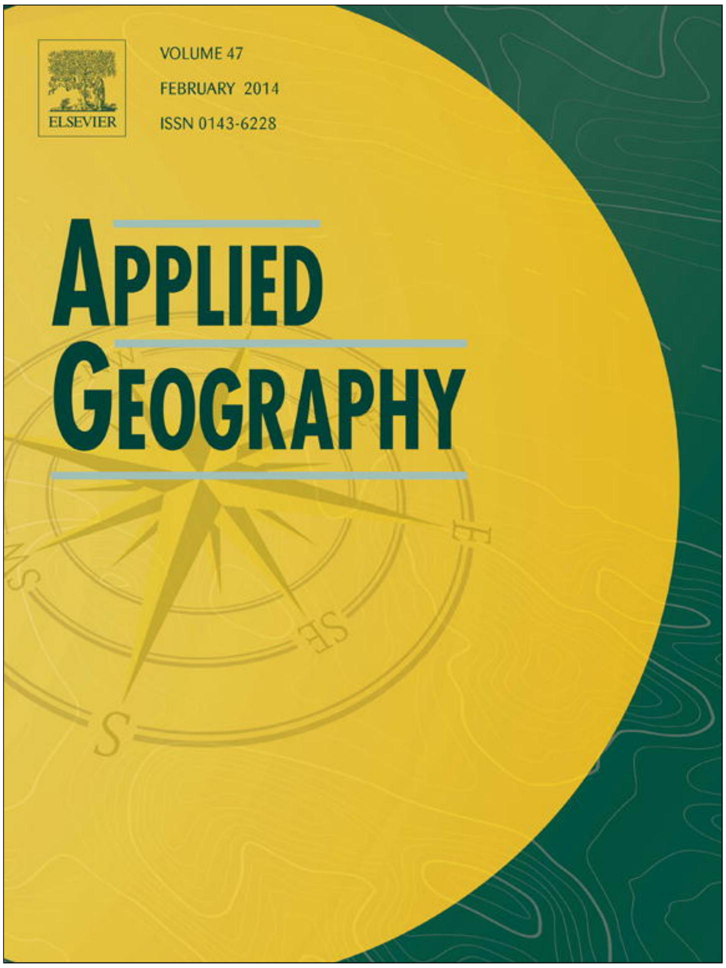
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Evaluating forest policy implementation effectiveness with a cross-scale remote sensing analysis in a priority conservation area of Southwest China

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ABSTRACT

China's Natural Forest Protection Program (NFPP) and Sloping Land Conversion Program (SLCP), introduced in 1998 and 1999, respectively, are integral parts of the world's largest reforestation effort. State-reported forest cover data indicate effective policy implementation through net forest cover expansion but overlook the scale-dependence of and spatial variation in forest cover change patterns and also lack reliable data on small-scale and illegal logging. As a result, there is considerable uncertainty over the spatial distribution of forest cover change and ultimately the policies' effectiveness at increasing forest cover. This research uses Landsat Thematic Mapper imagery-derived multitemporal Tasseled Cap variables and a decision tree classifier to map short- and long-term forest cover change across three administrative levels in the priority conservation area of Diqing Tibetan Autonomous Prefecture in Yunnan Province. Results indicate a 73% reduction in the rate of forest cover loss and a more than doubled rate of forest cover gain from 1990–1999 to 1999–2009 across the prefecture, both of which support a positive assessment of policy implementation. However, prefectural results are countered by spatially disparate forest cover gain and loss trends at the county- and township-level in the decade following the policies' introductions. Further, more than half of Diqing's townships, mainly those in the prefecture's south where tourism has been rapidly developing, saw continued net forest cover loss attributable to small-scale timber harvesting for tourism-driven construction. This research thus exposes cross-scale spatially disparate forest cover change indicative of highly differentiated policy implementation effectiveness, and shows the pattern by which regional development has redirected, rather than reduced, forest cover loss, contrary to the goals of the NFPP and SLCP.

Introduction

Introducing the NFPP and SLCP

Deforestation has been the dominant historical land cover change in China as forests have been cleared en masse for agricultural land use or harvested for fuelwood and timber (He, Ge, Dai, & Rao, 2008; Menzies, 1992). During the modern era of the People's Republic of China (PRC), the Great Leap Forward (1966–1976) followed by the opening of commercial timber markets in the early 1980's brought an increased annual rate of commercial harvesting in some regions to five times that of natural forest regrowth by the mid-1980's (Winkler, 2003). However, in the late 1990's, a dramatic shift in Chinese forest policy design came in response to a series of eight floods that swept through the Yangtze River in the summer of 1998 and took between two and four thousand lives and caused approximately 170 billion RMB (12 billion USD) in damages (Yeh, 2009). With deforestation identified as the primary factor responsible for the flooding, policy design shifted away from the commercial viability of forests and towards sustainable management (Liu & Tian, 2010; Zhang et al., 2000).

Introduced in August 1998, only days after the floodwaters had receded, the Natural Forest Protection Program (NFPP) (天然林保护工程), alternately translated as the Natural Forest Conservation Program (NFCP), sought to "protect natural forests, facilitate

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forestation, and build planted forests" (CAS, 2007). The NFPP closed timber markets in the upper Yangtze by September 1998 (Hillman, 2003), required the four largest logging companies to promptly halt logging in primary forests (Wang, Innes, Lei, Dai, & Wu, 2007), and initially banned all logging in the upper Yangtze though this complete ban was soon relaxed to allow for subsistence use. Similar restrictions soon spread to 17 provinces and autonomous regions in the Yangtze River headwaters containing 69% of China's total natural forest cover (Mullan, Kontoleon, Swanson, & Zhang, 2009; Yin, Xu, Li, & Liu, 2005).

The NFPP initially sought to increase national forest cover to 19% by 2010 (Zhang et al., 2000) and has since been renewed through 2020 with the goal of increasing national forest cover to 25% (SFA, 2011). In addition to the logging ban, the NFPP has funding for afforestation and reforestation through aerial seeding and manual planting. Afforestation has been aggressively pursued with widespread tree planting on hillsides and barren lands complemented by a complete restriction on resource use across 31 million ha of land that had been afforested or had the potential to support forests. In 1999, the NFPP was joined by the Sloping Land Conversion Program (SLCP) or "Grain for Green" program (退耕还林工程), a program designed to limit soil erosion across 25 provinces by decreasing agricultural cultivation on steeply sloped lands (Démurger, Fournier, & Shen, 2005). The goal of the SLCP is to convert over 14 million ha of agricultural lands to forests, which include 4.4 million ha of steep (greater than 25°) agricultural lands, and to afforest over 17 million ha of "wasteland," lands that are degraded or out of active land use for other reasons (Liu, Li, Ouyang, Tam, & Chen, 2008; Yeh, 2009).

