members, toward two fuelwood-related regulations to examine whether these policies affected the spatial and temporal distribution of fuelwood collection. The first regulation designated the allowable amount, time, and location of fuelwood collection. The second regulation forbad local residents to do eight specific activities during collection (see Table 2.1 at the end of this chapter). The regulations were released in 1984 (Wolong Nature Reserve, 2000b), about halfway through our study period. We also asked household heads whether they (1) knew about the regulations, (2) if yes, how long they had known about them, and (3) what effects the two regulations had on their fuelwood collection behaviors (e.g., amount collected, time spent, and species of tree collected).

Besides the attitudes toward these two regulations, we also surveyed the household economic status of 2001 to see if relatively richer households were different from the poorer ones in fuelwood collection activities of the 1990s (economic data of households in the 1970s and 1980s are not available). We indirectly gathered data on economic status during interviews by determining the sum of annual household expenditures for all items, such as food, education, energy consumption, farming, and medical services. When collecting this retrospective information, we incorporated a widely used method in social sciences, the life history calendar, to improve the respondents' recall accuracy (Caspi et al., 1996; Axinn et al., 1999). We often asked the interviewees some indirect questions on life events more readily remembered, such as births, marriages, deaths, household separations, to help them recall less salient facts related to our research interests, for example, the location of fuelwood collection and the year they knew a regulation was released.

We recorded global positioning system (GPS) measurements and current status of fuelwood sites in the forest stands (number of stumps left, stump diameters, and tree species) to verify whether sites recorded from interviews were actually used before. We visited and surveyed fuelwood sites of 15 randomly selected households we had interviewed, each having an area of 30×30 m^2 to match the habitat map.

With the knowledge of local guides (often participants in fuelwood collection), we located those sites around a heavily collected spot. Old stumps (from the 1970s) were identified by newly developed seedlings from them and the seedlings also helped us recognize tree species with the additional assistance of local botanists. We found that on average there were 56.5 stumps left with a mean diameter of 16.2 cm in each site. The average number of tree species in these sites was 9.7. In total, we identified 63 species of trees collected, of which seven were conifers and 56 were broadleaves. These species were also observed in fuelwood piles during our household interviews. Therefore, we are confident that the sites were used for fuelwood collection.

Road network

Records of transportation system development in the reserve were kept in the Department of Transportation in Wolong (Wolong Nature Reserve, 2005b). Road quality, construction/improvement time, and construction goals were well documented and road networks in different decades were mapped. Household surveys and all other non–spatial attribute data were managed in a Microsoft Access 2000 database. Spatial information (e.g., fuelwood sites, road networks, and the DEM) was warehoused in an ArcGIS 8.2 database for further analyses.

Data Analysis

Fuelwood collection sites

To characterize the topography of fuelwood collection sites, average elevation, aspect, and slope in 30×30 m^2 area (0.09 ha) around the sites were derived from the DEM. We chose this size as a conservative estimation of annual collection area for a household consuming a minimum amount of fuelwood (8 m^3) (An et al., 2001) and collecting a relatively large percent (around 60%, field observations, 2002) of trees in a mixed evergreen and coniferous forest stand (most frequently visited, with an average stock of approximately 120 m^3/ha,) (Bearer, 2005). This selection also matches the resolution (30×30 m^2) of available data (DEM and HSI map).

We used the point density function from Spatial Analyst Tools in ArcGIS 8.2 to generate density maps of fuelwood collection sites. The densities were arbitrarily categorized into three groups: 0–5, 5–10, and 10+ points per km^2. Then we identified newly emerging heavily used areas, usually centered by points with densities of 10+ points per km^2 as fuelwood collection hotspots by comparing the maps in different decades.

Distances between fuelwood collection sites and household locations

Because the household is a basic unit of many human activities in the reserve (An et al., 2003), their characteristics (e.g., location, economic status, labor) could be important in fuelwood site selection. To understand the temporal and spatial relationships between fuelwood sites and household locations, three distances were measured using ArcGIS. **ED** is defined as the Euclidean distance between a household and its fuelwood collection site. **TD** stands for the length of the shortest road traveled by a household to the corresponding fuelwood site in road networks. **ND** indicates the Euclidean distance from a fuelwood collection site to the location of the nearest household, which may not be the focal household. ED and TD were designed to describe the relationships between individual households and their fuelwood collection sites at the household level. ND reflects collective interactions between households and fuelwood collection locations at the reserve landscape level.

We used information on household expenditures of 2001 as a proxy of economic status of the 1990s. We categorized households into three groups by annual expenditures of 2001: low (≤5000 RMB, 8.25 RMB = US$ 1 in 2001), medium (> 5 000 and ≤10 000 RMB), and high (> 10 000 RMB). Annual per capita expenditures of 2001 were also classified into three categories: low (≤1400 RMB), medium (>1400 and ≤2800 RMB), and high (> 2800 RMB). The number of laborers in a household in 2000, derived from the 2000 population census data, was used to group the households to test whether it affected households in terms of fuelwood collection in the 1990s (data on the laborers in the 1970s and 1980s are not available). We treated household members from 18 to 60 years old as laborers, and distinguished households with two or fewer laborers from those with three or more laborers.

Relationships between fuelwood collection and panda habitat

To examine the spatial and temporal trends of the impacts of fuelwood collection on panda habitat, we took two measures. First, we calculated the distance (**HD**) from a fuelwood site to the nearest pixel of each type of habitat on the HSI map of 1974. Second, we derived the percentages of households collecting fuelwood in a certain type of habitat in a given decade by overlaying fuelwood sites on the HSI map. They may indicate temporal trends of fuelwood collection distribution in relation to panda habitat at the reserve landscape level rather than ED or TD at the household level.

We used t tests and analysis of variance (ANOVA) to test for differences of elevation, slope, ED, TD, and ND of the three decades. As an exception, the Mardia–Watson–Wheeler test was applied to test for the differences of aspects of fuelwood sites in the three different decades because aspects are circular measurements (Batschelet, 1981). In addition, we calculated and reported descriptive statistics on attitudes of local residents toward fuelwood policies.

RESULTS

Fuelwood Collection Sites

The temporal changes of three topographic characteristics (elevation, slope, and aspect) of fuelwood sites are illustrated in Figure 2.2 (a, b, and c). Our results suggest that local residents had to climb to physically challenging areas with an average elevation > 2000 m and mean slope > 30°. The one-way ANOVA test rejects the null hypothesis that the means of the three groups of elevations were equal ($F = 47.78$, $p < 0.0001$). The t tests (1970s versus1980s [$t = 6.57$, $p < 0.0001$] and 1980s versus 1990s [$t = 3.47$, $p = 0.0003$]) show that site elevation significantly increased over time (on average, 100–150 m per decade) (Figure 2.2a). The slopes of the three decades were not significantly different ($F = 2.73$, $p = 0.066$) while they increased only from the 1970s to the 1980s at the significance level of 0.05 ($t = 2.33$, $p = 0.016$) (Figure 2.2b). The Mardia–Watson–Wheeler test shows that there were no significant differences among the aspects of fuelwood sites during the three decades studied ($W = 5.92$, $p = 0.21$) (Figure 2.2c).

Density maps of fuelwood sites used during the 1970s, 1980s, and 1990s are plotted in Figure 2.3 and clearly indicate clustering of fuelwood collection across the reserve landscape. Several fuelwood hotspots had emerged over time in the reserve (Figure 2.3). We identified Area **A** as a hotspot in the 1980s by comparing the maps in the 1970s and 1980s (Figure 2.3b). Similarly, two hotspots, Area **B** and Area **C,** attracted many households for fuelwood in the 1990s (Figure 2.3c). Furthermore, linking road construction information with these hotspots shows that road development might have contributed to their emergence. Roads near Area **A** were constructed from a trail to improve local access to markets with support from the United Nations' World Food Programme for panda conservation in the early 1980s (Wolong Nature Reserve, 2005), but extended so far into the forests that they clearly facilitated fuelwood collection in Area **A**. Roads near Area **B** were originally developed for mining in 1987 and assisted many households in fuelwood collection in the 1990s (Wolong Nature Reserve, 2005). The quality of the main road across the reserve, from the east side to the lower southwest corner and constructed for commercial timber logging in the 1960s before the establishment of the reserve, was greatly improved in the early 1990s (it was paved, which was rare in western China during that time). These roads fragmented the reserve, and facilitated household fuelwood collection considerably. People living far away from the road could easily travel to Area **C**, which had high forest stock and was rarely used as a fuelwood site before the mid–1990s.

Distances between Fuelwood Collection and Household Locations

Besides climbing higher into the mountains, as mentioned above, local residents also traveled greater distances (**TD**) to fuelwood sites, because sites became increasingly farther away from households (**ED**) over time (Figure 2.4). On average, local households had to reach out an extra 20–50 m farther (**ED**) or travel 50–80 m more (**TD**) yearly to find good fuelwood sites. Although the distance difference seems small, it often occurred in steeper and higher mountainous areas, which meant greater hardship and more time required for fuelwood collection. Statistical evidence concerning the distance between a fuelwood site and its nearest household (**ND**) shows that, at the reserve level, fuelwood collection was expanding gradually farther away from residential areas (Figure 2.4).

From further analyses of spatial characteristics ED, TD, and ND, grouped by economic status of 2001 (annual household and per capita expenditures) and number of laborers in 2000, we found no significant differences between rich and poor households, or households with more or fewer laborers in terms of fuelwood site selection in the 1990s (Table 2). Presumably, this is because fuelwood collection was accomplished by groups of households rather than by individual households. Another reason might be that unavailability of fuelwood was the same for all households, whether they were poor or rich, with more or fewer laborers.

Relationships between Fuelwood Collection and Panda Habitat

The percentage of fuelwood sites in highly suitable panda habitat of 1974 increased from 6% to 21% during the three decades studied (Figure 2.5). The majority of fuelwood collection (varying between 68% and 78%) occurred in areas of highly suitable and moderately suitable panda habitat and much smaller percentages (ranging from 22% to 32%) in areas of unsuitable habitat (Figure 2.5). Surprisingly, no fuelwood collection appeared in any areas of marginally suitable habitat. The reason might be because marginally suitable habitat is characterized by steep slopes and high elevations (Liu et al., 1999c). From the perspective of the distance between a fuelwood site and its nearest habitat type, we found that local residents collectively went closer to highly suitable habitat (144 m, 132 m, and 105 m for the 1970s, 1980s, and 1990s, respectively) and farther from unsuitable habitat (90 m, 127 m, and 145 m for the 1970s, 1980s, and 1990s, respectively) to find good sites for fuelwood over time.

To further demonstrate the spatial trends of fuelwood collection impacts on panda habitat, we calculated the distance between a household and its nearest habitat pixel of a given type. The locations of households were relatively stable. Our results show that for highly suitable habitat, the average distance between households and the 1974 habitat (153.43 ± 131.59 m)was significantly shorter than the one between households and the 1997 habitat (330.86 ± 264.58) ($t = 12.80$, $p < 0.001$). Similarly, for moderately suitable habitat, the mean distance corresponding to the 1974 habitat (113.14 ± 99.11) was significantly shorter than the one corresponding to the 1997 habitat (236.35 ± 169.36) ($t = 13.86$, $p < 0.001$). Because the data for panda habitat in the 1980s were not available, we only analyzed the habitat change of the fuelwood sites from the 1970s to the 1990s by overlaying the fuelwood sites on the habitat maps in both 1974 and 1997. This analysis shows that more than 50% of fuelwood sites with highly suitable habitat in the 1970s had become unsuitable and the rest had no change. One-quarter of sites that were moderately suitable in the 1970s had become unsuitable and the rest were unchanged. In total, the quality of 18.8% of fuelwood sites in the 1970s had been reduced by the 1990s. To summarize, the continual collection of fuelwood in the 1970s, 1980s, and 1990s had degraded habitat quality and affected the spatial distribution of panda habitat; primarily, suitable habitat had been pushed farther away from households.

Knowledge about and Attitudes toward Fuelwood-related Policies

Dissemination of fuelwood-related policies to local residents within the reserve was effective. Among the 200 household heads interviewed, 134 (67%) said they had known about at least one regulation. Among these 134 respondents, 84 had known about the regulations for less than 10 years, while the rest had known about them longer than 10 years. However, as to the effects of the policies on fuelwood collection, only 42% of those interviewed (84 of 200) or 63% of those who knew the regulations (84 of 134) said that their fuelwood collection activities had been affected. Even among those who followed the regulations, only approximately half of them (56%) believed that less fuelwood was harvested because of the existence of regulations, while for others regulations had no impact on the amount of fuelwood collected. Regarding the effect of regulations on fuelwood collection time, 43% of household heads who followed the regulations thought that they spent less time while 31% spent more time and 26% saw no change. The major changes brought about by the policies were that the local residents went to more remote sites (77% of households who followed the regulations) and collected more small trees (93% of households who followed regulations). Thus, regulatory policies and the unavailability of the resource in places nearby might have contributed to the spatial trend of fuelwood collection activities moving farther away from households over time in the reserve.

DISCUSSION AND IMPLICATIONS

Our results reveal that local residents in Wolong Nature Reserve had to select gradually more distant sites at increasingly higher elevations to collect fuelwood during the last three decades of the 20th century, and the majority of tree fellings occurred in areas of highly suitable and moderately suitable panda habitat rather than areas of marginally suitable and unsuitable habitat. Fuelwood collection occurred frequently in areas close to households, while some new hotspots had emerged due to local road expansion. Many households were aware of the fuelwood collection regulations and understood their importance to panda conservation, but many of them did not comply strictly with them. As good forests receded from households at the reserve level, local residents experienced a gradually increasing hardship in their fuelwood collection, which exacerbated an already-existing conflict between people and pandas. The implications of our results for policy are discussed below.

Road Construction

Our study suggests that road systems facilitated fuelwood collection in suitable panda habitat. Therefore, road extension should be carefully planned, especially in conservation-oriented areas, such as Wolong Nature Reserve. Investment should be focused on improving the roads that may facilitate the access of local residents to markets to sell their agricultural products (e.g., cash vegetables like cabbage). Roads should not be expanded into areas without residents or into areas from which residents have been encouraged to move. Also, roads originally designed for mining or other non-agricultural activities in the past should have been closed to prevent illegal use for resource extraction.

Energy-related Policies

Over time, local residents have experienced increasing difficulties in collecting fuelwood, involving tedious trips to steep and remote mountains. Energy is a crucial issue for both human welfare and panda conservation. This is becoming even more important and serious, as fuelwood collection is no longer officially allowed. In 2001, the Natural Forest Conservation Program was initiated in the reserve. Each rural household was assigned one or more forest parcels to monitor for illegal harvesting and given a yearly subsidy (available until 2010) equal to one-quarter or more of household annual income. This direct income gained from NFCP along with serious law enforcement has prompted the majority of households to reduce fuelwood consumption since 2001 by switching to electricity (Wolong Nature Reserve, 2005b). The average electricity consumption per household increased from 800 kWh in 2000 to 2800 kWh in 2003 while fuelwood consumption per capita declined from 1.4 m^3 to 0.3 m^3 during the same period (Wolong Nature Reserve, 2005b). A new, so-called ecohydropower plant began operation in October of 2002, but the price of electricity, a widely proposed substitute (An et al., 2002; Wolong Nature Reserve, 2005b), is still high relative to household income (about 90% of the local rural residents interviewed complained about it). The effect of lowering the price of electricity on panda habitat can be significant. For example, a simulation study indicated that a reduction in electricity price by 0.05 RMB could save approximately 15 km^2 of panda habitat over a period of 30 years (An et al., 2006).

With substantial income losses when NFCP ends, the households will likely resile and cut down trees for fuelwood again. Economically affordable, socially acceptable, ecologically sound, and sustainable long-term alternatives are needed. An on-going Grain-to-Green Program applies a national policy that focuses on restoring ecological functions as well as encouraging economic development in steep cropland; the program requires at least 80% of trees planted for ecological restoration, and at most, 20% of trees for economic purposes (Ye et al., 2003; Zhu and Feng, 2003). However, it may not effectively address the local residents' main need: fuelwood in Wolong Nature Reserve. As suggested by some other scholars for other regions (Madeschin, 1999; Zhang et al., 2000; Kohlin and Parks, 2001; Richardson et al., 2002), we also recommend that the majority of steep cropland returned to vegetation should be designated specifically for growing fuelwood forests, providing both energy resources and ecological functions in the reserve. By continuing to use fuelwood, local residents (of three minority ethnic groups: Tibetan, Qiang, and Hui) may preserve their traditional lifestyles and cultures (Ngugi, 1988; Mahiri and Howorth, 2001).

Panda Habitat Conservation

Considering the reality that fuelwood collection is unavoidable, the impacts on panda habitat could be mitigated if more fuelwood collection were to occur in areas with panda habitat of relatively lower quality, where little fuelwood was collected in the past. It is evident that fuelwood policies did not change the local residents' fuelwood collection behaviors. There were three major reasons for the apparent failure of these regulations. First, law enforcement was weak: fuelwood collection occurred in topographically difficult and relatively large areas, but the Wolong Administration Bureau had limited staff for resource monitoring and protection (Wolong Nature Reserve, 2005b). Second, the tragedy of the commons (Hardin, 1968) is applicable in Wolong: collecting fuelwood from forests is free, except for the time it takes (Liu et al., 1999c), and, based on the current Chinese land system, local residents have only usufruct rights; therefore, there is little incentive for them to grow trees for fuelwood, use energy-efficient stoves, or reduce fuelwood needs.

Third, some of the local residents' basic needs (e.g., energy) were not well addressed (Sharma, 1990): many potential alternatives (e.g., biogas and wind/sun power) were unavailable, were expensive (e.g., coal, because of transportation), or had other negative environmental effects (e.g., greenhouse gases from burning charcoal and coal). Although the eight hydropower plants in the reserve had a total capacity of 33 960 kW in 2003 (Wolong Nature Reserve, 2005b) and local residents were willing to switch to electricity (An et al., 2002), the people could not afford to buy it and most of the electricity was sold to cities. It was found that at the average price of 0.13 RMB/kWh in 1999, a price decrease of 0.05 RMB would have doubled the number of households switching to electricity (An et al., 2002).

We suggest that resources or efforts should be shifted to monitor fuelwood collection in the areas of highly suitable and moderately suitable habitat. Currently, the farther an NFCP parcel is from the household assigned to monitor it, the more subsidies the household receives. To improve the efficacy of NFCP's investment, household should receive higher subsidies if their parcels are in better shape, i.e. the habitat quality is better.

Meanwhile, we suggest that households be officially allowed to collect dead tree branches and shrubs for fuelwood from nearby NFCP parcels, with a maximum limit. This compromise should be allowed only for a short period, because in the long run it may also have negative impacts on ecosystem health and services (Bengtsson et al., 1997; Aigner et al., 1998; Rosenstock, 1998; Kumar and Shahabuddin, 2005). This proposal is most likely feasible because of the successful implementation of NFCP: forest parcels were well monitored and very few were illegally harvested. This will also give enough time for the reforested trees in the Grain-To-Green Program to grow for fuelwood.

Understanding spatial and temporal patterns of fuelwood collection will not only help researchers scale up their evaluations of the impacts of fuelwood collection on panda habitats from the household level to the reserve landscape level, but also provide fundamental knowledge for reserve managers to make informed and effective decisions, and evaluate and adjust policies. For example, different conservation priorities could be set for areas with different types of habitat quality affected by fuelwood collection. Furthermore, the results obtained from and the methods used in this study may be useful for similar efforts in analyzing temporal and spatial patterns of fuelwood collection or other human activities in other parts of the world.

Table 2.1: Eight activities not allowed in fuelwood collection

Number	Description
1	Do not cut newly planted seedlings for fuelwood
2	Do not cut young trees for fuelwood
3	Do not cut trees in the previously harvested areas for fuelwood
4	Do not cut trees in the erosion-prone areas for fuelwood
5	Do not cut trees of rare and precious species for fuelwood
6	Do not cut riparian trees for fuelwood
7	Do not cut trees in research zones for fuelwood
8	Do not light a fire in forests

Source: Translated from government documents (in Chinese) (Wolong Nature Reserve, 1998b).

Table 2.2: Three types of distances between fuelwood sites of the 1990s and locations of households grouped by the total household expenditure of 2001 (A), household per capita expenditure of 2001 (B), and number of laborers in each household in 2000 (C)

Distance Types	A (total household expenditure, in RMB[a])			B (household per capita expenditure)			C (number of laborers)	
	≤5000	5000–10 000	>10 000	≤1400	1400–2800	>2800	≤2	≥3
ED (Euclidean distances between fuelwood sites and households, meters)	2096(2961)	1416(1179)	1771(1815)	1825(2639)	1505(1207)	2013(2247)	1746(2199)	1645(1375)
	0.33(0.57)			0.14(0.71)			0.11(0.74)	
TD (Travel distances between fuelwood sites and households, meters)	3721(4648)	2784(1699)	3218(2649)	3277(4177)	2893(1756)	3627(2937)	3176(3211)	3158(2173)
	0.42(0.52)			0.25(0.62)			0.00(0.97)	
ND (Euclidean distances between fuelwood sites and their nearest households, meters)	849(495)	833(530)	946(849)	846(523)	829(471)	1018(1071)	855(727)	937(539)
	0.79(0.37)			1.10(0.30)			0.63(0.43)	

[a] 1 RMB = approx. 15 cents U.S. currency

Note: For each type of distance measurement, in the first row, the number outside the parentheses is the mean of the distances in the group and the number inside is the standard deviation; in the second row, the number outside the parentheses is the F-statistic of one-way ANOVA of the groups by the factor A, B, or C and the number inside is the p-value of one-way ANOVA of three groups. The group factors A, B, and C are also shown in the first row of the table, and the group definitions for each factor are given as divided columns below the factors.

Figure 2.1 The location and elevations of Wolong Nature Reserve in China. The locations of Wolong and Gengda townships are also indicated on the map

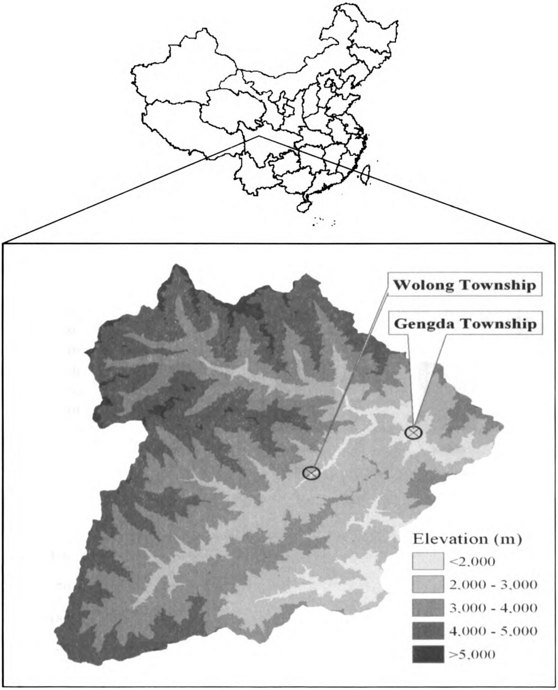
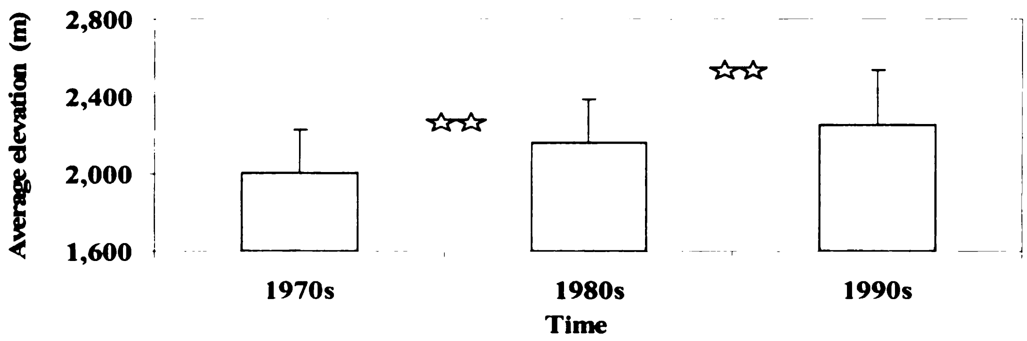
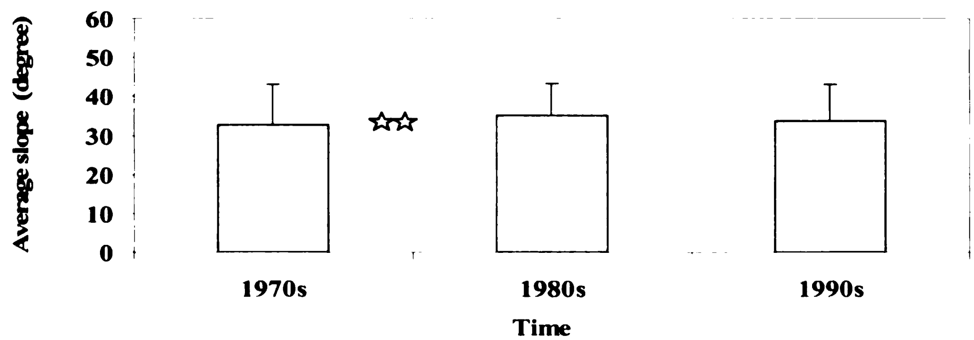


