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Effects of conservation policies on forest cover change in giant panda habitat regions, China

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ABSTRACT

After long periods of deforestation, forest transition has occurred globally, but the causes of forest transition in different countries are highly variable. Conservation policies may play important roles in facilitating forest transition around the world, including China. To restore forests and protect the remaining natural forests, the Chinese government initiated two nationwide conservation policies in the late 1990s – the Natural Forest Conservation Program (NFCP) and the Grain-To-Green Program (GTGP). While some studies have discussed the environmental and socioeconomic effects of each of these policies independently and others have attributed forest recovery to both policies without rigorous and quantitative analysis, it is necessary to quantify the outcomes of these two conservation policies simultaneously because the two policies have been implemented at the same time. To fill this knowledge gap, this study quantitatively evaluated the effects of the two conservation policies on forest cover change between 2001 and 2008 in 108 townships located in two important giant panda habitat regions – the Qinling Mountains region in Shaanxi Province and the Sichuan Giant Panda Sanctuary in Sichuan Province. Annual forest cover change rate was evaluated using a land-cover product (MCD12Q1) derived from the Moderate Resolution Imaging Spectroradiometer (MODIS). This product proved to be highly accurate in the study region (overall accuracy was ca. 87%, using 425 ground truth points collected in the field), thus suitable for the forest change analysis performed. Results showed that within the timeframe evaluated, 94% of townships (i.e., 101 out of 108) in both regions exhibited either increases or no changes in forest cover. After accounting for a variety of socioeconomic and biophysical attributes, a linear regression model suggests that the GTGP had a positive and significant effect on the annual forest cover change rate after seven years of implementation. Our results also suggest that elevation has a significant positive effect on forest cover change, while the percentage of agricultural population, initial forest cover in 2001, and the interaction term of elevation and slope had negative significant effects. Findings from this study will be useful for evaluating the implementation of current conservation policies, designing future conservation policies, developing future giant panda habitat conservation projects, and achieving forest sustainability in China and elsewhere.

Introduction

Unprecedented rates of human population growth and other factors (e.g., timber harvest, cropland cultivation, infrastructure construction) have caused the conversion of natural forests to other land cover types across the world (Myers, 1990; Pahari and Murai, 1999; Carr, 2004, 2005). However, while the overall amount of forest cover has been declining worldwide, an opposite trend – forest expansion – started to occur in France in the late 18th century (Mather, 1992), and then spread to other European, North American and Asian countries (Totman, 1986; Foster et al., 1998). With the spread of industrialization and urbanization, the trend of increase in forest cover also appeared later in many developing countries across the world. For instance, four major developing countries in Asia – China, India, Vietnam, and Bangladesh – have been experiencing forest regeneration since the 1980s (Rudel, 2005; Mather, 2007). During recent decades, a similar trend of positive forest cover change has also been identified in Latin American countries, such

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as Mexico, Ecuador, and Brazil (Klooster, 2003; Baptista and Rudel, 2006; Farley, 2007). This turning point of forest cover change from negative to positive was termed 'forest transition' (Mather, 1992, 2004; Mather et al., 1998, 1999; Mather and Fairbairn, 2000).

Forest transition has therefore been reported for many places around the world, and has been documented at length (Mather, 1992, 2007; Grainger, 1995; Mather and Needle, 1998; Rudel, 1998; Rudel et al., 2005, 2010; Barbier et al., 2010). In addition, an extensive body of literature exists on the many factors that play important roles as determinants of forest transition across the world (Kaimowitz, 1997; Foster and Rosenzweig, 2003; Klooster, 2003; Perz and Skole, 2003; Nagendra et al., 2005; Pan and Bilsborrow, 2005; Lambin and Meyfroidt, 2010). But two arguments have been suggested to generalize the observed patterns (Rudel, 1998; Rudel et al., 2005). The first one establishes that deforestation raises the price of wood and wood products, which not only induces people to harvest the remaining primary forests but also encourages them to plant more trees (Prunty, 1956; Hart, 1968, 1980; Sedjo and Clawson, 1983; Royer, 1987; Rush, 1991; Haeuber, 1993; Fairhead and Leach, 1995; Hardie and Parks, 1996; Walters, 1997). The second one states that industrialization creates many off-farm job opportunities that attract laborers to shift from farm to off-farm economic activities, leading to the abandonment of marginal farmland and its re-conversion to forests (Hart, 1968; Bentley, 1989). However, this binary rationale (i.e., wood scarcity and economic development) does not explain all forest-transition phenomena. A variety of causal factors (driving forces) that operate under different environmental, socioeconomic, and political contexts are also important (Mather, 2007; Trac, 2011), since neither development nor forest plantation alone can guarantee the emergence of a forest transition (Klooster, 2003; Perz and Skole, 2003; Perz, 2007). Therefore, it is important to develop a thorough understanding of the driving forces behind forest transitions under different contexts.

Governments play important roles in facilitating forest transition by establishing different mechanisms (e.g., policies) that try to preserve and/or restore forest cover (Grainger, 1995; Mather, 2007; Nagendra, 2007). Therefore, the role of government policies should not be overlooked in forest transition theory (Viña et al., 2011), particularly in developing countries (Jack et al., 2008). As a part of government activities, Payments for Environmental (or Ecosystem) Services (PES) have emerged globally during the past few decades (Ferraro and Kiss, 2002). These programs provide direct (e.g., land purchases, leases, and easements) or indirect (i.e., alternative economic and social benefits) incentives to individuals or communities for mitigating the overexploitation of natural resources and stopping the degradation of natural systems associated with them (Ferraro and Kiss, 2002). However, many externalities (e.g., natural disasters and economic recession) may lower the cost-effectiveness of indirect approaches (Ferraro, 2001; Ferraro and Kiss, 2002; Ferraro and Simpson, 2002). Therefore, direct incentives have become prevalent, and more direct conservation payment programs have been initiated by governments and international non-governmental organizations around the world (Milne and Niesten, 2009). These programs not only reward local communities for conservation activities, but also help them develop alternative income opportunities (James et al., 1999; Ferraro, 2001).

