Three Decades of Change in Giant Panda Habitat around and within Foping Nature Reserve, China

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DISCLAIMER

ABSTRACT

The giant panda (*Ailuropoda melanoleuca*) is one of the world's most endangered species and is threatened by many kinds of human activities such as logging, road construction and expansion of agriculture. To protect the giant panda and its habitat, more than sixty nature reserves have been established since 1963. More recently, a study conducted in Wolong Nature Reserve, which is a flagship nature reserve in giant panda conservation in China, has shown that the rate of loss of high-quality panda habitat after the reserve's establishment was much higher than before the reserve was created. This unexpected result shocked the world. In order to investigated if the same situation was also happening in other panda reserves, this study was designed to detect the change of panda habitats around and within Foping Nature Reserve – another key panda habitat - over the last three decades from 1970s to 2000s.

Three ecological factors including forest/non-forest, elevation and slope were taken into account when modeling the suitability of panda habitat in Foping, which was same as the study in Wolong. The forest cover in 1970s, 1980s and 2000s were classified using Landsat images. The change of forest cover and panda habitat around and within Foping Nature Reserve was detected. The fragmentation patterns of panda habitat were also analyzed using FRAGSTAS software.

The results revealed that the trends of panda habitat were changing and habitat fragmentation patterns were strikingly similar to the trend of forest cover change. The forest and suitable panda habitat inside Foping reserve were stable over the last three decades. On the other hand, the forests and panda habitats outside Foping reserve had changed dramatically. This implies that the habitats of Foping panda reserve are well preserved from human activities. In addition, the most severe forest and habitat degradation outside Foping reserve happened in the period of 1980s-2000s. Among the three different land use types, the activities of local communities contributed most to the change of the panda habitat.

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1. INTRODUCTION

1.1. Background

The giant panda (*Ailuropoda melanoleuca*) is one of the mammal species which is threatened by many kinds of human activities such as logging, road construction and expansion of agriculture (Liu, 2001). Historical records shows that the giant panda was formerly widespread in southern and eastern China, as well as neighbouring Myanmar and north Vietnam (Pan *et al.*, 2001). As a result of climate change and habitat alteration, the distribution range of the giant panda has shrunk dramatically. As a result, today the giant panda is only found in five isolated mountain ranges (*i.e.*, Qinling, Minshan, Qionglai, Liangshan and Xiangling) of three provinces of south-western China – Sichuan, Gansu and Shaanxi (Hu, 1993). Now, the giant panda is recognized as one of the world's most endangered mammals and it has gained wide attention from society (Feng *et al.*, 2008). A lot of conservation activities have been conducted to protect their habitat from degradation. Monitoring the giant panda habitat therefore becomes one of the major activities in giant panda conservation.

In order to assess the status of giant panda population and its habitat, three national-level ground surveys were conducted by the Chinese government in 1974-1977, 1985-1988 and 1999-2002, respectively (State Forestry Administration, 2006). In addition, a number of studies have been done to investigate the relationship between forest fragmentation and panda habitat (Liu *et al.*, 2001; Liu *et al.*, 2006; Wang *et al.*, 2010a). All these authors have reported that the forest fragmentation and degradation is the main reason for this species' decline. And the direct loss of forests was used as an important indicator of habitat degradation for giant panda. Both (Liu *et al.*, 2001) and (Loucks *et al.*, 2003) investigated the fragmentation and degradation of giant panda's habitats through the truth of the forest degradation, and in their studies, land cover was simply classified into forest and non-forest categories. Analysis of satellite images has shown that suitable habitat for pandas decreased by about 50% between 1974 and 1983 (De Wulf *et al.*, 1988; MacKinnon and Wulf., 1994). According to the third national giant panda survey conducted between 1999 and 2002, the number of giant panda individuals has increased in the last few decades, but their distribution is discontinuous, with 24 isolated populations (State Forestry Administration, 2006).

1.2. Problem statement

By using forest and non-forest as the key ecological variables for panda habitat assessment, a case study conducted by (Liu *et al.*, 2001) at Wolong Nature Reserve revealed that the rate of loss of high-quality panda habitat after the reserve's establishment was much higher than before the reserve was created. The problems of mismanagement and conservation politics were thought to be the underlying reason for unsuccessful conservation (Dompka, 1996; Schaller, 1994). We agree with the opinion that the development of the local community may cause great damage to giant panda habitat. However, we do not think the Wolong case could represent the situation of entire giant panda habitat in the nature reserves. Giant pandas are obligate bamboo grazers and they select habitat primarily on the basis of suitability for foraging (Schaller *et al.*, 1985). The typical panda habitat is the mountainous forest with plenty of bamboo. Therefore, the essence of panda habitat degradation is the loss of both canopy forest and understory bamboo. The timber harvesting in the Qinling Mountains adopts a system of partial or selective cutting instead of clear cutting to avoid unrecoverable damage to the forest. Although a selective logging strategy would maintain the significant forest cover and not change the pattern of forest, it still has big influence on the understory bamboos. In this regard, using forest and non-forest as the indicator of habitat degradation in Qinling Mountains may underestimate the unsuitable panda habitat, but it is still a very useful approach for long-term habitat monitoring.

1.3. Research objectives

1.3.1. General objective

The main objective of the research is to detect the change of giant panda habitats around and within Foping Nature Reserve over the last three decades, from the 1970s to the 2000s.

1.3.2. Specific objectives

- To map and detect the changes of forest and non-forest areas around and within Foping Nature Reserve over the last three decades.
- To assess the suitability of giant panda habitats and detect its change around and within Foping Nature Reserve over the last three decades.
- To quantify the fragmentation patterns of giant panda habitats around and within Foping Nature Reserve over the last three decades.

1.4. Research questions

- What changes in forest cover have occurred around and within Foping Nature Reserve over the last three decades?
- Is there a difference in forest cover change between the period 1970s -1980s and 1980s – 2000s?
- Is there a difference in giant panda habitat change inside and outside Foping Nature Reserve over the last three decades?
- Which areas have the most significant change occurred in giant panda habitat? And which land use type may contribute to this big change?
- What are the characteristics of panda habitat fragmentation around and within Foping Nature Reserve over the last three decades?

1.5. Research hypotheses

- There is no difference in the rate of forest cover change between the period 1970s – 1980s and 1980s – 2000s.
- There is no difference in the rate of panda habitat change between inside and outside Foping Nature Reserve.
- There is no difference in the rate of panda habitat change among the land use types.

1.6. Organization of the thesis and research approach

The thesis consists of five chapters, which are organized to answer the research questions above, listed as follows.

Chapter 1 introduces the general background and problem about the giant panda and its habitat assessment. At the same time, research objectives, research questions and hypotheses are defined.

Chapter 2 describes the study area, the input data used, and methods applied in this research. Aspects about how the methods were applied, included data collection, image pre and post processing, chosen software tools and some basic principles, are all well explained in this chapter.

Chapter 3 shows the results. The results are presented in three parts, change of forest and non-forest cover, change of giant panda habitat suitability and change of habitat fragmentation pattern over the past three decades.

Chapter 4 presents a discussion of the results and methodology of the whole study.

Chapter 5 presents the conclusions and recommendations for future research.

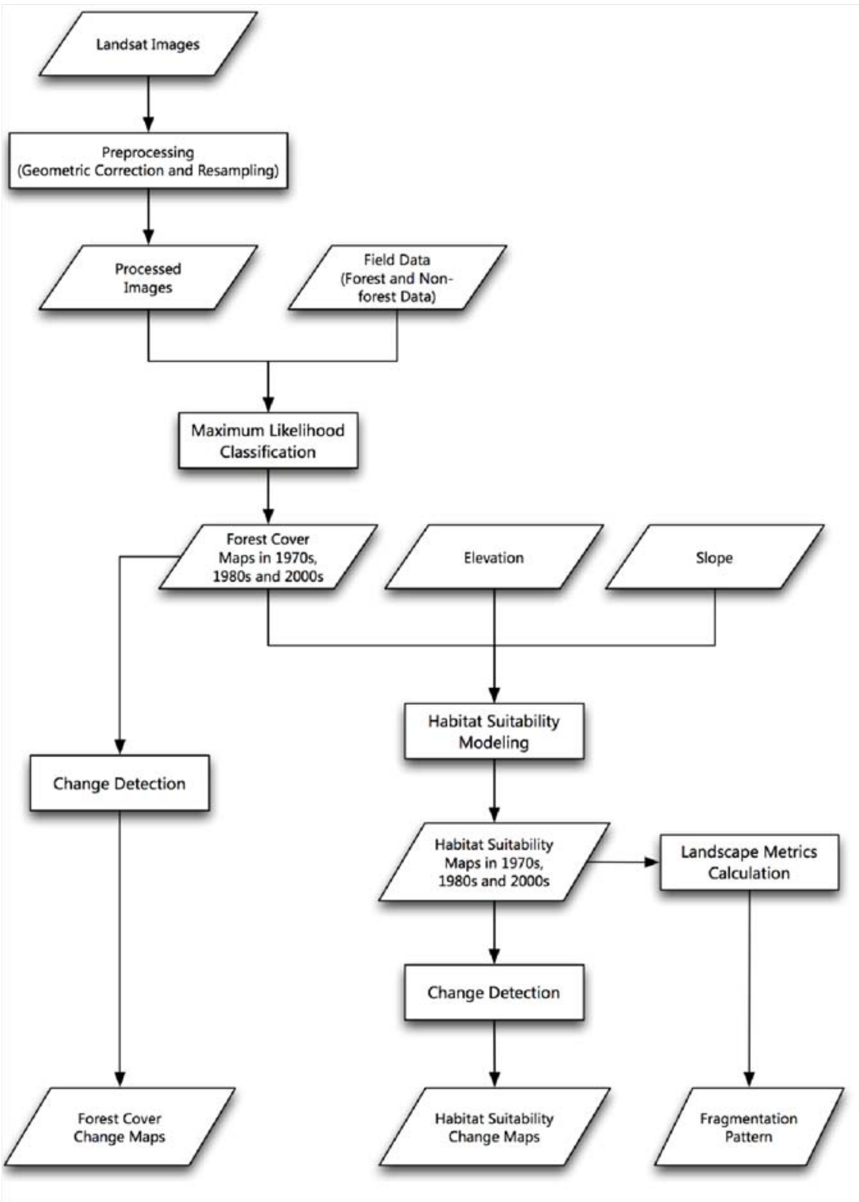

Figure 1. Research process flow chart

2. MATERIALS AND METHODS

2.1. Study area

Foping Nature Reserve is located on the middle part of the southern slope of the Qinling Mountains (33 °32'-33°45' N, 107°40'-107°55' E), and in the southern part of Shaanxi province (Figure 2). The reserve covers an area of 294 km² and its elevation ranges from about 980 to 2904 m. It was established in 1978 to conserve the endangered giant panda and its habitat. It is a reserve that is renowned for having the highest density of giant pandas in China, and thus of the world. An estimated 76 giant pandas live in the reserve.