Figure 2.2 Temporal dynamics of fuelwood collection sites in elevation (a), slope (b) and aspect (c) with 1 standard deviation. Two stars indicate that the value to their left was significantly smaller than the one to their right at the significance level of 0.05

a



b



c

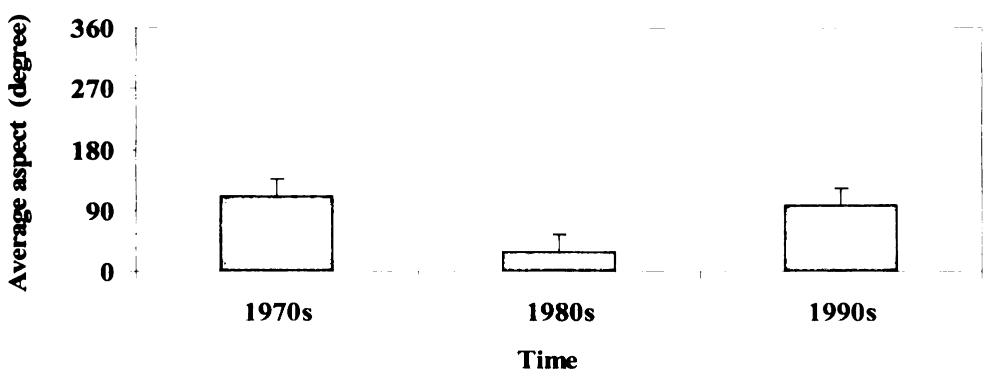


Figure 2.3 Fuelwood collection site density maps of the 1970s (a), 1980s (b), and 1990s (c), and emerging fuelwood hotspots in the 1980s (b), and 1990s (c). The density unit is points per square kilometer

a

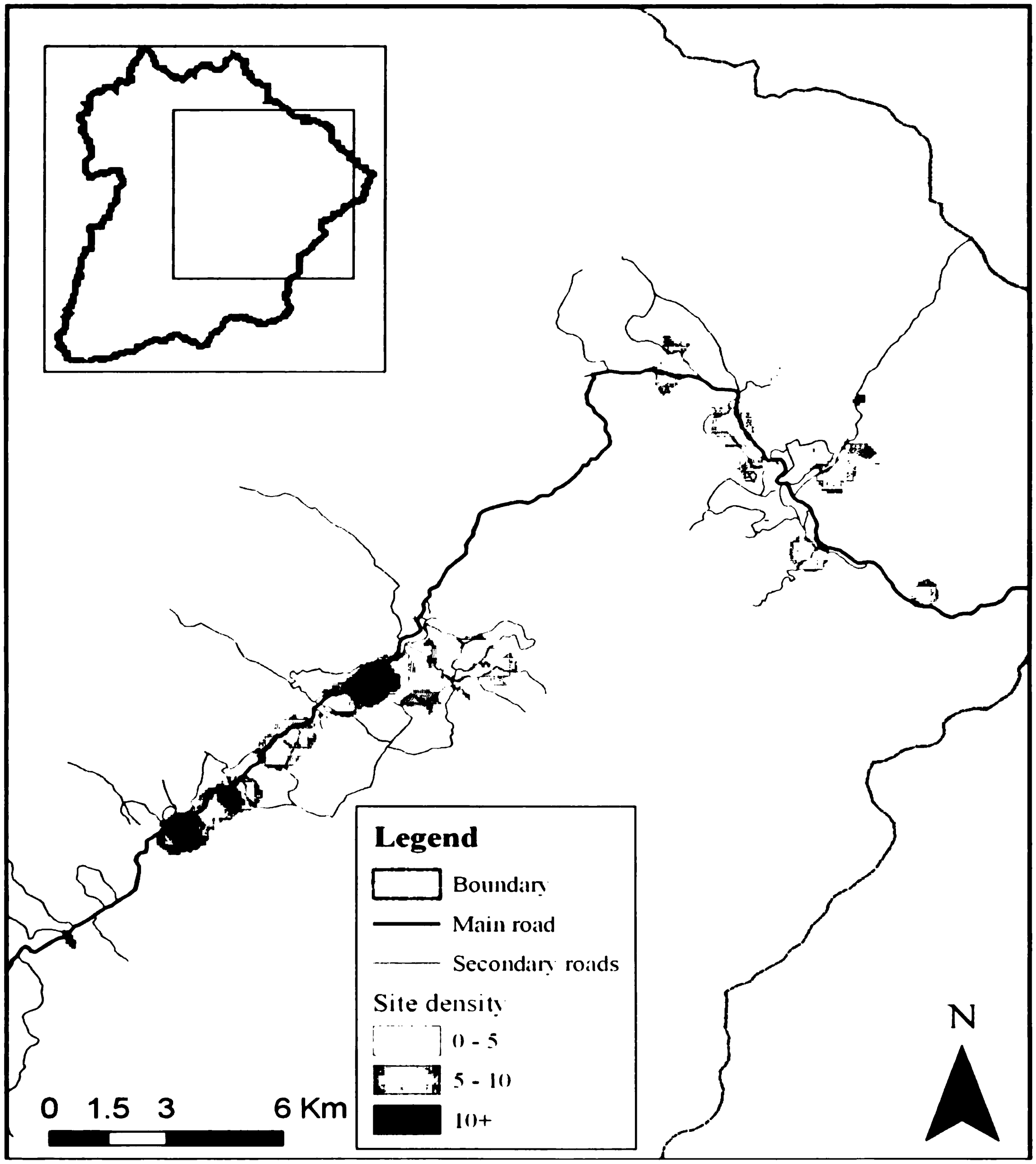


Figure 2.3 continued

b

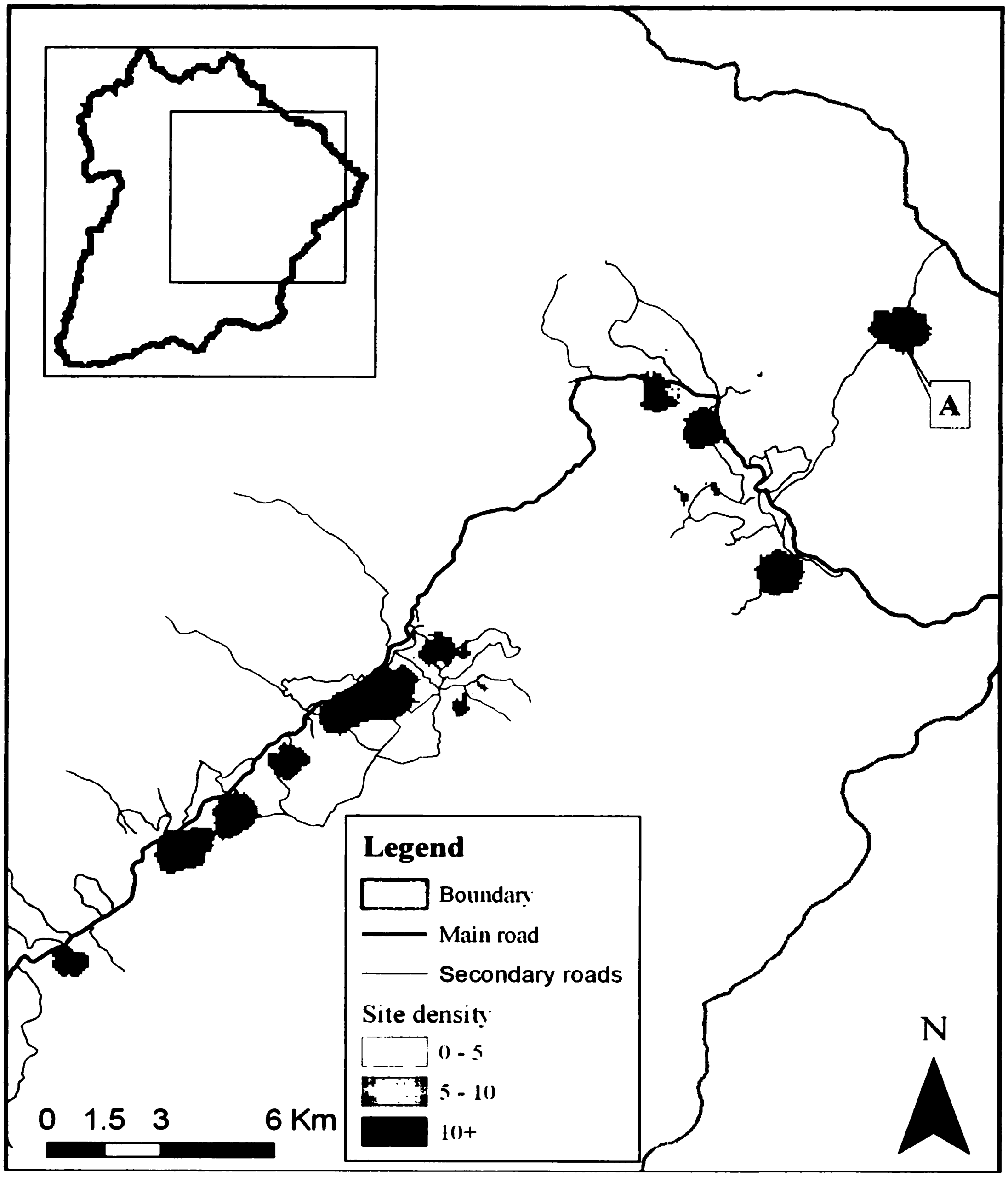


Figure 2.3 continued

c

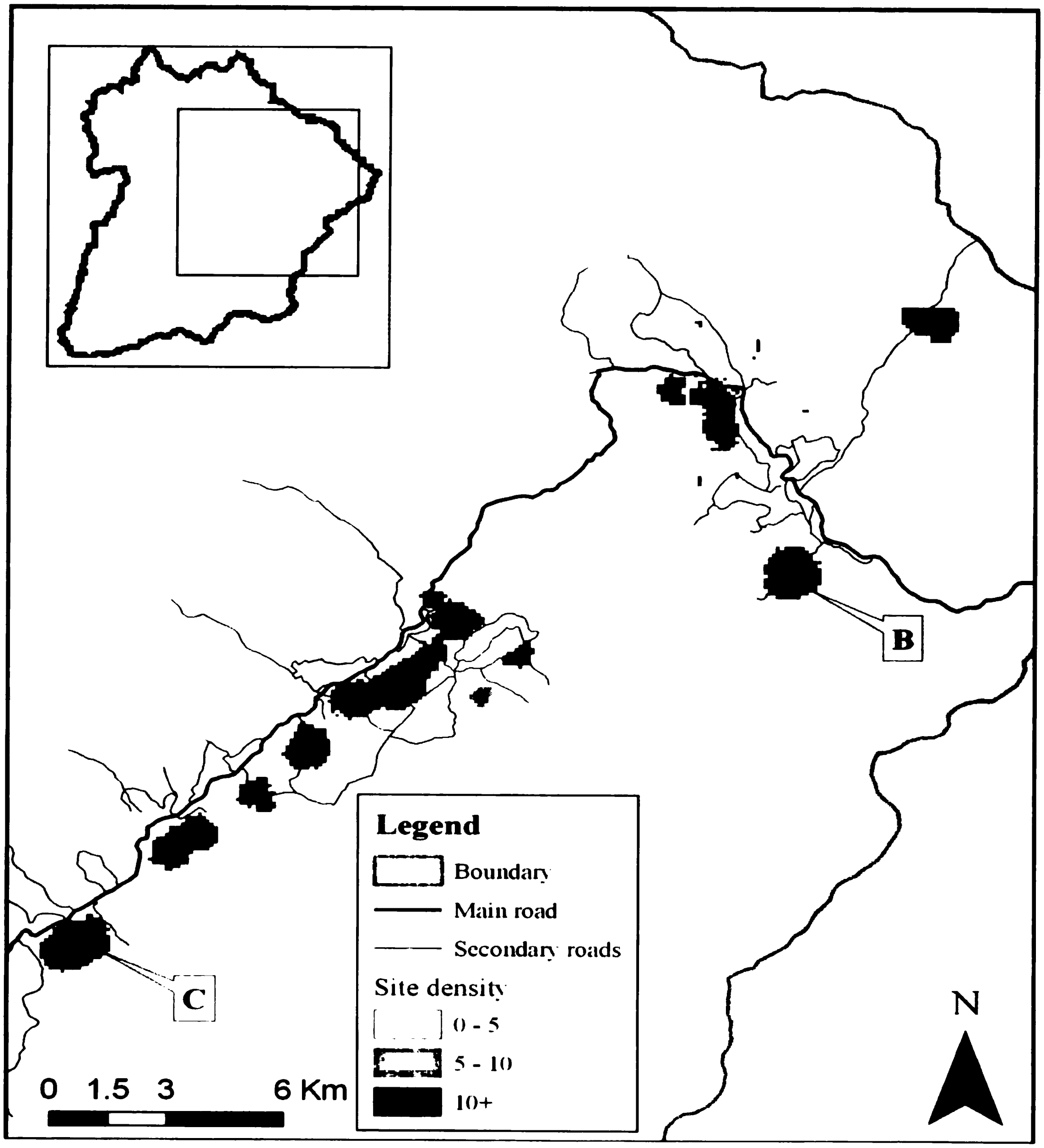


Figure 2.4 Temporal dynamics of distances (ED, TD, and ND) of fuelwood collection sites from household locations with one standard error of mean. Two stars indicate that the measurement to their left was significantly smaller than the one to their right at the significance level of 0.05, while one star indicates that at the significance level of 0.10

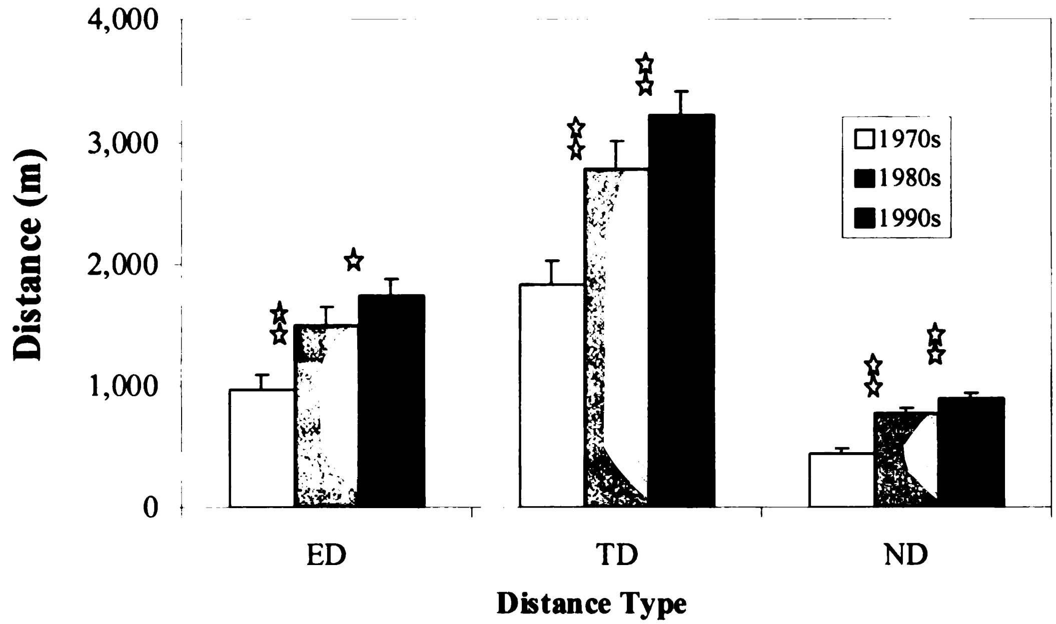
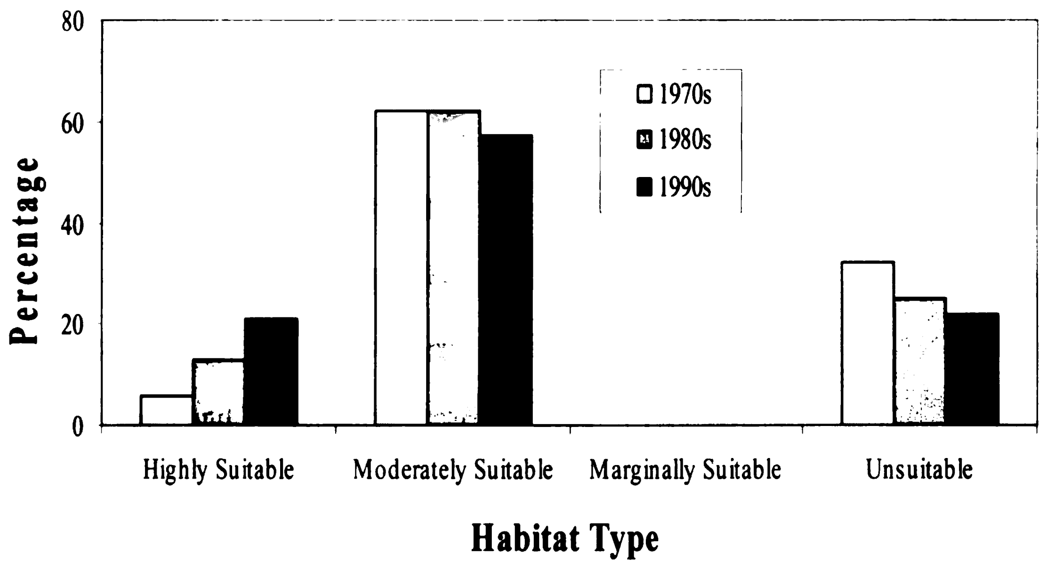


Figure 2.5 Percentages of fuelwood sites of three decades (1970s, 1980s, and 1990s) falling in four types of habitat (Highly Suitable, Moderately Suitable, Marginally Suitable, and Unsuitable) in 1974



CHAPTER 3

EFFECTS OF PAYMENT FOR ECOSYSTEM SERVICE PROGRAMS ON FUELWOOD CONSUMPTION OF RURAL HOUSEHOLDS IN WOLONG NATURE RESERVE, CHINA

ABSTRACT

Payment for ecosystem service (PES) programs are becoming popular worldwide in attempts to resolve conflicts between natural resource conservation and human development. Whether human society accepts them socially and economically and thus adjusts their behaviors largely decides the ecological success of those programs. Although natural resources are the major source of conflicts between conservation and development and household is the basic unit of decision making, relatively little effort has focused on understanding the effects of such policy interventions on resource-extractive behaviors at the household level. To fill this knowledge gap, I use Wolong Nature Reserve for Giant Pandas, China, as an example. The reserve is home to approximately 150 wild pandas and 1,000 households. Fuelwood collection has been one of the main driving factors of panda habitat degradation and loss in the past, and two PES programs—the Natural Forest Conservation Program (NFCP) and the Grain-to-Green Program (GTGP)—have been implemented since 2000. In 2002, my research group surveyed 200 rural households regarding their energy consumption switch from fuelwood to electricity after the implementation of the two PES policies. We also investigated what social, economic, and geographic factors of households affect the switch. We found that two-thirds of the fuelwood required by households for cooking human food was replaced by electricity, and the switch was not significantly related to any household characteristics; one-third of the household

fuelwood demand for heating houses was met by electricity, and household income and age of household members were the significant driving factors; and households were least apt to substitute electricity for the fuelwood needed for cooking livestock fodder, and the percentage of cropland converted in GTGP and household size significantly affected the decision to make this switch. NFCP and GTGP together reduced the energy dependence of rural households on fuelwood from 100% to approximately 64%. Even with substantial economic support from PES programs, it is hardly possible for rural households to switch most of their energy needs to electricity, especially for heating and cooking livestock fodder. Thus, other ecologically friendly and economically sound energy alternatives should be considered. One promising fuelwood source would be plantation forests, and local governments should encourage tree plantations for both household use (e.g., fuelwood) and ecosystem service (e.g., erosion control, biodiversity conservation).

KEYWORDS: fuelwood collection, payments for ecosystem services, Wolong Nature Reserve, China, wildlife conservation, Grain to Green Program (GTGP), Natural Forest Conservation Program (NFCP), fuel switch

INTRODUCTION

The damages of global environmental crises (such as global warming, flooding, deforestation, and desertification) to economies and human society have been increasingly recognized by many governments worldwide, even in developing countries. It is encouraging that in order to prevent such damages in the future, some of those nations have initiated and implemented large-scale conservation programs (Sayer et al., 2004; Weyerhaeuser et al., 2005; Chokkalingam et al., 2006; Engel and Palmer, 2008), for example, payments for ecosystem services (PES) in China (Daily and Matson, 2008; Liu et al., 2008b).

China's large-scale national conservation programs after the disastrous flooding along Yangtze River in 1998 are excellent examples (Trac et al., 2007; Liu et al., 2008b). Pilots of the Natural Forest Conservation Program (NFCP) began immediately following the flooding. Its short-term goals (1998–2000) were to eliminate or reduce timber harvesting from natural forests and create alternative employment for traditional forest enterprises. The medium-term goals (2001–2010) are to construct and protect forests for ecological benefits and to increase the capacity for timber harvesting from plantation forests. The long-term goal (2011–2050) is to restore natural forests and meet domestic demand for timber in plantation forests (Liu et al., 2008b). Started one year after NFCP, the Grain-to-Green Program (GTGP) in China aims to increase vegetative cover by 32 million ha by 2010 through the conversion of cropland on steep slopes to forest and pasture, with an additional "soft" goal of afforesting a roughly equal area of wasteland (Liu et al., 2008b). Pending successful completion, it could represent a 10–20% increase in China's national forest area and a 10% decrease in current cultivated area (Bennett, 2008). Although ecological impacts are rarely or too early to be confirmed by field observations (Trac et al., 2007; Wunder et al., 2008), social and economic successes have often been documented at large scales in both the scientific literature (Uchida et al., 2005; Shen et al., 2006; Xu et al., 2006a; Bennett, 2008; Goldman et al., 2008; Liu et al., 2008b) and government reports (such as from the State Forestry Administration). However, more studies on the effects of such programs at finer scales, such as the household level, are needed to understand the effects of these programs at larger scales (county, provincial, and national levels), adjust the policies, and improve implementation (Weyerhaeuser et al., 2005; Xu et al., 2006b; Trac et al., 2007; Turner et al., 2007).

Wolong Nature Reserve of China is an excellent site for studies to reduce this knowledge gap. The reserve, with approximately 36% forest cover in 2001 (Vina et al., 2007), has nearly 4,000 plant species and more than 2,200 insect and 124 animal species, including the endangered giant pandas (*Ailuropoda melanoleuca*) (Wolong Nature Reserve, 1998b). From a national survey conducted in 2000, 143 wild pandas were believed to cohabit the reserve with 4,498 people (63% of which are Tibet) in 968 households in 2003 (State Forestry Administration, 2005; Wolong Nature Reserve, 2005b). The reserve provides important ecosystem services such as flood control and biodiversity to the region. Both NFCP and GTGP have been initiated in the reserve since 2000 (Wolong Nature Reserve, 2005b). The collection of fuelwood, the major energy source of rural households, is one of the main threats to maintaining forest cover and wildlife habitat and population. If these two programs are to be successful in Wolong Nature Reserve, the local rural households must switch from fuelwood to electricity with the economic support from the programs, assuming other energy sources such as plantation forests are not considered (Bearer, 2005). Naturally, the next questions to ask are: How much do these two programs trigger households to stop fuelwood collection and switch to electricity? and What factors affect this decision process at the household level?

One of the most popular theories about household energy choice is the "energy ladder" model (Leach, 1992; Heltberg, 2005; Arnold et al., 2006). It predicts that with increasing affluence, households transition from relying solely on biomass to a mixed use of kerosene, coal and charcoal, and finally the cleanest fuels, liquid petroleum gas and electricity. This model prescribes income to be the only impact factor. Recently, several other factors have been considered (Heltberg, 2005; Farsi et al., 2007). These factors can be categorized into three groups: demographic, economic, and geographic.

Household demographic factors include education level and sex of household head (Farsi et al., 2007), labor force, household size, number of educated people in the household (Heltberg, 2004; Chen et al., 2006), and the highest education level of household members (Heltberg, 2004; Madubansi and Shackleton, 2007). The economic factors used most often in the literature are household income (Heltberg, 2004, 2005; Farsi et al., 2007; Madubansi and Shackleton, 2007), per capita expenditure (Heltberg, 2004), fuel price (Heltberg, 2004; Farsi et al., 2007; Hiemstra-van der Horst and Hovorka, 2008), and cropland size and wealth (Chen et al., 2006). For geographic factors, researchers have considered access to fuel sources (Masera et al., 2000), distance to forest (Chen et al., 2006), and regions (Heltberg, 2005).

The majority of fuel-choice or transition studies only consider fuel for cooking or total fuel usage, partly because most studies are conducted in tropical regions, where fuel needs for heating houses in winter may be negligible. However, fuelwood in many other regions is often consumed for three purposes: cooking human food, heating houses, and cooking livestock fodder. The consumption for each purpose may vary by geographic region. Different factors may play different roles in decisions to switch fuels. Most fuel-switch research has focused on the status quo of fuel consumption (Masera et al., 2000; Heltberg, 2005; Farsi et al., 2007) while little effort has linked the switching process to conservation interventions. Another common characteristic of such studies is that they concentrate at large scales such as multiple countries, provinces, and regions. These studies may not be so helpful to a relatively small area, such as Wolong Nature Reserve, because many macrofactors are similar or the same for all households; for example, fuel price, cultural preference, scarcity of fuelwood, law enforcement, and availability of electricity. These factors were not considered in this study. One exception is that Madubansi and Shackleton (2007) examined the changes in fuelwood use and selection in five villages of South Africa and found that even with a policy of 6kWh per month of free electricity, over 90% of households still used fuelwood for cooking and heating. Their study did not associate socioeconomic factors with the fuelwood consumption changes of different fuel-use purposes.

The goals of this chapter are to (1) estimate the effects of two PES conservation policies (NFCP and GTGP) on switching from fuelwood to electricity for three fuelwood consumption purposes at the household level; (2) identify social, economic, and geographic factors affecting the process; and (3) provide recommendations for adjusting NFCP and GTGP for panda conservation.

It is my hope that by providing a better understanding of how these PES programs affect rural household decisions, the programs can be adjusted not only to be more effective but to ensure the sustainability of both human society and panda habitat in the reserve. These insights may be also applicable to other areas covered by the PES programs and similar regions worldwide.

METHODS

Located in Sichuan Province, southwestern China (Latitude $30^{\circ}45'$–$31^{\circ}25'$N, Longitude $103^{\circ}52'$–$103^{\circ}24'$E, Figure 2.1) (He et al., 1996), Wolong Nature Reserve was established in 1963 and expanded to its current size of 2,000 km^2 in 1975. In 1980, Wolong Nature Reserve became a member of the Man and Biosphere Programme's World Network of Biosphere Reserves and, in 2006, was inscribed on the World Heritage List (UNESCO World Heritage Centre, 2006).

The reserve is administrated by Wolong Administrative Bureau and consists of two townships: Wolong and Gengda (Lü et al., 2003). Four major ethnic groups—Han, Tibetan, Chang, and Hui—constitute the rural population, most of which are farmers. Households use fuelwood as their main energy source for cooking human food and livestock fodder and heating in winter. Fuelwood needs for these three purposes consist of 18.3%, 45.7%, and 36.0% of the total energy demand, respectively (An et al., 2001). Many potential alternatives are unavailable (e.g., biogas and wind/sun power), expensive (e.g., coal, because of transportation), or have negative environmental effects (e.g., charcoal and coal). Electricity is the ideal substitute for fuelwood because the reserve's eight hydropower plants have an adequate capacity—33,960 kW in 2003 (Wolong Nature Reserve, 2005b). However, before 2000 many households consumed little electricity, primarily for lighting and electric appliances (e.g., TV and radio) because of low quality and the relatively high price (An et al., 2002). The annual amount of fuelwood consumed by each household ranged from 8 to 30 m^3, depending on household size, age structure, cropland area, and other socioeconomic conditions (An et al., 2001). This fuelwood consumption has caused a significant reduction in the quality and quantity of panda habitat (Liu et al., 1999c; An et al., 2005; Linderman et al., 2005).