The demands of its large population and booming economy have caused deforestation and many other environmental problems in China, particularly during the last 60 years (Liu, 2010). Excessive timber harvest of natural forests and reclaiming farmland on hillsides of the upper reaches of the Yangtze and Yellow Rivers are considered the main reasons for the frequent droughts and floods during the 1990s in the Yangtze and Yellow rivers floodplain areas (World Wildlife Fund, 2003; Liu and Diamond, 2005; Hu et al., 2006), which have demonstrated the urgency of stopping deforestation and expanding the areas under forest cover (World Wildlife Fund, 2003). But it was only after suffering severe droughts in 1997 and huge floods in 1998 (Weyerhaeuser et al., 2005; Liu et al., 2008) that the Chinese government initiated two nationwide PES programs [the Natural Forest Conservation Program (NFCP) and the Grain-to-Green Program (GTGP, also called Sloping Land Conversion Program, or Grain for Green Program) in 1998 and 1999, respectively] to restore the degraded forest ecosystems.

The main goals of the NFCP and GTGP are to conserve (through logging bans with regular patrolling, and payments for ecosystem services schemes) and restore (through afforestation and reforestation) forests in ecologically sensitive areas (e.g., areas with steep slopes). Besides regular patrolling by forest bureaus at county level and in very few places (e.g., Wolong Nature Reserve for giant pandas) decentralized household monitoring, provincial and local governments also set timber checking stations along main roads to control illegal logging. While in China, forests are managed at three organizational levels: state, collective, and household, NFCP targets the state-owned and collective-owned forests. The forest bureau in each county allows petitions of certain amount of timber extraction in collective-owned through applying permits. Local households also can collect fuelwood and timber in forest parcels where they have use rights. Details of these programs have been summarized in previous studies (Zhang et al., 2000; Xu et al., 2006; Liu et al., 2008; Chen et al., 2009). Government reports declare that both conservation policies have achieved the established goals. For instance, it has been reported that by the end of 2008, the NFCP had protected around 108 million ha of natural forests and planted about 5.7 million ha with trees (State Forestry Administration, 2009a). It has also been reported that by the end of 2008, about 9.1 million ha of cropland in steep areas and 13.6 million ha of barren land have been planted with trees through the GTGP (State Forestry Administration, 2010a). In addition, results of the 7th national forest resources survey (2004 through 2008) showed that forest cover in China grew steadily since the previous survey, from 18.2% of the country's area by the end of 2003 to 20.4% by the end of 2008 (State Forestry Administration, 2010b).

These two conservation programs have drawn worldwide attention due to their operating scales, amount of public investments, and environmental implications (Xu et al., 2000, 2004, 2007; Zhao et al., 2000; Ye et al., 2003; Shen et al., 2006; Uchida et al., 2007; Wang et al., 2007; Liu et al., 2008; Uchida et al., 2009; Cao et al., 2010). However, most published studies have focused on the evaluation of social, economic, and ecological effects of each of these programs independently, and acting at either the national level or the household level (Uchida et al., 2007; Xu et al., 2007; Liu et al., 2008), while very few studies have been conducted at township and county levels (Trac et al., 2007; Zhou et al., 2007). The township level, in particular, is highly relevant because townships constitute the basic implementation unit of the NFCP and GTGP (Zhu and Feng, 2003). In addition, township is the basic stratum of the overall 5-level planning system (i.e., National-Provincial-City-County-Township) for land use in China (Ou et al., 2002). As a basic administrative level, township-level statistical data are often collected each year, which are not only an important data source for higher administrative levels (e.g., county, province), but also provide relatively sufficient, proximate and accurate socioeconomic indicators that can be used for identifying driving forces of land-cover change. Township governments are in charge of making specific annual plans based on socioeconomic and biophysical conditions of the township, as well as tasks directly assigned by higher level governments (Zhu and Feng, 2003). In addition, very few studies have evaluated the simultaneous environmental effects of these two programs (Viña et al., 2011). This is important since conservation policies, such as the NFCP and GTGP, together with other driving forces (e.g., demographic, economic, technological, cultural and biophysical) may be some of the most important determinants of land use/cover change (Turner et al., 1993; Geist and Lambin, 2001). As budgets for conservation programs are usually limited, it is absolutely crucial to evaluate the effectiveness of conservation programs in different contexts, which will guarantee scarce funds to go as far as possible in achieving conservation goals (James et al., 1999; Ferraro and Pattanayak, 2006; Chen et al., 2010).

The main goal of this study was to evaluate the dynamics of forest cover at township level and their relations with the simultaneous implementation of NFCP and GTGP. Specifically, the study attempted to answer three questions: (1) What are the patterns of forest cover change since the implementation of conservation policies? (2) What driving forces underlie these forest cover change patterns? (3) Do conservation policies have positive effects on forest cover?

Methods

Study area

The study area is composed of two regions located in two different provinces. The first region is located in the middle part of the Qinling Mountains, Shaanxi Province. It includes 57 townships in three counties (Zhouzhi, Foping, and Yang). The second study region is the UNESCO Giant Panda Sanctuary, located in Sichuan province, and includes 72 townships in twelve counties (Baoxing, Chongzhou, Dayi, Dujiangyan, Kangding, Li, Luding, Lushan, Qionglai, Tianquan, Wenchuan, and Xiaojin) (Fig. 1). The township selection was based on whether these townships have panda habitat or potential panda habitat, together with conservation policy implementation. In Sichuan Province, the selection method was straightforward because the Sichuan Giant Panda Sanctuary has a well-defined boundary, thus all townships located within the Sanctuary were initially chosen. In the Qinling Mountains, we first selected all townships within counties reported to contain panda habitat by the 3rd National Survey Report on Giant Panda (State Forestry Administration, 2006). In the two regions, we then selected townships based on socioeconomic data availability and implementation of conservation policies. In the end, because of lack of socioeconomic data or conservation policy implementation, 21 townships were excluded from original pool, 10 of which were located in the Qinling Mountain area and 11 in the Sichuan Giant Panda Sanctuary.

The Qinling Mountains are an important landmark in China. They not only constitute the part of natural boundary (i.e., Qinling Mountains-Huai River Line) between southern and northern China, but also divide the Yangtze and Yellow River basins (Pan et al., 1988; Loucks et al., 2003). The Qinling Mountains are also a region with abundant biodiversity and home to many rare species, including the giant panda (*Ailuropoda melanoleuca*). Approximately 20% of all wild giant pandas (ca. 1600 individuals) live in the Qinling Mountains (State Forestry Administration, 2006). This region has been recognized as the one of the Global 200 Ecoregions defined by WWF (Olson et al., 2001). The elevation of the Qinling Mountains ranges from less than 500 to 3750 m (Fig. 1).