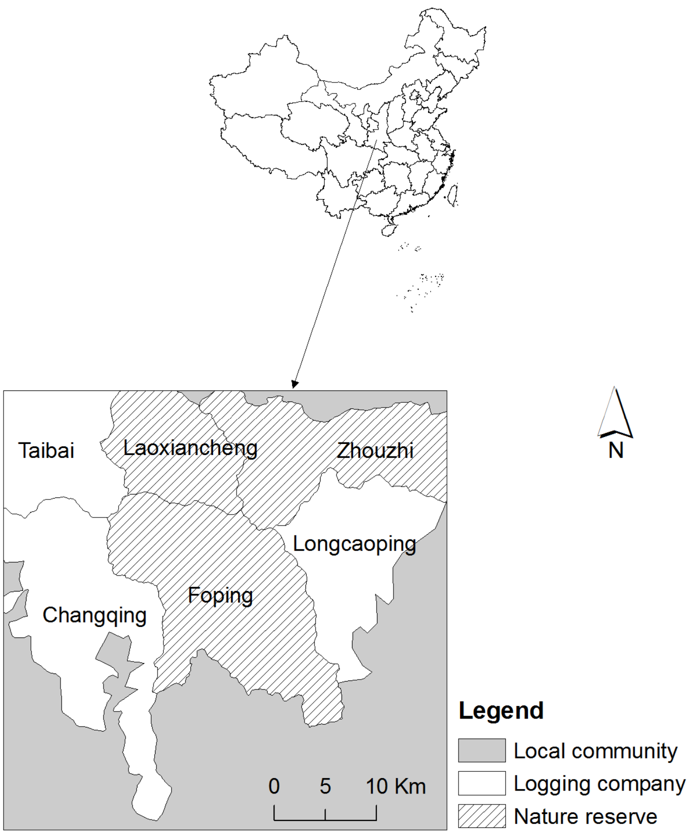

Figure 2. Location of the study area and the land use type

Natural vegetation grows well in Foping Nature Reserve. Forest covers over ninety percent of total land area in this reserve. The main vegetation types are deciduous broadleaf forests (below 2000 m), birch forests (2000-2500 m), conifer forests (above 2500 m), as well as shrub and meadow (Ren *et al.*, 1998). The cool, wet climate and fertile soils in Foping Nature Reserve provides ideal conditions for bamboo to thrive in the understory of multiple vegetation types. Two main bamboo species *(Bashania fargesii* and *Fargesia spathacea)* are widely found here offering giant panda the basic food resources (Ren *et al.*, 1998). From June through September, pandas eat *Fargesia spathacea*, which grows in an elevation range of 1900 – 3000 m. From October to May pandas eat *Bashania fargesii*, which grows in an elevation range of 1000 – 2100 m (Fu, 1998; Pan, 1995).

People who reside inside the nature reserve are local farmers and reserve managers. Farming and mushroom-production are the main human activities in the reserve having an influence on the giant panda habitats. Some conservation activities are conducted regularly, such as monthly patrols to record signs of panda and other animals as well as habitat information.

In order to analyze the difference between giant panda habitat changes both inside and outside the reserve, a surrounding area is created as a buffer area within a distance of 10 km from the boundary of Foping Nature Reserve. There are three main land use type in the surrounding area: protected area, logging company and local community. The surrounding area is divided into seven parts according to the different land use type and administrative region (Figure 2). The Foping Nature Reserve and its surrounding area constitute the whole study area, covering an area about 1873 km^2.

2.2. Field data collection

The forest and non-forest data was collected in the study area during the fieldwork from September to October in 2010. The data was used as ground truth to classify the three time periods of Landsat images, i.e. 1970s, 1980s and 2000s. In order to make sure the ground truth information collected during the fieldwork is suitable for three different time periods, the purposive sampling method was applied. Only the areas without land cover changes over the last three decades were selected. Hence, informal interviews of land owners and land managers were conducted during the field survey to obtain information on previous and current land cover. This information was complemented with high-resolution imagery obtained from Google Earth to account for areas with restricted accessibility. The field sample plot size is 60×60m, which is the size of the pixel of the classified images. A GPS receiver was used to record the coordinates of the samples.

In order to collect representative samples, the sampling route was designed try to across the entire study area. The selection of non-forest samples covered the varieties of non-forest cover, such as cropland, bush land, grass, bare land, water body and built up areas. As a result, 80 field samples were collected: 42 forest sample plots and 38 non-forest sample plots.

2.3. GIS layer and satellite imagery

2.3.1. Digital elevation model (DEM)

Elevation and slope information are two important abiotic variables in giant panda habitat modelling. The DEM used here was clipped from the ASTER Global Digital Elevation Model (ASTER GDEM) (http://www.gdem.aster.ersdac.or.jp/), and resampled to 60 m using a nearest neighbour operator in order to keep the resolution consistent among all raster data. Elevation was directly extracted from DEM using extraction tool, while information was computed using surface tool in ArcGIS.

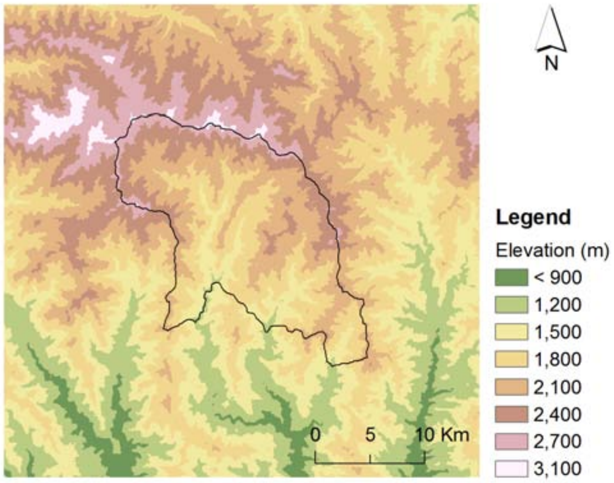

Figure 3. Elevation of the study area

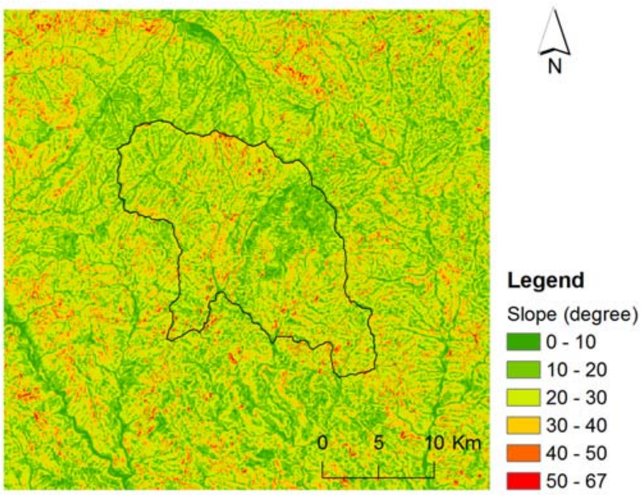

Figure 4. Slope of the study area

2.3.2. Satellite imagery processing

In order to compare the forest land cover change in 1970s, 1980s, 2000s, the images listed in Table 1 are selected from all the available Landsat series images. For each time period, winter and summer season images are available. The imaging dates for the same season are within a limited day interval (see Table 1) and suggest their observation link to the similar local vegetation phonology. Good quality and similar sun elevation for the image from the same season making them comparable.

The projection of all images was defined to WGS_1984_UTM_Zone_49N. The acquired images were subjected to geometric correction. This was done in ERDAS IMAGINE 9.2 using 11 ground control points (GCPs) from the 1:50000 topographic map of the study area. Then all the images with pixel size of 30×30m were resampled to 60×60m using nearest neighbour method. This approach has the advantage of being simple, efficient and preserving the original values (Foody *et al.*, 2003)

Table 1. Landsat images used in this study

Satellite	Season	Date	Source
Landsat 1 MSS	Winter	1973-12-31	USGS
Landsat 3 MSS	Summer	1978-8-19	USGS
Landsat 5 TM	Winter	1988-12-20	RSGS
Landsat 5 TM	Summer	1987-8-21	RSGS
Landsat 7 ETM+	Winter	2002-1-10	USGS
Landsat 5 TM	Summer	2000-7-30	RSGS

Forest cover mapping based on classification of remote sensing images from single sensor or limited amount of spatial, spectral, temporal properties has been found to be sometimes insufficient in practice. This is because the information provided by each individual sensor under a specific temporal point may be incomplete, inconsistent and imprecise for a given application (Xie *et al.*, 2008). Image fusion opens a new way to extract high accuracy vegetation covers by integrating remote sensing images of different spatial, spectral and temporal resolutions and images from different sensors to increase variation among classes (Xie *et al.*, 2008). The confusion between different cover types could then generally be reduced and finally improve the accuracy of classification. Images from different seasons are commonly utilized in practice. Broad research and application results supported that seasonal variability among images significantly affects the classification accuracy (Colstoun *et al.*, 2003; Schriever and Congalton, 1995).

Similarly, in this research, satellite images captured in both winter (senescence with snow cover) and summer (leaf on) time are utilized to make an accurate separation of forest cover regions from those without any forest cover using remote sensing image classification. For each period of time, two sets of images are collected. More specifically, there are eight bands of MSS images for 1970s, among which four bands are captured in the summer time and the other four are captured in the winter time. Among those TM and ETM+ images for 1980s and 2000s, there are 12 bands in total, half captured in summer and the other half captured in winter. Image fusion was carried out using Principal Component Analysis (PCA) tool in ERDAS and thus resulted in four new PCA bands for each date respectively.

2.4. Mapping forest and non-forest and detecting the changes

In this study, the land cover over the whole study area was classified into two main types, forest and non-forest, using traditional maximum likelihood classifier with MSS, TM/ETM+ imagery data in ERDAS 9.2. Samples data collected during the field work periods were utilized in both the procedure of MLC classification for training purposes and the procedure of post-classification accuracy assessment for evaluation purposes.