Policy implementation evaluations

In only the first two years following the NFPP's introduction, national timber harvest levels dropped from 29 million m^3 to 14 million m^3 (Zhang et al., 2000; Zhao & Shao, 2002) and, by 2009, China had established itself as the global leader in afforestation with nearly 6 million ha of afforested land (Wang et al., 2007; Yu et al., 2011). The State Forest Administration's (SFA) National Forest Resource Inventory (NFRI) data – based on county-level ground surveys every five years – has been the primary dataset used to quantify forest cover change. NFRI data show a 3.2% net national forest cover gain between 1995 and 2000 and a 3.6% net gain between 2005 and 2010 under expanded policy implementation (FAO, 2000, 2012). By 2010, Chinese national forest cover had already reached 22%, surpassing the NFPP's initial goal of 19% national forest cover (FAO, 2012; Xu, 2011), and was quickly approaching the goal of 25% forest cover by 2020.

While these trends suggest effective policy implementation, the value of NFRI data is limited by a host of reasons: the lack of spatially-explicit and historical inventories (Miao & West, 2004; Yin, Yin, & Li, 2009; Zhang & Song, 2006), shifts in the formal definition of "forest" (Ho, 2005; Miao & West, 2004), misleading reforestation assessments (Liu & Tian, 2010), and unaccounted for impacts of small-scale, selective or illicit logging (Melick, Yang, & Xu, 2007b; Xu & Wilkes, 2004). Further, NFRI data disagree with UNEP/SEPA (United Nations Environment Program/Strategic Environmental Policy Assessment) data on the amount of national forest cover in 2000 by as much as 7.5% of China's total land area (Sayer & Sun, 2003) as well as Liu et al. (2005) who measured a 0.52% decrease in national forest cover during the 1990's while NFRI data reported a contemporary increase of 1.94% (FAO, 2000).

Moreover, results from multiple case studies (e.g., Ives, 2006; Liu & Tian, 2010; Trac, Harrell, Hinckley, & Henck, 2007; Xu, Katsigris, & White, 2002) counter NFRI-backed claims of policy effectiveness and expose great variability in implementation (Yeh, 2009). Xu, Tao, and Amacher (2004) found that NFRI-reported gains in forest cover could not be verified during site visits across 28 provinces. Using 250-m resolution MODIS imagery, Li et al. (2013) measured regional variability of recent forest cover change in central China, and found "no significant change in forest cover" in over half of the studied townships. Collectively, these case studies illustrate cross-scale variability unseen in NFRI data but exposed through spatial disaggregation and inter-regional forest cover change comparisons.

Study overview

To measure the scale-dependent, spatiotemporal variability of forest cover change during NFPP and SLCP implementation, this research employs classified forest cover change maps based on Landsat satellite imagery in the priority conservation area of Diqing Tibetan Autonomous Prefecture, southwest China, in two ways that address the limitations of previous evaluations conducted at a single spatiotemporal scale. First, by measuring changes in the annual rate of forest cover change in Diqing across three administrative levels (i.e., prefecture, county, and township), this research exposes spatially differentiated forest cover change patterns resulting from various processes catalyzed by the policies' introductions. Second, by adopting two temporal scales (i.e., short- and long-term), this research examines the varying contributions of selective logging, industrial logging, and forest regeneration to forest cover change during policy implementation.

Study area

Because of its hydrologic importance at the Yangtze headwaters, history of widespread deforestation, and status as a biodiversity hotspot (Xu & Wilkes, 2004), Diqing Prefecture presents an ideal case study to evaluate the success of the NFPP and SLCP at promoting forest cover expansion. Diqing (Fig. 1) is located in northwest Yunnan Province just southeast of the Qinghai-Tibetan Plateau, straddles the north-south running Hengduan Mountains between 1500 and 6700 masl with an average elevation of 3400 masl, and sees 300–950 mm of annual precipitation, most of which falls between June and September (Sherman, Mullen, Li, Fang, & Wang, 2007). Diqing is approximately 2.3 million ha in size – slightly larger than the US state of New Jersey – and includes three counties, Deqin, Weixi, and Shangri-La, which collectively comprise thirty townships. Ethnic Tibetans account for 33% of Diqing's 350,000 residents across 1300 villages, towns, and cities (National Bureau of Statistics, 2005). Grasslands and pine forests are found at elevations up to 3000 masl; mixed alpine coniferous (fir, pine, and spruce) and oak trees constitute the majority of mid-elevation forests between 3000 and 4000 masl on south- and north-facing slopes, respectively; alpine heath and meadows occupy 3800 to 4800 masl; and alpine ecosystems extend to 6500 masl (Weyerhaeuser, Wilkes, & Kahrl, 2005; Willson, 2006; Winkler, 1998).

NFRI data report 65% forest cover in 2000, an amount well above the average of Yunnan Province (33%) or China (13%) (DYED, 2006) and which rose to 67% by 2005 and 75% by 2011 (Kunming Daily, 2011). There is no comprehensive report on the extent of historical forest cover change but available data suggest that over 20% of the prefecture's conifer forests were commercially harvested in the two decades prior to the NFPP's introduction (Xu & Ribot, 2004). The loss of forest cover to industrial logging was most pronounced in southern Weixi and Shangri-La counties, supported by existing roadway infrastructure and less topographic relief and better market access than the rest of Diqing (Hillman, 2003; Willson, 2006). Over 30% of Diqing's forests have been collectively managed since the mid-1960's and remained broadly off-limits to industrial logging (Qiang, H. Personal communication, July 20,

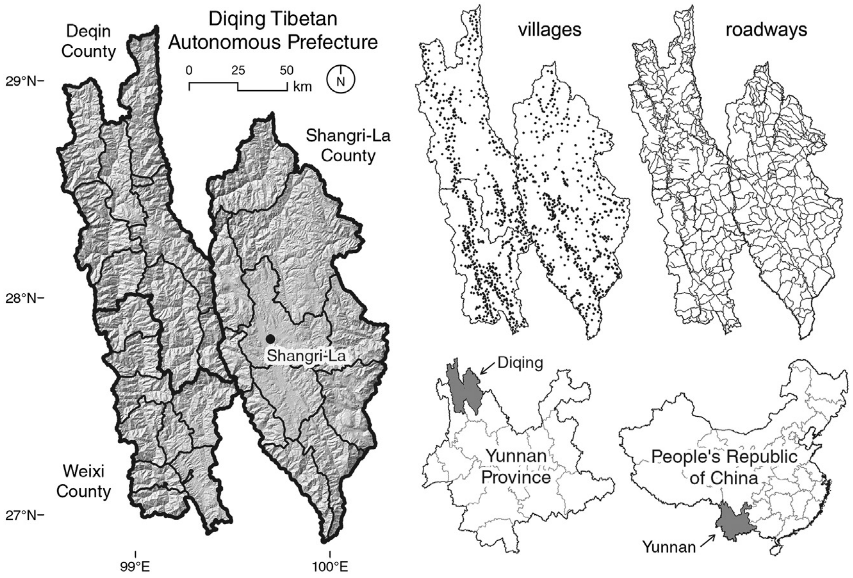

Fig. 1. Diqing Tibetan Autonomous Prefecture's topography, village distribution, and roadway network in northwest Yunnan Province, southwest China.

2010). Instead, collective forests supply villages with livestock fodder, housing timber, and fuelwood harvested through small-scale and spatially diffuse selective logging (Liu, 2001; Richardson, 1990).