The Sichuan Giant Panda Sanctuary was established as a member of the UNESCO World Heritage System in 2006. It is not only a refuge to diverse wildlife and plant species, but also home to more than 30% of the entire wild giant panda population (State Forestry Administration, 2006). In fact, the region is within one of the world's top 25 Biodiversity Hotspots (Myers et al., 2000; Liu et al., 2003a) and one of the Global 200 Ecoregions defined by WWF (Olson et al., 2001). The elevation within the Sanctuary varies significantly (from ca. 500 to 6200 m) (Fig. 1).

In addition to their enormous conservation value, both regions are ideal for evaluating the effects of conservation policies on forest cover change. First, both areas suffered intensive commercial logging before 1998, when the national logging ban was implemented (Pan et al., 1988; Yang and Li, 1992). In 2000, the NFCP and GTGP also started in both regions. Second, townships in both regions have various biophysical attributes and socioeconomic characteristics that may cause different effects brought by similar conservation efforts, thus contribute to different patterns of forest cover change. Third, as most townships in the two study regions have systematically published township-level statistical data in multiple consecutive years, it is possible to obtain the necessary socioeconomic data at the township level. Finally, both regions include important giant panda habitat, so the study of forest cover change will provide information useful for giant panda habitat conservation because forest cover is an essential component of panda habitat.

Forest cover change detection

The MODIS Land Cover Type product (MCD12Q1 Yearly L3 Global 500 m SIN Grid) was used for assessing forest cover changes. The International Geosphere-Biosphere Programme (IGBP) scheme, the primary one of five land cover classification schemes of this product, was used since it was specifically designed for the improvement of large-scale vegetation models needed for global and regional assessments (International Geosphere-Biosphere Programme, 2010). This scheme has also been proven to exhibit high accuracy in identifying land-cover types in China, especially after aggregating the original 17 classes into few combined land-cover classes (Wu et al., 2008; Ran et al., 2010).

Eight consecutive years of the MODIS Land Cover Type product (from 2001 to 2008) were downloaded from the Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/lpdaac/products/modis_products_table). The 17 different land-cover classes (i.e., water, evergreen needleleaf forest, evergreen broadleaf forest, deciduous needleleaf forest, deciduous broadleaf forest, mixed forest, closed shrublands, open shrublands, woody savannas, savannas, grasslands, permanent wetlands, croplands, urban and built-up, cropland/natural vegetation mosaic, snow and ice, and barren or sparsely vegetated) of the IGBP classification scheme were reclassified into two categories (forest and non-forest). The evergreen needle leaf forest, evergreen broadleaf forest, deciduous needle leaf forest, deciduous broadleaf forest and mixed forest were all placed in the forest category while the other land cover classes were placed in the non-forest category.

A total of 425 ground-truth plots with land-cover type information collected in both study regions (Qinling and Sichuan Giant Panda Sanctuary) from 2004 to 2007 were used to evaluate the accuracy of the forest/non-forest reclassification of the IGBP scheme. Among them, 175 and 250 points were collected in the Qinling Mountains and the Sichuan Giant Panda Sanctuary, respectively. The user's accuracy for non-forest and forest areas was 84% and 87%, respectively, and the overall accuracy was 87% (Table 1). Thus, the IGBF land-cover product merged into forest/non-forest cover provides sufficient classification accuracy to be used for detecting forest cover change in the two study regions.

Forest cover information from each township was extracted from the MODIS Land-Cover product by using a corresponding digitized township boundary. The proportion of each township under forest cover in each of the eight years available (2001 through 2008) was calculated by dividing the number of forest pixels by the total number of pixels within each township's boundary. Considering the inter-annual variability observed in the MODIS Land-Cover Type product, a linear-regression analysis was employed on a per-township basis to detect the trend of forest cover change between 2001 and 2008. For each township, if the regression line showed a significant ($p < 0.05$) trend (either positive or negative) of percent