2.4.1. Mapping forest and non-forest

Image classification, in a broad sense, is defined as the process of extracting differentiated classes or themes (*e.g.* land use categories, vegetation species) from raw remotely sensed satellite data. Techniques for extracting vegetation from pre-processed images are grouped into two types: traditional and improved methods. Traditional methods employ classical image classification methods, *e.g.* k-means and ISODATA for unsupervised classification and the maximum likelihood classifier for supervised classification. Improved methods, including artificial neural network (ANN), decision tree (DT), fuzzy logic, etc., are supposed to provide better results of classification. However, extensive field knowledge and auxiliary data are required and they also are relatively difficult to implement (Xie *et al.*, 2008).

The maximum likelihood classifier (MLC) was used to classify the forest and non-forest in this research. Based on parametric density distribution model, probability density functions are built within MLC classifier for each class based on the spectral properties of chosen training data. During the process of classification, each unclassified pixel is assigned with a value of class membership based on the relative likelihood (probability) of that pixel occurring within each class's probability density function. Then each unclassified pixel with the maximum likelihood is classified into the corresponding class.

MLC is one of the most powerful and popular supervised classification methods in the field of remote sensing image processing. This is because, in comparison to other existing traditional and improved classification methods, MLC has many advantages, such as its solid mathematical base of the Bayesian theory, its clear parametric interpretability, feasible integration with prior knowledge, and relatively simple realization (Lillesand *et al.*, 2004). Hence in the past ten years, the MLC approach has found wide applications. Thus, it is chosen as the classification method in this study to distinguish the forest covered land from areas of non-forest cover.

Eighty samples in total were collected from field work in the study area. All these samples were collected according to the suggestions presented in (Sensing, 1999). Being randomly selected form the 80 sample plots, 48 are utilized as training data for MLC classifier, and the other 32 samples were reserved for use in the accuracy assessment procedure. In order to increase the class separation and thus improve classification accuracy, before MLC classification, image fusion based on principal component analysis (PCA) were carried out upon each set of images captured in both summer and winter time for each time period. The final result of classification result will be presented in the chapter of "Results".

Table 2. Training and testing samples used in forest cover classification

Categories	Forest	Non-forest	Total
Training	24	24	48
Testing	18	14	32

2.4.2. Accuracy assessment of classification

Accuracy assessment, a procedure often also called result evaluation, is employed to determine the degree of 'correctness' of the classified land cover groups compared to the actual ones (Congalton, 1991; Xie *et al.*, 2008). It requires that a randomly selected set of test samples (pixels) for each land cover class is used for computing the classification accuracy, to evaluate the performance of remote sensing classifier (Richards, 1993). First of all, those ground true points for testing purpose should be carefully collected in such a manner that they are equally spread geographically within the set of training data points, in order to ensure the objectiveness of assessment result. Then the classified images were then interpreted and compared with the ground truth data to generate error matrices, based on which various accuracy measures as well kappa statistics could be calculated (Baatuuwie and Leeuwen, 2011; Congalton, 1991).

The error matrix, also known as a confusion matrix, is a contingency table or a classified error matrix. Generated by comparing the classification map with the reference map, the error matrix is always showed in a tabular form, as show in the following table (Congalton, 1991; Congalton and Green, 1999; Story and Congalton, 1986). The values of a_{ij} denotes the count of pixels that have been correctly or incorrectly classified during the classification procedure. Most pixels are counted in cells occupying the diagonal of the matrix, thus indicating mostly correct identification of pixels on the classified map. Cells identifying errors in classification occupy non-diagonal positions.

Table 3. The confusion matrix

	Forest	Non-forest
Forest	a_{11}	a_{12}
Non-forest	a_{21}	a_{21}

Commonly used accuracies are overall accuracy, mean accuracy, mapping accuracy for each class, producer's accuracy, user's accuracy, and so on (Congalton, 1991). Generally speaking, the overall accuracy and mean accuracy are adequate for simple accuracy assessment purposes.

A more comprehensive measure of the accuracy of a classification is the Kappa coefficient, also referred to as Kappa-hat or K-hat (Congalton, 1991; Skidmore *et al.* 1996). This measure compares the numbers of pixels in each of the cells in the matrix with a random or chance distribution of pixels. Among miscellaneous kappa guidelines, the Cohen's kappa statistic is a chance-corrected measure of agreement (Cohen, 1960). Due to the full use of the information contained in the confusion matrix, it becomes a common choice for accuracy assessment of image classification (Fielding and Bell, 1997). Kappa coefficient ranges from 0 to 1 and higher value indicates better performance (Cohen, 1960). In general, the mapping results are evaluated with levels of very good, better, good, normal, bad, worse and very bad. Corresponding Kappa values of these levels are 0.8-1.0, 0.6-0.8, 0.4-0.6, 0-0.2, and lower than 0 (Liu *et al.,* 1998).

Moreover, a significance test of difference between classification results could also be performed between the confusion matrices using the Z test (Congalton, 1991). The result of Z test evaluates the variances and consistency among classification results. Classification outputs can even be assessed qualitatively by visual examination of the classified maps in relation to the field knowledge.

In this study, to be simplified, only sufficient accuracy indexes including the overall accuracy, Kappa value and Z test are chosen in the accuracy assessment procedure. The results of the accuracy assessment and the corresponding explanation of these results will be provided in the chapter of "Results".

2.4.3. Detecting changes in forest cover

The technique to detect changes of land cover among different time periods is based on the overlay GIS operation, whose results could be utilized to determine whether there is any different in rates, trends, and the factors that cause land cover changes between two time periods.

In order to detect the forest cover change over the whole study area from 1970s to 1980s and from 1980s to 2000s, two change maps were obtained through an overlay with subtraction operator between the forest cover maps of 1970s and 1980s, and between of 1980s and 2000s. These two maps of forest cover changes are presented in the section 3.1.

Regions of different land use types act different during the process of forest cover change. It will be beneficial to investigate such difference when seeking for the reason why and how the forest cover change happened during the past three decades. Since human activity is believed to be the main reason of forest degradation, regions of different land use types tends to have different human activity intensity. So in the normal case, forest cover changes must be highly connected to a region's land use types. For this purpose, statistical analyses on the forest cover change are performed separately on regions grouped by their main land use types. The results of forest cover change detection are presented with thorough explanation in the chapter of "Results".

2.5. Modeling the suitability of giant panda habitats

2.5.1. Selection and analysis of environmental factors

The quality of giant panda habitats is restricted to many kinds of environmental factors. Liu *et al.* (1997) evaluated the habitat of Wolong Nature Reserve by applying GIS method and taking three factors of elevation, slope and bamboo into account. In this study, based on the previous research findings on giant panda habitat (Wu *et al.*, 2010; Xu *et al.*, 2006) and the actual conditions in the study area, forest cover, elevation and slope were selected as the factors when modeling the giant panda habitat. The suitability of each single factor was assessed and is divided into three categories: suitable, marginally suitable and unsuitable (Table 4).

Table 4. Criteria for suitability assessment of the biotic and abiotic factors

Suitability Score	Suitable	Marginally Suitable	Unsuitable
Forest	Yes (1)	Yes (1)	No (0)
Elevation	>1350 (2)	900-1350 (1)	<900 (0)
Slope	<35 (2)	35-45 (1)	>45 (0)

- Forest cover

Traditional ground survey to obtain the bamboo distribution is time-consuming, labour-intensive and the results could not be continuing in space. Understory bamboo could neither be identified from satellite images in a straightforward manner due to the interference of overstory canopies. In certain cases, the bamboo's spatial distribution and dynamics can be approximated by the spatial distribution and dynamics of forest, based on the assumption that the understory bamboo has a close connection to the overstory canopies. In case there are few or no overstory canopies, probability for bamboo to exist in the same area must also be quite low.

- Elevation

The limit of elevation for giant pandas is dependent on the intensity of human activities. The recorded lowest area that giant pandas could reach is around 800 m to 900 m (Pan *et al.*, 2001). However, because they have fertile soil and a favourable climate, the areas below 1350 m are disturbed by human activities, such as farming, negatively influencing the quality of giant panda habitats (State Forestry Administration, 2006). The upper limit of elevation for giant pandas to inhabit is 3100m, as there is no distribution of bamboo above 3100m. In fact, the highest elevation in this study area is below 3100 m. Hence, there is no upper limit of elevation for giant pandas to inhabit in this study.

- Slope

Considering the animal's energy maintenance, the factor of slope is also important in habitat evaluation because a steep slope is not suitable for giant pandas to move. Surveys show that it is statistically significant that giant pandas have particular topographic preference (State Forestry Administration, 2006). Giant pandas prefer to forage in the gently sloping area: the observation frequencies of pandas appear in the slope within the range of 0-35 degree making up 84.3% of the whole, the 14.3% were from 35 to 45 degree, and only 1.4% was from over 45 degree (Xu *et al.*, 2006). Therefore, 35 degree and 45 degree were chosen to separate the suitability levels.

2.5.2. Evaluation of the habitat suitability of giant panda

The habitat suitability in this study resulted from the combination of three factors of forest cover, elevation and slope. The evaluation of habitat suitability was carried out based on evaluation of each single factor using Table 5.

Table 5. Two-dimensional classification of potential habitat in the study area (2, 1, 0 refer to suitable, marginally suitable and unsuitable respectively)

	Slope Suitability					Elevation-Slope suitability			
Elevation Suitability	Score	2	1	0	Forest Suitability	Score	2	1	0
	2	2	1	0		1	2	1	0
	1	1	1	0		0	0	1	0
	0	0	0	0					

2.5.3. Detecting changes of habitat suitability

It is worthy of investigating the habitat suitability changes in order to reveal the patterns in changes, based on which corresponding reasons could be figured out. The procedure of habitat suitability modeling and evaluation results in maps of giant panda suitability evaluation. Given such maps, it is feasible to carry out change detection together with GIS overlay analysis tools. By subtracting the suitability map of habitat later period by that of its previous period, a change map of giant panda habitat suitability could be produced. Judging from these change maps of habitat suitability, location and quantity of changes could be accurately determined.

2.6. Habitats Fragmentation Analysis

Continued habitat loss and fragmentation will threaten the survival of giant panda (Wang, 2003). Thus a habitat fragmentation analysis is conducted in this study after mapping out the habitat suitability.

In this research, FRAGSTATS program is performed during habitats fragmentation analysis. It is a spatial pattern analysis program for quantifying landscape structure, *e.g.* it can quantify the areal extent and spatial distribution of patches within a landscape (Mcgarigal *et al.*, 2002). FRAGSTATS offers a comprehensive choice of landscape metrics.