At the outset of policy implementation in 1998, Diqing was a poor region within a poor province: the per capita GDP was only one-third of China's average and the shuttering of the commercial timber industry meant that the prefectural government lost 80% of its annual tax revenue (Hillman, 2003). In response, Diqing leadership established tourism as the centerpiece of local economies and tax revenue. By 2001, tourism was bringing approximately 68 million RMB in annual revenue to Diqing, 10 million RMB more than commercial logging had during its mid-1990's peak (Hillman, 2003). The growth of tourism was buttressed by the removal of travel restrictions to Diqing in 1997, construction of a new regional airport in central Shangri-La County in 1999, the re-naming of what had been known as Zhongdian County to Shangri-La County in May 2001 after the fictional Himalayan paradise in the novel, "Lost Horizon" (Hillman, 2003), expanded roadway coverage, and increased extraction of timber for construction of hotels and restaurants in defiance of NFPP restrictions (Melick, Yang, & Xu, 2007a; Menzies, 2007; Xu & Melick, 2007; Zackey, 2005).

Methods

Data and analytical design

To gauge changes in forest cover change under policy implementation, the extent, annual rate, and spatial pattern of forest cover change were measured with 30 m resolution multispectral

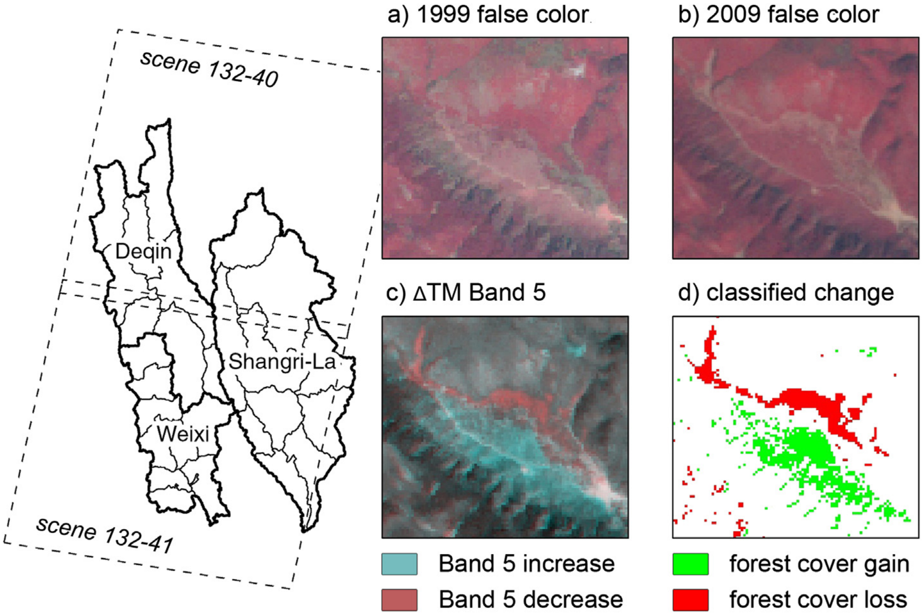

Fig. 2. Coverage of Diqing Prefecture by Landsat-5 TM scenes 132-40 and 132-41, and three Landsat-derived products: a) 1999 and b) 2009 false color imagery; c) an image of 1999–2009 ΔTM Band 5 used in visual interpretation of training data; and d) a classified forest cover change map. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Landsat-5 Thematic Mapper (TM) imagery collected in row/path 132-40 and 132-41 (Fig. 2). The temporal distribution of imagery (Table 1) is structured in a "change-in-change" approach that contextualizes forest cover change during policy implementation with preceding change trajectories. As persistent cloud cover limited the availability of TM imagery during the NFPP's introduction in September 1998, the nearest imagery date with less than ten-percent cloud or snow cover, October 28, 1999, was instead used to anchor the imagery's distribution. Radiometric correction was not applied to the imagery since the Multitemporal Tasseled Cap (MTC) indices used in this study and described below have been shown to perform as well at capturing changes in land cover with radiometric correction applied as without (Collins & Woodcock, 1996; Potere, Van Dellen, & Pollack, 2004).

Small-scale selective logging and forest cover expansion pose challenges to detection with coarse-scale TM imagery. Selective logging typically has a low magnitude, temporary impact on forest structure compared to clear-cutting associated with industrial logging that may lead to degradation or permanent deforestation (Healey, Yang, Cohen, & Pierce, 2006; Putz, Sist, Fredericksen, & Dyckstra, 2008). Similarly, forest regeneration is a gradual process requiring several years before new "forest" can be discriminated from the spectral characteristics of surrounding vegetation (Kennedy, Yang, & Cohen, 2010; Masek et al., 2008; Zhang, 2000). To detect short-term and long-term forest cover loss as well as long-term forest cover gain, two different temporal scales were used: three- to six-year study periods to identify short-term forest cover loss, and nine- to ten-year study periods to assess long-term forest cover gain, loss, and net change.

Satellite imagery processing and classification

Multitemporal Tasseled Cap indices are the independent variables used to map the dependent variable of forest cover change (Fig. 3). Based on the Gramm-Schmidt transformation, MTC indices are orthogonal (uncorrelated) indices calculated through a linear combination of imagery bands (Crist & Cicone, 1984; Kauth & Thomas, 1976). MTC indices are strongly related to physical changes in forest cover, provide a better indication of vegetative change than inter-date differences in values of a single Landsat band (Coppin, Jonckheere, Nackaerts, Muys, & Lambin, 2004; Rogan, Franklin, & Roberts, 2002), and have been used to accurately map locations of change across a diversity of forests and change conditions (e.g., Healey, Cohen, Yang, & Krankina, 2005). For each change pair, MTC indices represent a change in brightness (ΔB) (the change in soil brightness or total reflectance based on a weighted sum of TM bands), change in greenness (ΔG) (relating the change in green vegetation based on the difference between weighted visible and near-infrared bands), and change in wetness (ΔW) (representing a change in canopy and soil moisture based on the difference between the sum of weighted visible and near infrared bands with the sum of weighted mid-infrared bands) as well as stable brightness (B), greenness (G), and wetness (W), the latter three of which account for scene variation unrelated to vegetative change. To aid discrimination of different land covers with comparable change indices, stable Tasseled Cap indices were merged with change indices in a six-band change image.

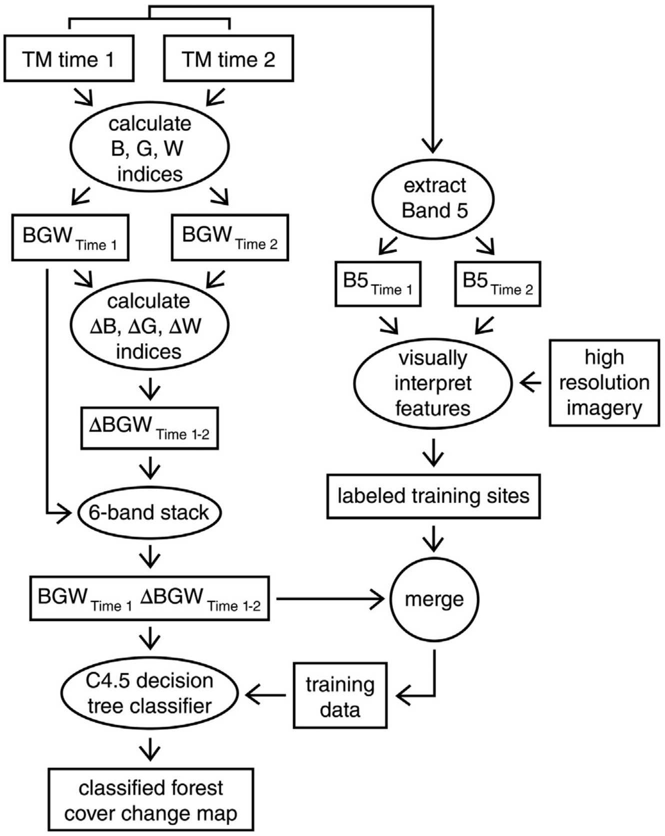

Fig. 3. Overview of forest cover change methodology where B, G, and W refer to Tasseled Cap Brightness, Greenness, and Wetness indices, respectively.