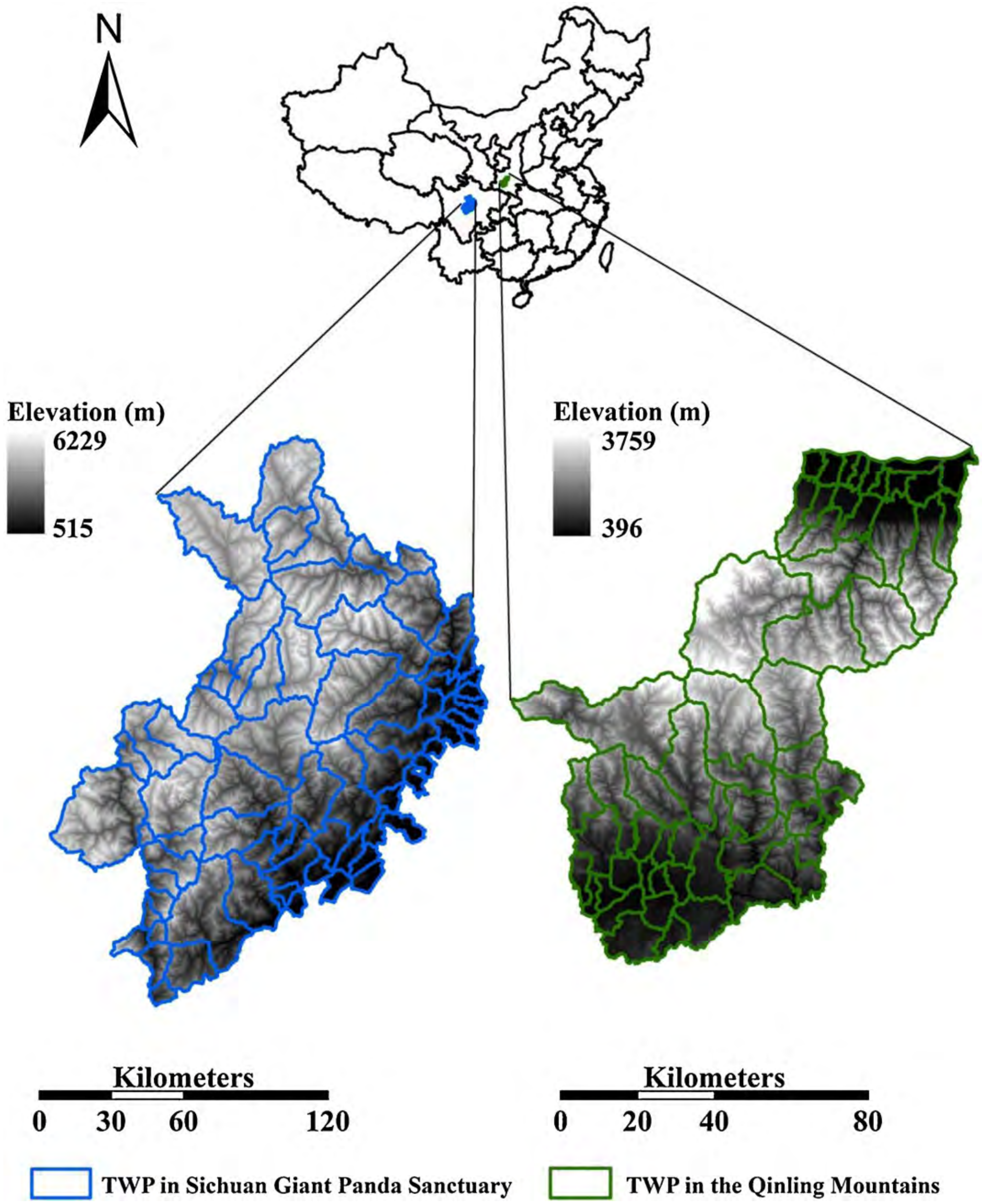

Fig. 1. The study regions are: the Sichuan Giant Panda Sanctuary (blue boundary map on the left), which includes 72 townships in 12 counties and the Qinling Mountains Region (green boundary map on the right), which includes 57 townships within 3 counties. Of the 129 townships, 108 townships were included in the final analysis while the remaining 21 were excluded due to reasons such as data availability. Elevation data were obtained from a Digital Elevation Model (DEM) derived from the Shuttle Radar Topography Mission (SRTM). Areas with darker color have lower elevation. Elevation in the Qinling Mountains ranges from 396 m to 3759 m, while in the Sichuan Giant Panda Sanctuary ranges from 515 m to 6229 m. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1
Error matrix of the MODIS derived IGBP classification scheme, merged into two land cover classes (forest and non-forest). The matrix was generated using 425 ground truth points collected in the field between 2004 and 2007.

		Ground truth points		
		Non-forest	Forest	Row Total
MODIS product	Non-forest	16	3	19
	Forest	53	353	406
	Column total	69	356	425
		User's accuracy		
		Non-forest = 16/19 = 84%		
		Forest = 353/406 = 87%		
Overall accuracy = (16 + 353)/425 = 87%				

forest cover change with respect to time (i.e., year), then the estimated annual forest cover change rate (i.e., the slope of the forest cover trend analysis) was used as the dependent variable in further regression analyses to examine factors associated with forest cover change rate. Otherwise, if the regression line showed a non-significant trend, the estimated annual forest cover change rate was considered as 0. Examples of these trends in three different townships are shown in Fig. 2.

Forest cover change attribution

We used linear regression models to estimate the effects of socioeconomic factors, biophysical factors, and conservation implementation status (GTGP and NFCP) on the estimated annual

Table 2
Descriptive statistics of the variables used in the regression model of forest cover change rate.

Variable	Description	Mean (S.D.)
FCCR	Estimated annual forest cover change rate with consecutive MODIS images from 2001 to 2008 (%)	0.51 (1.27)
POPDEN	Population density of a township (individuals/km^2)	136.66 (253.68)
PAPOP	Percentage of agricultural population (%)	0.90 (0.15)
HHSIZE	Average household size (individuals)	3.77 (0.49)
PCROPL	Percentage of cropland area within the township boundary (%)	0.08 (0.13)
UPCROP	Unit production of cropland (ton/mu, 1 mu = 1/15 ha)	0.34 (0.14)
FOR2001	Forest cover in year 2001 (%)	60.14 (28.09)
ELEVATION	Average elevation of the township (m)	432.33 (236.21)
SLOPE	Average slope of the township (degree)	8.92 (1.85)
RDDEN	Road density of each township (m/km^2)	398.83 (161.53)
GTGP	Percentage of the GTGP area within a township boundary (%)	0.04 (0.04)
NFCP	NFCP implementation status: 0 for non-NFCP implementation and 1 for NFCP implementation	0.89 (0.32)
REGION	Regional difference: 0 for townships in the Giant Panda Sanctuary and 1 for townships in the Qinling Mountain region	0.44 (0.50)

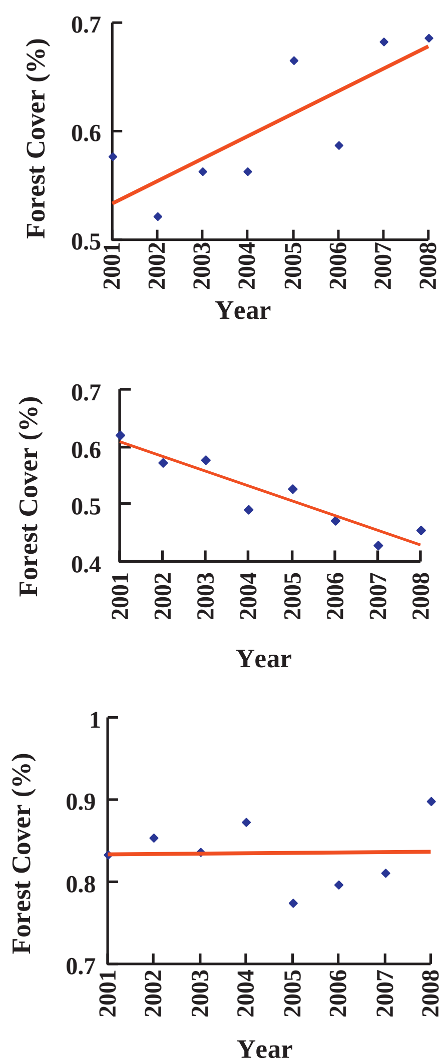

Fig. 2. Three representative townships are shown to illustrate three contrasting trends of forest cover change. For each township, the *X*- and *Y*-axes represent year and percent forest cover, respectively. The regression line (in red) shows trend of forest cover change from 2001 to 2008. Top: Daheba Township had a significant increase (+ Δ forest); middle: Shiguan Township had a significant decrease (– Δ forest); bottom: Wushan Township had a non-significant trend (i.e., Δ forest = 0). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