Patch density, edge density and mean patch area are three landscape metrics frequently used to measure the habitat fragmentation (Wang *et al.*, 2010b; Zhang *et al.*, 2008) and these also were used in this study. The expression of the three metrics is as below:

- Patch Density (PD)

Patch density is the number of corresponding patches divided by total landscape area. Holding class area constant, a landscape with a greater density of patches of a target patch type would be considered more fragmented than a landscape with a lower density of patches of that patch type. Similarly, the density of patches in the entire landscape mosaic could serve as a good heterogeneity index because a landscape with greater patch density would have more spatial heterogeneity.

- Edge Density (ED)

Edge density is the sum of the lengths of all edge segments involving the corresponding patch type, divided by the total landscape area. Edge density standardizes edge to a per unit area basis that facilitates comparisons among landscapes of varying size. High values of edge density indices mean that the edge present, regardless of whether it is 10 m or 1,000 m, is of high contrast, and vice versa.

- Mean Patch Area (AREA）

Mean patch area is the sum of the areas of all patches of the corresponding patch type, divided by the number of patches of the same type. Mean patch area reflects the average value of the patch area, and it comprising a landscape mosaic is perhaps the single most important and useful piece of information contained in the landscape. This information is the basis for many of the patch, class, and landscape indices.

3. RESULTS

3.1. Change of forest and non-forest

3.1.1. Maps of forest and non-forest

Figure 6 shows the distribution patterns of forest and non-forest in 1970s, 1980s and 2000s. In general, forest covers most of the study area in all three images, especially inside Foping Nature Reserve.

The accuracy of the classification is showed in Table 6. The accuracy assessment of three forest cover mapping shows that their overall accuracies are 87.5% for 1970s-image, 87.5% for 1980s-image and 90.63% for 2000s-image, respectively, and the corresponding kappa values are 0.746, 0.75 and 0.808. These three kappa values are all greater than 0.6, which indicates the mapping results meet the accuracy requirement. The Z test result is listed in Table 7, which indicates that there is no significant difference between the classification results of any two images.

Table 6. Accuracy assessment of classification results

	Overall accuracy	Kappa	Kappa variance
1970s	87.5%	0.746	0.003335762
1980s	87.5%	0.75	0.003329467
2000s	90.63%	0.808	0.002603553

Table 7. The result of two class Z test

Pairs of Classification Results	Z value
1970s-1980s	0.048606225
1970s-2000s	0.804083353
1980s-2000s	0.752991461

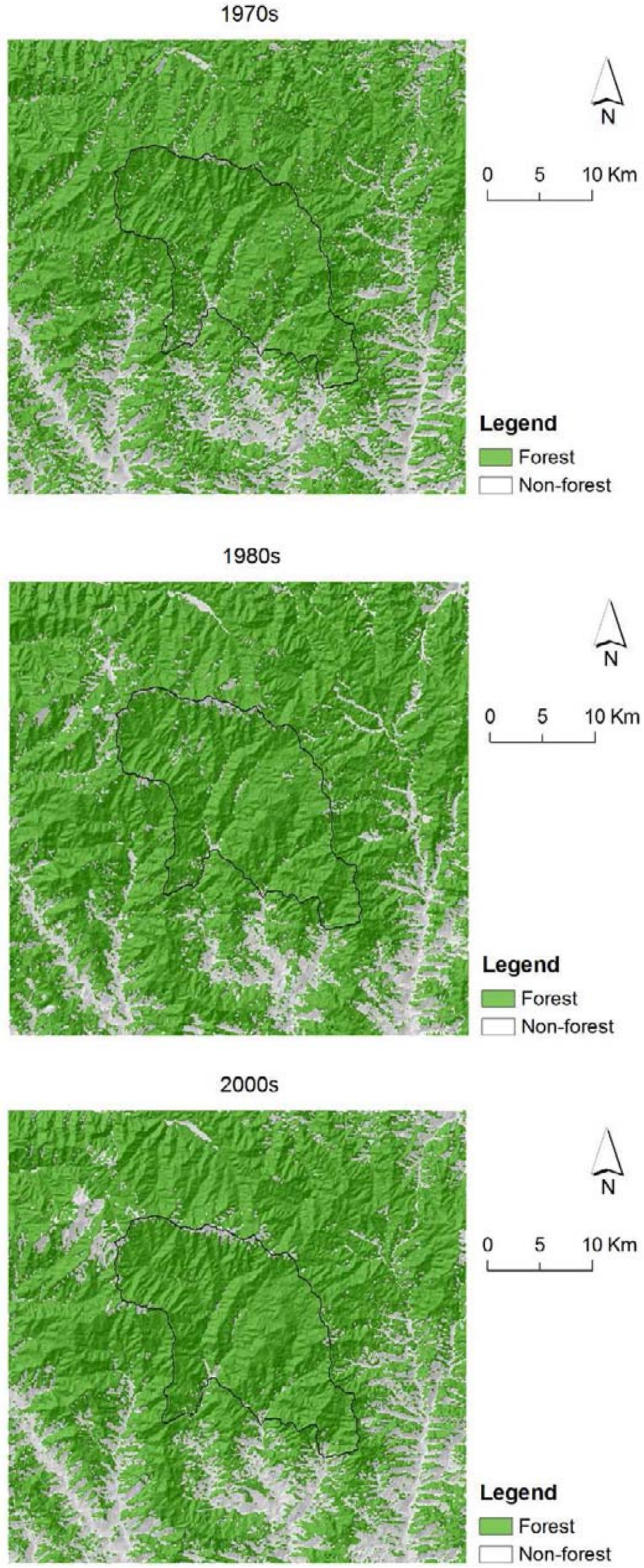

Figure 5. Maps of forest and non-forest in 1970s, 1980s and 2000s

3.1.2. Forest change in the whole study area

Figures 6 and-7 describes the trend of forest and non-forest change during the period of 1970s-1980s and 1980s-2000s. It clearly shows that, in the period of 1970s-1980s, the overall trend was toward an increase of forest over time, with a change ratio of 7.91% according to the statistically analysis (Table 8). While in the period of 1980s to 2000s, the forest in the study area had been significantly transformed to non-forest, with the proportion of forest in the study area decreased from 84.05% to 78.50%.

As shown in figure 6, the most obvious change appears in the southern part of the study area, and only a few changes are detected inside Foping Nature Reserve. In the southern part of the study area, there was obvious increase of forest from 1970s to 1980s, while there was a loss of forest from 1980s to 2000s. Another obvious change occurs in the area to the northwest of Foping Nature Reserve. Forest degradation in this area occurs both from 1970s to 1980s and from 1980s to 2000s.

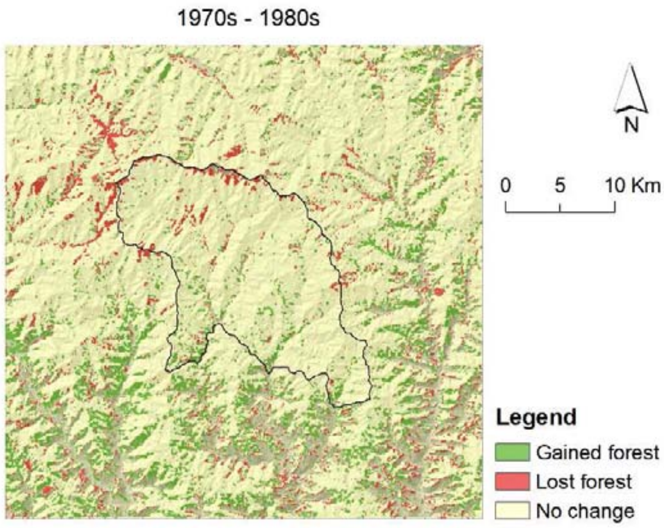

Figure 6. Forest cover change map during the period of 1970s-1980s

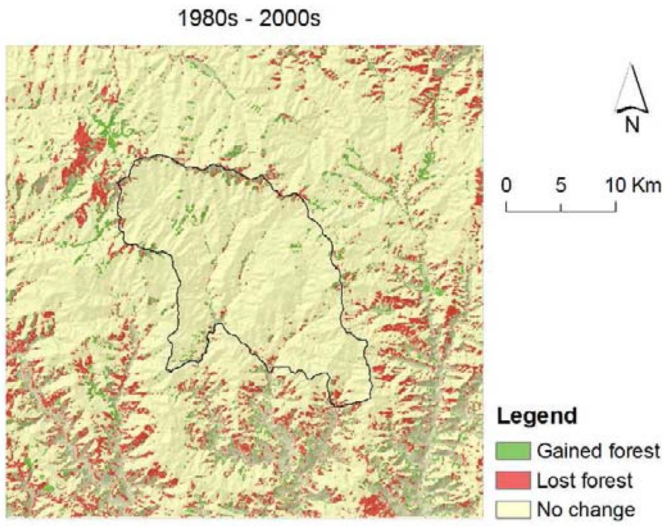

Figure 7. Forest cover change map during the period of 1980s-2000s

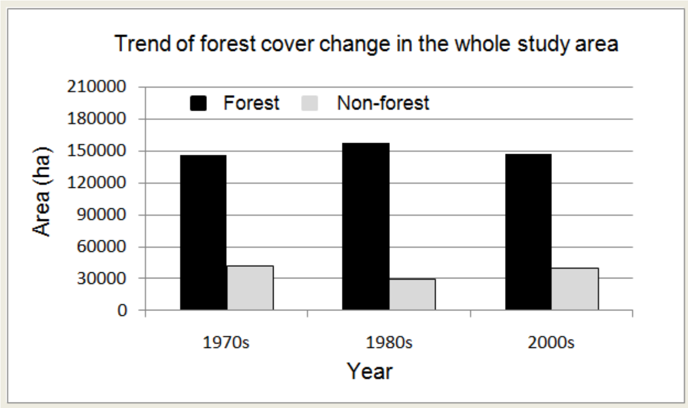

Figure 8. Trend of forest cover change over the whole study area in 1970s, 1980s and 2000s

Table 8. Areas and rates of forest cover change over the whole study area in 1970s, 1980s and 2000s

	70s	80s		2000s	
	Area (Ha)	Area (Ha)	Change Rate (%)	Area (Ha)	Change Rate (%)
Forest	145961.8 (77.89%)	157509.5 (84.05%)	7.91%	147100.2 (78.50%)	-6.61%
Non-forest	41436.2 (22.11%)	29888.5 (15.95%)	-27.87%	40297.8 (21.50%)	34.83%