Training data for each study period were comprised of one hundred randomly sampled locations from a six-band MTC change image, labeled through visual interpretation of a TM near-infrared Band 5 temporal composite as well as high resolution Google Earth-hosted Quickbird imagery collected between 2002 and 2009. Training features considered in the direct change classification include forest, non-forest, and water as well as the image date-specific features of cloud, snow/ice, and shadow that were abundant across Diqing's mountainous terrain and contributed to inter- and intra-image variability (Table 2). Features were thematically merged into three classes used in the forest cover change classification: *forest cover loss* (forest-to-non-forest), *forest cover gain* (non-forest-to-forest), and *stable non-forest or forest*. With these training data and a six-band change image as input, a Unix-implemented C4.5 decision tree classifier with pruning and boosting (Quinlan, 1993) was used to classify forest cover change for each study period. This decision tree classifier was selected because of its ease of implementation and ability to map forest cover change manifest as spectrally non-contiguous clusters like those associated with selective logging or forest regrowth.

Table 1
Temporal distribution of Landsat-5 TM imagery.

imagery date	short-term change maps	long-term change maps
20-Nov-90		
	1990-1996	1990-1999
6-Dec-96		
	1996-1999	
28-Oct-99		
	1999-2004	1999-2009
27-Nov-04		
	2004-2009	
24-Nov-09		

Table 2
List of visually interpreted training data feature types and thematically merged feature classes depicted in classified change maps. Note that *forest cover gain* was only classified for long-term change maps.

Feature number	Feature type	Feature class
1	Unshaded forest to unshaded non-forest	Forest cover loss
2	Shaded forest to shaded non-forest	
3	Unshaded non-forest to unshaded forest	Forest cover gain
4	Shaded non-forest to shaded forest	
5	Stable forest (unshaded)	Stable non-forest or forest
6	Stable forest (shaded)	
7	Stable forest (unshaded to shaded)	
8	Stable forest (shaded to unshaded)	
9	Stable non-forest (unshaded)	
10	Stable non-forest (shaded)	
11	Stable non-forest (unshaded to shaded)	
12	Stable non-forest (shaded to unshaded)	
13	Cloud to forest	
14	Cloud to non-forest	
15	Cloud to snow	
16	Forest to cloud	
17	Non-forest to cloud	
18	Snow to cloud	
19	Stable cloud	
20	Snow to forest	
21	Snow to non-forest	
22	Forest to snow	
23	Non-forest to snow	
24	Stable snow	
25	Stable shadow	
26	Shadow to cloud	
27	Cloud to shadow	
28	Shadow to snow	
29	Snow to shadow	
30	Stable water	

Cross-scale forest cover change

Shifts in forest cover change under policy implementation were assessed in three ways. First, annual rates of forest cover change were measured at the broad prefecture-level, the intermediate county-level, and the fine township-level. At each administrative level, forest cover change area was normalized by the study period duration and regional area under consideration, yielding the annual change rate relative to regional extent (e.g., Puyravaud, 2003). Annual change rates were compared across spatial scales, and shifts in trajectories of annual change rates at each administrative level were evaluated across short- and long-term study periods as a preliminary assessment of policy implementation effectiveness.

Second, the pattern of forest cover change at the township-level was quantified using aspatial and spatial indicators of variability including first-order global and local measures of Moran's I, widely used geostatistical indices of spatial autocorrelation (Anselin, 1995; Tiefelsdorf & Boots, 1997). Global Moran's I is a single prefecture-wide value that relates the degree to which annual forest cover change rates are clustered across Diqing's townships. Local Moran's I, on the other hand, is calculated for each township and represents the similarity in annual change rate between a given township and those immediately proximate. Given its township-by-township calculation, local Moran's I is more capable of exposing regional spatial variability that may go undetected with the global indicator.

Third, respective contributions of short- and long-term forest cover loss during a given long-term study period were discriminated. Measurements of short- and long-term loss are not independent since, for example, a long-term loss event in 2000 and measured in the 1999–2009 study period also contributes to short-term loss measured in the 1999–2004 study period; in effect, long-term loss would be double-counted. With the assumption that short-term forest cover loss does not directly contribute to long-term loss, the *actual* short-term loss that occurred over a long-term study period was estimated by calculating the difference between the amount of loss over two consecutive short-term study periods (e.g., 1990–1996 and 1996–1999) from that which occurred during the contemporary long-term study period (e.g., 1990–1999). The difference in the amount of *actual* short-term loss from 1990–1999 to 1999–2009 relative to the 1990–1999 *actual* short-term loss was then assessed as an indicator of changes in selective and small-scale logging under policy implementation.

Accuracy assessment

Validation data to assess forest cover change classification accuracy were collected through a class-stratified random sample of one hundred locations in each of the six classified change maps; these data were sampled independently from training data to limit the bias that may be introduced by spatially dependent training sites (Pal & Mather, 2003). Confusion matrices and producer's (PA), user's (UA), and overall accuracies (OA) were calculated using an area-adjusted calculation with class weights inversely proportional to class areal extent (Card, 1982). The area-adjusted calculation reduces the potential for bias associated with different proportions of training data size and actual land cover class extent and mitigates the influence of the large but analytically irrelevant *stable non-forest or forest* sites.

Results

Accuracy of derived change maps

The average area-adjusted UA of short- and long-term loss was 83% and 83.5%, respectively, and 81.5% for long-term gain (Table 3). For both short- and long-term change maps, the presence of training and validation data at a class' spectral or a feature's spatial boundary as well as the abundance of snow/ice would have introduced more error; for example, the lower accuracies of 1999–2004 and 2004–2009 change map were likely influenced by the greater snow/ice and cloud coverage in 2004 as evidenced by snow/ice making up one third of misclassified forest cover loss pixels. Though no standard exists for forest cover change mapping accuracy, this study's accuracies support a confident examination of forest cover change trends.

Inter-regional comparison of short-term forest cover loss

Considering short-term forest cover loss trajectories, Diqing's annual loss peaked at 0.9% in 1996–1999 (Fig. 4); this rate declined by 37% in 1999–2004 following the NFPP's introduction and

Table 3
Area-adjusted producer's (PA), user's (UA), and overall accuracy (OA) for classified change maps. Note that *forest cover gain* was only classified for long-term change maps.