forest cover change rate. The selection of potential explanatory variables (e.g., socioeconomic and biophysical) was based not only on the approaches undertaken in previous studies by combining remote-sensing data with spatially explicit information (Pahari and Murai, 1999; Mertens et al., 2000; Gautam et al., 2004; Ali et al., 2005; Armenteras et al., 2006; Chowdhury, 2006; Ferreira et al., 2007), but also on the availability of data for the entire study area. Both demographic and economic data at township level were acquired from the statistical yearbooks of each county. Information on the implementation of the NFCP and GTGP (e.g., implementation date, total planned area, and total implementation area) was obtained from government sources (i.e., Forestry Bureau, Center of NFCP and Office of GTGP) and from published reports of the NFCP and GTGP implementation, when available. Topographic data (i.e., elevation and slope) were obtained from a Digital Elevation Model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) (90 m × 90 m) (Rabus et al., 2003). Data on elevation and slope were averaged by all pixel values within each township boundary in order to obtain specific topographic attributes (i.e., slope and elevation) for each township. Since statistical yearbooks of 11 townships (5 townships in Lushan County and 6 townships in Dujiangyan County) in the Sichuan Panda Sanctuary were not available and 10 townships in Zhouzhi County of Shaanxi Province are located in flat areas with neither forest cover present nor conservation policy implementation within their boundaries, a total of 108 townships (83.7% of all townships in the two study regions) in 13 counties were used for analysis. Table 2 shows descriptive statistics of the explanatory variables used in the linear model. The population density variable was excluded in the final regression model because of multi-collinearity with other variables.

Because the townships are spatially contiguous, there may be spatial autocorrelation effects on both the dependent and explanatory variables. Significant spatial autocorrelation may induce a violation of the assumption of independently distributed errors in classical statistical tests (e.g., ordinary least square (OLS)), which may lead to incorrect results (Lichstein et al., 2002). Therefore, we developed an OLS regression and then tested whether there is a significant spatial autocorrelation of the residuals of this OLS regression. A significant spatial autocorrelation of the residuals indicates that a spatial autoregressive model should be used (Anselin, 1988; LeSage and Pace, 2009), while a lack of significance indicates that the use of the OLS regression is appropriate. A spatial weighting matrix for testing spatial autocorrelation was created using the OpenGeoDa software (version 1.0, GeoDa Center for Geospatial Analysis and Computation at Arizona State University). For defining neighbors to test for spatial autocorrelation we

Table 3
Variable coefficients of the Ordinary Least Squares regression model of forest cover change rate developed at township level. The dependent variable was the annual forest cover change rate based on the forest trend analysis obtained from consecutive classified MODIS images (i.e., into forest and non-forest covers) from 2001 to 2008. The number of observations (i.e., townships) was 108. The R-squared was 0.324 and the adjusted R-squared was 0.239. Moran's I of model residuals was 0.250 ($p > 0.1$), suggesting that they are spatially independent.

Variable category	Variable	Coefficient	Standard error
Socioeconomic variables	PAPOP	−0.018*	0.010
	HHSIZE	0.002	0.003
	PCROPL	−0.027	0.019
	UPCROP	0.012	0.010
	RDDEN	0.131e−04	0.100e−04
Biophysical attributes	FOR2001	−0.237e−03***	0.062e−03
	ELE	0.019e−03*	0.011e−03
	SLP	−0.429e−05	0.946e−03
	ELE*SLP	−0.116e−04***	0.413e−05
	REGION	0.004	0.003
Conservation policies	GTGP	0.068**	0.034
	NFCP	−0.001	0.004
	Constant	0.008	0.005

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

used both the Queen (i.e., common borders and corners) and the Rook (i.e., common borders) contiguity approaches. In addition, the default first order contiguity was used.

Results

After seven years of GTGP and NFCP implementation the forest areas expanded and the non-forest areas decreased in many townships across the entire study areas (Fig. 3). Visually, many forest patches connected with each other and many non-forest patches disappeared. However, in both study regions, besides conspicuous areas with forest gain, forest loss can still be observed, but particularly in the lower part of the Qinling Mountains region.

Results from the regression analysis of forest cover change vs. time at the township level show that 43% of the townships (i.e., 46 out of 108) had a significant increase, while 6% (i.e., 7 out of 108) had a significant decrease in forest cover change from 2001 to 2008. The remaining townships (i.e., 55 out of 108) did not show significant changes in forest cover (Fig. 4). 58% of the townships (i.e., 42 out of 72) in the Sichuan Giant Panda Sanctuary exhibited forest cover gains, while in the Qinling Mountains 53% of the townships (i.e., 25 out of 47) showed no change in forest cover. In addition, 6 out of 7 townships that exhibited significant forest cover losses were located in the Qinling Mountains region (Fig. 4). The 11 townships in the Sichuan Giant Panda Sanctuary excluded from the regression analysis due to a lack of socioeconomic data also exhibited forest cover gains (Fig. 4).

Diagnostics for spatial dependence suggest that the residuals of the OLS regression do not have a significant autocorrelation, irrespective of the spatial weighting matrix used (i.e., Queen or Rook contiguity approaches). For the first order Queen and Rook contiguity approach, the values of Moran's I were the same (Moran's $I = 0.250$, $p > 0.10$). Therefore, the use of OLS regression seems to be appropriate in this study.

Among the five socioeconomic variables evaluated in the OLS model (Table 3), percentage of agricultural population (PAPOP) had a negative effect ($p < 0.1$) on the estimated annual forest cover change rate. The initial forest cover in 2001 (FOR 2001) and the interaction term of elevation and slope (ELE*SLP) also showed significant negative effects ($p < 0.01$). In contrast, elevation (ELE) ($p < 0.1$) and the Grain-To-Green Program (GTGP) ($p < 0.05$) had positive effects.

All the 108 townships used in the regression analysis are partly or entirely located in the mountainous region and are covered by one or both conservation policies. There are 13 townships covered by one conservation policy, including 12 townships that are only covered by the GTGP and 1 township only covered by the NFCP. All other townships are covered by both conservation policies. Among the 13 townships with single conservation policy implementation, 5 showed forest cover losses from 2001 to 2008, and 3 showed stable forest cover. Based on this small sample size, it was not possible to empirically quantify the interactive effects of the two policies. However, theoretically the implementation of a single policy may produce less forest cover gains due to a smaller implementation area than the two policies combined.