3.1.3. Forest change inside and outside Foping Nature Reserve

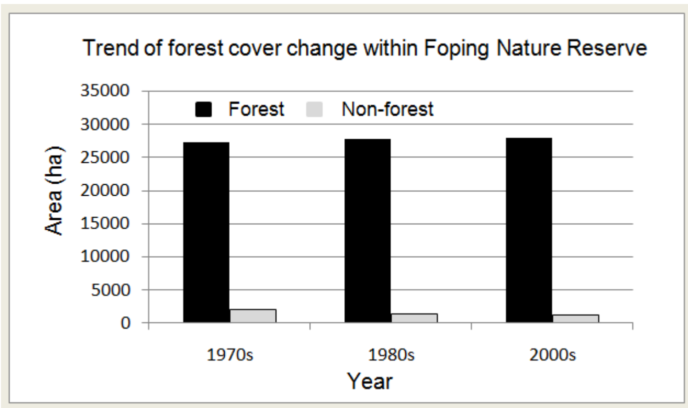

Figure 9. Trend of forest cover change within the Foping Nature Reserve during 1970s, 1980s and 2000s

Table 9. Areas and change rates of forest cover change within Foping Nature Reserve during1970s, 1980s and 2000s

	70s	80s		2000s	
	Area (Ha)	Area (Ha)	Change Rate (%)	Area (Ha)	Change Rate (%)
Forest	27232.8 (93.08%)	27806.2 (95.04%)	2.11%	27985.4 (95.65%)	0.64%
Non-forest	2023.9 (6.92%)	1450.5 (4.96%)	-28.33%	1271.3 (4.35%)	-12.36%

Above Figure 9 and Table 9 show that the forest cover inside Foping Nature Reserve almost has no change over the last three decades. The forest cover is taking a proportion of 93.08% of Foping NR in 1970s, and increase only 2.11% in 1980s which is 27806.2ha with a proportion of 95.04% of the reserve. A similar situation appears in the period of 1980s to 2000s, the forest cover has a change rate of less than 1%, increase from 27806.2ha to 27985.4ha.

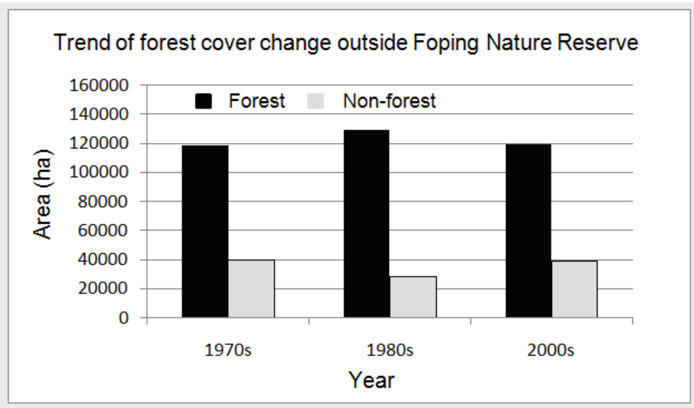

Figure 10. Trend of forest cover change outside Foping Nature Reserve during 1970s, 1980s and 2000s

Compared to the forest cover change inside Foping Nature Reserve, forest cover outside Foping Nature Reserve has undergone great changes and similar with the change in the whole study area. From 1970s to 1980s, the forest cover outside Foping Nature Reserve increased from 118720.8ha to 129697.4ha, with a change rate of 9.25% which is four times as the change rate inside the reserve. From 1980s to 2000s, different with the forest increase inside the reserve, severe forest degradation occurs outside the reserve. Forest cover accounts for 82.01% of the area outside Foping Nature Reserve in 1970s, but decreases to 75.32% in 2000s, with a change rate of 8.17%.

Table 10. Areas and change rates of forest cover change outside Foping Nature Reserve during 1970s, 1980s and 2000s

	70s	80s		2000s	
	Area (ha)	Area (ha)	Change rate (%)	Area (ha)	Change rate (%)
Forest	118720.8 (75.07%)	129697.4 (82.01%)	9.25%	119105.5 (75.32%)	-8.17%
Non-forest	39420.5 (24.93%)	28443.8 (17.99%)	-27.85%	39035.7 (24.68%)	37.24%

3.1.4. Forest change in different land use types

As shown in Figure 11-13, the areas of different land use types have different forest cover changes. Over the last three decades, the areas of protected area and logging company almost remain stable, while the areas of community have very significant forest changes. From the1970s to 1980s, forest in these three land use types increased with a small change rate of 2.78% for protected areas, 3.03% for logging companies and a great change rate of 20.08% for community. From 1980s to 2000s, forest degradation happens in the areas of the three land use types, and the community has the strongest decrease of forest, with a change rate of 15.64% which is much higher than the change rate in the protected area and logging company area.

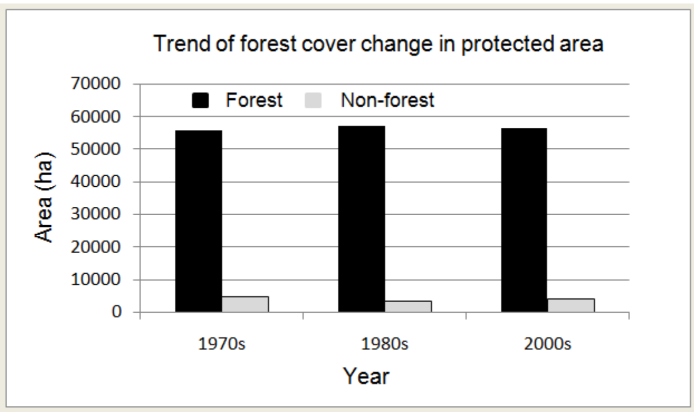

Figure 11. Trend of forest cover change in protected area

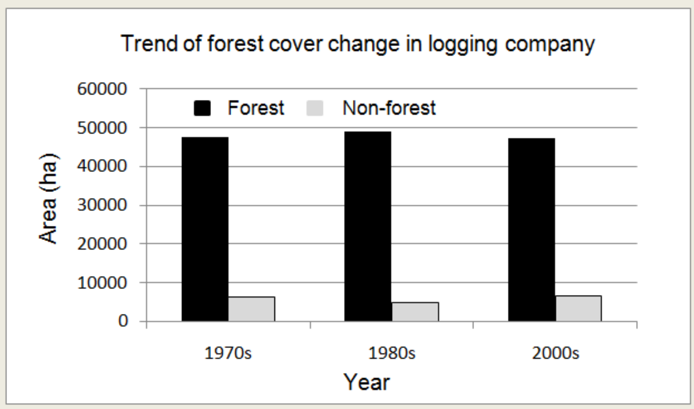

Figure 12. Trend of forest cover change in the logging company area

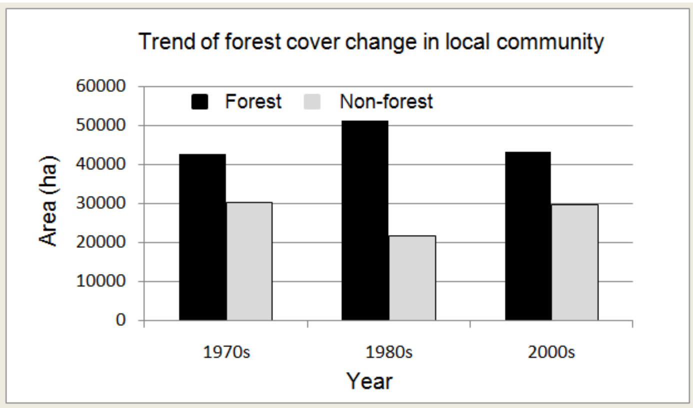

Figure 13. Trend of forest cover change in local community area

Table 11. Forest cover change rates for protected area, logging company area and community area

	Forest		Non-Forest	
	1970s - 1980s	1980s - 2000s	1970s - 1980s	1980s - 2000s
Protected area	2.78%	-1.31%	-32.37%	23.19%
Logging company	3.03%	-3.37%	-22.66%	33.55%
Local community	20.07%	-15.64%	-28.25%	36.85%

3.2. Change of giant panda habitat suitability

3.2.1. Maps of giant panda habitats

The suitability of giant panda habitat was mapped out using the established habitat suitability model. The distribution patterns of habitat types from three different-period images were shown in Figure 14. It is clear that suitable habitat covers most of the study area, most of the marginally suitable and unsuitable habitats are scattered in the southern part of the study area.