Almost 100% of households in the reserve participated in both NFCP and GTGP (Wolong Nature Reserve, 2005b). Farmers who participated in GTGP received 2,250 kg of grain and 300 yuan (1 USD = 6.8 yuan in 2008) per ha of converted cropland per year. More than 50% of cropland in the reserve (367.3 ha) has been enrolled in GTGP. A group of households was assigned a forest parcel for collectively monitoring illegal harvesting and each household was subsidized with an average of 1,210.04 ± 14.39 yuan per year, which was 19.24 ± 0.96% of the yearly household income in 2001. Direct cash gains from GTGP contributed a very small portion (1.51 ± 1.39%, Table 3.1) to the total household income, but the cash value of the grain equaled 17.14 ± 1.16% of the average household income (the agricultural benefits of planting corn, potato, cabbage, and other crops if the land was not converted were not deducted). However, households may save rather than consume the income gains (Ravallion and Chen, 2005). Even if they decide to consume, they might not spend money to reduce resource extractive activities (e.g., consuming less fuelwood and more electricity) but in other areas such as education and health. Administering NFCP and GTGP differently from other conservation programs, China has dispatched about 60,000 specially trained forest police to emphasize program enforcement (Wang et al., 2007). Together with the monitoring efforts by households, the existence of such a forest policy force in the reserve (approximately 50 people) has helped monitor the implementation of those policies in remote areas and has led to almost no occurrence of illegal forest harvesting and poaching (Wolong Nature Reserve, 2005b). Partially because of this, households may have to switch from fuelwood to electricity to meet their energy needs.

We interviewed 200 households (about one-fifth of the total rural households in the reserve) in the summer of 2002. Those households were sampled based on a random sampling method stratified by three community organizational levels (township, village, and group) using the population census data of the year 2000 (Wolong Nature Reserve, 2000a). We collected household demographic and socioeconomic data, including cropland returned to forest through GTGP and economic gain from GTGP and NFCP (Table 3.2). Particularly, we surveyed the percentages of energy consumption switched from fuelwood to electricity for each of the three purposes (cooking human food, heating, cooking livestock fodder) after the implementations of the two conservation programs in the reserve. Before 2000, little electricity was consumed for the three purposes but for some household electric appliances such as radios and TVs because of the low quality of electricity. We chose the household heads or their spouses as interviewees because they are usually the decision makers of household affairs. Of the

200 households interviewed, seven were excluded from analysis because their households did not complete all the questions.

We summarized and reported descriptive statistics of demographic, economic, and geographic factors affecting households' decisions to switch from fuelwood to electricity. We also used t tests and analysis of variance (ANOVA) to test for differences of the percentages of fuelwood switched among the three consumption purposes. Furthermore, we applied linear regression models to estimate the effects of these household characteristics (independent variables) on the percentages (dependent variables) of fuelwood for each of the three consumption purposes switched to electricity.

RESULTS

The demographic, economic, and geographic characteristics of the surveyed households are summarized in Table 3.1. Surveyed households had an average size of 4.44 members in 2002 but decreased to 3.86 in 2006. Approximately one-third of the households had at least one senior member older than 60 years. Our respondents had low levels of education with a mean of 2.96 years. Most households had constructed or remodeled their houses more than a decade before 2002. The average per capita cropland was 2.12 mu (1 ha = 15 mu) but more than half of the households (54.72%) were enrolled in GTGP. The average per capita household income was 2,416.21 yuan in 2001. NFCP directly contributed 19.24% of the household income while the contribution of GTGP was negligible. The average household elevation of 1,862.53 m confirms that most are located in higher mountains, which may require more energy for heating in winter. The mean distance from a household to the main road was 528.04 m.

Approximately 46% of surveyed households were from Wolong Township, located in the southwestern part of the reserve (Figure 2.1).

The effects of the two PES programs on rural households' switch from fuelwood to electricity varied for the three fuelwood consumption purposes. Households switched a major amount (66.92 ± 2.42%) of fuelwood need for cooking human food to electricity. The switched percentage of fuelwood need for cooking livestock fodder is the least (22.62 ± 2.61%). A little more than one-third of fuelwood need for heating in winter (37.05 ± 3.12%) was met by consumption of electricity. The one-way ANOVA ($F_{2,576} = 68.41$, $p < 0.0001$) demonstrates that households switched significantly different percentages of fuelwood consumption for the three purposes. Further, one-tail paired t tests indicate that the switch percentage of fuelwood need for cooking human food is statistically higher than it is for heating ($t = 9.69$, $p < 0.0001$), which is higher than the switch percentage for cooking livestock fodder ($t = 4.39$, $p < 0.0001$).

Effects of the demographic, economic, and geographic characteristics of households on the switch of fuelwood for each of the three consumption purposes under the two PES programs GTGP and NFCP are presented in Table 3.2. The three groups of household attributes explained 26% and 23% of the variance of the percentages of switching from fuelwood for heating ($F = 5.27$, $p < 0.001$) and for cooking livestock fodder ($F = 4.53$, $p < 0.001$), respectively. We found that no geographic attributes of households were significantly related to the fuelwood-to-electricity switch for these three fuelwood consumption purposes. Although none of the household characteristics significantly affected households to switch fuelwood need for cooking human food to electricity ($R^2 = 0.06$, $F = 0.96$, $p = 0.484$), economic factors affected by the two PES programs significantly impacted the switch for the other two fuelwood uses. For the switch-to-electricity percentage of fuelwood for heating, per capita income ($t = 3.215$, $p = 0.002$) was positively and significantly associated and age of house ($t = -2.484$, $p = 0.014$) was negatively and significantly associated. The percentage of cropland returned to forest through GTGP positively influenced the switch of fuelwood to electricity for cooking livestock fodder ($t = 3.186$, $p = 0.002$). Household size affected that switch negatively ($t = -3.5097$, $p = 0.077$).

DISCUSSIONS AND CONCLUSIONS

Our results indicate that rural households in the reserve had switched different portions of fuelwood need for different consumption purposes to electricity under the two PES programs NFCP and GTGP. A higher percentage of the fuelwood need for cooking human food was switched, followed by heating and cooking livestock fodder. Overall, approximately 36% (18.3% × 66.92% + 36.0% × 37.05% + 45.7% × 22.62% = 35.9%) of fuelwood dependence was reduced. Multiple fuel sources would coexist for long terms, and this finding is consistent with the literature (Masera et al., 2000; Arnold et al., 2006). Furthermore, the regression analysis showed that socioeconomic factors directly related to the two PES programs together with some demographic characteristics of households significantly impacted the process of switching from fuelwood to electricity for two major consumption purposes while geographic factors were not significant.

The difficulty of switching fuelwood for cooking livestock fodder to electricity may be explained by two reasons. One is that the amount of fuelwood need for this purpose was big (45.7% of the total fuelwood demand). The other is that proper cookware for using electricity did not exist to efficiently cook livestock fodder. These two reasons did not exist for cooking human food, which may explain why households chose to buy electricity to replace most of the fuelwood for that need.

Households need a relatively large amount of fuelwood for heating (36.0% of the total fuelwood demand). House quality and structure may play more important roles when switching fuelwood to electricity. We observed that many old houses in the reserve were built with stones and soil and new ones with bricks and cement. More affluent households are more apt to upgrade their houses. Therefore, it is likely more difficult for households living in older houses (often poorer) to switch more fuelwood to electricity for heating. Fuelwood for heating may be the only case where people can sacrifice their own welfare to reduce the need and cost if they do not have alternatives, and this is true in the reserve. Thus, more investment from the two PES programs can increase the switch to electricity in two ways. Investments can be made to help poor households remodel their houses and increase the per capita payments, which will improve heating efficiency and encourage households to consume more electricity for heating.

An et al. (2001) showed that the amount of cropland for corn (20–30% of the total acreage) was positively correlated to the fuelwood consumption for cooking livestock fodder. This may explain why more GTGP-converted cropland correlated to a higher switch from fuelwood to electricity for cooking livestock fodder. Although this is positive for conservation, the potential impacts on economy (e.g., pigs may grow slower) and culture (the local residents prefer pork from pigs fed by cooked food) are not clear and deserve more research.

One limitation of the study may be that it was conducted only one year after NFCP and GTGP were initiated in the reserve. This is reflected in that household characteristics explained merely a little more than 20% of the variance, although the relationships between some households attributes affected by the programs and the switch of fuelwood to electricity for heating and cooking livestock fodder were significant. Our survey may be better interpreted as short-term responses of rural households to these programs. Another uncertainty is that during the beginning of the implementation many households still had a substantial amount of fuelwood left from previous years. Although our study demonstrates that rural households responded significantly differently for the three fuelwood consumption purposes, more recent data are necessary to enhance the understanding of the effects of the PES programs on fuel switch of rural households.

This analysis can provide some useful implication for PES policy design and implementation and for panda conservation. To encourage households to switch more fuelwood to electricity for heating, the reserve needs to consider more measures; for example, distributing more economic benefits from ecotourism to the local communities (He et al., in press) and off-farm economic activities (Zhang et al., 2008) to improve the income of households so they can buy more electricity or remodel their houses for higher energy efficiency. Realizing the challenge of completely substituting fuelwood with electricity and in order for the two PES programs to succeed in the long run, we may consider that an appropriate balance needs to be achieved between amelioration of the negative consequences of fuelwood on the environment and improvement of human well-being. This is especially important in the areas where fuelwood has been traditionally consumed and treated as part of the culture of the rural communities (Ngugi, 1988; Mahiri and Howorth, 2001; Wolong Nature Reserve, 2005b). Community forestry and plantation forests have the potential to address fuelwood scarcity and energy crisis (Bearer, 2005; Cooke et al., 2008). One option would be the use of GTGP plantation forests, currently few of which were designed and are suitable for fuelwood, and the government should encourage households to plant trees for both household uses (e.g., fuelwood and furniture) and ecosystem services (e.g., erosion control and biodiversity conservation). These efforts will likely sustain the achievements of NFCP and GTGP and eventually improve panda habitat by reducing fuelwood collection from natural forests in the reserve. The results from this study may also have broad implications for other human-populated protected areas in China and other parts of the world.

Table 3.1: Demographic, economic, and geographic characteristics of the surveyed households

Category	Variable name	Description	Mean (Standard deviation)
Demographic	hh_size	Household size	4.44 (1.54)
	has_senior	Whether household has at least one senior member older than 60 years (1: yes, 0: no)	0.32 (0.47)
	head_edu	Education (years) of household head	2.96 (1.00)
Economic	house_age	Age of house (years)	16.05 (13.50)
	capita_income	Per capita income (yuan)	2416.21 (2099.44)
	gtgp_income_pct	Percentage of income from GTGP	1.51 (1.39)
	nfcp_income_pct	Percentage of income from NFCP	19.24 (13.31)
	gtgp_cropland_pct	Percentage of cropland returned in GTGP	54.72 (17.64)
	capita_total_cropland	Per capita cropland (mu, 1 ha = 15 Mu)	2.24 (1.63)
Geographic	loc_code	1: Wolong; 0: Genda	0.46 (0.50)
	elevation	Elevation of house (meter)	1862.53 (223.65)
	dist2road	Distance from house to the main road (meter)	528.04 (696.85)

Table 3.2: Effects of household characteristics on the switch of fuelwood for the three consumption purposes to electricity

Independent variables	Fuelwood consumption purposes		
	Cooking human food	Heating	Cooking livestock fodder
Intercept	71.6696(0.174)	98.6604(0.102)	84.4945(0.101)
hh_size	-2.5670(0.206)	-0.1336(0.954)	-3.5097(0.077)
has_senior	1.5795(0.772)	-1.7085(0.784)	1.2881(0.809)
head_edu	3.0229(0.246)	3.2673(0.273)	-3.7281(0.143)
house_age	-0.1246(0.511)	-0.5382(0.014)	-0.0834(0.652)
capita_income	0.0006(0.720)	0.0065(0.002)	0.0018(0.288)
gtgp_income_pct	-1.6675(0.499)	-2.6947(0.340)	-3.1658(0.189)
nfcp_income_pct	-0.1136(0.670)	-0.0688(0.821)	0.2802(0.282)
gtgp_cropland_pct	0.1963(0.193)	0.2294(0.183)	0.4667(0.002)
capita_total_cropland	-2.1318(0.283)	-3.2908(0.148)	-2.4721(0.202)
loc_code	-1.4961(0.913)	0.8715(0.956)	-10.5706(0.430)
elevation	-0.0006(0.984)	-0.0413(0.234)	-0.0316(0.284)
dist2road	-0.0034(0.571)	-0.0009(0.900)	0.0083(0.158)
	$R^2 = 0.06$ $F = 0.96$ $p = 0.484$	$R^2 = 0.26$ $F = 5.27$ $p < 0.001$	$R^2 = 0.23$ $F = 4.53$ $p < 0.001$

Note: Numbers in front of the parentheses are coefficients and numbers inside are p-values for the independent variables or intercepts in the same row; the last row indicates the other results of linear regressions for the fuelwood consumption purposes in the same column.

CHAPTER 4

WOW: A WEBGIS-BASED DECISION SUPPORT SYSTEM FOR PANDA CONSERVATION

ABSTRACT

A daunting challenge for conservation scientists is to assist various geographically dispersed stakeholders in understanding the dynamics of complex human-nature systems and making informed decisions. Traditionally, decision support systems (DSSs) have been widely prescribed as an analysis tool to help the decision-making process. However, several characteristics of these DSSs (e.g., desktop-based, high costs, complicated interfaces) have limited the access by multiple stakeholders such as scientists, reserve managers, policy makers, non-profit conservation organizations, and the general public. With the development of Internet technology, web-based DSSs have emerged with a universal user interface but usually are loosely integrated and often lack spatial components. During my research, I developed a web-based DSS named WOW (**W**olong **O**nline **W**ebGIS) that is integrated with geographic information systems (GIS), system modeling, and decision analysis for wildlife conservation. We applied the system to Wolong Nature Reserve, one of the largest reserves in China for conserving the endangered giant panda (*Ailuropoda melanoleuca*). Although the main purpose of WOW is to help with increasingly complex decisions of general wildlife conservation, the methodology developed here has broad applications in integrating multiple sources of data and multiple disciplines to tackle natural resource management issues in many other coupled human-nature systems worldwide.

KEYWORDS: decision support system, systems modeling and simulation, multicriteria decision analysis, wildlife conservation, web, giant panda, China

INTRODUCTION

Wildlife conservation challenges often arise in coupled human-nature systems(Liu et al., 2007b). Human actions may have economic and social impacts on human society as well as ecological effects on wildlife habitat and population across time and space (An et al., 2005; An et al., 2006; Liu et al., 2007a). It is crucial for various geographically dispersed stakeholders (e.g., the general public, conservation mangers, decision makers, interested groups, and conservation scientists) to understand the dynamics of such complex systems. The keen competition between conflicting interests of stakeholders makes decisions and decision support even more challenging. This challenge is also being exacerbated by lack of appropriate decision support tools that evaluate these conflicts integratively.

Many applications have been developed to tackle this challenge rooted in such complex systems. However, the stakeholders have limited access to them. The primary reasons may include complicated user interfaces targeting mainly professionals/experts (Tang et al., 2004; Mysiak et al., 2005; Paassen et al., 2007), high costs to deploy usually due to expensive specialized software (Kearns et al., 2003; Adinarayana et al., 2006; Paassen et al., 2007), lower degree of reuse and share of data and knowledge (Poch et al., 2004; Wong et al., 2007), and without persistent storage of simulation results and decision options allowing re-access by users.

With recent technological innovations in computer sciences, the Internet is remarkably popular in both developed and developing countries. For example, as of December 31 , 2007, the Internet population in mainland China was estimated to be over 210 million, only 5 million away from replacing USA as the world's largest wired nation (China Internet Network Information Center, 2008). It is worth noting that 40% of China's new Internet users in 2007 were from rural areas (Schwankert, 2008). This provides a good user base for Web-based applications in China. WebGIS-based decision support systems (DSSs) are becoming the ideal solution to the aforementioned challenge (Bhargava et al., 2007b). Though researchers have claimed that "the Web is now the platform of choice for building DSS" (Bhargava and Power, 2001), few applications that address conservation are seen in the literature.

WebGIS-based DSS is advantageous to its classical standalone forerunners in several ways. The availability of the systems on the World Wide Web (Web) naturally expands accessibility of the systems and this may potentially generate public awareness, a critical factor in the successes of conservation practices (Shunula, 2002; Solh et al., 2003; Dobson, 2005). It also improves effectiveness of the system by a universal interface allowing almost zero learning cost (Tang et al., 2004; Bhargava et al., 2007a). No further investment (i.e., for often expensive GIS and database software) for end users except a "free" internet browser, e.g., Netscape or Internet Explorer, is another benefit. Domain knowledge and expertise can also be easily distributed and shared across time and space by users of the systems without extra costs. All these advantages together may promote democratic decision making and encourage public participation in wildlife conservation.

Based on previous research efforts (Liu et al., 1999c; An et al., 2001; Liu et al., 2001b; An et al., 2002; An et al., 2005; Linderman et al., 2005; An et al., 2006), we have developed a new Web-based DSS, Wolong Online WebGIS (WOW). Different from most existing Web-based applications with only data query and/or map browsing services (Kearns et al., 2003; Lu, 2004; Sante et al., 2004; Mathiyalagan et al., 2005), this system is additionally equipped with spatial analysis functionalities and simulation models, which are necessary to demonstrate and illustrate the complicated interrelationships among people, pandas, and policies in our study site—Wolong Nature Reserve, China.

The rest of this chapter introduces the study area, system design, and implementation of WOW. I also present the results and a discussion. Finally, conclusions and future research directions are presented.

METHODS

Study Area

Wolong Nature Reserve is located in southwestern China (see Figure 4.1). It was designated as a nature reserve in 1963 with an area of 200 km^2 and expanded to 2,000 km^2 in 1975, with about 10 % of China's wild pandas living in the steep mountains from 1,200 m to 6,500 m in elevation (Figure 4.1). Pandas' survival relies on the quality and quantity of habitat that consists of forests as shelter and bamboo as their staple food source. They prefer flat terrain or areas with gentle slopes for ease of movement. Mixed conifer and broadleaf forests with understory bamboo located in the elevation range of 2,250–2,750 m are the most suitable habitat for giant pandas (Schaller et al., 1985).

However, the reserve is also home to more than 4,500 rural residents in about 1,100 households (Wolong Administration Bureau Department of Social and Economic Development, 2006). Most of the local residents are farmers, living in a subsistence economy and extracting "free" forest resources through agriculture expansion, road construction, housing building, Chinese medicine gathering, and fuelwood collection.

Human activities are the major factor threatening panda habitats in the reserve (Liu et al., 1999c).

The interactions among people, pandas, and policies are complex (Figure 4.2). Rapid human population increase, changes in household structure and size, and fast economic development have accelerated the panda habitat degradation (Liu et al., 1999c; Liu et al., 2001b; Vina et al., 2007). This negative impact has endangered the panda population to the brink of extinction, and triggered the government to implement many conservation-oriented policies historically and continually. For example, three programs have been initiated in the reserve since 2000: hydropower plants provide electricity to local residents to help them eliminate fuelwood use, the Grain-to-Green Program (GTGP) provides subsidies to farmers with grain and cash if they convert their cropland to forested land (by 2003, 75% of cropland, or 560 of 742 ha, had been planted with trees or bamboos), and the Natural Forest Conservation Program (NFCP) provides subsidies to households for monitoring one or several forest parcels from illegal harvesting (e.g., fuelwood collection) (Vina et al., 2007; Liu et al., 2008b). These policies are aimed to directly change human social and economic behaviors and indirectly protect panda habitats and populations. For instance, under serious enforcement of and with direct grain or cash subsidies from these policies, many households dramatically reduced fuelwood consumption by switching to electricity after 2000 (Wolong Nature Reserve, 2005b). It was estimated that about 60–80% and 30–40% of the energy needs for cooking human food and heating houses in winter, respectively, were switched from fuelwood to electricity (see chapter 3). Another notable change is that a number of local households, especially those located in lower elevations, started to feed their pigs uncooked fodder during periods that varied from one month to a whole year. This accounts for a reduction of 20–30% in fuelwood for cooking livestock fodder (see chapter 3). These changing processes and their potential impacts on panda habitat are characterized with nonlinearity and delay and may end up with unexpected results (Liu et al., 2007a). It is essential for decision makers to understand the dynamics of these interactions in the long run.

We consider fuelwood collection, a main human activity affecting panda habitat and population, to be a key link among people, pandas, and policies in the reserve. In WOW, models were developed to simulate the dynamics of rural human population at the individual and household levels, calculate fuelwood consumption based on demographic and social factors of households, estimate fuelwood production if harvesting plantation forests, and predict the locations of fuelwood collection and the costs of using electricity for each household. WOW can also evaluate the dynamic impacts of fuelwood collection on panda habitats at the reserve landscape level given different policy scenarios. Based on the multicriteria decision-making (MCDM) methodology (Malczewski, 1999), we also developed a policy scenario evaluation component to help decision makers assess and compare different policy scenarios and then choose the best based on their own ecological, economic, and social preferences.

WOW is web-enabled and accessible to stakeholders from anywhere and at any time. Stakeholders for panda conservation in Wolong may include local residents spatially dispersed in the reserve, reserve managers and government officials of various administrative levels (e.g., county, province, and nation) geographically distributed in

China, as well as scientists, NGOs, and the general public geographically isolated worldwide.

System Design and Structure

The WOW system consists of four components: browsers, Web server, Web application server, and database in a three-tier framework as illustrated in Figure 4.3. Users interact with the system through the Web as a universal interface in a browser. They send requests from browsers to the Web server. The Web server filters those requests for WOW and passes them to a dedicated instance of the Web application server. The application server parses them and invokes the models, which then interact with the GIS server and the database server to retrieve spatial and non-spatial data and execute necessary spatial and non-spatial operations. These two latter servers finish most computational tasks in the models. When this step is done, the application server transfers the resulting outputs into the format of HTML and sends them through the Web server back to browsers for users to view.

In WOW, most computationally intensive operations such as spatial analyses and system simulation are done in the server side located remotely (e.g., the Web server and the Web application server). In this way, domain models and expensive GIS software are shared. It also eases data management and promotes information sharing. This design may reduce system performance because more transportation between clients and servers is required. Thus, several endeavors were made to use computing capabilities in the client side (i.e., users' browsers) as well, e.g., mouse positions and actions on GIS maps were collected by JavaScript, and a system menu implemented in JavaScript facilitates navigation between Web pages.

We chose Internet Information Services 6.0 (IIS) as our Web server, Tomcat 5.0 as the Web application server, ESRI ArcGIS Server 9.0 as the GIS Server, and Oracle Express 10g as the database server. The system supports most standard browsers, such as Internet Explorer and Netscape. All components are free under GNU licensing terms or bundled with hardware or are discounted for educational uses. WOW was developed and deployed as a part of the Web application server. The system was integrated in a Windows server 2003 environment and is accessible at http://panda.csis.msu.edu/wow.

System Development and Implementation

Java was chosen as the primary development language because it enables interoperability and is free (Palmer, 2000). System models work tightly with the ArcGIS server, providing access to spatial data and GIS functionalities. User information and policy scenarios are stored in databases, allowing later evaluation and re-access from different users. The Web interface was implemented using JavaServer Page (JSP) technology based on JavaServer Faces (JSF) framework (Armstrong et al., 2005). Model results are visualized in the form of graphs, tables, and maps. A typical work flow for a new user of the system is illustrated in Figure 4.4. System development and implementation are detailed below.

Models

The core of WOW is the model base consisting of seven models. Figure 4.5 illustrates an overview of the input, analysis processes, data flow, and the output of these models. The human population dynamics model and fuelwood consumption model (An et al., 2001; An et al., 2002; An et al., 2006) are briefly discussed first. The other five models are then described in more detail.

consumption model (An et al., 2001; An et al., 2002; An et al., 2006) are briefly discussed first. The other five models are then described in more detail.

The human population dynamics model simulates yearly events of individuals in each rural household in the reserve since 1996, including birth, death, marriage, and migration (out of or into the reserve because of education or marriage) (An et al., 2001). Household dynamics (e.g., creation, dissolution) are also considered (An et al., 2001). After this simulation, the fuelwood consumption model predicts the amount of fuelwood each household consumes each year based on the household size and structure, and other socioeconomic factors such as the amount of cropland belonging to the households (An et al., 2002; An et al., 2006). To simulate the years after 2000, the effects of NFCP and GTGP can be considered if users prefer to do so. A user can specify a switch rate from fuelwood to electricity for each component of fuelwood consumption (cooking human food, cooking livestock fodder, and heating houses). These switch rates are applied to each household in the reserve while the rates for the years before 2000 are calculated based on the socioeconomic conditions of specific households (An et al., 2002).

Reforestation for fuelwood model: Though there are plenty of plantation forests, mainly of Japanese larch (*Larix kaempferi* (Lamb.) Carr.), from afforested croplands or reforested clear-cut timberland in the reserve (Wolong Nature Reserve, 2005b), which are believed to not be suitable habitat for pandas (Bearer, 2005; Bearer et al., 2008), households are not allowed to harvest them for fuelwood by the present regulations. This model estimates the production of fuelwood if afforested larch plantations are thinned in the reserve given different combinations of thinning intensity, starting year, and thinning cycle. A larch plantation growth model under thinning was derived from the literature. Households are assumed to collect fuelwood from thinning plantation stands rather than in natural forests if this model is included in the simulation. If fuelwood is not needed from natural forests, no fuelwood collection site is allocated for the households by the fuelwood site distribution model.

Economic impact of fuelwood collection model: The less fuelwood households collect from natural forests or plantation forests, the more electricity they consume and the more cash they need to pay. Using standard heating conversion equations for fuels (Forest Products Laboratory, 2004), we convert a certain volume (in cubic meters) of fuelwood substituted by electricity to the equivalent amount (in kWh) of electricity and calculate the costs of electricity (in USD) for each household. Finally, the model reports the total annual electricity expenses as

$$\text{ElectricityExpense}_i = \left(\sum_{1}^{N}\text{FWSubstituted}_{ij}\right) \times 0.7 \times 574{,}000 / 3{,}340 \times \text{ElectricityPrice} / 7.0, \qquad [4.1]$$

where $\text{ElectricityExpense}_i$ is the total electricity expense (USD) of the year i, $\text{FWSubstituted}_{ij}$ is the volume of fuelwood (cubic meters) switched to electricity in the year i for the household j (j is from 1 to N, the total number of households), 0.7 is the average density (ton/m^3) of fuelwood, 574,000 is the net heating value of a unit of fuelwood (Btu/ton), 3,340 is the net heating value of a unit of electricity (Btu/kWh), ElectricityPrice is 0.10 RMB/kWh in or before 2000, 0.18 RMB/kWh after 2000, and 7.0 is the currency exchange rate from RMB to USD (RMB/USD).