Discussion

Results of the linear regression model show that forest cover change is best explained by multiple factors acting synergistically rather than by single-factor causation, which is in accord with many other studies about causes of forest cover change (Burgess and Sharpe, 1981; Southgate et al., 1991; Bawa and Dayanandan, 1997; Geist and Lambin, 2001). The township-level forest cover change map (Fig. 4) shows that although both regions started to implement conservation policies at about the same time, they had quite different recovery patterns and processes. Most of the townships in the Sichuan Giant Panda Sanctuary experienced forest cover gains, while most of the townships in the Qinling Mountains showed unchanged forest cover. Historically, most changes in forest cover result from human activities (Houghton, 1991; Meyer and Turner, 1992; Jorgenson and Burns, 2007; Carr, 2008), so various demographic pressures may cause significant differences in forest cover change between the two study regions. Since the percentage of agricultural population for townships in the Qinling Mountains is significantly higher than in the townships of Sichuan Giant Panda Sanctuary ($p < 0.05$), forests in the Qinling Mountains region may face higher human pressures than those in the Sichuan Giant Panda Sanctuary. Moreover, results showed that demographic characteristics (i.e., percentage of agriculture population) are important determinants of forest cover change, having significantly negative effects. This supports the negative relationship between forest cover and population pressure reported by previous studies (Allen and Barnes, 1985; Carr et al., 2005; Jha and Bawa, 2006). The change in agricultural population alters the demand for land and forests, which are expected to supply food, fuel, and other environmental services for local people (Mikesell, 1960; Allen and Barnes, 1985; Williams, 1989). Before conservation policies were implemented, larger percentages of agricultural population meant more demand for natural resources (e.g., timber, fuelwood, and forestry products) and more land conversion from forest to non-forest. After 2000, both the NFCP and GTGP were implemented in these regions, and logging was banned. Although large-scale commercial timber harvest has ceased and illegal logging has been controlled (Zhang, 2006), higher population pressures may reduce the forest cover gains. In order to meet the demands of local people, fuelwood consumption and timber used in new housing construction still has a significant impact on forest restoration (Q. Liang, personal communication). A higher percentage of agricultural population may also cause greater dependency on fuelwood for cooking and heating (Krutilla et al., 1995). In addition, other activities, such as cultivation and grazing conducted by local agricultural populations, may also offset part of the forest gains brought about by conservation policy implementation. It is important to note that Sichuan province is also a major source of rural–urban labor migration in China. Each

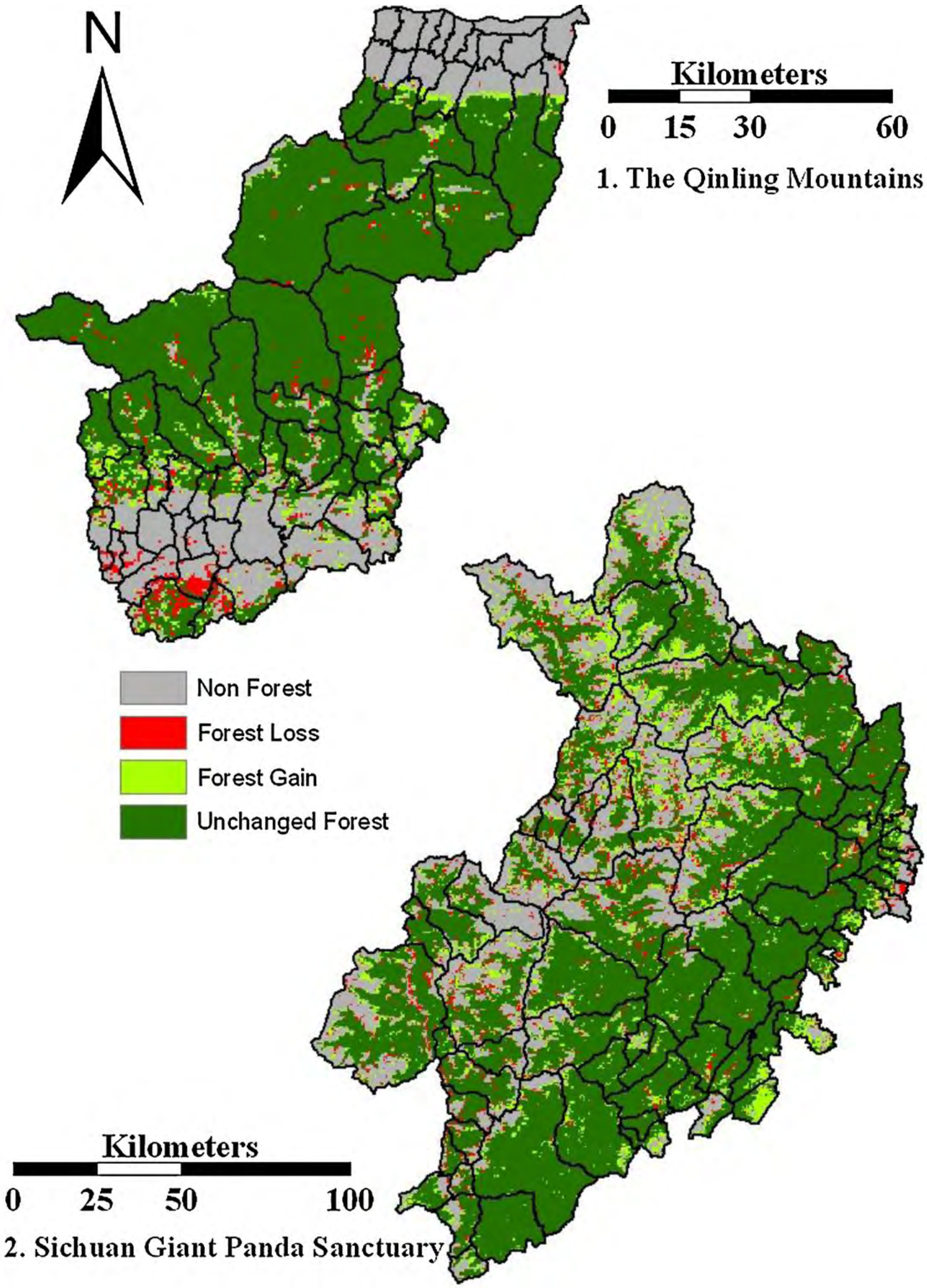

Fig. 3. Forest cover change at pixel level from 2001 to 2008 (1. The Qinling Mountains; 2. The Sichuan Giant Panda Sanctuary). Four different colors represent four types of land cover change from 2001 to 2008 in both study regions. Grey represents non-forest areas (in both 2001 and 2008); red represents areas with forest loss (i.e., from forest in 2001 to non-forest in 2008); light green represents areas with forest restoration (i.e., from non-forest in 2001 to forest in 2008); dark green represents areas with stable forest cover (i.e., forest in both 2001 and 2008). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