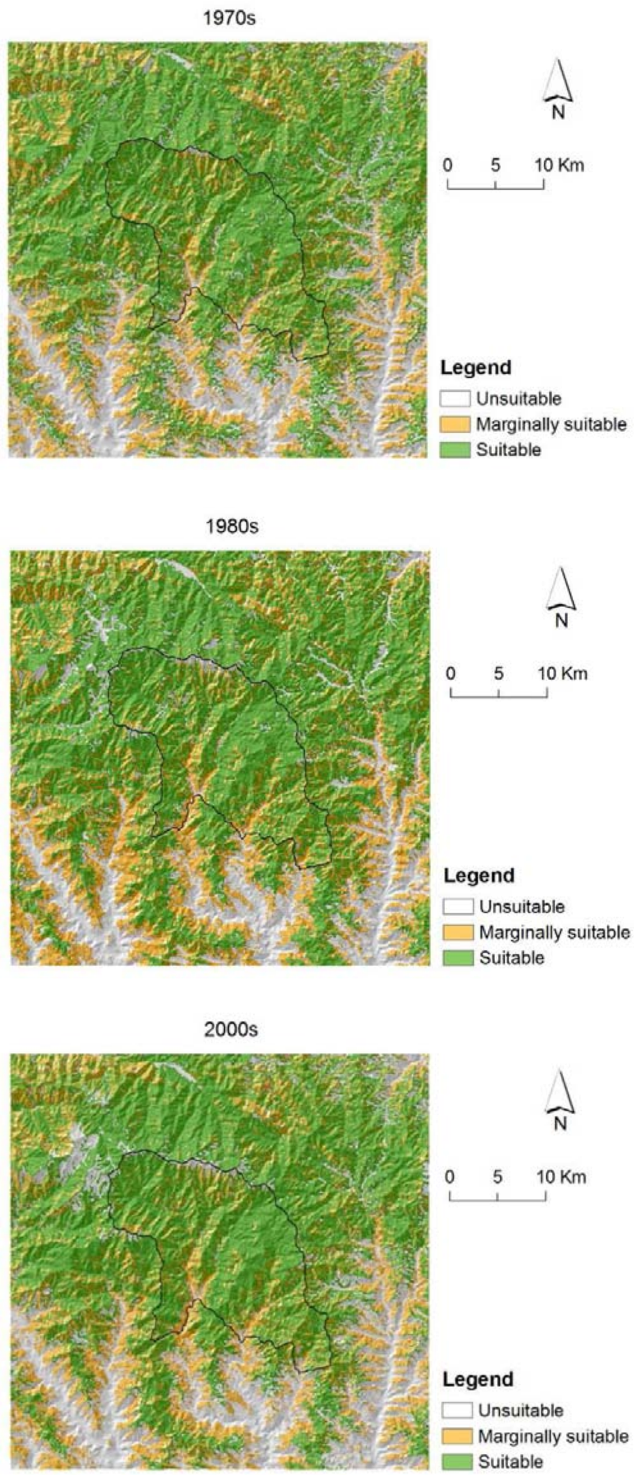

Figure 14. Map of giant panda habitat in 1970s, 1980s and 2000s

3.2.2. Habitat change in the whole study area

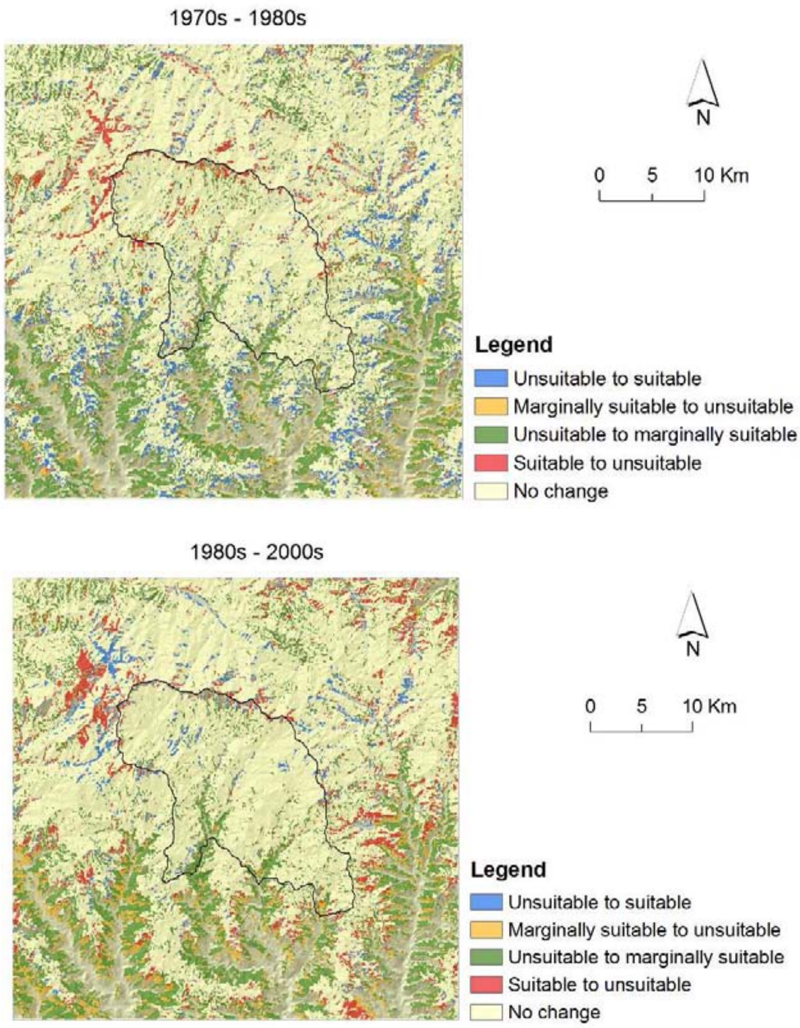

Figure 15. Map of giant panda habitat change from 1970s to 1980s, 1980s to 2000s

The habitat change maps (Figure 15) were obtained through a subtraction between the habitat suitability maps of 1970s and 1980s, and between 1980s and 2000s. From visual interpretation, the change of habitat types mostly appears in the southern part of the study area, and it exhibits a trend of habitat restoration from 1970s to 1980s, but a trend of habitat degradation from 1980s to 2000s (Figure 16).

Quantification result (Table 12) provides some detailed change information. The proportion of suitable habitat of the study area is always around 60% over last three decades. It experienced an increase of 6.06% from 1970s to 1980s, and a decrease of 4.98% from 1980s to 2000s. The proportions of marginally suitable habitat as well as unsuitable habitat are small. However, their change rates are high, especially for the unsuitable habitat which decreased 26.40% from the 1970s to 2000s, and increased 31.52% from 1980s to 2000s.

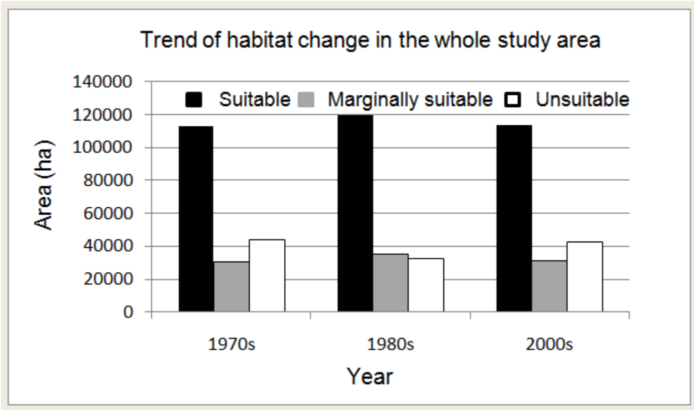

Figure 16. Trend of panda habitat change in the whole study area

Table 12. Area and change rate of panda habitat in the whole study area

	70s	80s		2000s	
	Area (Ha)	Area (Ha)	Change Rate (%)	Area (Ha)	Change Rate (%)
Suitable	113057.0 (60.33%)	119912.4 (63.99%)	6.06%	113942.5 (60.80%)	-4.98%
Marginally Suitable	30467.7 (16.26%)	35196.8 (18.78%)	15.52%	30988.6 (16.54%)	-11.96%
Unsuitable	43873.3 (23.41%)	32288.8 (17.23%)	-26.40%	42466.9 (22.66%)	31.52%

3.2.3. Habitat change inside and outside Foping Nature Reserve

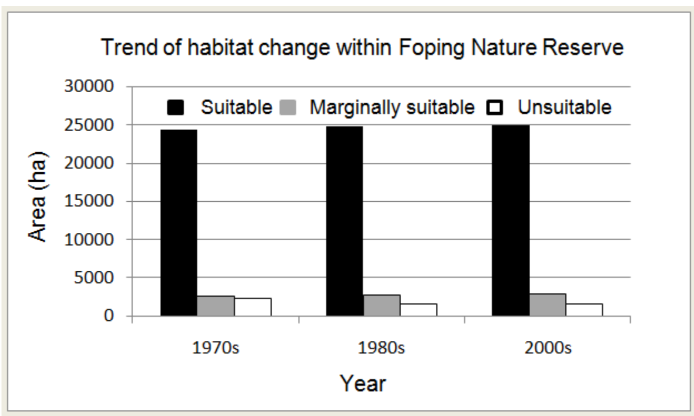

Figure 17. Trend of panda habitat change within Foping Nature Reserve

Table 13. Area and change rate of panda habitats within Foping Nature Reserve

	70s	80s		2000s	
	Area (Ha)	Area (Ha)	Change Rate (%)	Area (Ha)	Change Rate (%)
Suitable	24331.3 (83.16%)	24854.4 (84.95%)	2.15%	24883.6 (85.05%)	0.12%
Marginally Suitable	2663.3 (9.10%)	2753.9 (9.41%)	3.40%	2857.5 (9.77%)	3.76%
Unsuitable	2262.1 (7.73%)	1648.4 (5.63%)	-27.13%	1515.6 (5.18%)	-8.05%

Figure 17 visually describes the trend of habitat change within Foping Nature Reserve, it clearly displays that the habitat types nearly remain relatively stable, only with obvious decrease in unsuitable habitat over last three decades. Statistical analysis (Table 13) shows that suitable habitat has the lowest change rate both in the period of 1970s-1980s and 1980s-2000s, then marginally suitable habitat with the change rate of 3.40% for the period of 1970s-1980s and 3.76% for the period of 1980s-2000s. The unsuitable habitat is decreasing over the last three decades, the area has shrunk from 2262.1ha in 1970s to 1648.4ha in 1980s, and finally covers 1515.6ha in 2000s.

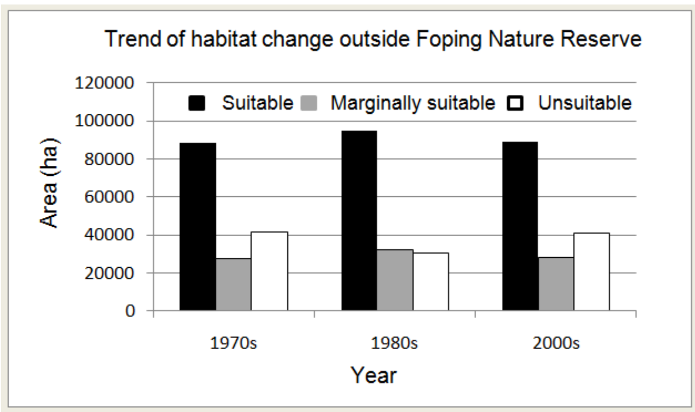

Figure 18. Trend of panda habitat change outside Foping Nature Reserve

Table 14. Area and change rate of panda habitat outside Foping Nature Reserve

	70s	80s		2000s	
	Area (Ha)	Area (Ha)	Change Rate (%)	Area (Ha)	Change Rate (%)
Suitable	88718.9 (56.10%)	95051.7 (60.11%)	7.14%	89051.7 (56.31%)	-6.31%
Marginally Suitable	27806.5 (17.58%)	32445.7 (20.52%)	16.68%	28133.1 (17.79%)	-13.29%
Unsuitable	41615.9 (26.32%)	30643.8 (19.38%)	-26.37%	40956.5 (25.90%)	33.65%

Figure 18 shows the trend of habitat change outside Foping Nature Reserve over last three decades. It clearly shows that the giant panda habitats outside Foping Nature Reserve changed much more dramatically than that inside the Foping Nature Reserve. The giant panda habitat quantity increased from the 1970s to 1980s, while it decreased from 1980s to 2000s. From 1970s to 1980s, the suitable habitat and marginally suitable habitat increased 7.14% and 16.68% respectively, while the unsuitable habitat has significant decrease, with a change rate of 26.37%. From the 1980s to 2000s, the change rate of unsuitable habitat is highest, then marginally suitable habitat and suitable habitat in turn. The proportions of the three habitat types in 2000s almost remained the same as in 1970s, such as the suitable habitat which accounted for 56.10% in 1970s and 56.31% in 2000s.