Study period	Area-adjusted accuracies						
	Forest cover loss %		Forest cover gain %		Stable non-forest or forest %		OA %
	PA	UA	PA	UA	PA	UA	
1990–1996	99.98	85.00	–	–	9.10	99.00	85.21
1996–1999	99.97	86.00	–	–	15.10	99.00	86.32
1999–2004	99.97	80.00	–	–	11.57	99.00	80.49
2004–2009	99.97	81.00	–	–	3.92	97.00	81.13
1990–1999	91.50	84.00	99.43	81.00	17.05	93.00	82.05
1999–2009	99.81	83.00	99.83	82.00	16.96	96.00	82.96

subsequently plummeted to approximately 0.2% in 2004–2009. Deqin and Shangri-La counties nearly paralleled the prefecture-level loss trajectory with steadily declining loss rates from 1996–1999 through 1999–2004 and 2004–2009 but Weixi County's loss rate remained relatively stable into 1999–2004, only dropping by 7%. Indeed, Weixi maintained nearly twice the prefecture's overall rate of forest cover loss during the first five years of policy implementation, indicating a spatially disparate lag in policy implementation effectiveness when compared to the other two counties. This lag in the reduction of Weixi's loss rate is not unexpected as Weixi led the prefecture in short-term forest cover loss prior to the NFPP in great part due to widespread industrial logging throughout the 1990's (H. Qiang, personal communication, July 20, 2010).

At the township-level, the peak rate of forest cover loss occurred in 1996–1999 for 25 of Diqing's 30 townships with the remaining five townships measuring a peak loss in 1999–2004. As at the prefecture- and county-level, there was a great decline in the average township-level rate of forest cover loss in 2004–2009 (74%) but such declines were not consistent across Diqing's townships as the coefficient of variation (CV) of forest cover loss rate also saw its highest value (0.83) in 2004–2009. This suggests that even though the typical township saw reduced rates of forest cover loss, there was a greater relative diversity in the township-level rate of loss during policy implementation. Changes in the spatial distribution of forest cover loss are most apparent in the relative intensification of loss in the southernmost townships of Shangri-La and Weixi counties during 1999–2004 (Fig. 5a), changes which went undetected at prefecture-and county-level measurements. A regionalized, increased concentration of loss with a concomitant reduction elsewhere like this is commonly known as "leakage" and discussed below.

Spatial variability of short-term loss

Global Moran's I trajectories show increased spatial autocorrelation (i.e., less spatial variability) of forest cover loss in 1999–2004 and moderate spatial autocorrelation in 2004–2009 (Table 4). Local Moran's I values, on the other hand, expose an overall lack of spatial homogeneity of township-level forest cover loss (Fig. 6a). In each study period, over two-thirds of Diqing townships expressed statistically insignificant spatial autocorrelation of forest cover loss indicating a highly variable pattern of loss prior to and during policy implementation. Of townships showing significant spatial autocorrelation, "low" forest cover loss townships were found across Deqin county in the 1990's, expected given the relative absence of industrial logging in Deqin, while Weixi County – the hotspot of pre-NFPP industrial logging – was host to spatially autocorrelated "high" loss townships through 1999–2004. In 2004–2009, however, significantly autocorrelated "high" loss townships were redistributed to Shangri-La County – the current tourism hotspot – offering another indication of forest cover loss leakage during policy implementation.

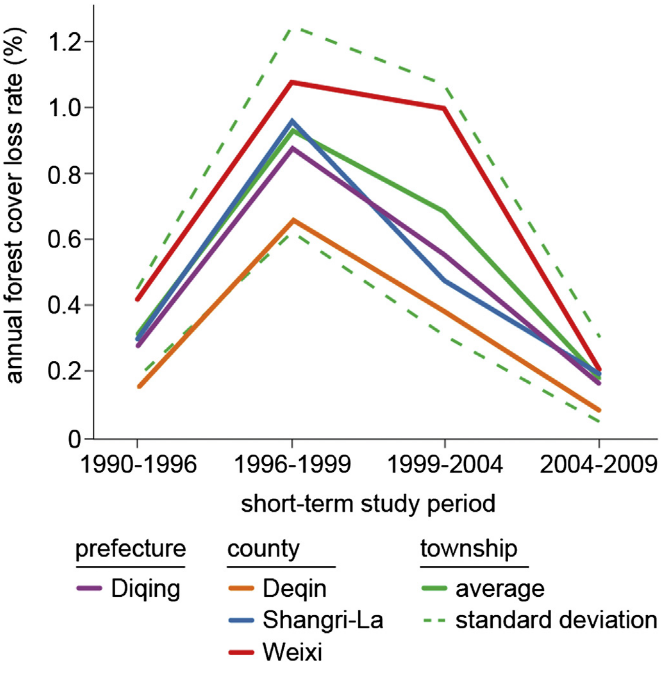

Fig. 4. Trajectories of annual short-term forest cover loss.

Intra-regional comparison between short- and long-term forest cover change

Compared to short-term loss trajectories, the reduction in long-term loss presents a much more favorable view of policy implementation. Diqing showed a 73% reduction in forest cover loss and a more than doubled rate of forest cover gain between 1990–1999 and 1999–2009, yielding a net loss of 0.18% during the first ten years of policy implementation (Fig. 7). This net change, while still a loss, is an impressive improvement on the 2.21% net loss in the decade prior to the policies' introductions. Though the three counties had nearly equalized rates of short-term loss in 2004–2009, long-term county-level loss rates were much more variable in 1999–2009 as Weixi's loss rate was nearly triple that of Deqin. At the township-level, 87% saw a decreased rate of long-term loss in 1999–2009 yet only 40% realized a net gain. As with short-term loss, the spatial redistribution of long-term township-level forest cover change is obvious: forest cover loss was further concentrated in the prefecture's south and forest cover gain migrated north (Fig. 5b). In fact, of the 21 townships in Weixi and Shangri-La, only five reached a net forest cover gain in 1999–2009.

To discriminate between short- and long-term forest cover loss, changes in *actual* short-term loss were compared across spatial scales (Table 5). *Actual* prefecture-level short-term loss in 1999–2009 increased by 23.7% relative to 1990–1999, indicating the expansion of small-scale (i.e., selective) harvesting despite the logging ban. At the county-level, Deqin showed a comparable rise of 46.3% while Weixi increased by 59.5% and Shangri-La saw a slight reduction of 9.0% in short-term harvesting. Though average township-level values of *actual* short-term loss were comparable with prefecture- and county-level values, the average increase during policy implementation was over 75%, a stark example of how small-scale harvesting increased in the 2000's despite the general reduction in township-level forest cover loss.

As would be expected with the closure of Diqing's commercial timber markets, long-term township-level forest cover loss was less spatially variable after the NFPP's introduction. Indeed, global Moran's I values (Table 4) suggest that long-term loss was more spatially variable in 1990–1999 than short-term loss during any study period, reflecting the more regionalized impacts of industrial logging and spatially diffuse impacts of selective logging. Local Moran's I values indicate a complete lack of significant spatial autocorrelation of township-level net change during policy implementation (Fig. 6b). Shangri-La's internal spatial variability of forest cover change as well as the very few townships in Weixi County showing significant spatial autocorrelation of loss or gain in 1999–2009 echo short-term assessments of high spatial variability of change during policy implementation.