year, more than 10 million rural people migrate from their hometowns to other places inside or outside Sichuan Province to seek off-farm job opportunities (Guo, 2005). This yearly large-scale labor migration may reduce demographic pressures on food supply (e.g., farming) and natural resources consumption (e.g., fuel wood) (Qin, 2010). In addition, the proportion of the total population classified as agricultural population is lower in the Sichuan Giant Panda Sanctuary area than in the Qinling Mountains, which also may explain the different forest recovery patterns and process exhibited by both regions under similar conservation policy implementation procedures.

The initial forest cover often determined the level of implementation of conservation policies. In order to preserve species and their habitat or prevent flooding and soil erosion, local

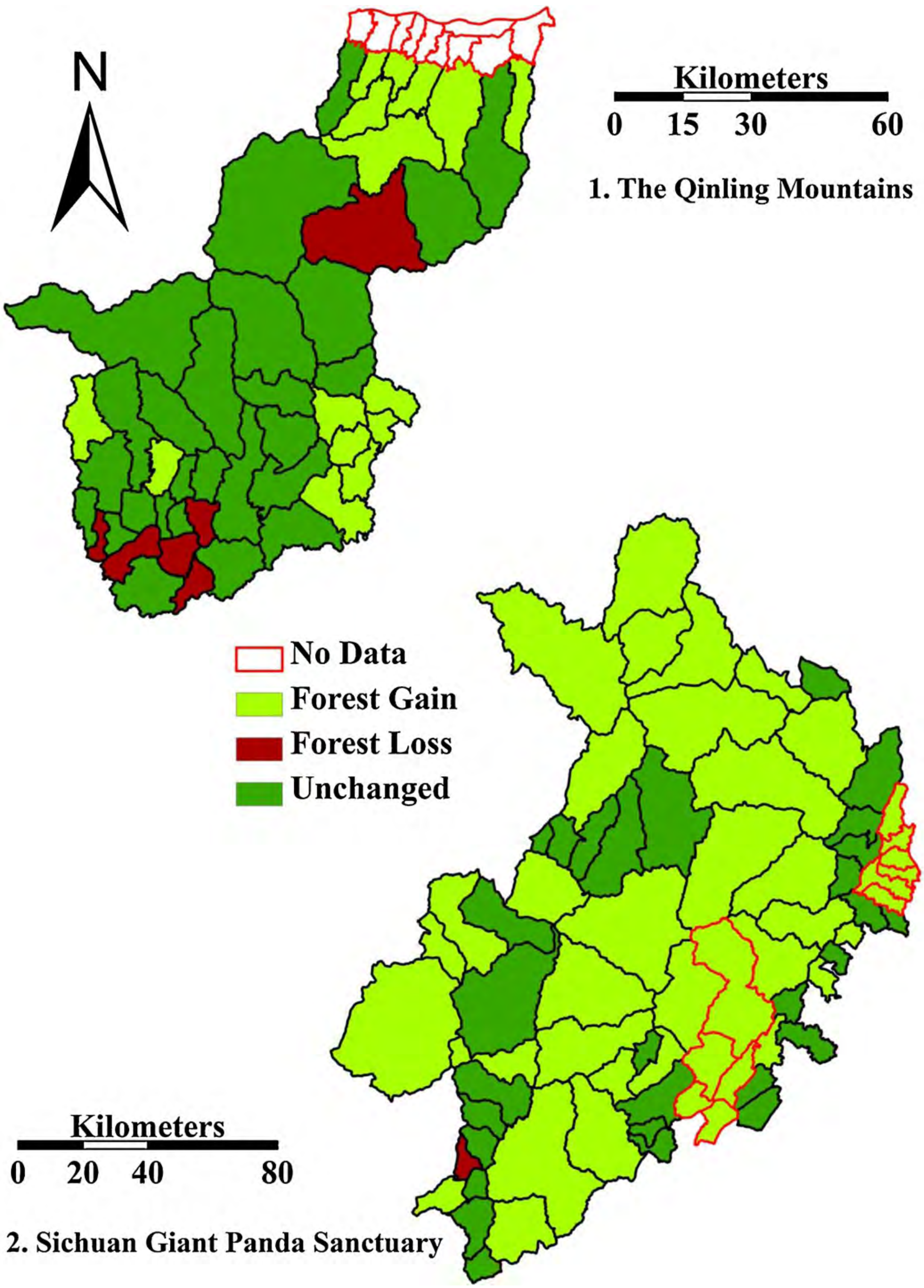

Fig. 4. Forest cover change at township level from 2001 to 2008. Three colors represent three types of townships with different trends of forest cover change. Townships in light green exhibited statistically significant forest cover increases from 2001 to 2008 (i.e., + Δ forest); townships in dark green represent no change in forest cover from 2001 to 2008 (i.e., Δ forest = 0); townships in red color exhibited statistically significant forest cover decreases from 2001 to 2008 (i.e., − Δ forest). Townships with a red boundary line in the Sichuan Giant Panda Sanctuary lack pertinent socioeconomic data, while those in the Qinling Mountains region lack forest cover and conservation policy implementation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

governments are under pressure to protect the remaining forests and implement conservation policies (Grainger, 1995). Forest plantation is a fast and direct way to help forest recovery and reach the transition point (i.e., from forest cover loss to forest cover gain). In townships with a larger area of clear-/selectively cut areas, barren lands, or sloping croplands it may be a priority to apply reforestation and afforestation methods, such as tree planting and aerial seeding. On the contrary, in townships with larger areas of remaining forest, forest protection and surveillance will be applied first, and forest restoration will rely mainly on natural regeneration.