3.2.4. Habitat change in different land use types

As shown in Figures 19 to21, the protected area and logging company area do not show significant habitat change over last three decades, while the habitat change in the local community area is obvious. The habitat changes for each type are quantified as shown in Table 15. The protected area and logging company area are dominated by suitable habitat, and the quantity of suitable habitat remains nearly stable with the change rate less than 4% both in the period of the 1970s-1980s and 1980s-2000s. However, in the local community area, unsuitable habitats occupy a moderately large part of the area, and the change rate of all the three habitat types are much higher than them in protected area and logging company area. For example, the suitable habitat in the local community area decreased with a change rate of 13.63% from 1970s to 1980s which is almost four times as the change rate in the protected area and logging company area.

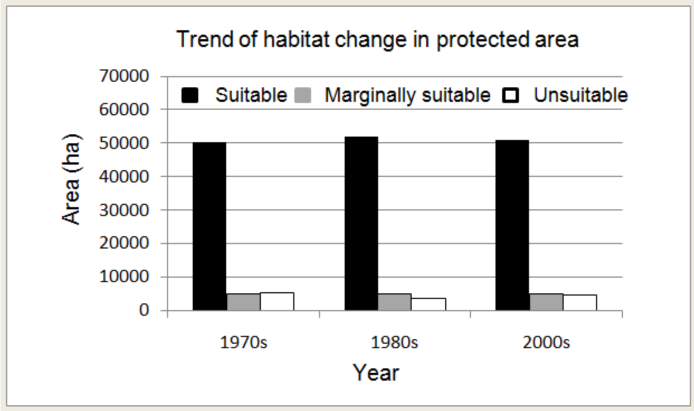

Figure 19. Trend of panda habitat change in protected area

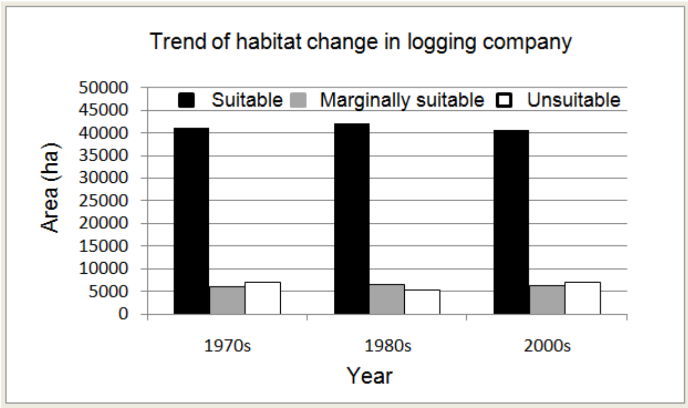

Figure 20. Trend of panda habitat change in logging company

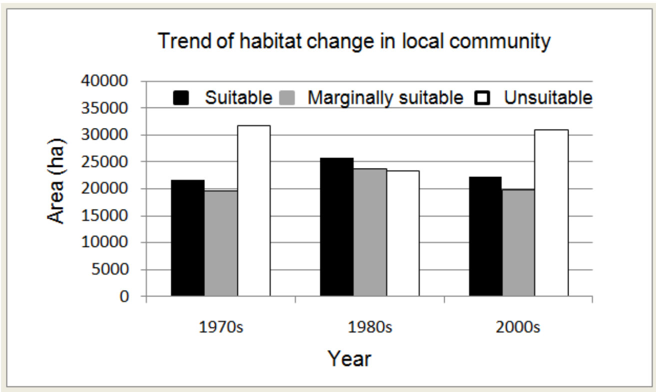

Figure 21. Trend of panda habitat change in local community

Table 15. Change rate of panda habitat in different land use types during 1970s, 1980s and 2000s

	Suitable		Marginally suitable		Unsuitable	
	70s - 80s	80s - 00s	70s - 80s	80s - 00s	70s - 80s	80s - 00s
Protected area	3.95%	-3.61%	-1.22%	0.74%	-33.41%	48.07%
Logging company	2.69%	-3.56%	7.78%	-4.05%	-22.83%	33.17%
Local community	19.41%	-13.63%	21.43%	-17.10%	-26.47%	32.53%

3.3. Landscape fragmentation analysis for the giant panda habitat suitability

3.3.1. Fragmentation of giant panda habitats in the whole study area

Table 16. Results of fragmentation analysis upon the whole study area using the FRAGSTATS program

	PD			ED			AREA		
	70s	80s	2000s	70s	80s	2000s	70s	80s	2000s
Suitable	0.33	0.22	0.35	31.86	27.59	28.22	178.88	279.86	171.33
Marginally suitable	3.13	2.96	3.01	29.91	30.61	29.57	5.18	6.49	5.51
Unsuitable	1.67	1.27	1.177	26.72	19.68	22.71	13.94	13.61	19.24

Table 17. Change rate of landscape fragmentation for the whole study area

	PD		ED		AREA	
	70s-80s	80s-2000s	70s-80s	80s-2000s	70s-80s	80s-2000s
Suitable	-32.91%	56.83%	-13.38%	2.29%	56.45%	-38.78%
Marginally suitable	-5.26%	1.29%	2.36%	-3.41%	25.09%	-15.26%
Unsuitable	-23.78%	-7.96%	-26.34%	15.36%	-2.43%	41.41%

The statistical results (Table 16-17) reveal that the fragmentation of the habitat over last three decades is coincide with the situation of habitat loss. The suitable habitat in 1980s shows a less fragmented landscape compared with 1970s, whereas continues habitat fragmentation of suitable habitat happens from the 1980s to the 2000s. The patch density and edge density in suitable habitat and marginally suitable habitat decreased from 1970s to 1980s, but increased from the 1980s to 2000s. The mean patch area of suitable habitat change significantly over last three decades, it firstly increased from the 1970s to 1980s, and then dramatically decreased from 1980s to 2000s. In contrast, the mean patch area of unsuitable habitat largely increased over last three decades, from 13.94ha in 1970s to 19.24ha in 2000s.

3.3.2. Fragmentation of giant panda habitats in areas of different land use types

Habitat fragmentation varied among different land use types, judging from results listed in Table 18. The community area has the biggest change amount of patch density and edge density for suitable habitat. It is noteworthy that during the period from 1980s to 2000s, the reduction of Mean Patch Area for suitable habitat within protected area was much higher than that which happened in the community area. This result seems to be contradictory to PD and ED results. It was only because the mean patch area of suitable habitat within the protected area used to be much larger than that in the community area. By converting the amount of changes into ratio again the total area of suitable habitat, the results become more acceptable.

Table 18. NP, ED, PD and AREA change amount upon areas of different land use types

	Suitable		Marginally suitable		Unsuitable	
Patch Density	70s-80s	80s-00s	70s-80s	80s-00s	70s-80s	80s-00s
Protected area	-0.10	0.12	1.32	-2.10	-1.77	1.66
Logging company	-0.09	0.16	-0.13	-0.01	-0.71	0.05
Community	-0.19	0.20	-0.25	0.15	0.00	-0.11
	Suitable		Marginally suitable		Unsuitable	
Edge Density	70s-80s	80s-00s	70s-80s	80s-00s	70s-80s	80s-00s
Protected area	-4.12	-0.14	3.42	-7.70	-7.86	7.75
Logging company	-3.50	-0.06	-0.02	-0.52	-6.37	2.64
Community	-4.26	2.00	1.92	-2.01	-8.89	6.26
	Suitable		Marginally suitable		Unsuitable	
Mean Patch Area	70s-80s	80s-00s	70s-80s	80s-00s	70s-80s	80s-00s
Protected area	187.7	-203.4	-2.6	5.8	2.5	-2.4
Logging company	82.5	-122.9	0.5	-0.3	1.0	1.8
Community	37.7	-36.6	3.5	-3.1	-8.5	10.5

4. DISCUSSION

4.1. Change of panda habitat inside Foping Nature Reserve

The quantity and quality of suitable habitats inside Foping Nature Reserve has kept steadily increasing over the last three decades, which indicates that the Foping Nature Reserve has been successfully preserved rather than a failure in protecting habitat. This result is totally different from the study in Wolong Nature Reserve (Liu *et al.*, 2001). By analyzing remote sensing data of the Wolong Nature Reserve, Jianguo Liu and his colleagues demonstrated that serious panda habitat degradation occurred inside the Wolong Nature Reserve since its creation in 1975. By examining the underlying reasons, this difference could be explained.

Different management strategies in these two reserves result in distinct effects. Most of the "exceptional financial and technical support" provided to Wolong has been invested in captive breeding programs and a research station to support these programs, rather than on habitat protection (Schaller *et al.*, 1985). In effect, the Wolong Nature Reserve has been managed primarily for economic development and captive breeding (BWG/CCICED, 2000). It is no surprise that it has not achieved conservation of wild habitat.

In addition, merely creating legal protection is evidently not sufficient (Liu *et al.*, 2001; Liu *et al.*, 2004). The social and economic conditions of the local people also have an influence on the successful of the reserve protection (Harris, 2004). For Wolong Nature Reserve, China's one-child policy does not apply to most of the reserve's residents, resource use is virtually unrestricted, and tourism has been heavily promoted with little regard to its environmental impact or to generation of local benefits. People in the reserve do not benefit from the energy alternatives available in surrounding areas and therefore continue to rely on timber for fuel. In the case of Foping Nature Reserve, the human population inside the reserve was small. At the same time, the region was really remote because a large area was not accessible by vehicles.

Therefore, although Wolong is not alone among China's more than 60 giant panda reserves in the human pressures that it faces, it is far from representative. The comparison between Wolong and Foping nature reserves shows that the establishment of a protected area is necessary. Effective management strategies are important to the effectiveness of protected areas. It also gives a message to the managers of newly created panda reserves. If the building of roads and other facilities continue proceeding in reserve for tourism, it is likely that in a few decades many other reserves will face similar situations as Wolong does today - conveniently connected with well developed transportation systems and visited by tens of thousands of tourists a year.

4.2. Change of panda habitat in different land use type outside Foping Nature Reserve

Both the cases in Wolong and Foping Nature Reserve demonstrate that the development of the local community may cause great damage to giant panda habitat. Human activities have radically altered the earth's surface, oceans, and atmosphere, especially over the past 200 years (Turner, 1990). Demographic and socioeconomic factors of individual people and households may have significant impacts on their environment, which in turn may affect the spatial-temporal dynamics of wildlife habitat and local biodiversity (An *et al.*, 2006). As an area has the highest density of human population in the study area, there are a variety of economic activities in local community, including agriculture, timber harvesting, fuel wood collection, road construction and maintenance, as well as Chinese herbal medicine collection. The large shrinking of agricultural land after the expiry of Great Leap Forward during 1970s and 1980s created conditions that were beneficial to the recovery of giant pandas. Whereas, there is a rapid increase in local population in the period of 1980s-2000s, the development of advance agricultural practices, modern communications, roads, electricity, and other technological advancements has allowed humans to utilize more land. As a consequence, after the forests with easy access or close proximity to people were exhausted, forests in more remote areas at higher elevations became targets of destruction.