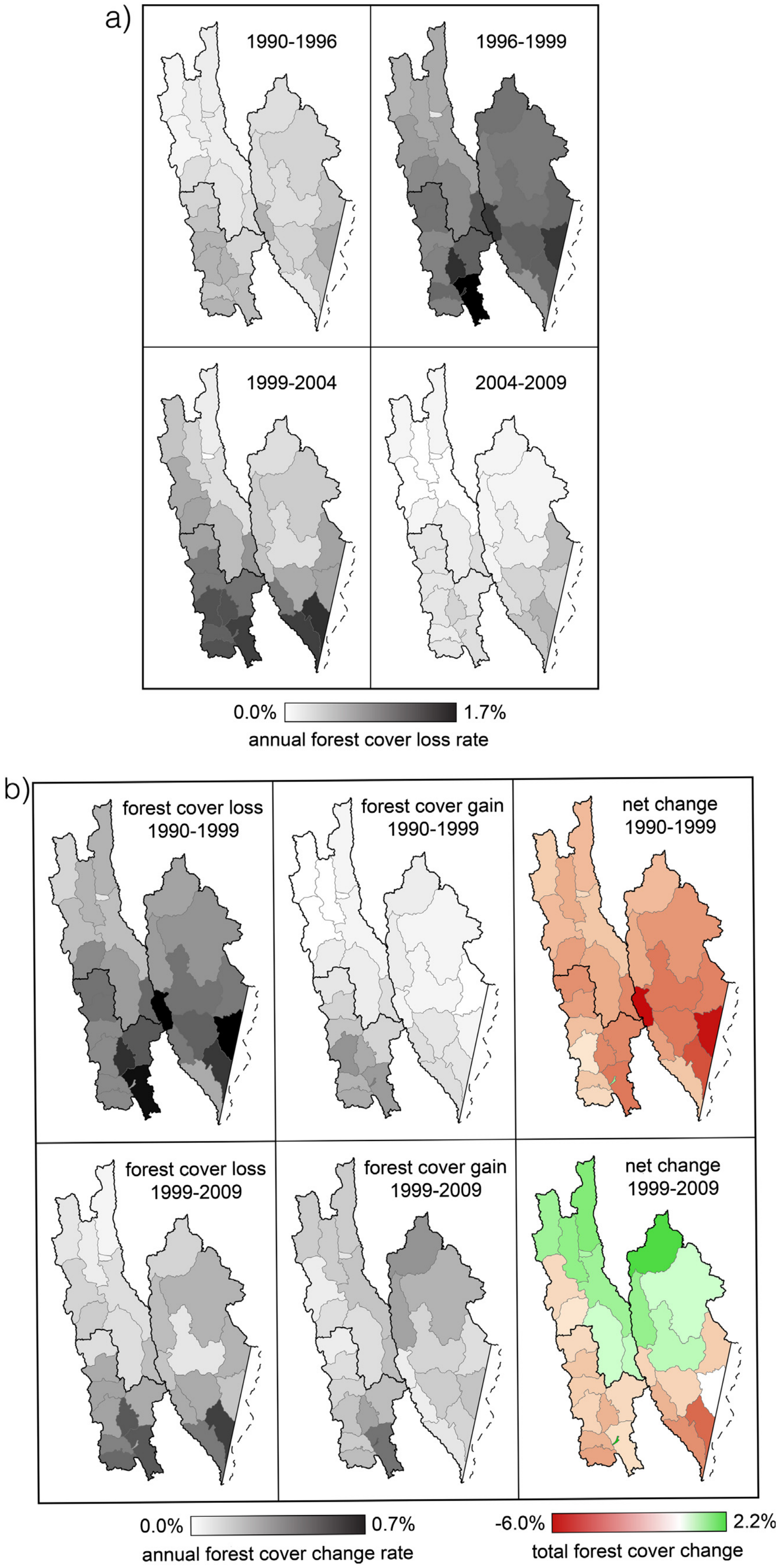

Fig. 5. Township-level forest cover change rates during a) short-term and b) long-term study periods.

Table 4
First-order global Moran's I values for township-level forest cover change; values equal to one indicate pure spatial autocorrelation.

Study period	Global Moran's I (pseudo p-value $< = 0.004$)		
	Annual forest cover loss %	Annual forest cover gain %	Total net forest cover change %
1990–1996	0.527	–	–
1996–1999	0.462	–	–
1999–2004	0.618	–	–
2004–2009	0.510	–	–
1990–1999	0.381	0.685	0.285
1999–2009	0.545	0.330	0.311

Discussion

Policy-relevant evaluation of forest cover change

Diqing made important strides towards balancing forest cover loss and gain under the NFPP and SLCP, most notably by reducing the rate of forest cover loss by 37% in the first five years of policy implementation and doubling the annual rate of forest cover gain between 1990–1999 and 1999–2009. Though indicative of successful policy implementation at the prefecture-level, these results differ from the annual change rates calculated by Brandt et al. (2012) who found nearly stable loss between the decades before and during policy implementation. This study's results also disagree with NFRI data that claim net forest cover gains of 2% and 8% across Diqing in 2000–2005 and 2005–2011, respectively (DYED, 2006; Kunming Daily, 2011). While a direct comparison cannot be drawn between this study and NFRI data, it nonetheless remains difficult to see how Diqing could have mustered successive net gains in 2000–2005 and 2005–2011 when this study measured a 0.18% net *loss* in 1999–2009. This disparity results in part from the lack of accounting in NFRI data for small-scale logging as evidenced by the NFRI-reported *zero* cubic meters of timber extracted in 1999 (Bull & Nilsson, 2004; Melick et al., 2007b) as well as an overestimation of forest regeneration (Liu & Tian, 2010; Zhang & Song, 2006).

Any assessment of policy implementation effectiveness based on shifting trajectories of annual change rates should be tempered by indications of spatiotemporal variability of forest cover change. While the typical township saw reduced loss rates under policy implementation, only 13 of 30 townships realized a net gain in 1999–2009 during which time *actual* short-term loss increased by nearly 24%. Meanwhile, forest cover gain retreated to northern Deqin and Shangri-La townships, producing a spatially divergent pattern of net forest cover change rather different than that seen in 1990–1999. As a result, Diqing's forest cover change reflects a split personality: the historically less-deforested northern townships yielded gains in forest cover that led the prefecture as a whole towards a net gain in 1999–2009 but the re-concentration of loss in Diqing's southern townships ensured a net loss. These results expose the non-stationarity of forest cover change and the redistribution of forest cover loss during policy implementation, findings supported by reports of forest cover loss leakage at the village-level (e.g., Ives, 2006; Xu & Melick, 2007; Yeh, 2009).