Fuelwood site distribution model: To analyze the impacts of fuelwood collection on panda habitat, we need to know where households collect fuelwood. To achieve this, we adopted an empirically based methodology from our field observations and household surveys conducted in 2002 about farmers' behaviors of fuelwood collection (Neto, 2003). The methodology is depicted in Figure 4.6.

Fuelwood collection in natural forests is often accomplished yearly in the winter by groups of 10–20 people in the reserve. Most group members are neighbors, friends, or relatives. They shared fuelwood sites to increase efficiency and minimize risks in the rugged high mountains. Households usually do not change areas for fuelwood over time unless fuelwood stock runs low enough in those areas (the model used 20% as the threshold based on our household surveys). Otherwise, they may find another spot close to the previously used one. Thus, we defined these areas as potential fuelwood collection areas (PFAs) which are topographically similar polygons, each associated with a group of households that collect fuelwood collaboratively. The 280 NFCP parcels were delineated (Sichuan Forestry Survey Institute and Wolong Nature Reserve, 2000b) so that they are topographically similar to facilitate forest monitoring. A more recent survey also shows that local households collected dead trees or branches (illegally), often in their own parcels, after NFCP was started (Chen et al. unpublished). Thus NFCP parcels could be treated reasonably as PFAs in WOW.

The initial PFAs of the 200 households surveyed are the NFCP parcels where they collected fuelwood in the 1990s. The initial PFAs of the remaining households were determined to have been those of their nearest-neighbor households that we surveyed. Newly formed households use the same PFAs as their parental households. In the simulation, a randomly selected point (pixel) inside a PFA polygon is assigned to the household associated with the PFA as its fuelwood collection site in a given year if the household needs to collect fuelwood from natural forests. The algorithm to determine if a household collects fuelwood from natural forests is described in Figure 4.7.

Habitat impact assessment model: After the fuelwood collection site (point) was derived for each household, the type of habitat where fuelwood collection occurs was determined by overlaying fuelwood sites on a map of the panda habitat suitability index (HSI) in the habitat impact assessment model with a 30×30-meter resolution. The resulting maps were used for further landscape-level spatial pattern analyses of human activities and panda habitat. For example, the total areas of habitat affected by fuelwood collection grouped by habitat type were calculated as a preliminary indicator of the impact on panda habitat in WOW.

Multicriteria decision-making model: Generally speaking, all conservation actions can directly and indirectly have ecological, economic, and social impacts on human communities and/or wildlife habitat and populations (Rossi et al., 2008). Therefore, WOW was designed to allow each decision maker to integratively evaluate a scenario (defined by the parameters from all the models) from the three criteria (Ecological, Economic, and Social). Each decision maker has three weights assigned to one criterion. Each is ranged from 0 to 1 and totaled to 1; the higher the weight is, the more important a scenario is from the corresponding criterion. Based on the output from the scenario simulation and their personal preferences, decision makers then assign a score to the scenario for each criterion. The score is in the scale 0–10; the higher the score is, the less negative impact the scenario has on the corresponding criterion and the more the scenario is preferred from the corresponding criterion. The most commonly used decision rule, Simple Average Weighting (SAW), of the multicriteria decision-making methodology (Malczewski, 1999) was implemented to summarize these scores, as briefly explained below.

The score S_{ij} (0–10) that a scenario i receives from a user j is calculated as

$S_{ij} = \sum_{k=1}^{n} (W_k \times S_{kij})$, where W_k is the weight of the k^{th} criterion the user j perceives, n (= 3 in our case) is the number of criteria the user j has, and S_{kij} is the score the user j gives to the scenario i based on his/her criterion k. The total performance score s_i (0–10) of the scenario i is given as $S_i = (\sum_{j=1}^{m} S_{ij}) / m$, where j represents the j^{th} user who evaluates the scenario, and m is the number of users who evaluate the scenario i. Based on the S_i, the scenarios can be ordered. The higher the score is, the better the scenario is perceived collectively by evaluators or stakeholders and integratively from social, ecological, and economic perspectives.

In this prototype, WOW provides information mainly on the ecological, economic, and social impacts of scenarios. WOW is aimed to provide a platform and support the stakeholders in organizing and synthesizing information for the issue under consideration. Some other impacts are left to stakeholders to explore (Mysiak et al., 2005; de Anguita et al., 2008): the possible human health improvement if switching from fuelwood to electricity, the monetary value and cost of habitat restoration, the effects of human activities on panda behavior, and the economic effects of NFCP and GTGP on governments and rural households. WOW users or scenario evaluators may express their opinions on these impacts by adjusting the scores to the scenarios when evaluating these impacts.

Database

To simulate fuelwood needs and collection and their impacts on panda habitat, WOW processes and manipulates two major types of data: spatial and non-spatial. They are stored in different places with appropriate formats. Demographic data on 4,413 individuals and 893 households in 1996 (An et al., 2001; An et al., 2006) are stored in two text files as initial states of the models and loaded into the computer memory when the system is initialized. Replicates are made in computer memory every time a new simulation starts. Locations of households and their associated PFA polygons and HSI maps from 1997, derived from remotely sensed imagery (An et al., 2001), exist as files and are managed as layers in the ArcGIS server. They are accessible to models through Java codes. Information about WOW users (name, password, email address, etc.), their preference weights of evaluation criteria, their proposed scenarios (consisting of model parameters), scenario simulation results including number of households, number of individuals, fuelwood demand, fuelwood produced from reforestations, annual electricity expense, and areas of impacted habitat by type, and scenario evaluations (evaluation scores, see Table 4.2) are stored in an Oracle Express database and updated on-the-fly. Some examples of intermediate data are information on the amount of fuelwood consumption of each household, newly born babies, new households, and fuelwood collection sites. They may be kept temporarily or cleared when a new simulation is initialized to save storage space on the server side.

Interface

To facilitate efficient and effective use of the system, WOW's interface was designed for desktop application, following the Model-View-Controller (MVC) pattern widely practiced in software engineering (Sun Microsystems Inc., 2002). Users can accomplish most tasks (e.g., model parameter input, systems simulation, scenario evaluation and management) and view results in a single web page after logging onto the system without navigating to other web pages. Each action updates only the corresponding part(s) on the page. This page is divided into four parts and the screenshot in Figure 4.8a demonstrates this.

Users can change the parameters of models and simulations and start a simulation in the upper left part (Figure 4.8b). The simulation results are shown as colored lines with legends in the lower left corner (Figure 4.8c). Most key tasks (updating criteria; creating, deleting, updating, loading, and evaluating a scenario) related to scenario management can be done in the lower right part (Figure 4.8d). In the upper right part (Figure 4.8e), household locations, HSI, and other complementary information of the system are shown and users can operate most basic GIS functionalities (e.g., zoom in and out, pan, identify, layer control, scale, overview). Some complementary information, such as user name and currently loaded scenario ID, is shown above this part under the page title (Figure 4.8e). Other supporting documentations such as help are deployed on other web pages as well. All the web pages are driven by a menu located at the top of the screen (Figure 4.8f). Because of the universal interface of Web and online help (e.g., when the mouse pauses on a button for a while, the functionality of the button will show up in a separate, small window), little time is needed for users to learn. The basic GIS capabilities can help users become familiar with the study area and the research issues

(Figure 4.8e). Further information about the system models and the study site is provided as web links of referenced literatures, which can be opened in a separate browser window.

RESULTS

Model Testing

Most of the models used in WOW have been verified and validated in published literature. For example, the human population dynamics and fuelwood consumption models were developed and validated in An et al. (2001; 2005; 2006), the reforestation for fuelwood model in Li et al. (2000) and Ma et al. (1998), and the habitat suitability map used in the habitat impact assessment model in Liu et al. (1999c). The equations and parameters used for the economic impacts of the fuelwood collection model have been tested by the U.S. Forest Service (Forest Products Laboratory, 2004). The fuelwood site distribution model was validated by comparing the simulated fuelwood collection locations with the ones from surveys conducted in 2002 (He et al., in review). The results show that all surveyed sites in the 1990s were inside the fuelwood collection buffer zone defined as the maximum polygon that contains all the predicted locations during the same period. Approximately 64.5% of surveyed fuelwood sites in the 1990s were within 120 m of predicted locations during the same period, 21.6% were within 120–180 m, and the remaining 13.9% were within farther distances. In summary, the models work well and WOW's integration with these models gives us reasonable confidence for later decision analysis.

Scenario Simulation

To demonstrate the functionalities and capabilities of the WOW system, four scenarios were simulated for a period of 20 years (1997–2016) with 20 replicates. Parameters used for each model in the four scenarios are shown in Table 4.1. We intended to show the effects of NFCP and GTGP and thinning plantation forest stands for fuelwood, so human population parameters were set the same for those scenarios. Scenario ***A*** is the baseline assuming NFCP and GTGP were not implemented and without thinning plantation forests for fuelwood. Scenario ***B*** simulates fuelwood consumption under the impact of NFCP and GTGP. Scenario ***C*** simulates fuelwood consumption under the impact of NFCP and GTGP and fuelwood supply from harvesting plantation forest stands. Scenario ***D*** assumes higher rates (than ones used in scenarios ***B*** and ***C***) of switching from fuelwood to electricity, and determines whether fuelwood supply from plantation forests meets the consumption need. Some of the results on fuelwood need and supply are shown in Figure 4.9.

Compared to Scenario ***A***, Scenario ***B*** showed that implementation of NFCP/GTGP may reduce approximately 30% of the fuelwood consumption of households but households still need to cut natural forests to meet the remaining 70% of fuelwood. Considering reforested stands as the source of fuelwood, Scenario ***C*** may reduce 50% of fuelwood needs from natural forests. Harvesting plantation forests could provide a substantial portion of fuelwood needs. The existing larch plantations could supply enough fuelwood for all households so that no natural forests are needed any more if higher rates of switching to electricity could be realized, possibly by greater investment of NFCP and GTGP after year 9 (Scenario ***D***). Consequently, a large amount of panda habitat could be preserved from reduced fuelwood collection in natural forests (Figure

4.10). Compared to Scenarios ***A*** and ***B***, Scenario ***C*** saved more than 50% of affected habitat of each type (Highly, Moderately, Marginally suitable and Unsuitable) during most of the simulated years. Since in Scenario ***D*** fuelwood needs of households are reduced (e.g., by 50% of the needs in Scenario ***C***, Figure 4.9a), the areas of affected habitat of all types are gradually decreased to zero (year 9). Meanwhile, we should notice that the economic burden on households to pay for electricity is increasing (Figure 4.9b). The annual electricity expense per capita in Scenario ***D*** doubles the ones in Scenarios ***B*** and ***C***, which double the one in Scenario ***A***.

Scenario Evaluation

We made the system public through several listservs of professional organizations such as the Ecological Society of America (ESA), the United States Regional Association of the International Association for Landscape Ecology (US-IALE), and the Society of Conservation Biology (SCB) in early October 2008. As of November 1, 2008, 76 users worldwide (eight countries in four continents) had registered in the system. Thirty-six of them have evaluated these four scenarios and more than 50 new scenarios have been constructed and simulated. The statistics of the scenario evaluation are shown in Table 4.2. Scenario ***D*** is preferred by most evaluators, followed by Scenarios ***B***, ***C***, and ***A***. The ranks of these four scenarios may change when more users evaluate the scenarios.

DISCUSSION

This preliminary WebGIS-based DSS was designed and developed to demonstrate the capability of integrating Web, GIS, DSS, and system modeling and simulation for coupled human-nature systems (Liu et al., 2007a; Liu et al., 2007b). Several models in the system were simplified and could be refined. For example, in the fuelwood site distribution model, fuelwood sites were randomly chosen in the PFA polygons in order to improve the computational performance. This may not represent the real-world situation because the pixel with more fuelwood stock in the PFA is usually favored. However, it could be enhanced by storing the fuelwood stock of the pixels in the PFA polygons and assigning the pixel with the maximum amount of stock to the household that collected fuelwood in the PFA.

The resulting dynamics of the numbers of households, household size, and fuelwood consumption and supply can be illustrated for only one scenario at one time. The current implementation does not allow comparisons of the results across scenarios simultaneously. This weakness could be overcome by extending the current visualization functionality. By design, a new plug-in (e.g., a Java class) can be added and the corresponding JSP could be easily modified for the plug-in without compiling the source codes of the core models or making major changes to the system structure.

The simulation of four scenarios showed that the proposal of harvesting larch plantations could provide substantial fuelwood or even more than the total need after year 10. The ideally best scenario (Scenario ***D*** with the switch probability to electricity from fuelwood for cooking, heating, and feeding pigs is 90%, 65%, and 35%, respectively) is reasonable based on our current field observations in the reserve. With NFCP and GTGP, and economic structure adjustments (especially because of ecotourism development, W. Liu at al. unpublished data), local household income may increase gradually and more electricity would be consumed in the future. We believe that it is feasible because a complex program such as NFCP has been implemented and enforced successfully by the local government (Wolong Nature Reserve, 2005b; Vina et al., 2007; Liu et al., 2008b).

The multicriteria decision-making method SAW used to evaluate decision alternatives in this study is utility-based, dominated in the multicriteria based-GIS applications (Malczewski, 2006). The outranking relation-based method, the other of the two main families of methods, may be useful since it allows the scenario evaluators to consider qualitative evaluation criteria for which preference interval ratios have no sense, limit the compensation between evaluation criteria, and in general, require limited information from the decision makers (Chakhar and Mousseau, 2008).

The four scenarios were introduced as a demonstration of the capabilities of WOW. Other scenarios (e.g., by changing demographic factors) can be proposed as they are being constructed by users worldwide in the search of the best policy interventions. The proposal of new and different scenarios is an indication of collaborative decision-making processes using WOW as a platform.

CONCLUSIONS

We presented a WebGIS-based DSS WOW to tackle a complicated wildlife conservation issue in coupled human-nature systems. With this platform, various geographically dispersed stakeholders can simulate the dynamics of human population and fuelwood needs, predict the locations of fuelwood collection, and then assess the impacts of fuelwood collection on the human community and panda habitat in Wolong Nature Reserve. Besides this, it demonstrates how such a spatial DSS can provide a set of solution spaces on which decision makers can focus their discussions and make collective choices assisted by multicriteria decision-making methodology. It can also enable decision makers to have a better view of the problem and to test different scenarios by varying the objectives, constraints, and parameters of the models.

The functionalities and capabilities were shown as well. The system presented here can potentially help stakeholders understand the dynamics of complicated coupled human-nature systems across different temporal and spatial scales. The demonstrated methodology can facilitate and assist decision-making processes because it integrates multiple sources of data and multidisciplinary knowledge within a universal user-friendly framework. The development done here also provides a good foundation that allows future extension and refinement of operational systems. This methodology can be used for similar issues in many other parts of the world.

Furthermore, the system enables group decision making. Although conservation problems encompass multiple stakeholders and their preferences should be combined to choose the best option, in reality, decisions are often made by one or few interest groups, such as central governments. Usually community members, NGOs, and the general public do not have a say or their inputs are rarely considered in the decision-making process. WOW provides an open platform for them to participate in the decision making. WOW can also be used as an educational tool for the general public to facilitate understanding of the dynamics of complex human-nature systems.

Table 4.1: Four simulation scenarios in WOW

Model	Variable	Scenario			
		A	B	C	D
Human population	Fertility (children/woman)	2.5	2.5	2.5	2.5
	Marriage age (years)	22	22	22	22
	College attendance rate (%)	1.92	1.92	1.92	1.92
	Female marry-out rate (%)	0.28	0.28	0.28	0.28
	Male marry-out rate (%)	0.043	0.043	0.043	0.043
	Female marry-in rate (%)	0.19	0.19	0.19	0.19
	Male marry-in rate (%)	0.043	0.043	0.043	0.043
	Leave home intention rate (%)	42.0	42.0	42.0	42.0
Fuelwood consumption	Rate switching to electricity from fuelwood for cooking (%)	N/A	70	70	95
	Rate switching to electricity from fuelwood for heating (%)	N/A	35	35	65
	Rate switching to electricity from fuelwood for raising pigs (%)	N/A	25	25	35
Reforestation for fuelwood	Thinning cycle (years)	N/A	N/A	1	1
	Age to start thinning (years)	N/A	N/A	10	10
	Thinning intensity (%)	N/A	N/A	3	3
	Age to end thinning (years)	N/A	N/A	60	60

Table 4.2: Scenario evaluation results from 36 evaluators

	Scenario A	Scenario B	Scenario C	Scenario D
Number of evaluators	36	35	35	33
Average scores	4.41	5.55	5.53	6.33
Standard deviation	2.28	1.95	1.86	1.67

Note: the average scores of the four scenarios are significantly different ($F_{3,128} = 8.33$, $p < 0.001$ from a one-way ANOVA test) and the mean score of Scenario ***D*** is significantly greater than the second biggest score of Scenario ***C*** ($t = 1.78$, $p = 0.039$, $df = 66$ from a one-tail t test).

Figure 4.1 Study site – Wolong Nature Reserve

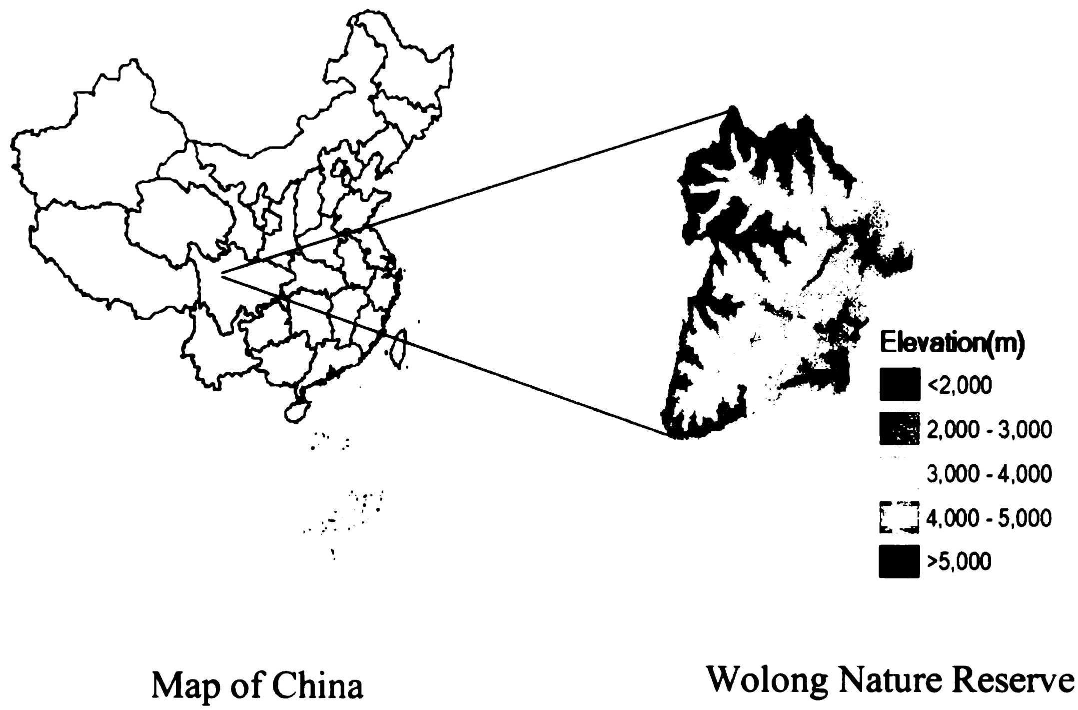
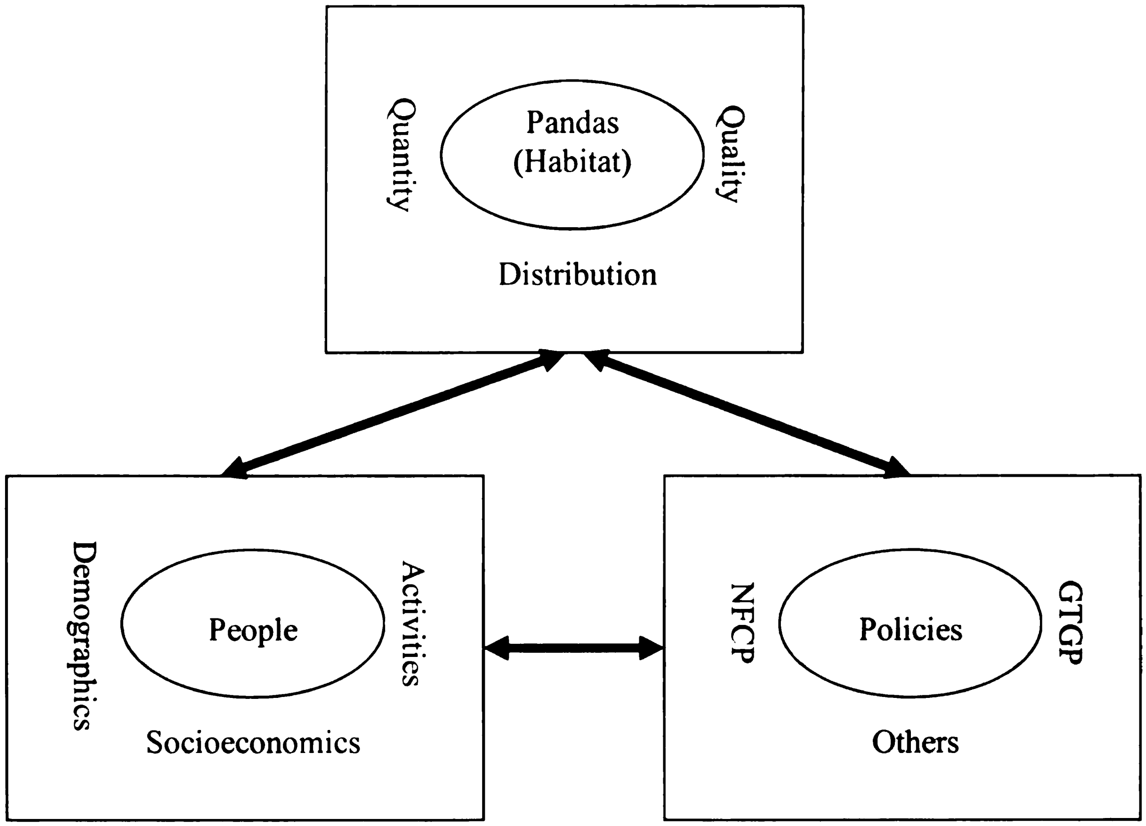