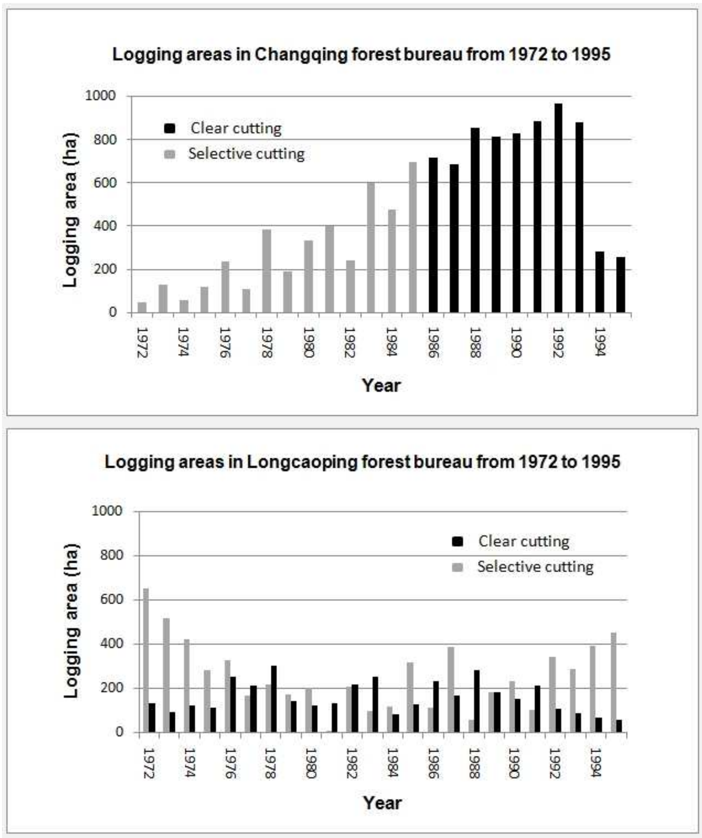

Figure 22. Cutting strategies adopted in Changqing and Longcaoping forest bureau

It is surprising to find that the logging company area, which is thought to be one of the biggest threats to giant panda habitats, did not show obvious bigger change compared to the protected area outside Foping Nature Reserve. This is because that the change of forest cover is largely determined by the cutting method selected by the logging company. In the early years of 1970s and 1980s, selective cutting was widely applied and the pattern of forest cover was retained. But in 1990s, clear cutting became the standard cutting method, resulting in severe forest loss (**Error! Reference source not found.**).

4.3. Mapping of forest and non-forest and its implications for panda habitat assessment

As an important part of this study, the classification accuracy of forest and non-forest has a big influence on the result of habitat change detection. The maximum likelihood classifier has proven to be a robust and consistent classifier for multi-date classifications (*e.g.* Shalaby and Tateishi, 2007; Wu *et al.*, 2006; Yuan *et al.,* 2005). However, as a supervised classification, this method does require prior knowledge of the ground cover in the study area (Rogan and Chen, 2004). For long term change detection like the three decades change detection in this study, it always the lack of historical ground data which will influence the accuracy of classification. In order to solve this problem, informal interviews of land owners and land managers were conducted during field survey to obtain information on previous and current land cove and training areas for the spectral signatures of older images were selected in those sites where land cover remained unchanged during the classification (Schulz *et al.*, 2010). This method has proved to be effective to improve the classification accuracy of forest and non-forest classification in this study. The accuracy assessment of three time periods of forest cover mapping shows that the mapping results are good. The Z test result indicates that there is no significant difference between the classification results of any two images. Hence, it is feasible to use the classification approach presented here when monitoring long term land cover change.

Three national panda surveys conducted by the Chinese government in 1974-1977, 1985-1988 and 1999-2002 (State Forestry Administration of China, 2006) show that the observation of giant panda in this area keeps decreasing. The change trend of giant panda habitat does not totally coincide with the real situation. Using forest and non-forest as the indicator of habitat degradation seems to underestimate the degree of habitat degradation in this study. This is because, as discussed above, the change of forest cover is largely determined by the cutting method selected by the logging company. The logging strategy of selective cutting could reduce the measured forest loss. However, after selective cutting, many forests have become severely degraded and not suitable for panda to inhabit. As selective cutting was adopted widely during the last three decades in the Qinling Mountains, the degree of habitat degradation has been underestimated by using forest and non-forest as the indicator. Apart from the logging strategy in the study area, information regarding several factors affecting panda habitat, such as bamboo distribution, was not available and was thus not considered in this study, and this will also contribute to some of the underestimation of the unsuitable panda habitat.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The objective of this study was to detect the change of giant panda habitats around and within Foping Nature Reserve over the last three decades from 1970s to 2000s using Landsat satellite images. In order to reach this objective, the forest cover and giant panda habitat were mapped and their changes were detected. As a result, the fragmentation patterns of giant panda habitat were quantified in this research. Based on the analysis results of this study, the conclusions can be summarized as follows:

Research questions 1: What changes in forest cover have occurred around and within Foping Nature Reserve over the last three decades?

In the whole study area, there was a distinct forest change in the period 1970s-1980s and 1980s-2000s, but the forest area in 2000s finally recovered to the level of 1970s. Within Foping Nature Reserve, the forest cover remained stable or even increased from 1970s to 2000s. While the forest cover around the Foping Nature Reserve has changed dramatically, it first increased from the 1970s to 1980s, and then decreased from the 1980s to 2000s.

Research questions 2: Is there a difference in forest cover change between the period 1970s - 1980s and 1980s – 2000s?

The forest cover change between the period 1970s-1980s and 1980s-2000s was significantly different. From the 1970s to 1980s, the forest cover in study area showed an obvious trend of increase. While from the 1980s to 2000s, a large area of forest disappeared. Based on this result, the hypotheses 1 (Section 1.5) of this study can be rejected.

Research questions 3: Is there a difference in giant panda habitat change inside and outside Foping Nature Reserve over the last three decades?

Inside Foping Nature Reserve, the giant panda habitat remained almost stable and even had small increase of suitable habitat over the last three decades. However, the giant panda habitats outside Foping Nature Reserve have changed much more dramatically than that inside the Foping Nature Reserve. The suitable habitat outside the reserve increased in the period 1970s-1980s, but significantly decreased in the period 1980s-2000s. As a result, the hypotheses 2 (Section 1.5) of this study can be rejected.

Research questions 4: Which areas have the most significant change occurred in giant panda habitat? And which land use type may contribute to this big change?

The most significant habitat changes occurred in the southern part of the study area, which are the regions occupied by the local communities. But the panda habitats within the protected areas and logging companies did not show significant changes over the last three decades. As an area which has the highest human population density in the study area, the human activities in local community are more intensive than in other areas and contribute to the large change in panda habitat. As a result, hypotheses 3 (Section 1.5) of this study can be rejected.

Research questions 5: What are the characteristics of panda habitat fragmentation around and within Foping Nature Reserve over the last three decades?

Although the suitable panda habitat was less fragmented in 1980s than that in 1970s, severe habitat fragmentation happened in the period 1980s-2000s. The degree of habitat fragmentation in 2000s is much larger than that in 1970s.

5.2. Recommendations

- Foping Nature Reserve has played an important role in protecting forests and giant panda habitats over the last three decades. Hence, it is highly recommended that the establishment of protected areas is necessary. Effective management strategies are important to the effectiveness of protected areas. However these strategies need to be reinforced in other panda reserves as well in the future.
- The local community based activities are the major reasons that caused the upmost loss and degradation of forests in the past, rather than the commercial timber harvesting carried out by logging companies. Therefore, sustainable forest management and use in community area should be carried out in the future.
- The selective cutting strategy adopted in the Qinling Mountains helps to avoid serious forest loss and degradation. In case of termination of the logging ban in future, such a sustainable logging strategy should be encouraged for the sake of protection of the forest cover as well as the protection of giant panda habitats.

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APPENDIX

Appendix 1. Recordings of forest sample points in the field

Forest		
ID	X	Y
1	33.76382	107.9788
2	33.75642	107.9894
3	33.67264	107.8177
4	33.47267	107.8477
5	33.49861	107.6181
6	33.56891	107.5798
7	33.71434	107.5830
8	33.69722	107.6854
9	33.43395	107.8535
10	33.65330	107.9723
11	33.71692	107.9668
12	33.68098	107.8466
13	33.67922	107.8424
14	33.6250	107.7923
15	33.67165	107.5823
16	33.67518	107.5892
17	33.65944	107.5679
18	33.65167	107.7809
19	33.59775	107.9813
20	33.59661	107.9814
21	33.64430	107.7896
22	33.65300	107.7899
23	33.67086	107.8112
24	33.67084	107.8138
25	33.74736	107.9728
26	33.67477	107.8176
27	33.65167	107.8009
28	33.49659	107.8286
29	33.54873	107.5755
30	33.67765	107.6021
31	33.68921	107.6088
32	33.67832	107.9805
33	33.68493	107.8534
34	33.67633	107.8331
35	33.57594	107.7792
36	33.51446	107.6258
37	33.66727	107.5779

38	33.70978	107.7716
39	33.64501	107.7987
40	33.58988	107.9907
41	33.67410	107.8143
42	33.67301	107.8112

Appendix 2. Recordings of non-forest sample points in the field

Non-forest		
uid	X	Y
1	33.66402	107.9682
2	33.6564	107.9677
3	33.59494	107.9756
4	33.5346	107.9874
5	33.54644	108.0271
6	33.53022	107.9876
7	33.52037	107.9795
8	33.52206	107.9826
9	33.79581	107.7542
10	33.5346	107.9874
11	33.59877	107.9768
12	33.64602	107.7960
13	33.60009	107.7757
14	33.55919	107.8225
15	33.81283	107.9764
16	33.51896	107.8136
17	33.45065	107.8528
18	33.74194	107.6565
19	33.74913	107.6678
20	33.76457	107.6617
21	33.75303	107.6696
22	33.45392	107.9386
23	33.71968	107.759
24	33.71466	107.7746
25	33.56452	107.9899
26	33.69995	107.913
27	33.52754	107.9865
28	33.53137	107.8207
29	33.52535	107.9832
30	33.71016	107.9574
31	33.63951	107.7917
32	33.5517	107.8209
33	33.52372	107.982
34	33.59319	107.9752
35	33.71686	107.7552
36	33.6938	107.9501
37	33.64878	107.7977
38	33.47507	107.6681