Drivers of forest cover change patterns

Just as patterns of forest cover change are scale-dependent (e.g., Overmars, de Koning, & Veldkamp, 2003), so too are drivers of such change. At the prefecture-level, exogenous social factors, such as state environmental policy, are expected to influence patterns of land change whereas village or community socio-economic drivers, institutional factors, and household decision-making processes are typically the most relevant at the local-scale (Rindfuss et al., 2002; Walsh & Welsh, 2003). In the case of the NFPP and SLCP, forest cover patterns result from a host of indirect drivers catalyzed by the policies' introductions, the most prominent of these being spatially disparate tourism development, changes in access to forest resources through expanded road coverage, and spatially variable responses to changing livelihood opportunities following the commercial logging ban. These mechanisms produce locally differentiated and sometimes contradictory incentives for forest resource use, yielding diverse patterns of forest cover change that could not be anticipated by policy designers nor readily explained by policy implementation alone.

Tourism development

Environmental and cultural tourism are often seen as a means to incentivize local, effective management of environmental resources while supporting sustainable livelihoods (Balmford et al., 2009; Li & Han, 2000). Tourism development is widely considered to be a massive success in Diqing, so much so that Diqing is considered a "model" of tourism development for other regions in China to follow (Hillman, 2010). However, the results of this research as well as Peng, Liu, Shen, Han, and Pan (2011) and Zackey (2007) suggest that tourism has actually promoted inter- and intra-township variability of forest cover loss for two key reasons. First, tourism development has been centered on the town of Shangri-La in western Shangri-La County – a principal indirect driver of forest cover loss leakage in 1999–2009 – with little development to speak of in northwest Diqing's mountainous communities where road access is poor and there is a lack of surplus labor for tourism employment. Indeed, only 37% of Diqing's households earned over half their income from tourism and 23% earned no income from tourism at all (Yang, Hens, Ou, & De Wulf, 2009). The economic impact of tourism development at the household level can thus hardly be said to be consistent across the prefecture, nor can its impact on forest cover.

Second, villages with tourism income tend to build larger houses that require more wood (Zackey, 2005) and outsource timber or fuelwood harvesting to nearby, poorer communities who harvest their own collective forests and transport timber into wealthier villages (Peng et al., 2011; Van Den Hoek, 2012). These mechanisms yield an intra-regional leakage of forest cover loss not readily detectable in maps of forest cover change and which goes unreported in studies that do not consider inter-village timber harvesting relationships (e.g., Brandt et al., 2012). Without initiatives that build sustainable harvesting systems to meet the increased need for timber in developing tourism centers, such leakage and regional exploitation of forests is likely to remain the norm.

Expanded road construction and forest access

It is a testament to the relative remoteness of Diqing's forests that they persisted through the upheaval of the Great Leap Forward, Cultural Revolution, and the intensification of industrial logging operations through the 1980's (Menzies, 1992; Richardson, 1990). This is especially true in Deqin County where the lack of road access and difficult terrain constrained the potential for industrial logging and supported greater forest cover gain rates compared to Weixi or Shangri-La. The recent expansion of the roadway network has shifted the "forest frontier" by permitting newfound access to remote, primary forests (Melick et al., 2007b; Zhang, 2000) and has contributed to inter-village variability in forest resource use, as villages with better access are able to harvest more frequently while villages with higher transportation costs harvest more intensely on a given trip or over a larger extent (Trac et al., 2007).

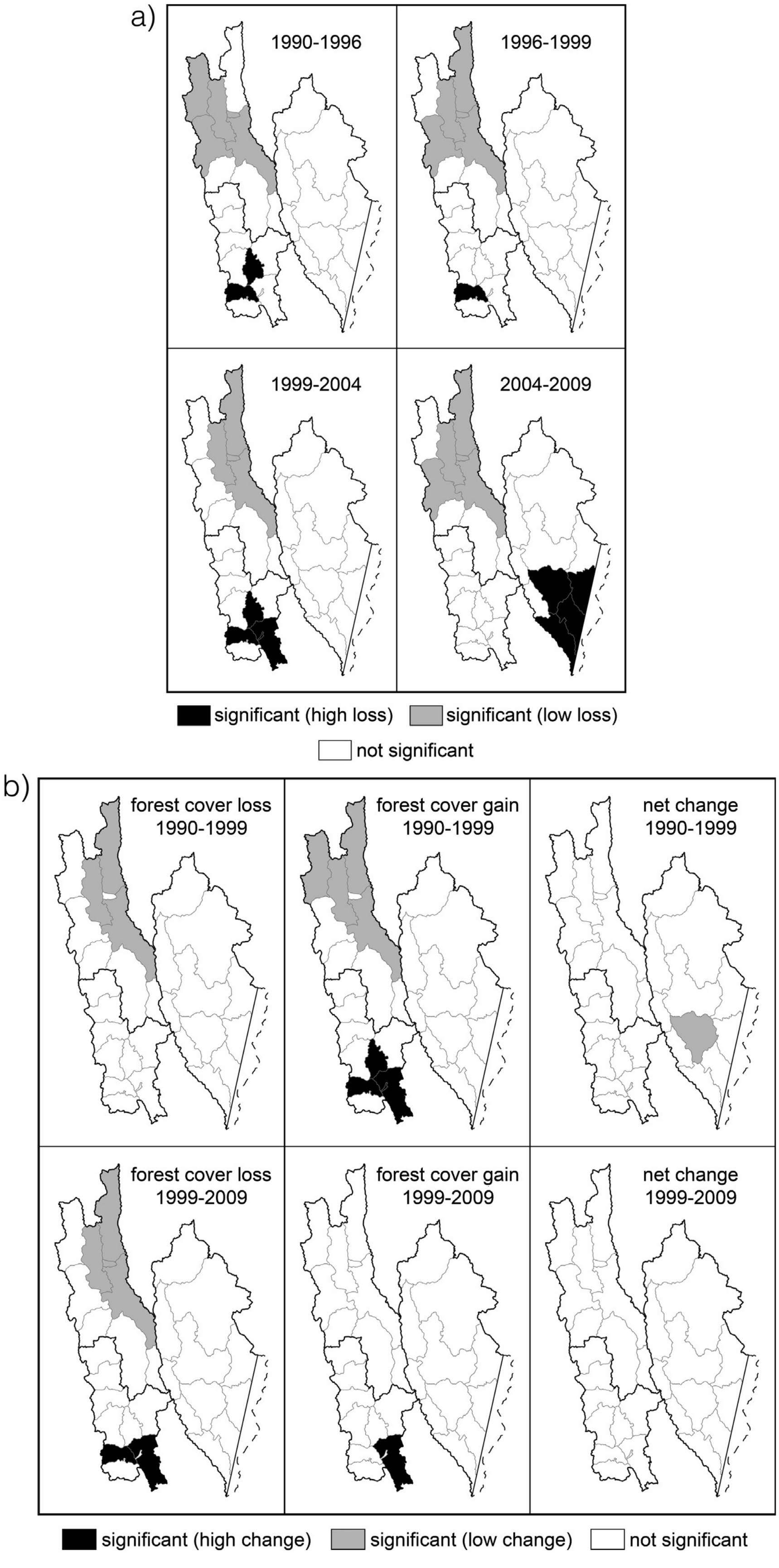

Fig. 6. Results of local Moran's I tests (p-value = 0.01) for annual rates of township-level a) short-term loss and b) long-term change.