Reforestation and afforestation usually produce faster effects than natural regeneration during the initial period of forest recovery (Liu et al., 2010). Furthermore, because the initial percent forest cover in 2001 is relatively high, averaging 60% (Table 2), the regeneration potential for townships with higher initial percent forest cover should be lower than those with lower initial percent forest cover. Therefore, the townships with lower initial percent forest cover may have relatively greater forest cover gains as compared with other townships with higher initial percent forest cover.

Elevation and slope are important biophysical attributes for forest regeneration. On the one hand, high elevation or slope reduces human access and thus may promote forest recovery. On the other hand, slopping land has lower capacity of retaining water and soil, which may reduce the rate of forest regeneration. These reasons may explain why elevation has a significant positive effect on forest cover change rate, while the interaction term of elevation and slope has a significant negative effect.

In mountain regions, cropland is a major non-forest land cover type. The GTGP encourages local households in farmsteads to convert steep-slope cropland into forests. Results from this study suggest that this program appears to contribute to forest cover gains in most townships implementing it. Usually, fast-growing local tree species are selected for tree planting under the GTGP (Chen et al., 2012). These planted tree species may not only benefit the environment (e.g., reduce soil erosion and increase tree cover) but also increase the income of enrolled local households within a relatively short period of time (Zhang et al., 2003). In addition, substantial labor supplies have been released from agriculture and attracted to local off-farm work or even more urbanized regions through labor migration (Peng et al., 2007; Uchida et al., 2009), which not only enhance the conversion of abandoned marginal cropland to forest, but also reduce the pressure of local populations on natural resources (Peng et al., 2007; Qin, 2010).

Although we did not observe a significant effect of NFCP on the estimated forest cover change rate, it does not mean that NFCP is not important for forest recovery. One of the reasons may be that our analysis is at township level and there are only 12 townships without NFCP implementation and thus the variance is not big enough to observe a significant effect. In addition, compared with GTGP, the NFCP mainly focuses on current natural forest management and protection and also involves the logging ban, which prevents deforestation and enhances natural regeneration of the forest (Zhang et al., 2000). In addition, previous results by our research team have shown that there is a significant positive effect of NFCP on forest cover at local scales, using a pixel-based analysis (Viña et al., 2011). In future research we will conduct analyses at multiple levels (i.e., pixel, township, and county levels) to improve our understanding of the effects of NFCP on forest cover change.

Conclusions

After seven years of implementation, conservation policies seem to be achieving one of their main goals, that of restoring forest cover and conserving natural forests (Liu et al., 2008). These results, however, only point to a stabilization or increase in total forest cover, and not on the type of forests that are being recovered. Future studies should therefore evaluate the type of forests that are being restored (including their qualities in terms of biodiversity and ecosystem function), as well as if they correspond to plantations, re-plantations or naturally regenerated forests.

While our results suggest that the percentage of agricultural population has significant negative effects on forest cover change, more than 90% of townships in the study area exhibited either forest regeneration or have effectively protected their remaining forests. In order to prevent deforestation and forest degradation and to promote the current positive trend of forest cover change, conservation efforts through the GTGP and the NFCP should continue. The GTGP was recently renewed for another eight years while the NFCP was renewed for another 10 years. In order to mitigate the negative effects caused by the driving forces of deforestation described above and to enhance the positive effects of conservation policies on forest cover change, local governments should consider implementing two additional actions. On the one hand, they should help local households switch their energy sources from fuelwood to others, such as electricity and methane. Generally, methane has the advantages of being cheap, easy to generate, and multifunctional, as it can be generated by fermentation of human and livestock waste, or of corn and/or wheat stalks, thus providing energy for cooking and heating. For the households that cannot switch from fuelwood to other energy sources, the government and non-governmental organizations may help them change their stoves to fuelwood-saving types, although care should be taken to ensure that the stoves provided are not only efficient but long-lasting, to guarantee their continuous use for long periods of time. In our study area, both regions have started to use these strategies to reduce the negative effects on forest cover (World Wildlife Fund, 2004; State Forestry Administration, 2009b). On the other hand, besides energy substitution strategies, rural–urban labor migration may also reduce human impacts on forests. For this, local governments should stimulate education attainment (including finishing middle and high school) (Liu et al., 1999a,b, 2003b; An et al., 2003) as well as providing training for local people in order to increase their skills to improve their job opportunities in urban areas. It is also important for local governments to increase alternative income sources for the agricultural population, which may also facilitate the promotion of alternative energy sources in traditionally fuelwood consumption areas. For example, the development of road networks and improved road conditions may increase other income sources such as tourism. Both study regions have developed or are planning to develop tourism activities in order to increase local farmer household's income (Li and Han, 2001; Fang, 2002; Li, 2004; He et al., 2008; Luo and Zheng, 2008). For instance, the number of tourists in Wolong Nature Reserve, one of the most important giant panda nature reserves in China and located within the Sichuan Giant Panda Sanctuary, increased from 130,000 in 2000 to 206,100 in 2005 (He et al., 2008). But the development of tourism should pay special attention to the needs of local households in order to reduce the unequal distribution of benefits, not only among local households but also between locals and outsiders (He et al., 2008; Liu et al., 2012).

Forest transition in China is not a unique case in Asia. India and Vietnam have also undergone forest transition during the last decade (Foster and Rosenzweig, 2003; Meyfroidt and Lambin, 2009). In addition, many other developing countries around the world have slowed down deforestation and may step into a forest transition within the near future (Henson, 2005; Wannitikul, 2005). Therefore, it is necessary to understand the underlying driving forces of these observed patterns and their ecological effects, which may contribute to understanding a possible emerging trend that would have important implications for future forest resources worldwide.

Finally, although the GTGP has shown a positive effect on forest cover not only in the study area, but also in China as a whole (Liu et al., 2008), we should not ignore potential global environmental implications (Liu and Raven, 2010). Today, China has become a world-leading timber importer and wood product exporter (U.S. Office of the Environmental Investigation Agency, 2007). Implementation of forest conservation policies in China has raised global concerns that as a result of these policies, China's timber import is exerting enormous pressures on the forests of other regions such as Southeast Asia (e.g., Burma and Indonesia), Madagascar, and eastern Russia, often in the form of illegal logging (Laurance, 2008; Center for International Forestry Research, 2010). Future research, therefore, needs to assess the effects of China's domestic forest conservation policies on forest resources in other countries.

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