Figure 4.2 Interactions among pandas, people, and policies



Note: NFCP, Natural Forest Conservation Program; GTGP, Grain-to-Green Program

Figure 4.3 Three-tier architecture of the WOW

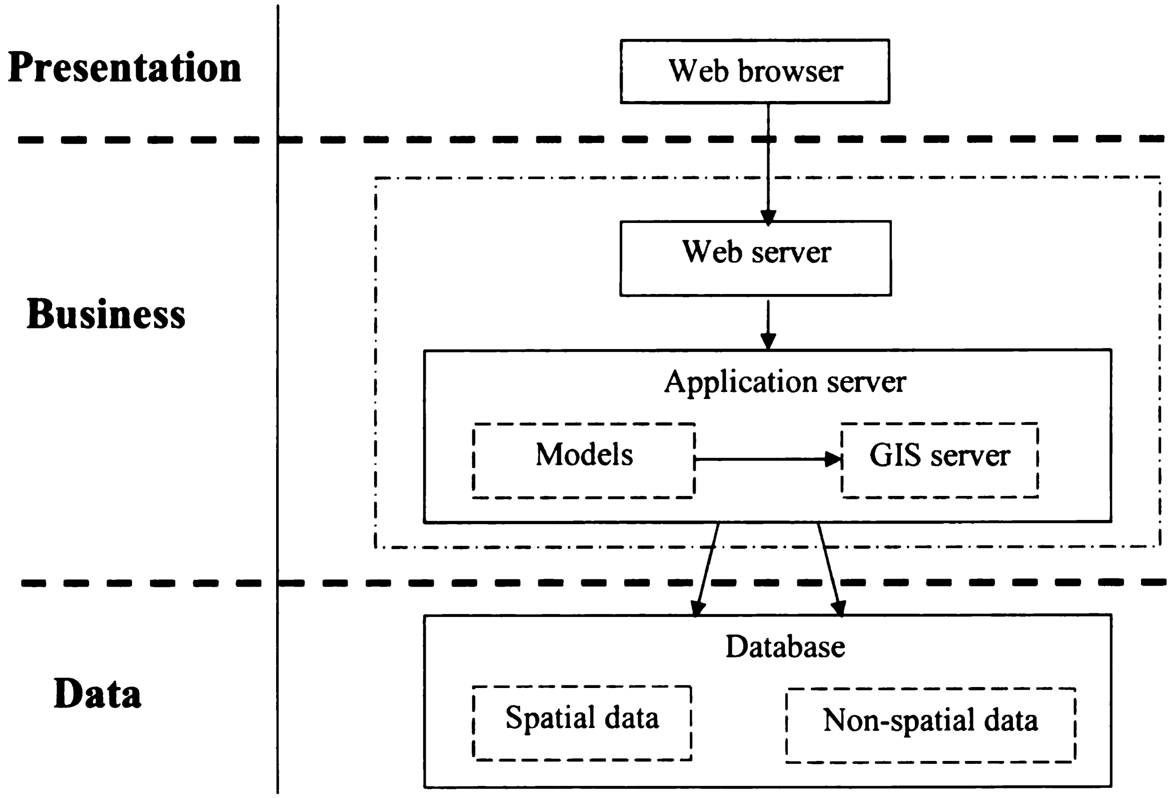


Figure 4.4 A typical work flow for a new user in the WOW

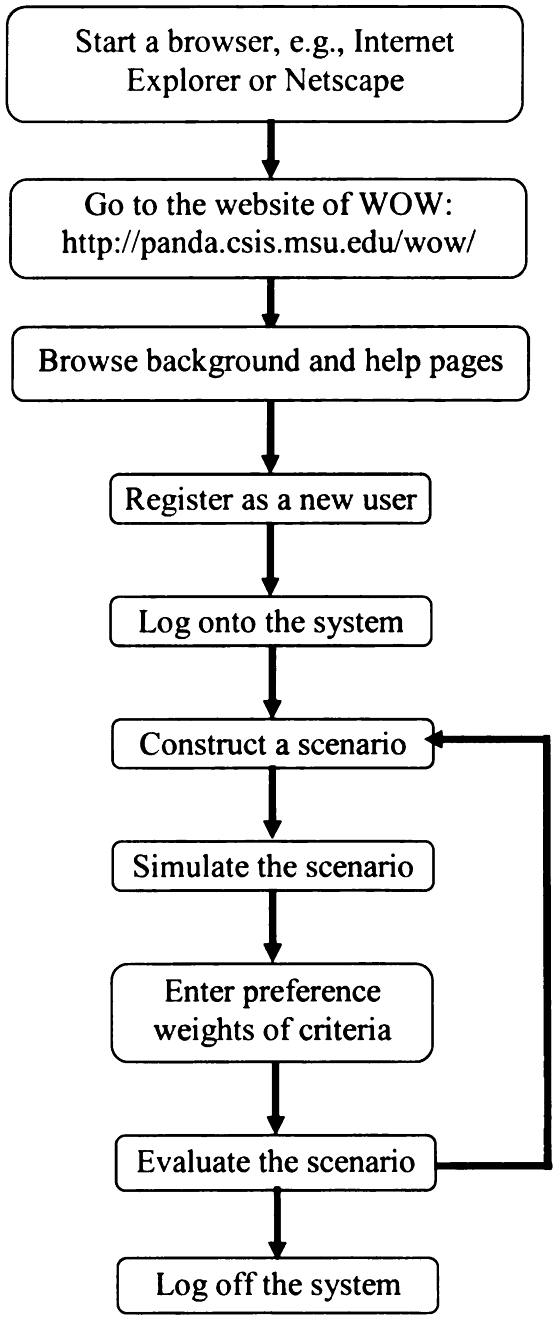


Figure 4.5 Overview of the input, output, and analysis flow of the WOW

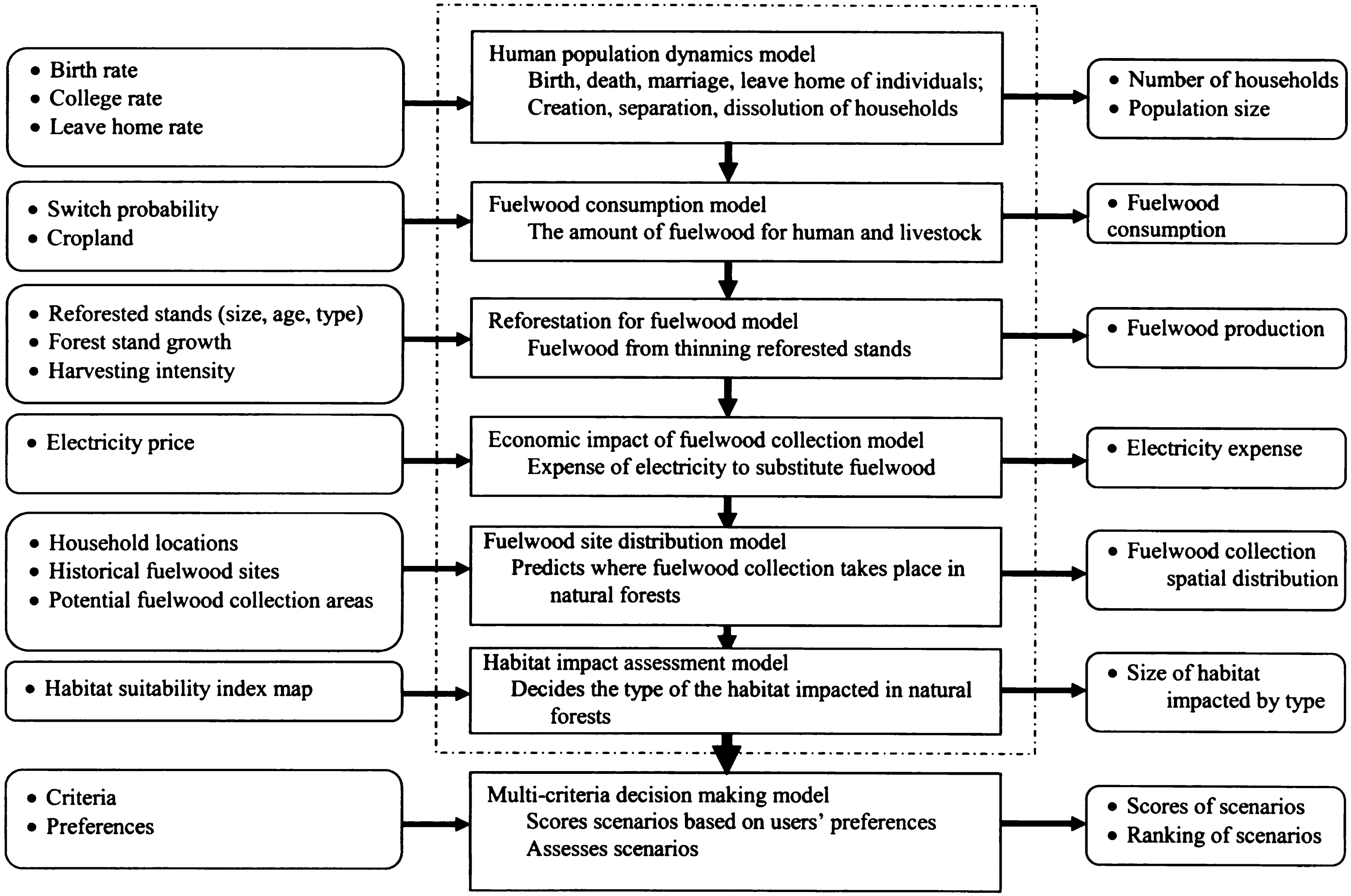


Figure 4.6 Algorithms of predicting the location of fuelwood collection

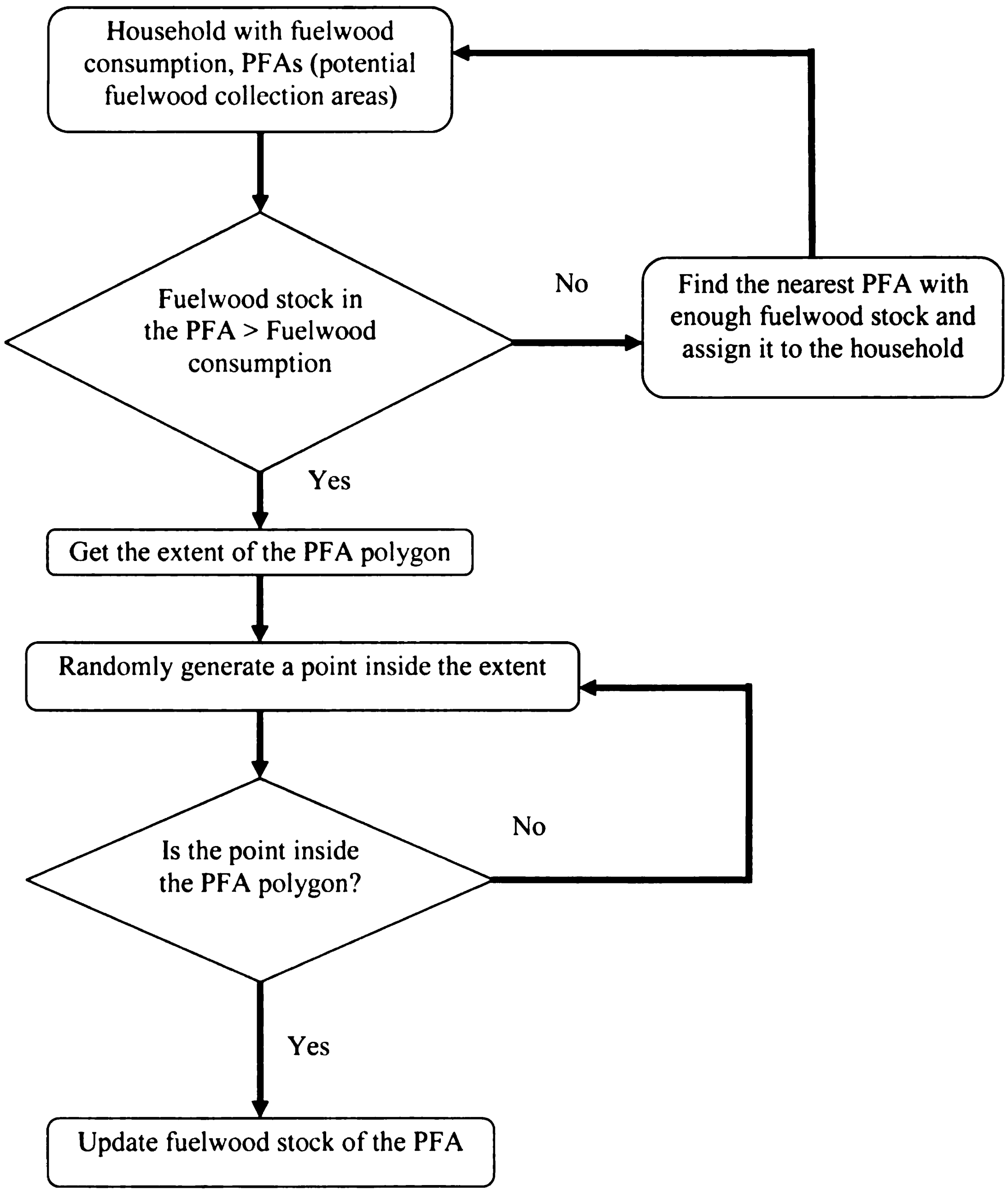


Figure 4.7 Algorithms of determining whether or not a household collects fuelwood from natural forests

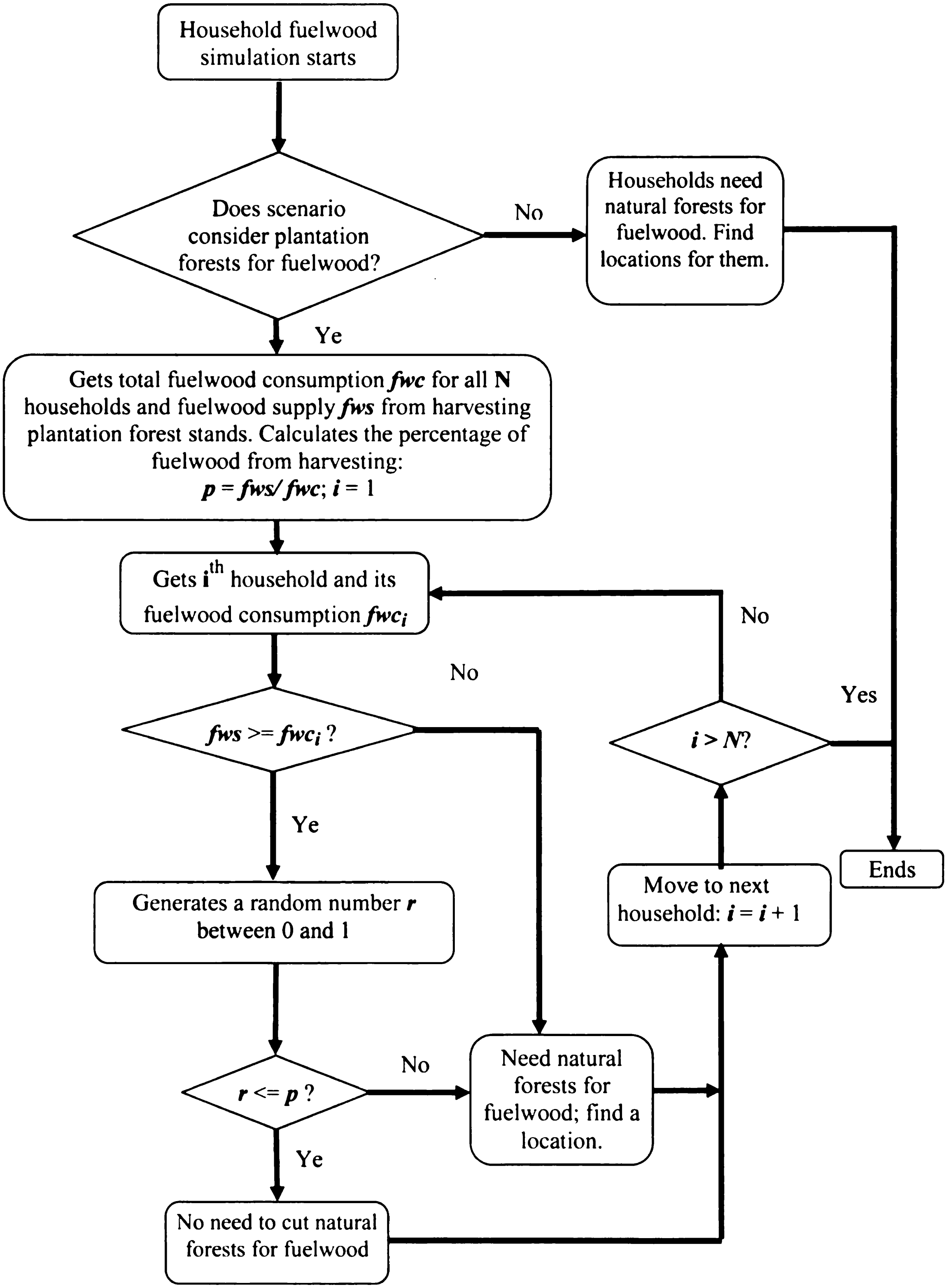


Figure 4.8 Screenshots of the WOW illustrating (a) the layout of the main page with four parts, (b) models, (c) simulation results, (d) scenario management, and (e) GIS layers in map, and (f) menus used for navigation into other pages

a

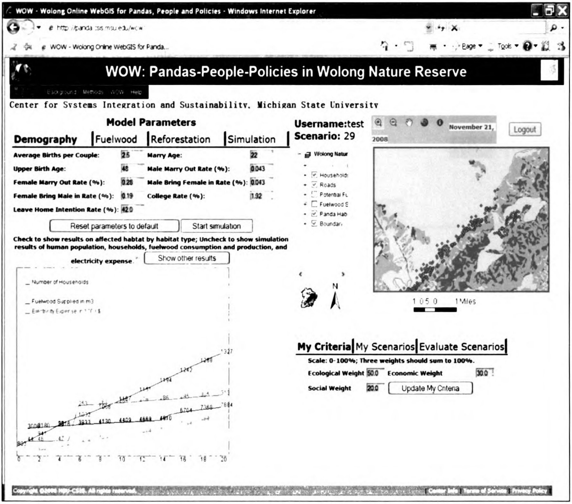


Figure 4.8 continued

b

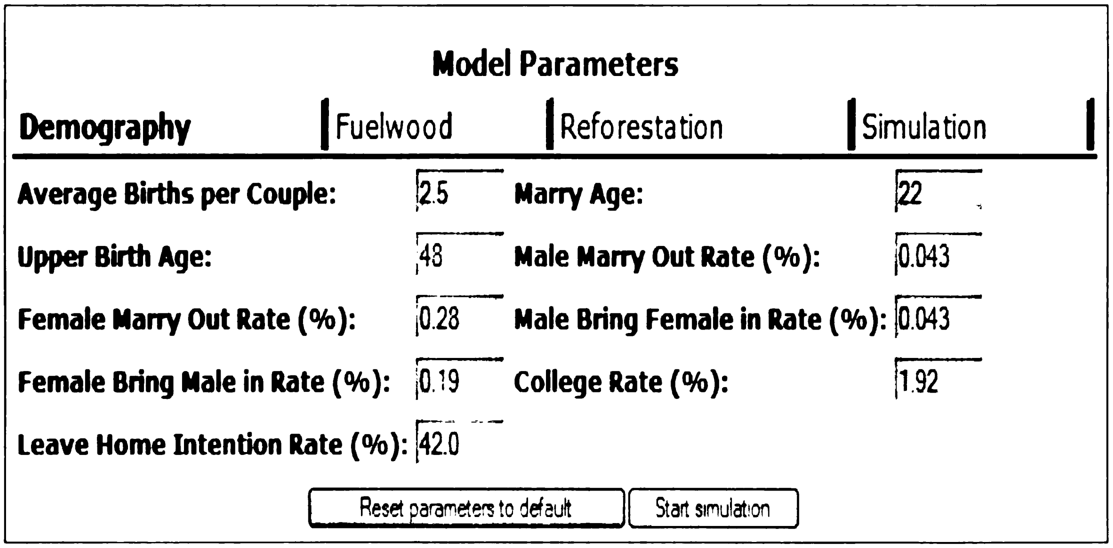


Figure 4.8 continued

c

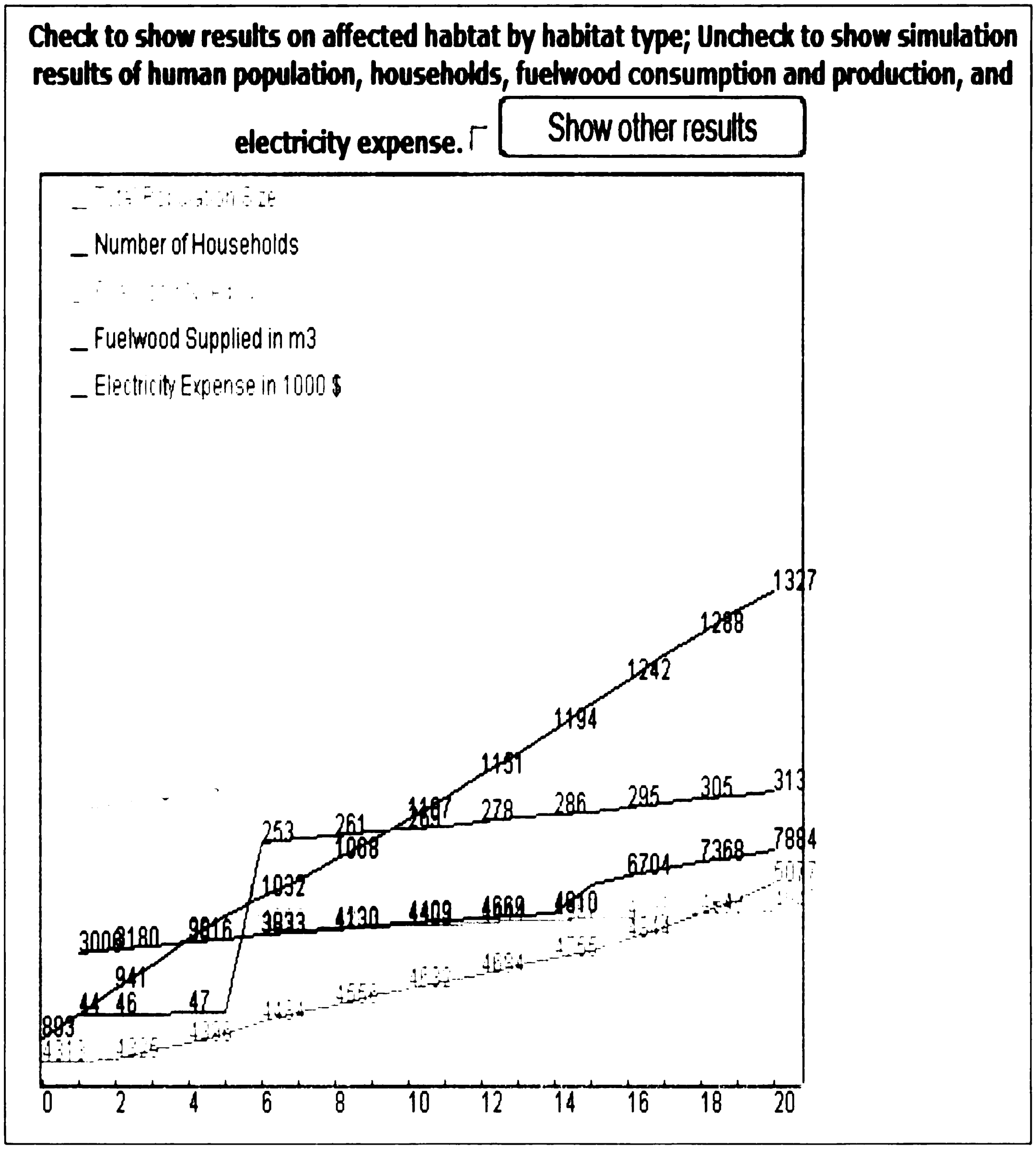


Figure 4.8 continued

d

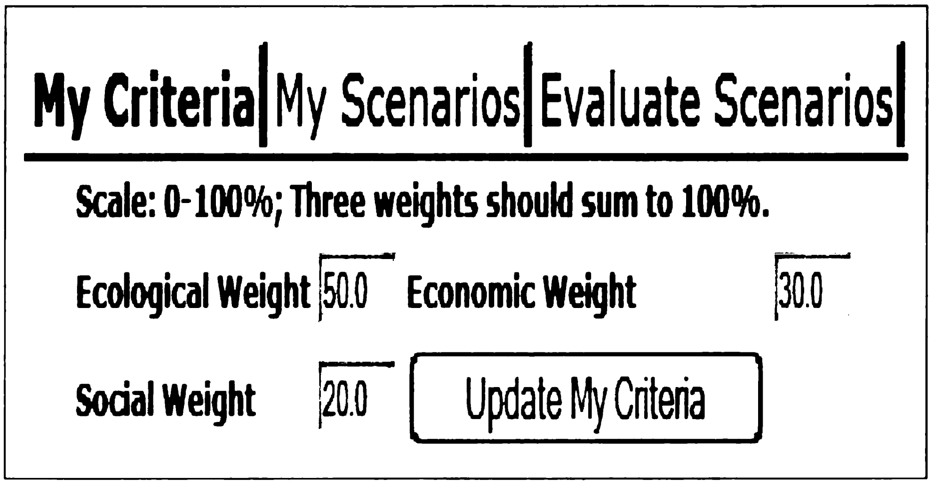


Figure 4.8 continued

e

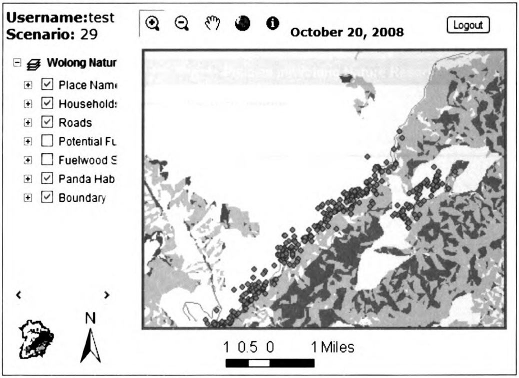


Figure 4.8 continued

f

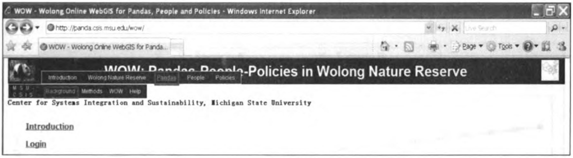
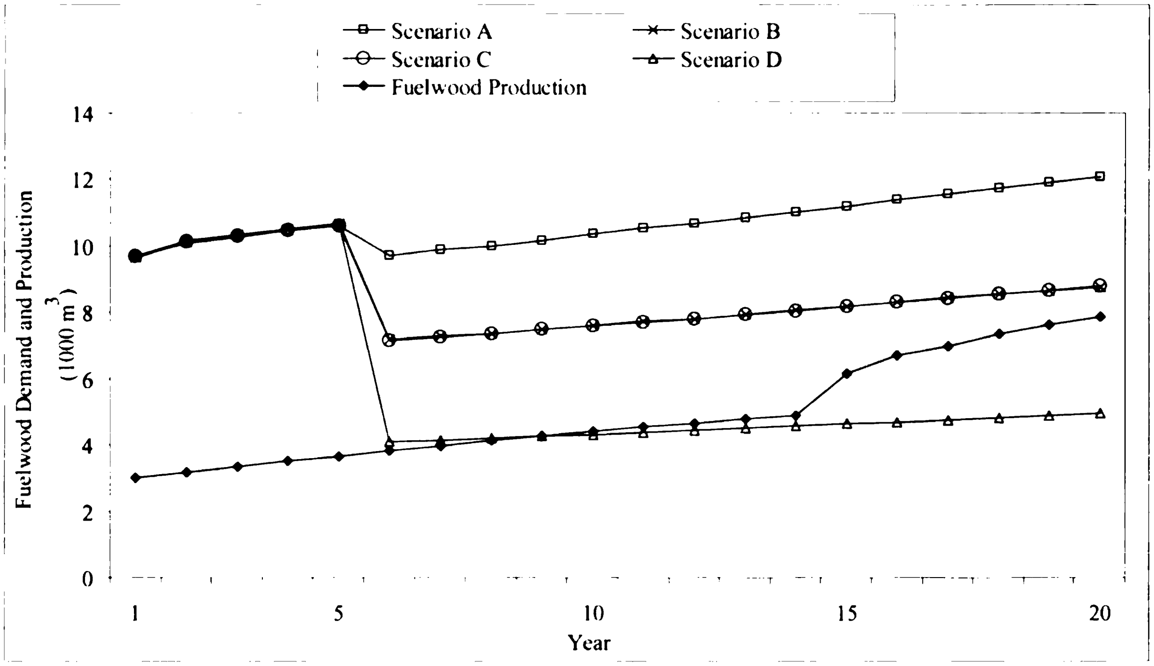


Figure 4.9 Fuelwood (a) demand and supply and (b) electricity expense dynamics of four scenarios

a



b

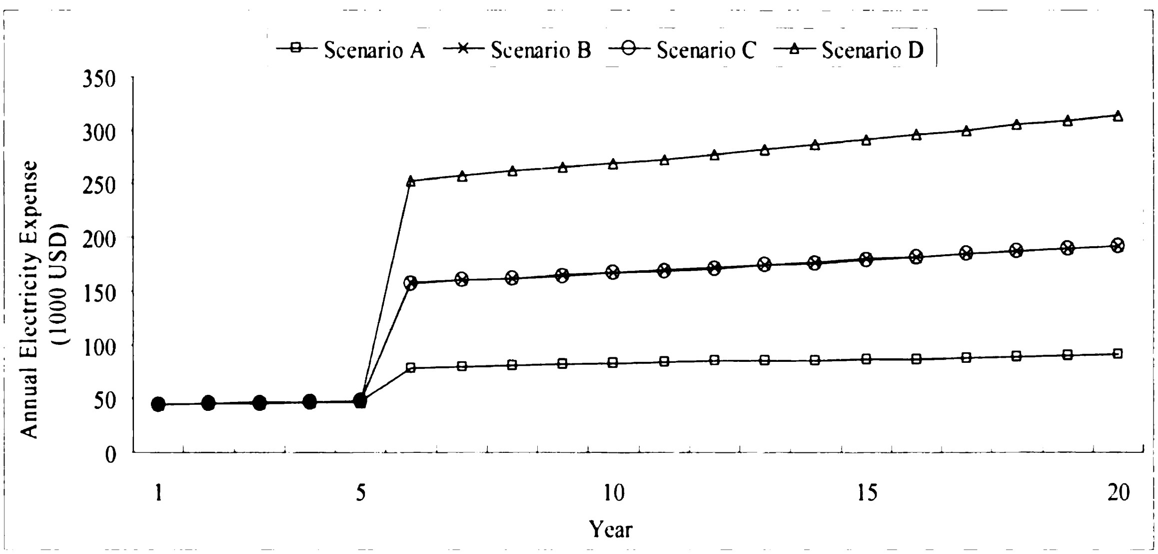
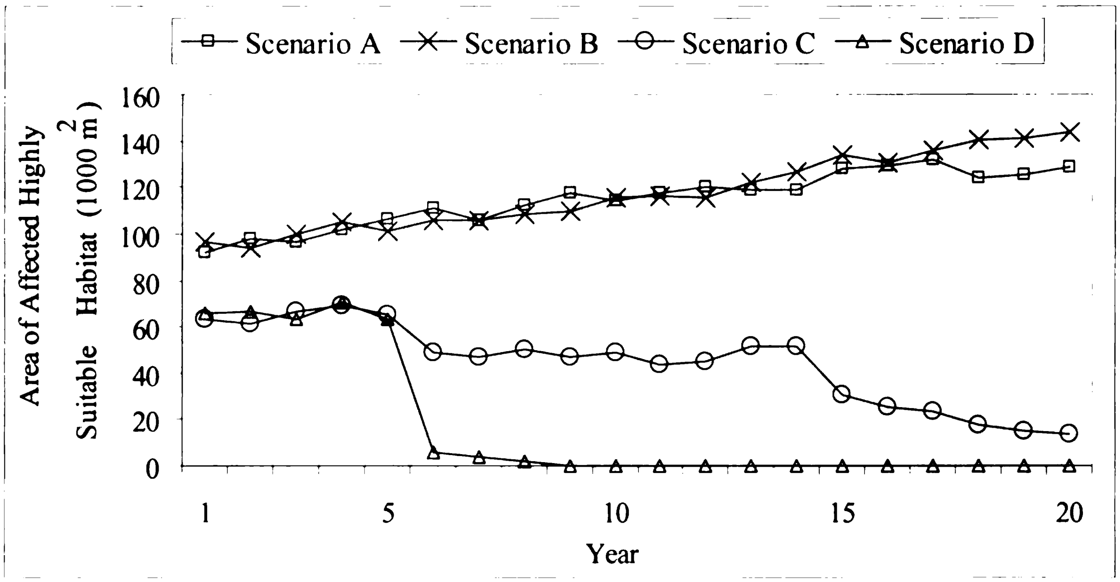


Figure 4.10 Impacts of four scenarios on panda habitat of four types: (a) highly suitable, (b) moderately suitable, (c) marginally suitable, and (d) unsuitable

a



b

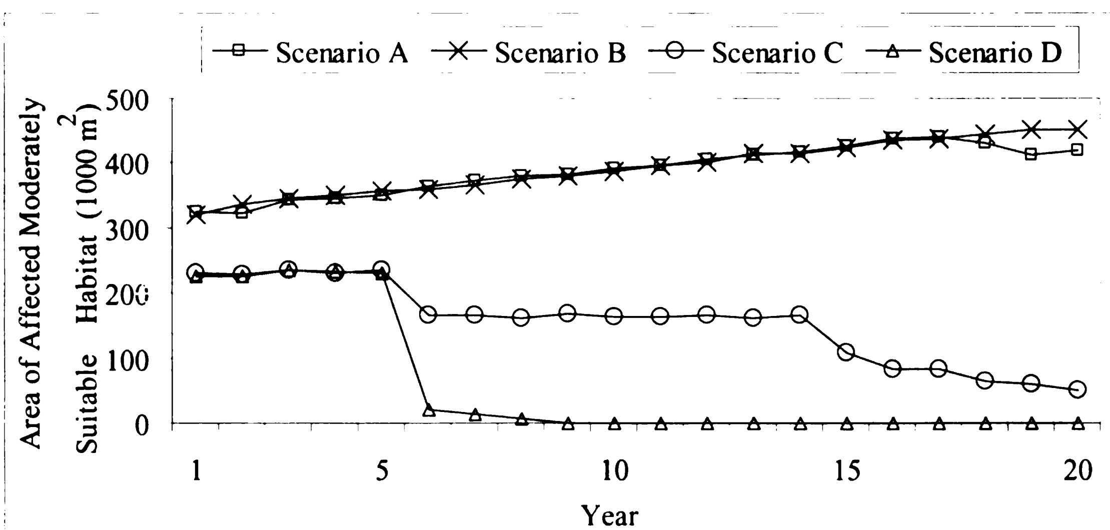
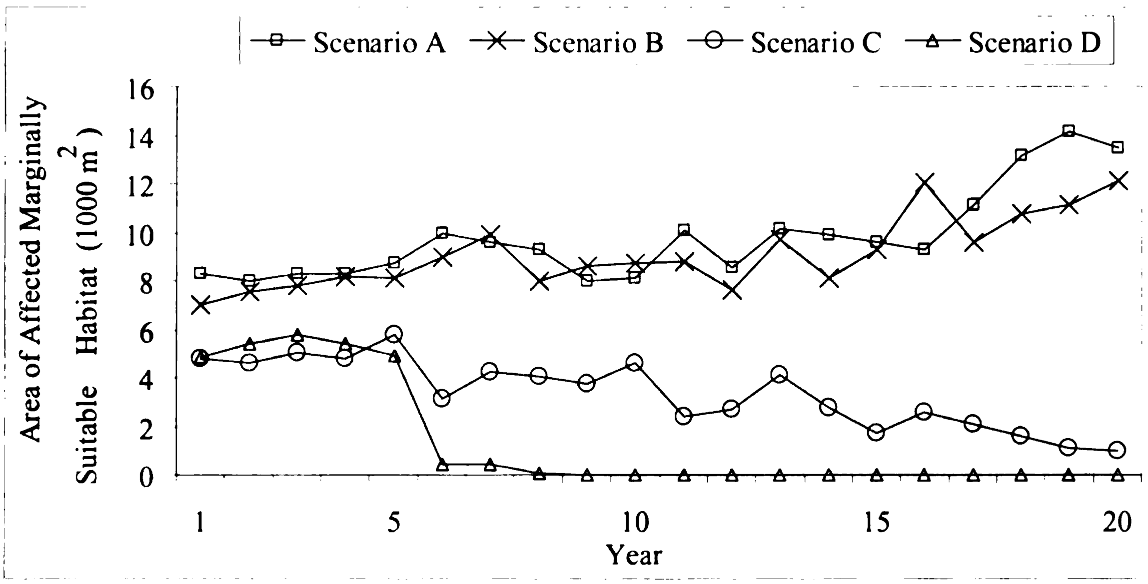
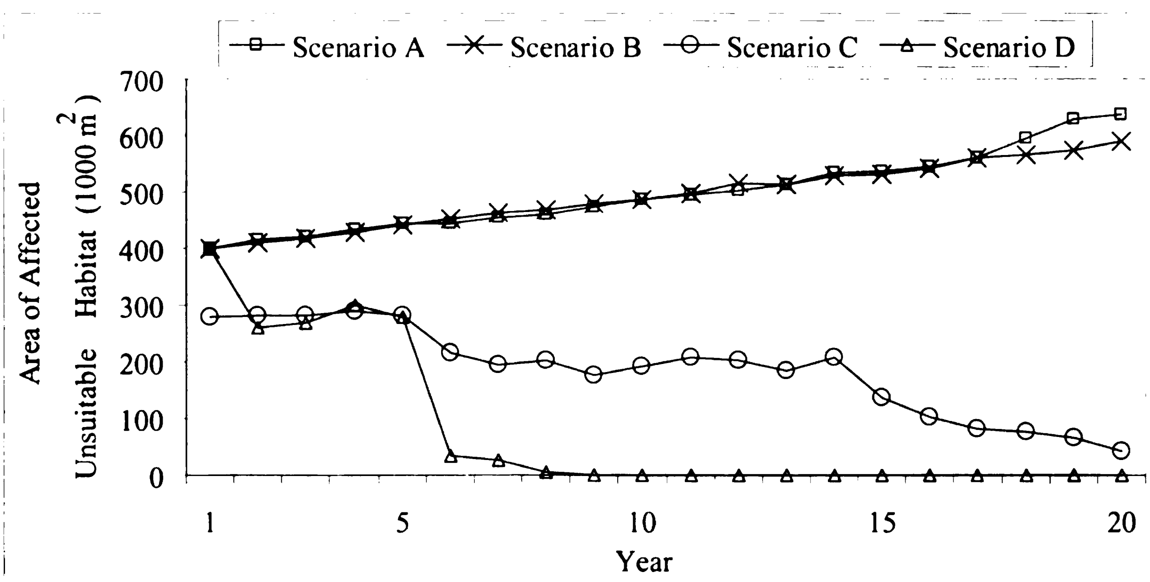


Figure 4.10 continued

c



d



CHAPTER 5

THINNING PLANTATION FORESTS FOR FUELWOOD: SEARCH FOR SUSTAINABILITY

ABSTRACT

When wildlife and humans compete for natural resources and their needs conflict, conservationists often blame human beings and tend to create nature reserves, where resource-extractive activities are normally not allowed. Especially in developing countries, human communities usually live a traditional subsistence lifestyle heavily dependent on the extraction of natural resources, but possible sustainable resource-use schemas are rarely explored. In the case of giant panda (*Ailuropoda melanoleuca*) conservation in China, there is no exception. Human activities such as timber harvesting, fuelwood collection, Chinese medicine gathering, agriculture, urbanization, and tourism have led to habitat fragmentation and loss. Many of those activities, such as commercial timber harvesting and fuelwood collection, have been completely or partially banned in panda reserves. Requirements of such dramatic changes in human behaviors are often deemed to fail in the long term because of economic and/or social reasons. This chapter presents a case where a sustainable resource-use schema could be achieved with appropriate policy design. I use Wolong Nature Reserve, the flagship for giant panda conservation in China, to demonstrate that its 967 ha of existing plantation forests can sustainably provide approximately 1,000 local rural households with enough fuelwood, the primary energy source for heating and cooking, if deliberate forest thinning plans and conservation policy regulations were applied. This chapter may also shed some light on the current energy crisis worldwide.

KEYWORDS: plantation forests, fuelwood supply and demand, thinning, sustainable resource, giant panda, Wolong Nature Reserve, China

INTRODUCTION

Sustainability of conservation policy and practices is key to successful wildlife conservation in the long run. In coupled human-nature systems (Liu et al., 2007a; Liu et al., 2007b), with the increasing population growth and technological development, human communities often overexploit natural resources such as forests on which wildlife also depends and thus endanger the survival of wildlife populations. Though it is arguable that conservation should be based on biocentralism or anthropocentrism (Lowry, 1984; Brown, 2003; Redford and Sanjayan, 2003; Chan et al., 2007), conservation practices considering human interests without impairing the environment can often be more acceptable and lead to successes (Arambiza and Painter, 2006; Kaimowitz and Sheil, 2007). Therefore, conservation policies and practices that create ecologically sound, economically feasible, and socially amiable sustainable prescriptions for human society are vital (Robinson, 2006; Chan et al., 2007). However, in reality, such potential sustainable resource-use options are rarely explored deliberately by conservation decision makers before creating protected areas and banning extractive human activities within such regions (Salafsky et al., 2001). It may be because of the political pressures from higher government administration and international interest groups (Orr, 2003). It may also be because of the ignorance of knowledge about sustainable natural resource uses (Boot and Gullison, 1995; Van Rijsoort and Zhang, 2005).

Thus, this chapter aims to present a case study of searching for sustainable natural resource uses in a protected area. This effort was assisted by WOW, a WebGIS-based DSS. The study site is located in mountainous western China and cohabitated by farmers and wildlife, including giant pandas. The farmers live in a traditional subsistence lifestyle and traditionally cut trees for fuelwood from natural forests, which often are suitable wildlife habitat (He et al., in review). A survey of fuelwood collection locations over the last three decades of the 20th century reveals that the farmers had to select gradually more distant sites at increasingly higher elevations, and the majority of tree felling occurred in areas of highly suitable and moderately suitable panda habitat (He et al., in review). The annual amount of fuelwood consumed by each farmer household ranged from 8 to 30 m^3, depending on household size, age structure, cropland area, and other socioeconomic conditions (An et al., 2001). From 1975 to 1998, the human population and the number of households increased by 69% and 124%, respectively, while fuelwood consumption in the reserve doubled from 5,000 m^3 to 10,000 m^3 (Liu et al., 1999c). Electricity, an ideal substitute of fuelwood, is expensive and was mainly used for lightening and other household electronic appliances such as radios and TVs before 2000 (see chapter 3). With subsidies from several conservation programs (discussed later) started since 2000, households have begun to buy electricity for cooking human food and heating houses in winter (see chapter 3). This switch did not totally reduce the dependence of household energy need on fuelwood. A sustainable source of fuelwood for rural households in the reserve is necessary in the long run, especially in the context of the current energy crisis worldwide (Fargione et al., 2008; Sedjo, 2008) and natural disasters such as the recent earthquake in southwest China (Wang et al., 2008).

Considering the acreage (967 ha) of existing plantation forests in the reserve (Table 5.1), we propose harvesting those forested stands through thinning as alternative fuelwood sources. Most plantations are monocultures of Japanese larch (*Larix kaempferi* (Lamb.) Carr.) with a high tree density. These even-aged stands are not suitable habitat for the panda because there is no understory bamboo and they are close to roads and local residents, thus prone to human disturbances (Bearer, 2005). If these areas were aimed for panda habitat in the future, the plantations would have to be thinned and bamboo and/or other tree species intercropped to allow the adjustment of forest stand structure in the long run. Besides this, there are several other benefits of collecting fuelwood in plantation forests. Obviously, it reduces the destruction of natural forests. Because most of these plantation forests are close to human settlements and natural forests are farther away, less time is needed for collecting fuelwood. As the electricity price increases, plantation forests can also decrease the economic burden of local residents, who can then spend the saved money for other uses. The availability of fuelwood from local plantation forests is better than other energy sources, especially in the event of natural disasters (e.g., earthquake).

Thinning is a natural process for forest stands responding to tree competition for light and it takes place when intense competition from surrounding trees starts to slow tree growth. The naturally annual thinning rate of a Japanese larch plantation varies from 3.2% to 4.3% (Su et al., 2003). Proper artificial thinning can keep volume productivity and even increase the timber yield and quality (Dong et al., 1999; Archabald and Naughton-Treves, 2001). A strategy that the first thinning occurs at 7–9 years old and the second 4–6 years later was introduced in southern China (Li et al., 2000), while one in which the first thinning with high intensity occurs at age 12–13 years and 5–6 years before the second thinning (with low intensity) in northern China was also documented (Dong et al., 1999). If stands are managed for timber, 2–3 thinnings with long thinning cycles and high thinning intensities (e.g., 10–30%) are often practiced (Li et al., 1992; Dong et al., 1999). Both tree stems and branches from thinning could be used as a source of fuelwood. Studies on Japanese larch stand biomass (Su et al., 2003; Zhang et al., 2005) reported that the ratio of branch biomass to stem biomass ranges between 1:5 and 1:3.

Several questions are critical for conservation managers to answer in deciding whether to adopt thinning of plantation forests to meet fuelwood needs of local residents: Does it provide enough fuelwood for rural households? If so, when is it available? and What is the best thinning schema, defined by start thinning age, end thinning age, thinning intensity, and thinning cycle? To answer these questions, we used a systems model to simulate dynamics of households, estimate fuelwood consumption, calculate fuelwood production from thinning, estimate the cost of electricity expense, and predict the impact of fuelwood collection on panda habitat under different scenarios over a period of 30 years from 1997 to 2026. Then we compared fuelwood consumption and production under various scenarios to assess the sustainability of thinning plantation forests for fuelwood in our study site, Wolong Nature Reserve.

METHODOLOGY

Study Area

Wolong Nature Reserve, created in 1963, is located in southwestern China and comprises 2,000 km^2 with elevations from 1,200 to 6,500 m. About 10% of China's wild pandas and 4,500 farmers in approximately 1,100 households cohabitate the reserve (State Forestry Administration, 2005). Most households are located lower than 2,500 m in elevation. Pandas usually use areas with elevations from 1,500 m to 3,500 m (Schaller et al., 1985). Panda's staple food sources of arrow and umbrella bamboo (*Bashania fangiana* and *Fargesia rebusta*) disappear in the areas with elevations higher than the upper limit of 3,500 m. The other major component of panda habitat is forests used as shelter. Mixed conifer and broadleaf forests with understory bamboo located in the elevation range of 2,250–2,750 m are the most suitable habitat for giant pandas (Schaller et al., 1985). On the other hand, most farmers also use these forests for their subsistence economy and extract "free" forest resources through agricultural expansion, road construction, house building, Chinese medicine gathering, and fuelwood collection.

Since the establishment of the reserve, the local governments have tried to ban fuelwood collection but rarely succeeded (He et al., in review). They have wanted the residents to use more electricity, but the substitute electricity was low quality and too expensive for most rural households. Since 2000, GTGP has started to revert cropland to forests or bamboos through payments to households and NFCP has subsidized households to monitor assigned forest parcels for illegal harvesting (Liu et al., 2008b). Meanwhile, electricity quality and availability have been greatly improved due to a national enhancement program of rural utility systems (Wolong Nature Reserve, 2005b). NFCP and GTGP have explicitly forbidden any type of fuelwood collection. During the beginning of these programs (2000–2003), few instances of illegal harvesting or collection of branches were seen, partially because many households still had some previous years. As a result, it was also observed that 60–80% of the energy needed for cooking human food and about 30–40% needed for heating houses in winter were switched from fuelwood to electricity. Since 2004, as the leftover fuelwood was used up, the gathering of dead tree branches has been seen and even allowed officially (Chen et al, unpublished).

Fuelwood is also important for the residents to keep their traditional lifestyle. One of their major nutrition sources is smoke-dried pork, which also attracts tourists and transfers their crops to cash. A sustainable source of fuelwood is urgently needed.

Fuelwood Consumption

Fuelwood consumption by households consists of three components: for cooking human food, for heating houses in winter, and for cooking pig fodder. The volume of each component (in m^3) is a function of economic and demographic attributes of the household as described below (An et al., 2001).

For cooking human food = $0.467 \times$ Household size + 0.703

For heating = 8.63 if household has one or more senior members; 7.23 if not

For cooking pig fodder = $24.856 \times$ corn land area (in mu, 1 ha = 15 mu) / 15.0

After NFCP and GTGP were started, households switched a portion of fuelwood consumption to electricity. We observed switches of approximately 70%, 35%, and 25% for each component mentioned above, respectively. After 2000, we considered this reduction of fuelwood demand. Another change after 2000 was that an average of 45% of each household's cropland was converted to tree and/or bamboo plantations. Thus, the acreage of corn land was reduced proportionally to calculate fuelwood needs for cooking pig fodder after 2000.

Fuelwood Production from Thinning Plantation Forests

A total of 487 ha of areas previously harvested for commercial timber have been reforested since 1975 and 480 ha of cropland has been afforested since 1986 (Wolong Nature Reserve, 2005b, see Table 5.1). The majority of those plantation forests was monocultural and designed for timber harvesting and/or ecological services (e.g., erosion control). Less than 5% of cropland converted in 2000 was planted with species (e.g., Longpeduncled alder, Table 5.1) suitable for fuelwood needs of local residents. The most common species planted is Japanese larch, which is insect and disease resistant (He, 1991) and fast growing (Yan and Liang, 1993) even on a very nutrient-deficient site (Kochenderfer et al., 1995). Japanese larch, though not the most favored species for fuelwood, has been consumed by households (He et al., in review).

Though Japanese larch has been present in Sichuan since the 1970s, little is known about its growth in plantations in Wolong or areas nearby. Only a few scattered records were found in the literature (Li, 1982; Yang, 1989; The Editorial Board of Forests in Sichuan, 1992; Yan and Liang, 1993). We choose the growth model developed by Ma et al. (1998) in Liaoning Province, northern China, where Japanese larch was first brought into China in the 1920s and was believed to grow more slowly than in Wolong (Yan and Liang, 1993). The model estimates the volumes as a function of site index (SI), density, and age of forest stands. It is in the form of

$$V_t = 7.2927 \times SI^{1.4577} \times (1 - e^{-0.0023 N_t^{0.3761} t})^{1.8956}, \qquad [5.1]$$

where V_t is volume (m^3/ha) and N_t is density (trees/ha) at age t (years). We used the only existing forest stand records from Wolong and nearby areas to validate these where V_t is volume (m^3/ha) and N_t is density (trees/ha) at age t (years). We used the only existing forest stand records from Wolong and nearby areas to validate these models. Table 5.2 shows that Japanese larch plantations in Miyaluo (located in Li County, north of Wolong) followed the growth trend of their counterparts in Liaoning with an SI of 20. The model provides conservative estimations of the growth of Japanese larch plantations in Wolong, an environment ecologically similar to Miyaluo. Fuelwood production from stems could be estimated from the growth model discussed above.

In summary, we fixed the SI of Japanese larch plantation stands as 20, and used equation 5.2 to predict volume production given stand ages and densities. For initial values of parameters of stands planted in different years, see Table 5.3.

$$V_t = f(SI, N_t, t) = 7.2927 \times SI^{1.4577} \times (1 - e^{-0.0023 N_t^{0.3761} t})^{1.8956} \times (1 + 0.25), \quad [5.2]$$

where V_t = volume production (m^3/ha), SI = 20, N_t = stand density (trees/ha), and t = stand age (years). The average ratio 1:4 of branch biomass to stem biomass was used to calculate fuelwood production of tree branches from thinning. The fuelwood production FW_{ti} from a plantation forest stand i at the year t when thinning occurs is calculated as

$$FW_{ti} = f(SI, N_{ti}, t)/N_{ti} \times (N_{ti} \times TI_i) \times A_i = f(SI, N_{ti}, t) \times TI_i \times A_i, \quad [5.3]$$

where TI_i is thinning intensity of stand i, A_i is area of stand i (ha), SI is fixed as 20, and N_{ti} is stand density of stand i at the year t (trees/ha).

by perturbing each major parameter by a certain magnitude, and calculating the sensitivity index (Jørgensen, 1986) as

$$S\chi = (d\chi/\chi)/(dP/P) \, , \qquad [5.4]$$

where P is the value of the independent variable, dP is the value for a small change of P, χ is the value of the dependent variable, and $d\chi$ is the corresponding change in χ in response to the change in P. We assessed the model by increasing each input parameter—SI, initial density of forest stand, and the branch biomass to stem biomass ratio—by 10% and calculating the sensitivity index for each year during simulations. The minimum and maximum sensitivity indexes for each parameter are reported.

A thinning scenario can be defined by thinning cycles, thinning intensity, ages of thinning, and mature stand ages (when harvested). To examine how those parameters affect the fuelwood production, we chose three groups of scenarios with different levels of fuelwood demand (i.e., less, status quo, and more). We keep mature stand age at 60 years unchanged, which allows all the plantation forest stands to remain unharvested in a simulation of 30 years. Thinning cycle varies from 1 to 3 years; thinning intensity from 3 to 15%; and age to start thinning from 10 to 14 years. We designed the scenarios in a way that if the thinning cycle increases by 1 year, thinning start age is delayed by 2 years and thinning intensity doubles. Three groups of the thinning scenarios with different combinations of parameters are listed in Table 5.4. The status quo scenarios reflect the situation of household fuelwood consumption reflected in the empirical data: with the implementation of NFCP and GTGP, the rates of switching to electricity from fuelwood for cooking human food, heating, and cooking pig fodder are approximately 70%, 35%, and 25%, respectively. Scenarios with more fuelwood assume that without for cooking human food, heating, and cooking pig fodder are approximately 70%, 35%, and 25%, respectively. Scenarios with more fuelwood assume that without NFCP and GTGP in place households do not replace any portion of fuelwood consumption. Scenarios with less fuelwood assume that if NFCP and GTGP increase their investments households may meet their energy needs by switching to electricity. In this case, the three switch rates from fuelwood for cooking human food, heating, and cooking pig fodder are 90%, 65%, and 35%, respectively.

Implementation

Models for household fuelwood consumption and production from thinning plantation forests were incorporated and implemented in WOW. WOW includes models to simulate the dynamics of rural human population at the individual and household levels (Human population dynamics model), calculate fuelwood consumption based on demographic and social factors of households (Fuelwood consumption model), estimate fuelwood production if thinning plantation forests (Reforestation for fuelwood model), and predict the locations of fuelwood collection (Fuelwood site distribution model) and the costs of using electricity for each household (Economic impact of fuelwood collection model). Then the system evaluates the dynamic impacts of fuelwood collection on panda habitats at the reserve landscape level given different policy scenarios (Habitat impact assessment model). Based on the multicriteria decision-making (MCDM) methodology (Malczewski, 1999), a policy scenario evaluation component (Multi-criteria decision making model) was also developed to help decision makers assess and compare different policy scenarios and then choose the best based on their own ecological, economic, and social preferences. For details on design and implementation of those models and the system, see chapter 4. Because most models are stochastic, each scenario was simulated with 20 replicates to examine the fuelwood balance of households and the impact of fuelwood consumption on panda habitat during a simulation of 30 years. The averages of measurements (e.g., fuelwood demand and areas of impacted suitable habitat) were reported.

RESUTLS

Sensitivity Analysis

Table 5.5 lists the minimum and maximum sensitivity indexes of the three model parameters against model output fuelwood production during a 30-year simulation. Site index is the most sensitive parameter, followed by initial stand density and branch biomass to stem biomass ratio.

Scenario Simulations

The results show that thinning plantation forests can satisfy a substantial portion of fuelwood demand (Figures 5.1–5.3) and lessen the impact on suitable panda habitat (Figures 5.4–5.6). However, the fuelwood-balanced year, when plantation forests produce enough fuelwood to offset household demands so that no natural forest cuts are needed and the size of affected suitable habitat is zero, is different under different scenarios. Most status quo scenarios and all the scenarios with less fuelwood can reach the balance during the 30-year simulation.

None of the scenarios with more fuelwood (B1–B9) reaches a fuelwood-balanced year during the 30-year simulation length (Figures 5.1 and 5.4). However, during some years (e.g., the harvesting years after year 17 for Scenarios B5 and B6 (Figure 5.1b), and after year 20 for Scenarios B7, B8, and B9 (Figure 5.1c)), fuelwood production is greater than demand. Fuelwood demands of the status quo scenarios are reduced by 40% after year 5. When there is no thinning rotation (i.e., thinning cycle = 1 year), the fuelwood-balanced years of Scenarios C1, C2, and C3 are years 28, 16, and 15, respectively (Figures 5.2a and 5.5a). When 2 or 3 years of thinning rotations are applied, thinning plantation forests during the harvesting years after year 6 (for C4, C5, and C6, see Figures 5.2b and 5.5b; for C7, C8, and C9, see Figures 5.2c and 5.5c) can produce more fuelwood than the reduced fuelwood demands. The extra fuelwood from the harvesting years may be enough to offset the fuelwood demands of the following non-harvesting years before the next harvesting and thus no suitable habitat is affected (Figure 5.5). The fuelwood-balanced years of some scenarios come 10 or more years later (years 18 and 16 for Scenarios C5 and C6, respectively; year 18 for Scenarios C8 and C9), while Scenarios C4 and C7 can not yield the balanced years during the 30-year simulation. The scenarios with less fuelwood reach a fuelwood-balanced year earlier than the status quo scenarios: year 9, 6, and 6 for Scenarios D1, D2, and D3, respectively, with no thinning rotations (Figures 5.3a and 5.6a); year 10, 6, and 6 for Scenarios D4, D5, and D6, respectively, with a 2-year thinning rotation (Figures 5.3b and 5.6b); and year 12, 6, and 6 for Scenarios D7, D8, and D9, respectively, with a 3-year thinning rotation (Figures 5.3c and 5.6c).

Of the status quo scenarios, the earliest one to reach the balanced year is Scenario C3 (year 15). Most of the scenarios with less fuelwood reach the balance in year 6. Since there is still extra unconsumed fuelwood in the scenarios with less fuelwood, the switch rates from fuelwood to electricity were decreased in order to reduce the electricity costs of households. The switch rates used in those scenarios for cooking human food, heating, and cooking pig fodder are 90%, 65%, 35%, respectively. After several tests of combinations of lower values of these three rates in WOW, we found that using 80%, 30%, and 30% rates, respectively, and the same thinning schema as in Scenario D3, the fuelwood-balanced year of the newly created scenario (named CD3) would be year 15 and the electricity cost would be reduced to the status quo level. Because the status quo switch rates (70%, 35%, and 25%) are close to these, NFCP and GTGP may not need to invest too much in order to achieve the higher rates as in the scenarios with less fuelwood. This effort also demonstrates a way to use WOW to find a better decision alternative.

DISCUSSIONS

We demonstrated the feasibility of thinning existing plantation forests in Wolong Nature Reserve to meet the fuelwood demands of approximately 1,000 rural households. The earliest fuelwood-balanced year of the status quo scenario (C3), which does not require rural households to collect fuelwood from natural forests, is year 15 of simulation, and scenarios with less fuelwood can reach a fuelwood-balanced year as early as year 6 and still produce surplus fuelwood. An optimal scenario (CD3) for which rural households spend less on electricity than in scenarios with less fuelwood was found through WOW. However, it is worth discussing several limitations of this analysis.

We assumed that energy need and consumption structure do not change over time and household fuelwood demands are still functions of social and economic characteristics of households. However, as the difficulty of collecting fuelwood increases, because of stricter law enforcement and less availability of fuelwood nearby, and the price of electricity also increases, households will likely reduce the demand by possibly increasing use efficiency, thereby sacrificing human welfare; for example, in winter people may start heating later and stop heating earlier. If this is the case, our study overestimates the fuelwood demand and actually increases the feasibility of thinning existing plantation forests because less forest acreage or less intensity of thinning is needed to meet the lower demand. On the other hand, there may be more households and households may be richer. Both may require more fuelwood. Our models have considered the population dynamics during the 30-year simulations and the latter deserves a further consideration.

In the status quo scenarios and the scenarios with less fuelwood, we assume that NFCP and GTGP will continue and/or increase their investments during the simulation periods so that households would maintain current fuelwood-electricity switching rates or consume more electricity. This increases the economic burden of the governments. One way to alleviate the burden is to use non-forested land suitable for forests and shrub land suitable for fuelwood. Plots close to human settlements in such land, potentially not suitable for panda habitat, can be chosen to plant trees for fuelwood. Harvesting forests close to human settlements have minimal impacts on panda habitat as those areas are rarely used by pandas (Bearer et al., 2008). The other way may include increasing fuelwood productivity through better management of forest stands and species selection (Bisong et al., 2007; Kang et al., 2007; Kumar, 2008).

Our results reflect the general growth trends of the plantations of Japanese larches. To be more realistic, data on the growth of local forest stands should be collected to verify and/or adjust the models adopted from the limited literature. To implement the ideal of thinning plantation forests for fuelwood, a strategy similar to NFCP may be adopted. Assigning plantation forest parcels to households for fuelwood and monitoring illegal harvesting should be considered. Operational and administrative costs of thinning forest stands, harvesting and monitoring fuelwood collection, and distributing fuelwood to households, were not main themes in this analysis. An economic feasibility analysis considering these costs and benefits, such as reducing household expenditures of buying electricity, should be conducted while evaluating and choosing optimal thinning scenarios and before implementing the selected scenarios.

CONCLUSIONS AND CONSERVATION IMPLICATIONS

Using systems modeling and scenario simulations, this chapter demonstrates the potential that harvesting 967 ha of plantation forests can provide a substantial portion of the energy needs of local rural households without cutting natural forests in Wolong Nature Reserve. Meanwhile, this may keep the traditional fuelwood-dependent lifestyle of minority ethnic groups in the reserve. Most of the status quo scenarios and the scenarios with less fuelwood can reach the fuelwood-balanced year between year 6 and year 28 of simulation. Because thinning can maintain the health of forest stands and provide an opportunity to adjust the monocultural structure of plantation forests (e.g., interplanting bamboo) toward suitable panda habitat, we encourage reserve managers to consider this idea and incorporate it with on-going conservation programs such as NFCP and GTGP as soon as possible.

It is worth noting that the intention of the study is not to replace electricity with fuelwood but to diversify energy sources of rural households. Efforts to improve quality and decrease price of electricity should continue and complement the idea of harvesting plantation forests for fuelwood. This study builds a useful foundation and provides reserve managers with scientific information and tools to explore such a proposal of sustainable natural resource use that benefits both local people and pandas in the reserve. The promising results also have important implications for the current global energy crisis. Plantation forests, one of many renewable biofuel resources, may continue to be used as a traditional and sustainable energy source, especially in those remote and rural regions with long-lasting conflicts of human development and wildlife conservation.

Table 5.1: Areas of plantations since the establishment of Wolong Nature Reserve

Time	Area (ha)	Species planted	% of cropland
1975–1977	487.06	Japanese larch (*Larix kaempferi Carr.*), Chinese larch (*Larix potaninii Batal.*), masters larch (*Larix mastersiana*), Chinese spruce (*Picea asperata Mast.*)	(cutover areas)
1986	113.00	Japanese larch	15
2000	266.60	Japanese larch, Chinese fir (*Cunninghamia lanceolata (Lamb.) Hook.*), maple (*Acer L.*), longpeduncled alder (*Alnus cremastogyne* Burkill), Japanese cedar (*Cryptomeria japonica (L. f.) D.Don*), water fir (*Metasequoia glyptostroboides Hu et Cheng*)	36
2001	66.67		9
2002[a]	81.83		11
2003	34.00		5
Subtotal[b]	562.00		76
Grand Total	1049.06		N/A

[a] In 2002, cropland converted for bamboo plantations was not counted for fuelwood production

[b] Sum of cropland converted since 1986

Note: N/A = not applicable.

Source: compiled from government documents (in Chinese) (Wolong Nature Reserve, 2005b)

Table 5.2: Comparisons of characteristics of Japanese larch plantations in the model and Miyaluo

Source	Age (years)	DBH (cm)	Height (m)	Density (trees/ha)	SI	Volume (m^3/ha)
Model[a]	20	12.5	13.78	2,006	20	192.00
Miyaluo a[b]	18	14.6	10.52	2,080	N/A	183.6
Miyaluo b[c]	20	14.7	13.6	N/A	N/A	224.3

[a] From Ma et al. (1998)
[b] From Yang (1989)
[c] From Yan and Liang (1993)
Notes: DBH = diameter at breast height; SI = site index, N/A = not available.

Table 5.3: Initial values of parameters of stands planted at different times

Year planted	Site index (SI)	Initial density (trees/ha)	Age in 2005 (years)	Year of first thinning
1975-1977	20	1,288[a]	28	2005
1986	20	2,006[a]	19	2005
2000	20	3,976[b]	9[b]	2006
2001	20	3,976[b]	8[b]	2007
2003	20	3,976[b]	6[b]	2009

[a] Derived from Wang and colleagues' model (1996).
[b] Data from Moy (2005).

Table 5.4: Three groups of thinning scenarios

More fuelwood	Status quo	Less fuelwood	Thinning cycle (years)	Age to start thinning (years)	Thinning intensity (%)	Age to end thinning (years)
B1	C1	D1	1	10	3	60
B2	C2	D2	1	10	4	60
B3	C3	D3	1	10	5	60
B4	C4	D4	2	12	6	60
B5	C5	D5	2	12	8	60
B6	C6	D6	2	12	10	60
B7	C7	D7	3	14	9	60
B8	C8	D8	3	14	12	60
B9	C9	D9	3	14	15	60

Note: The rates of switching to electricity from fuelwood for cooking, heating, and cooking pig fodder are as follows: 0% for scenarios B1–B9; 70%, 35%, and 25%, respectively, for scenarios C1–C9; 90%, 65%, and 35%, respectively, for scenarios D1–D9.

Table 5.5: Sensitivity test results for 30 years of simulations

Parameter	Default value	+10% perturbation	Sensitivity Index	
			Minimum	Maximum
Site Index (SI)	20	22	1.490	1.493
Initial stand density	1288, 2006, 3976[a]	1416.8, 2206.6, 3614.5[a]	0.361	0.492
Branch biomass to stem biomass ratio	0.25	0.275	0.198	0.202

[a] The first two numbers are the initial densities of stands planted in 1975–1977 and 1986, respectively; the last number is for total stands planted in 2000, 2001, and 2003 (see Table 2 for their default values).

Figure 5.1 Comparisons of fuelwood demand and production of the worse scenarios (a) B1-B3, (b) B4-B6, and (c) B7-B9. Black filled squares represent fuelwood demand and non-filled shapes are for fuelwood production. Fuelwood demands are the same in the three figures (a, b, and c)

a

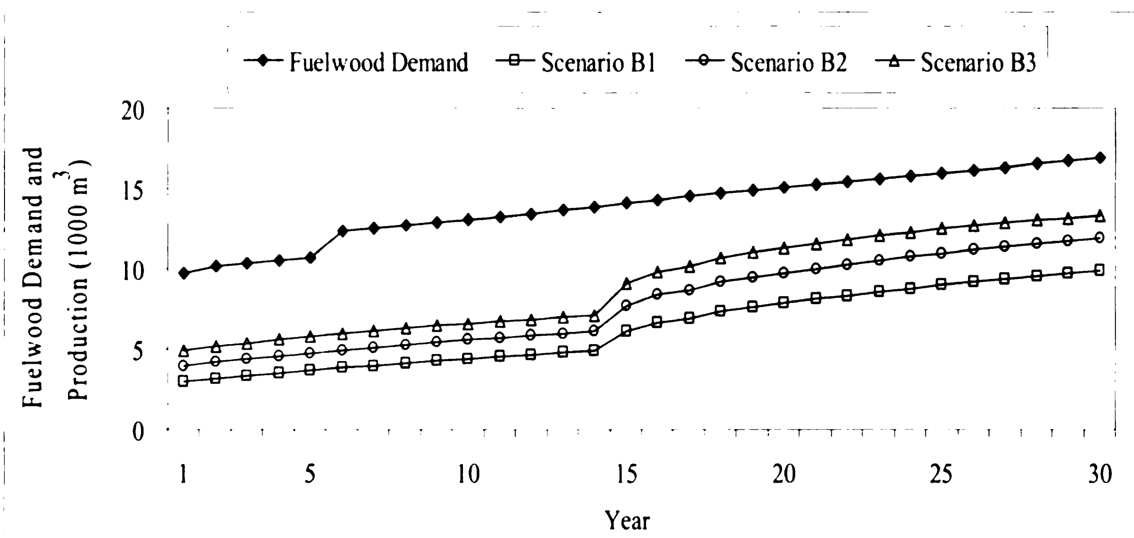


Figure 5.1 continued

b

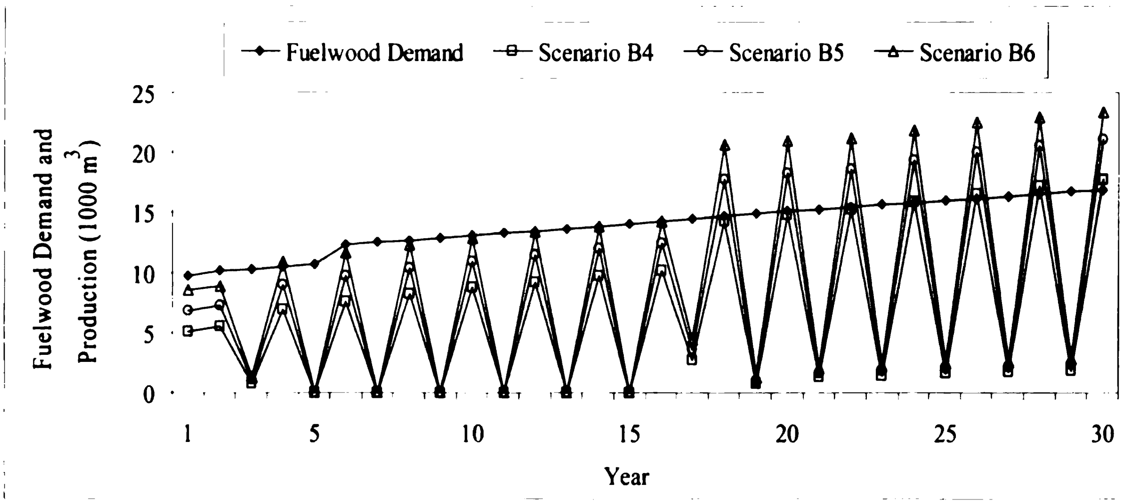


Figure 5.1 continued

c

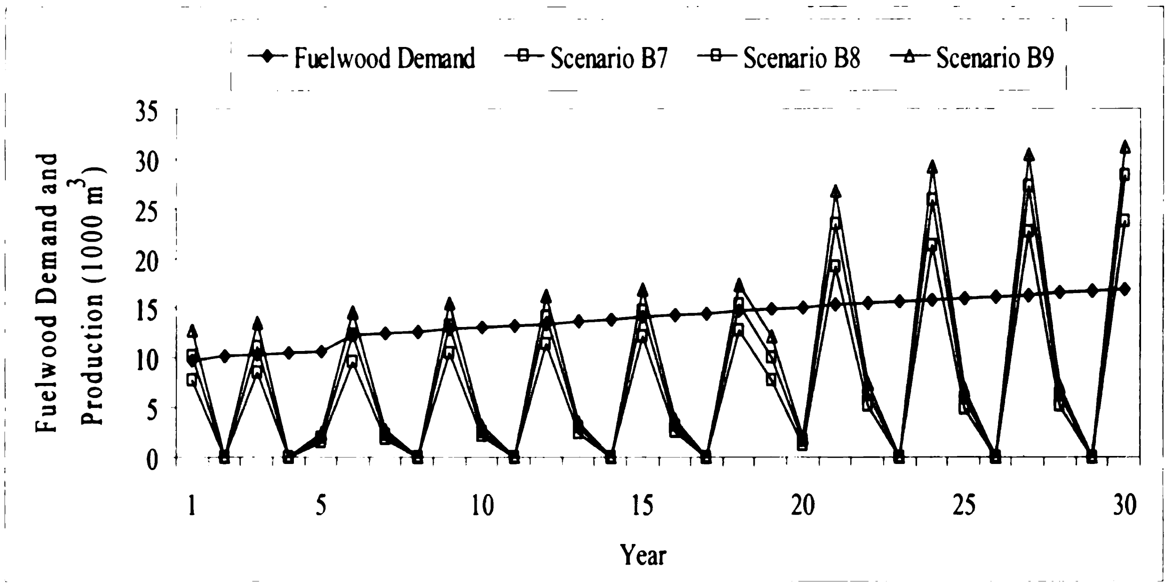


Figure 5.2 Comparisons of fuelwood demand and production of the status quo scenarios (a) C1-C3, (b) C4-C6, and (c) C7-C9. Black filled squares represent fuelwood demand and non-filled shapes are for fuelwood production. Fuelwood demands are the same in the three figures (a, b, and c)

a

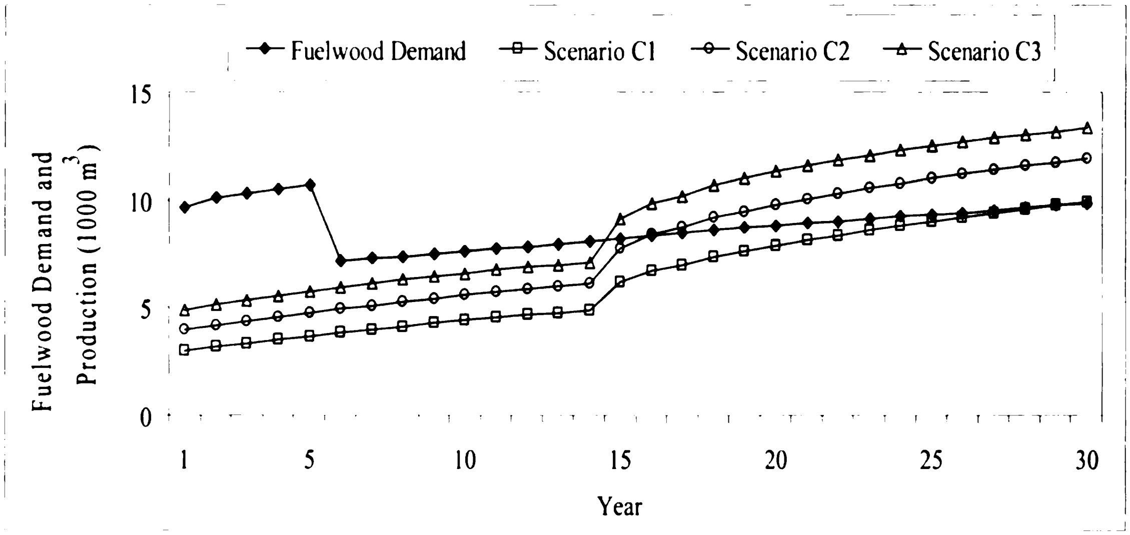


Figure 5.2 continued

b

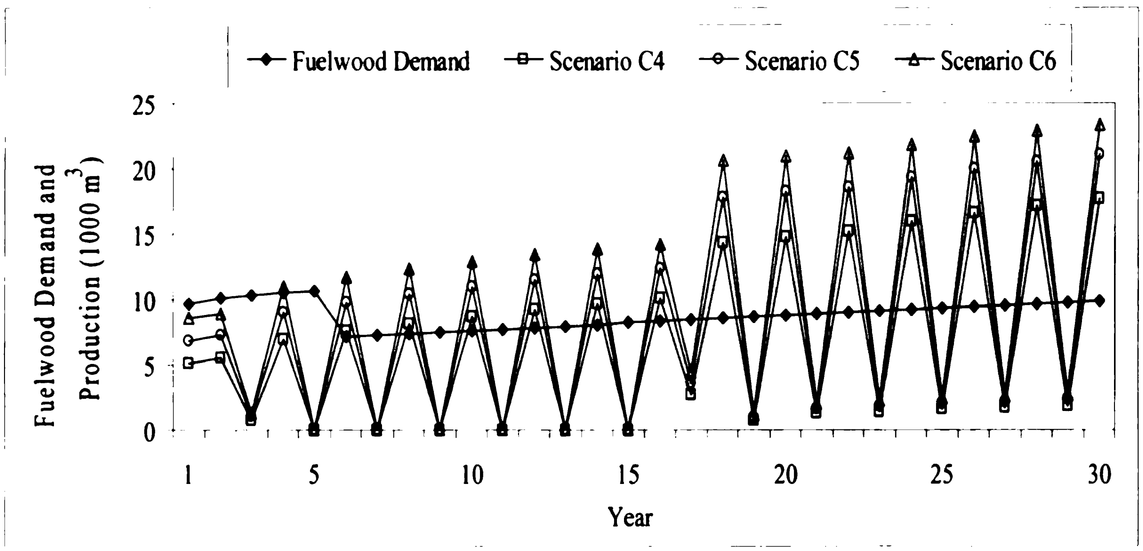


Figure 5.2 continued

c

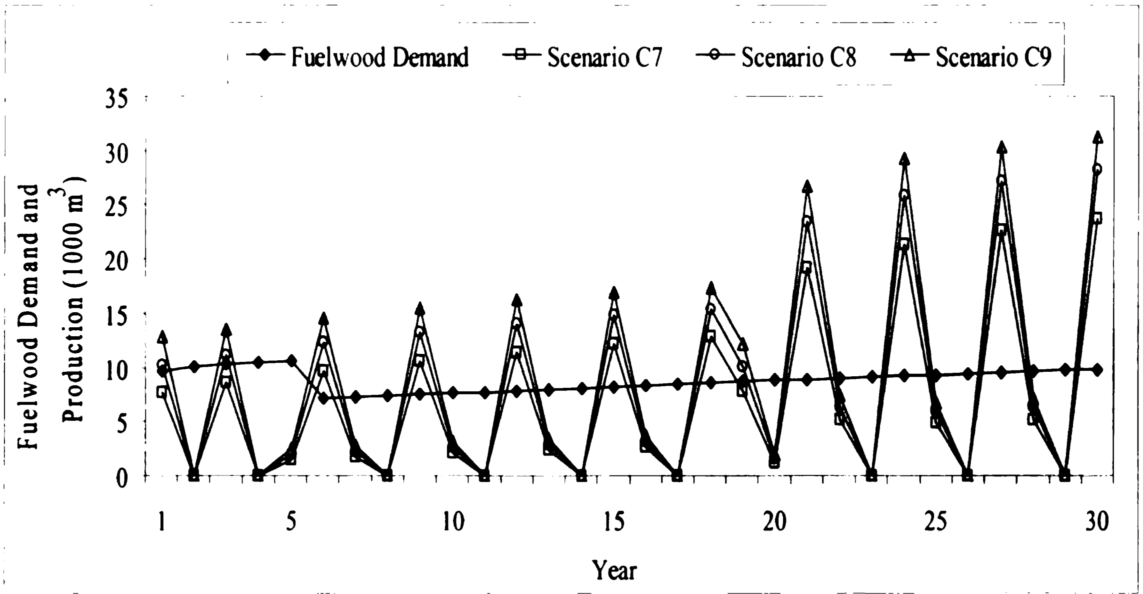


Figure 5.3 Comparisons of fuelwood demand and production of the better scenarios (a) D1-D3, (b) D4-D6, and (c) D7-D9. Black filled squares represent fuelwood demand and non-filled shapes are for fuelwood production. Fuelwood demands are the same in the three figures (a, b, and c)

a

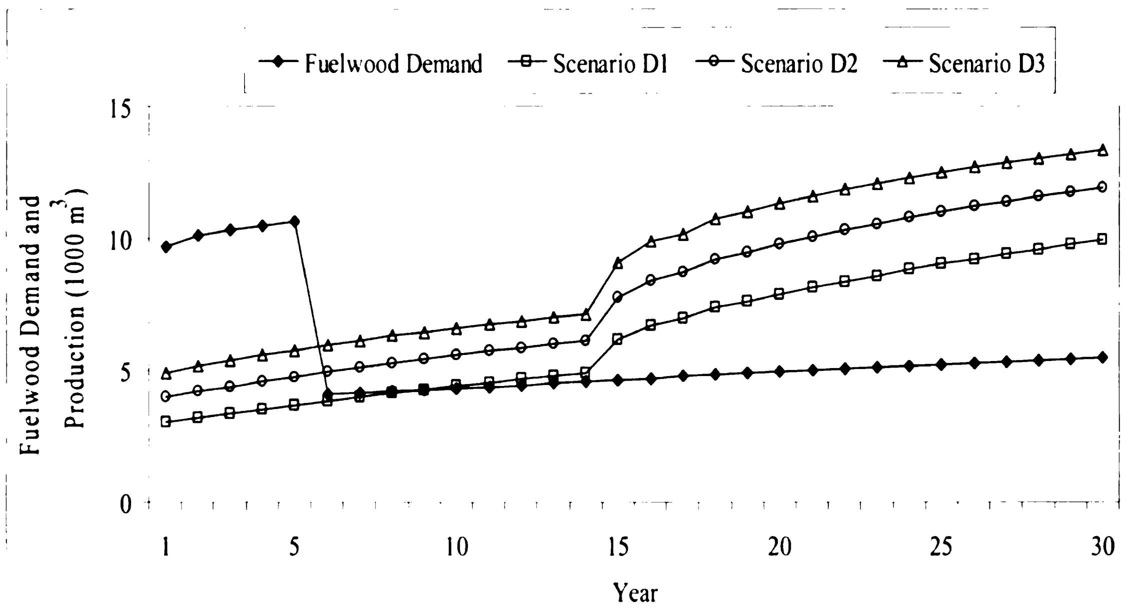


Figure 5.3 continued

b

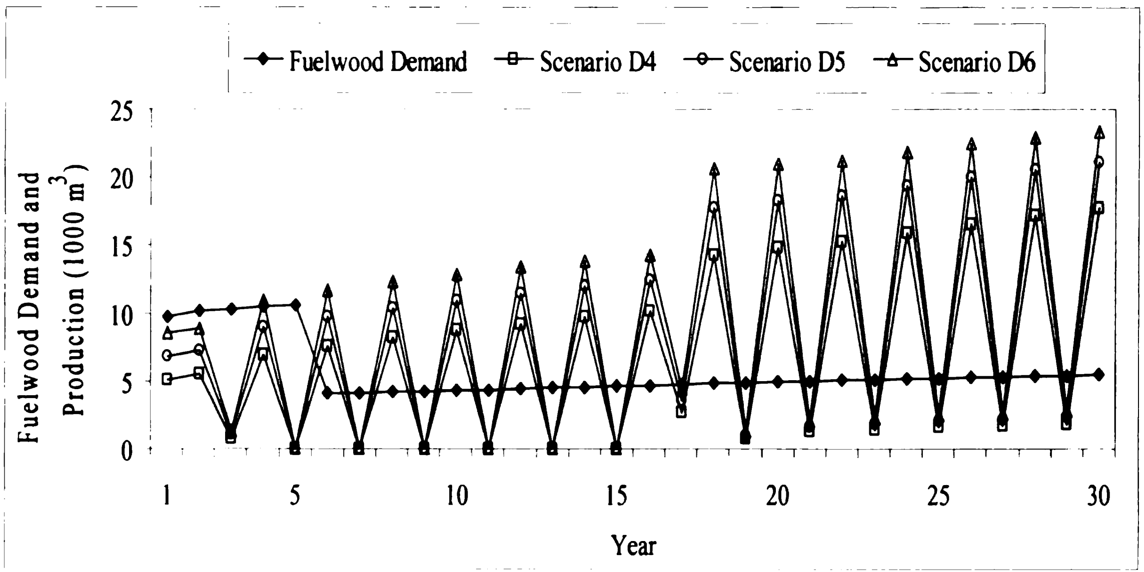


Figure 5.3 continued

c

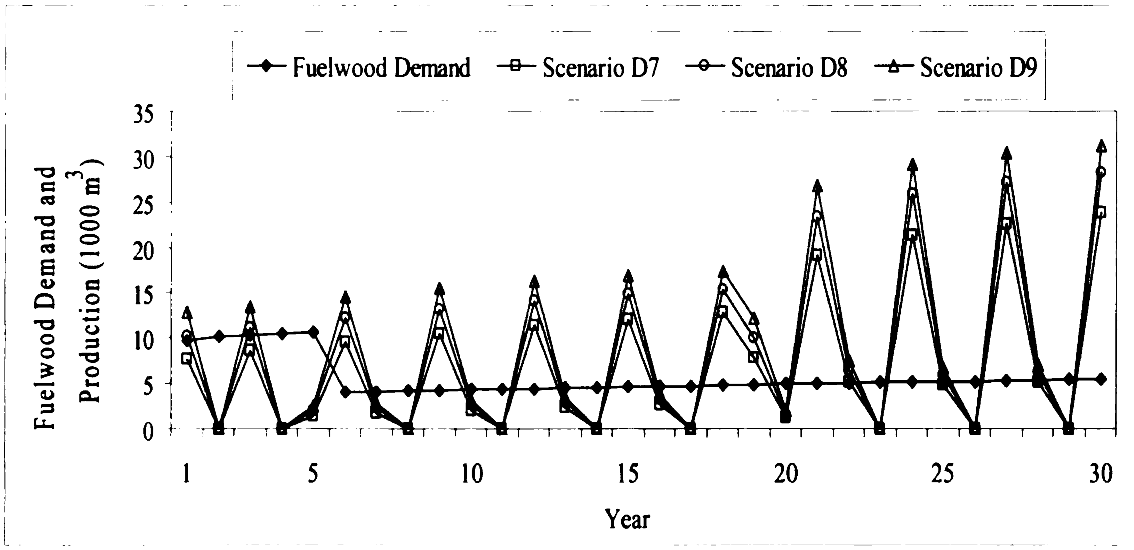


Figure 5.4 Different impacts of thinning plantation forests on highly and moderately suitable panda habitat of the more fuelwood scenarios (a) B1-B3, (b) B4-B6, and (c) B7-B9

a

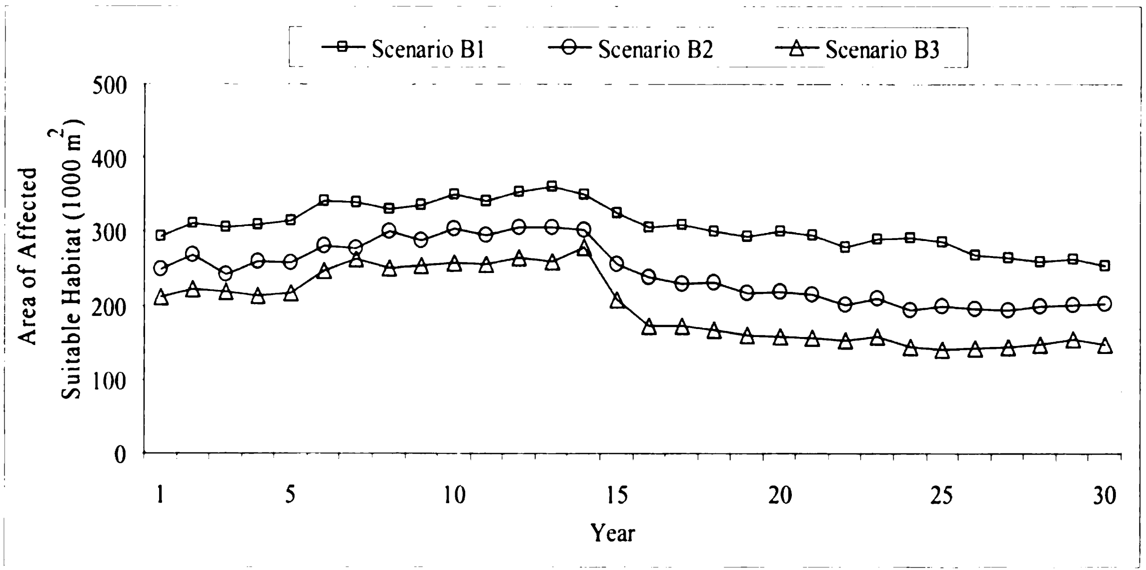
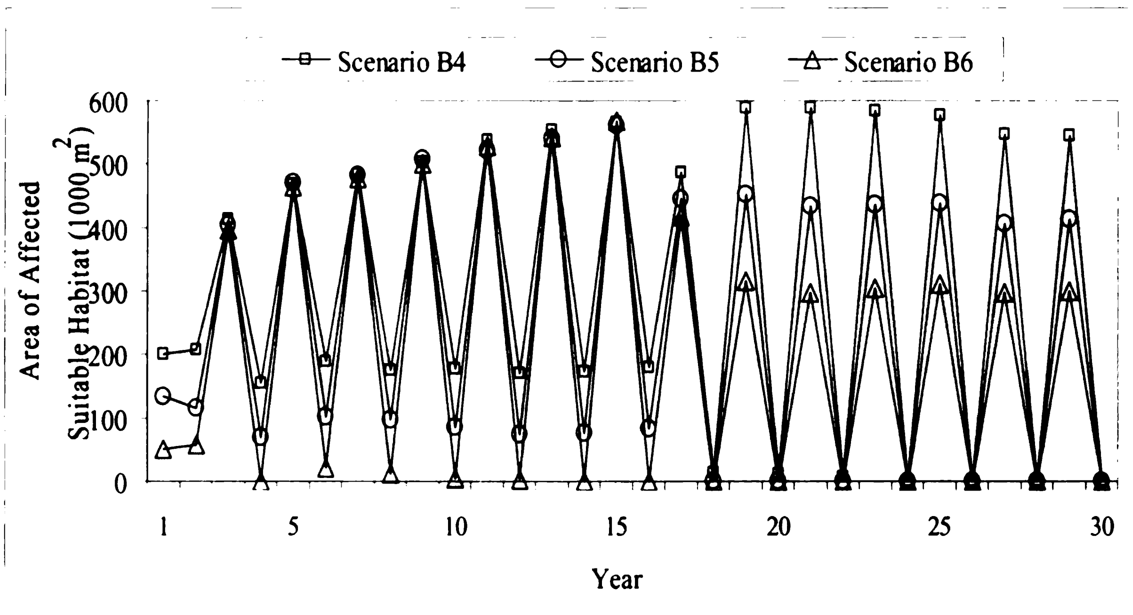


Figure 5.4 continued

b



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c

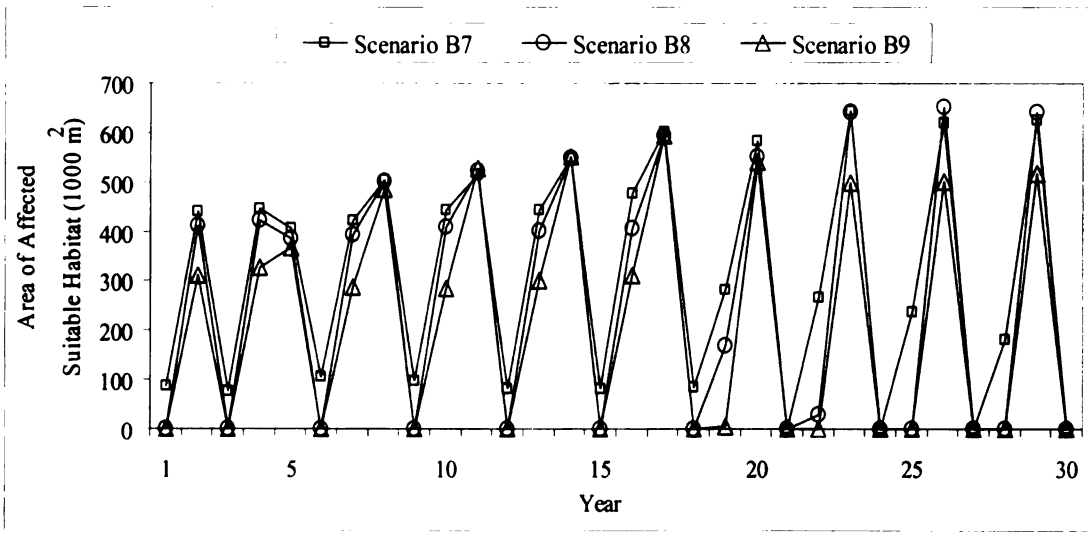


Figure 5.5 Different impacts of thinning plantation forests on highly and moderately suitable panda habitat of the status quo scenarios (a) C1-C3, (b) C4-C6, and (c) C7-C9

a

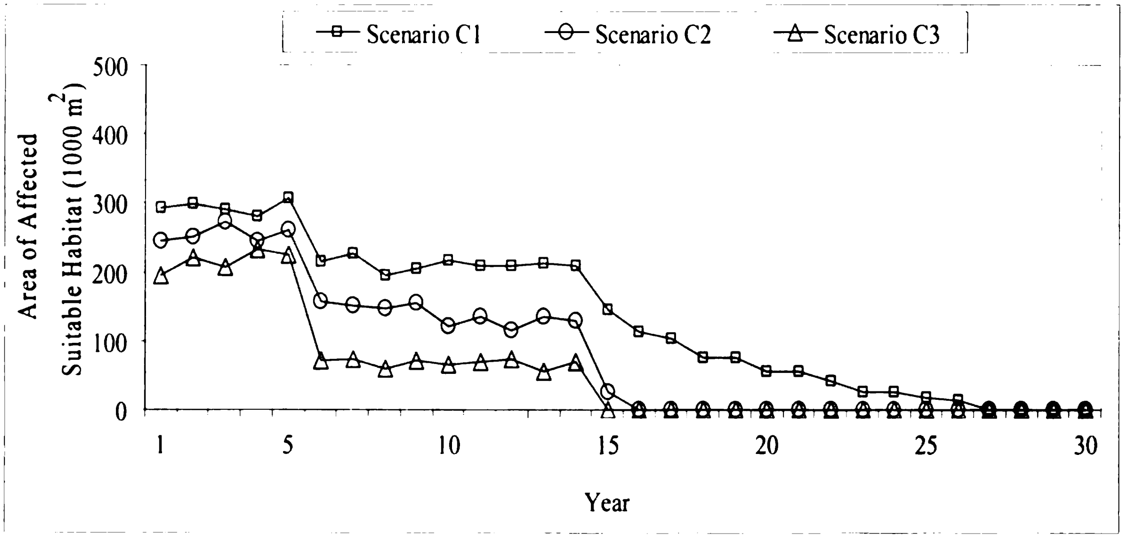


Figure 5.5 continued

b

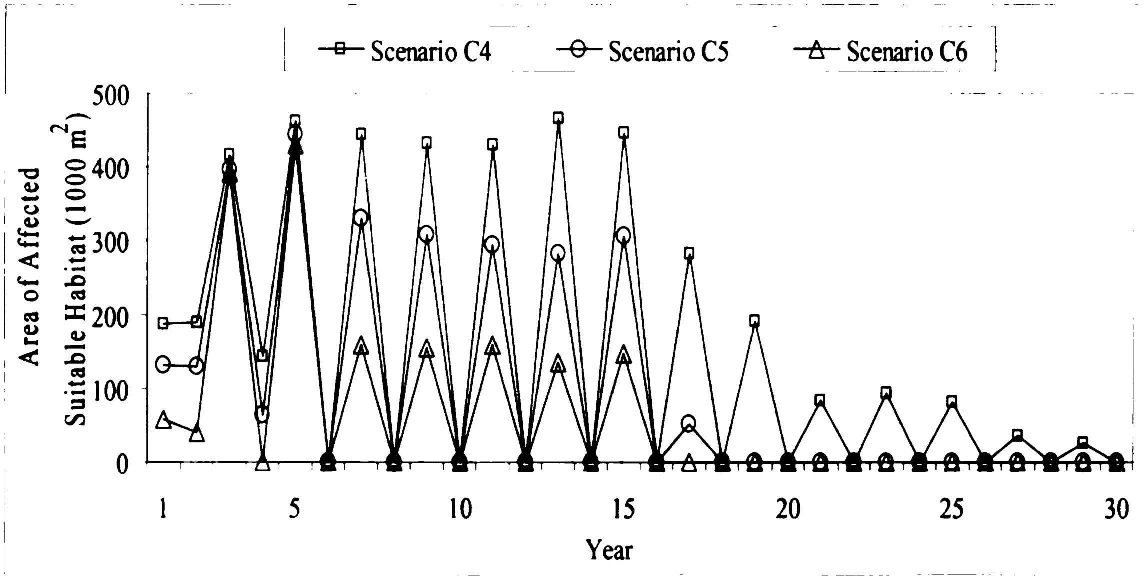


Figure 5.5 continued

c

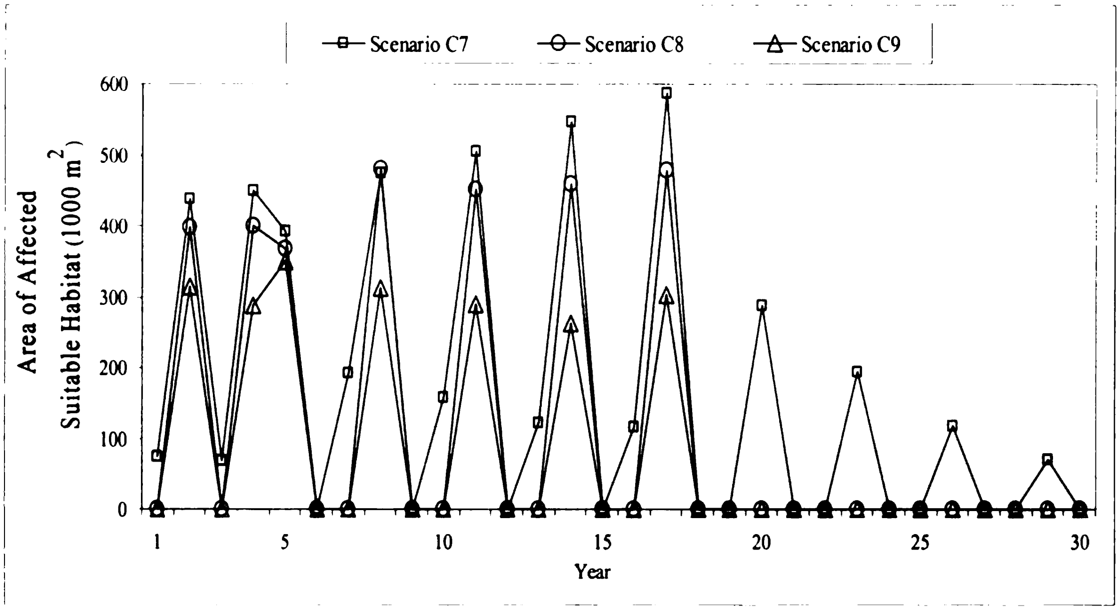


Figure 5.6 Different impacts of thinning plantation forests on highly and moderately suitable panda habitat of the less fuelwood scenarios (a) D1-D3, (b) D4-D6, and (c) D7-D9

a

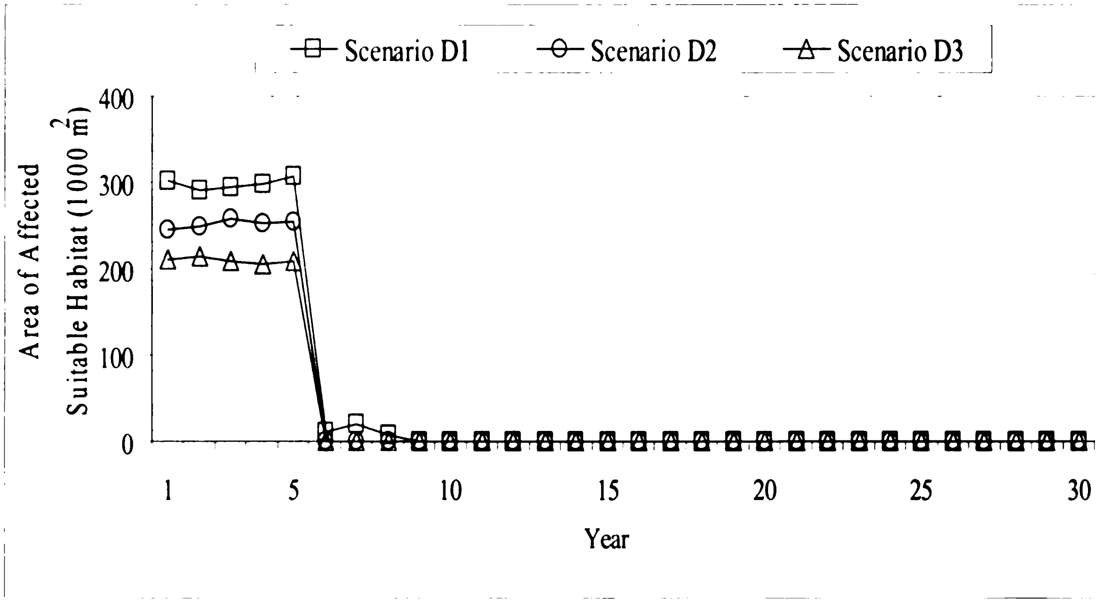


Figure 5.6 continued

b

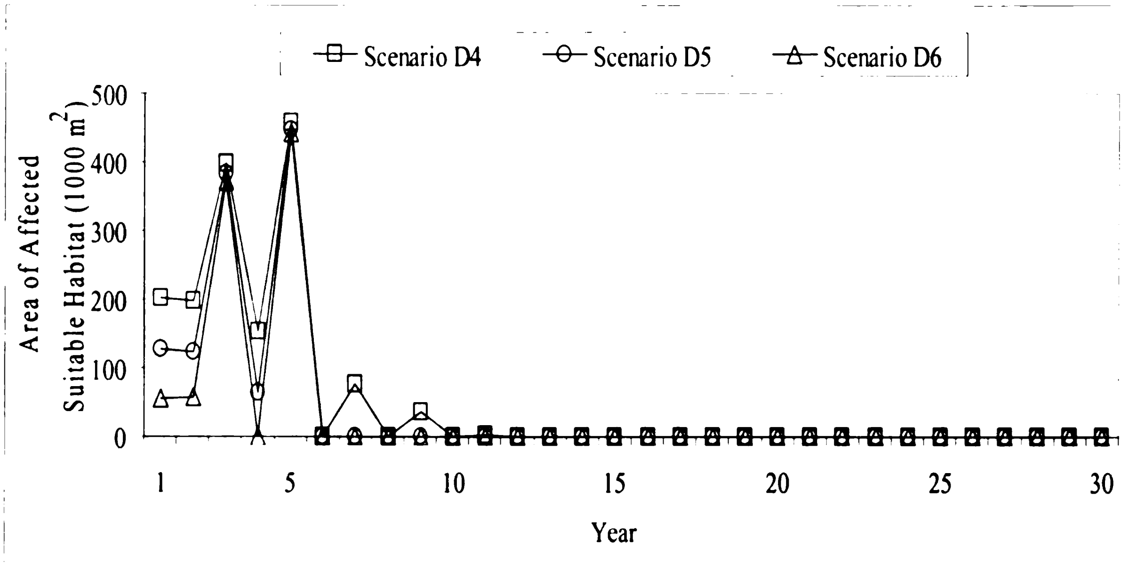
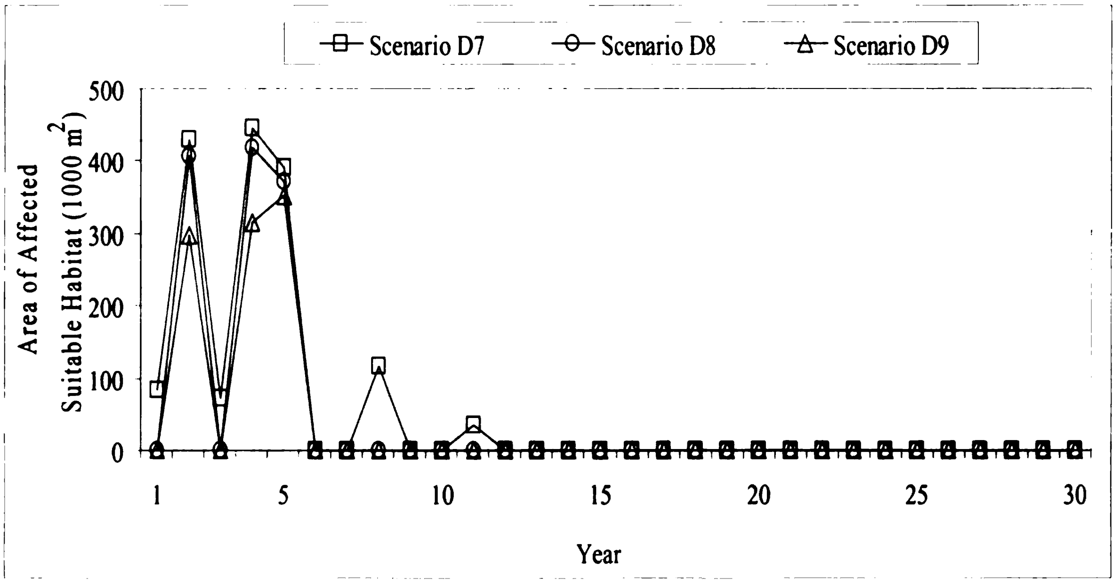


Figure 5.6 continued

c



CHAPTER 6

SYNTHESIS AND CONCLUSIONS

The challenge to understand the dynamics of coupled human-nature systems across time and space for balancing human energy needs and wildlife conservation can be tackled with assistance from decision support systems (DSSs). In this dissertation, a Web-based DSS named WOW was developed to analyze the interactions among human society, policy interventions, and wildlife habitat for Wolong Nature Reserve for giant pandas in China. With this system, various geographically dispersed stakeholders can simulate the dynamics of human population and fuelwood needs, predict the locations of fuelwood collection, and then assess the impacts of fuelwood collection on the human community and panda habitat. Different policy scenarios defined by the input parameters of models in WOW can be constructed and evaluated based on the ecological, economic, and social preferences of stakeholders.

The dissertation starts from an analysis of the spatial and temporal trends of fuelwood collection in the last three decades of the 20th century (1970s, 1980s and 1990s). Two hundred rural households were interviewed for their locations of fuelwood collection sites during the three decades and other relevant ecological, economic, social, and demographic data. The surveys showed that households tended to use previous fuelwood sites or nearby areas for fuelwood and tens of adult males from a number of households collected fuelwood collectively in order to increase efficiency and minimize risks in the topographically challenging high mountains. It was also found that fuelwood collection sites were moving toward higher elevations that are more distant and closer to highly suitable panda habitat. Consequently, fuelwood collectors were traveling longer distances to physically challenging areas, in our case, to areas of high-quality panda habitat. Fuelwood collection occurred frequently in areas close to households, while some new hotspots had emerged due to local road expansion. Many households were aware of the fuelwood collection regulations and understood their importance to panda conservation, but many of them did not comply strictly with the regulations on fuelwood collection. Furthermore, this analysis reinforces the importance of addressing the needs of local communities for the success of conservation practices.

Recognizing the devastating impacts of human activities on ecosystems and human society, the Chinese government has been implementing several conservation policies in the reserve since 2000. These policies have direct and indirect effects on households. The dissertation continued to use household surveys to show that the effects of NFCP and GTGP on rural households' switch from fuelwood to electricity varied for the three fuelwood consumption purposes, of which the one for cooking human food was the highest (66.92%) followed by the one for heating (37.05%) and the one for cooking pig fodder (22.62%). The energy dependence of households on fuelwood was estimated with a reduction of approximately 36%. This study implied that fuelwood as an energy source for rural households may co-exist with other sources such as electricity for the long term. The results also suggested the challenge of ameliorating the environmental impacts of human activities through programs such as NFCP and GTGP and the necessity of searching for other sustainable natural resource uses.

Results from these two studies were then incorporated into a fuelwood consumption model and a fuelwood site distribution model in WOW. Other models in

WOW include human dynamics, reforestation for fuelwood, economic impact of fuelwood collection, habitat impact assessment, and multicriteria decision making (MCDM). WOW is accessible at http://panda.csis.msu.edu/wow. As a demonstration of the capability of the system, four scenarios were designed to show the effects of NFCP and GTGP and thinning plantation forest stands for fuelwood; human population parameters were set the same for all scenarios. The implementation of NFCP and GTGP may reduce approximately 30% of the fuelwood consumption by households but households still need to cut natural forests to meet the remaining 70% of their fuelwood demand (Scenario B). Thinning plantation forests could provide a substantial portion of fuelwood needs: Scenario C may reduce household fuelwood needs by 50 %. Presumably, if the switch rates from fuelwood for cooking human food, heating, and cooking pig fodder are 90%, 65%, and 35%, respectively, the areas of affected habitat of all types are gradually decreased to zero after the simulation year 10 (Scenario D).

Thirty-six out of 76 registered users from eight countries in four continents have evaluated these four scenarios using the MCDM component in WOW. The preliminary results showed that the thinning scenario (Scenario D) was preferred by the stakeholders. Besides the evaluations, more than 50 new scenarios have been constructed and simulated in WOW after being made public through the listservs of three conservation-related organizations in early October 2008. It is expected that more scenarios will be created and the ranks of existing evaluated scenarios will be changed.

As implied from the aforementioned studies, fuelwood will likely exist as an important energy source of rural households in the long term and it is worth a further search for an optimal schema of thinning plantation forests for fuelwood in WOW. The

As implied from the aforementioned studies, fuelwood will likely exist as an important energy source of rural households in the long term and it is worth a further search for an optimal schema of thinning plantation forests for fuelwood in WOW. The earliest fuelwood-balanced year of the status quo scenario (C3) is year 15 of simulation, and the scenarios with less fuelwood can reach balance as early as year 6 and still produce surplus fuelwood. An optimal scenario (CD3) in which rural households spend less on electricity than in the scenarios with less fuelwood but can still reach fuelwood balance at year 15 of simulation was found through WOW. This exercise indicated the potential that thinning plantation forests can satisfy a substantial portion of fuelwood demand and lessen the impact on suitable panda habitat. This effort also demonstrated a way to use WOW to find a better decision alternative.

WOW lays a good foundation for analyzing the dynamics of coupled human-nature systems and evaluating policy scenarios. It can also be used as a communication and educational tool for increasing awareness of conservation from the public. However, as most similar systems, it has its limitations. Based on feedback from users, future efforts with WOW may focus on refining the models and improving usability and performance toward an operational and collaborative system.

There is no compelling evidence that the current global energy crisis may disappear or slow down in the near future. Therefore, the methodology presented in this dissertation also has important and broad implications in the search of sustainable solutions balancing human energy needs and wildlife conservation worldwide, especially in those remote and rural regions with long-lasting conflicts of human development and biodiversity conservation.

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