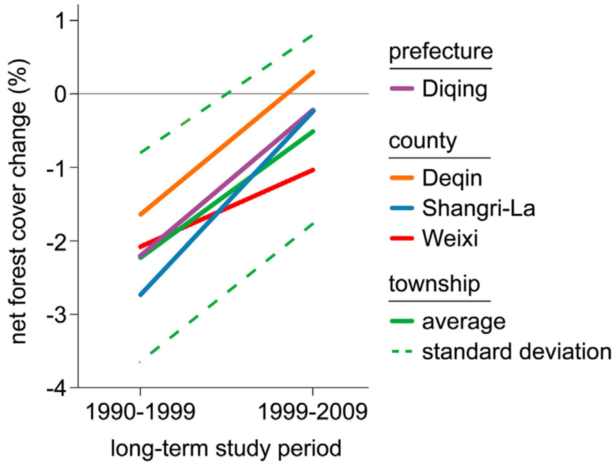

Fig. 7. Net forest cover change trajectories before and during NFPP and SLCP implementation.

The change in the pattern of forest cover loss already caused by increased road coverage may also improve the potential for local tourism development that, in turn, would reconfigure patterns of forest cover loss as described above (Li et al., 2013). However, while village-level research points to forest access as a driver of forest cover loss, this relationship may not persist at broader scales as Brandt et al. (2012) found that road density is not a significant predictor of township-level forest cover loss during policy implementation.

Changing livelihoods and land tenure

Diqing's governments have promoted tourism as a livelihood alternative to commercial logging but in areas lacking viable alternatives, many households have chosen to continue commercially harvesting timber (Melick et al., 2007a; Xu & Ribot, 2004), spurred on by a near doubling of the price of timber early into policy implementation (Mullan et al., 2009; Zackey, 2005). The continuation of pre-NFPP livelihoods was most pronounced in Weixi County which only saw a slight reduction in annual loss rates from 1996–1999 to 1999–2004 as communities with livelihoods traditionally tethered to local forests continued to harvest timber for sale (Hobley, 2005; Zackey, 2007). While some communities sustained their commercial, albeit illicit, logging practices, the lack of forest-derived income plunged others into deeper poverty (Démurger et al., 2005; Xu & Ribot, 2004).

The NFPP-imposed shift from commercial logging also contributed to tenure insecurity, identified as a principal factor leading to forest mismanagement and over-harvesting in the world's forests (Paneque-Gálvez et al., 2013; Robinson, Holland, & Naughton-Treves, 2013). In Diqing, the apparent "seizure" of collective forests under the NFPP's logging ban was seen by some communities as only the most recent change in a long history of alternating forest use rights (Yin et al., 2005). Resentment towards the NFPP and villagers' feelings of economic inequality or marginalization overshadowed the illegality of continued commercial logging and at times led to an intensification of forest harvesting (Xu & Ribot, 2004; Zackey, 2007). Such resistance to policy implementation is not uncommon in rural forests customarily-managed but held to state-defined conditions of access and use (Genin, Aumeeruddy-Thomas, Balent, & Nasi, 2013).

Broader implications of forest policy implementation

In their design and implementation, the NFPP and SLCP have, first, overlooked the diversity of spatially variable and scale-dependent social and environmental conditions (Xu, 2011), and, second, aggravated the potential for local forest management by forcing a mismatch between policy restrictions, pre-existing socioecological relationships, and potential livelihoods that vary within and between spatiotemporal scales (Fremier et al., 2013). With negligible input and feedback from local communities, neither the NFPP nor the SLCP have mechanisms in place that address the political, economic, and social factors that drive local-level forest cover change and which propagate to broader spatial scales (Cao, Wang, Song, Chen, & Feng, 2010; Miao & West, 2004). Without addressing the complicated mosaic of changing livelihoods, economic opportunities, and changes in forest cover change discussed above, NFPP and SLCP implementation will continue to promote spatially disparate forest cover change contrary to the policy's goals.

China's forests have socioecological importance that eclipses their industrial commercial value or mere areal coverage and are critical to sustaining rural livelihoods, the extraction of diverse products, and preserving communities' territorial integrity (Brown, Durst, & Enters, 2001; Genin et al., 2013). Of primary concern is that forest cover expansion has not come through natural regeneration but rather through monocultural afforestation and reforestation with Yunnan pine and non-native species during NFPP and SLCP implementation as well as following industrial logging in the 1990's (Mansourian, 2005; Zhang & Song, 2006). Monocultural forests restrict the habitat for the many kinds of flora and fauna in this biodiverse region and limit the potential yield of timber, fuelwood, and non-timber forest products (NTFPs) like commercially profitable mushrooms (Robinson et al., 2013). Moreover, several scholars (e.g., Brandt et al., 2012; Melick et al., 2007b; Salick et al., 2007; Xu & Wilkes, 2004) have found that most of the forest cover lost during policy implementation has come at the cost of Diqing's old growth forest and regions of higher biodiversity. Unfortunately, these trends are not unique to Diqing, as Xu (2011) described how primary and secondary forests are commonly cut for commercial sale, only to be replaced by monocultural stands planted by households seeking SLCP compensation.

The impacts of NFPP implementation extend well beyond China's borders by influencing global climate change and the international timber trade (Bonan, 2008; Wang et al., 2007; Xu, Qi, & Gong, 2000). Even though the bulk of China's young forests are

Table 5
Change in amount of *actual* short-term forest cover loss under policy implementation. Relative change between 1990–1999 and 1999–2009 is calculated as the difference between each study period's *actual* short-term loss values normalized by 1990–1999 values.

	1990–1999			1999–2009			Relative change in actual short-term loss
	90–96 + 96–99	90–99	Actual short-term loss	99–04 + 04–09	99–09	Actual short-term loss	
Diqing Prefecture	4.30%	3.04%	1.26%	3.58%	2.02%	1.56%	23.71%
Deqin County	2.93%	2.16%	0.77%	2.32%	1.19%	1.13%	46.25%
Weixi County	5.75%	3.92%	1.83%	6.01%	3.08%	2.93%	59.46%
Shangri-La County	4.67%	3.33%	1.34%	3.38%	2.17%	1.21%	−8.96%
Township average	4.68%	3.31%	1.37%	4.32%	2.29%	2.03%	75.71%

plantations, they nonetheless offer exceptional carbon sequestration potential and are particularly valuable in mitigating the impacts of climate change (Pan et al., 2011; Xu & Li, 2010). Of China's forests planted under the NFPP between 1998 and 2004, over half of the sequestered carbon was found in upper Yangtze River Basin forests, including those of Diqing (Liu et al., 2008). These impressive domestic results should be assessed in the broader context of China becoming the world's largest timber importer (Laurance, 2008; Liu & Raven, 2010). Just as inter-township leakage was measured in Diqing, so too is leakage manifest at the national-level.

Study limitations

This study is limited for a host of reasons. The lack of Landsat imagery coverage of eastern Diqing Prefecture may have skewed measurements of relative area and spatial variability of forest cover change; a denser temporal distribution of imagery would have aided in detecting shifts in forest cover change pattern immediately before and following policy introduction; and, despite the spatial variability of change, this study did not assess the spatial nonstationarity of error or the spatial variation of classification accuracy (e.g., Comber, Fisher, Brunsdon, & Khmag, 2012). Moreover, this study did not attempt to determine whether forest cover loss resulted from fuelwood or timber harvest or dieback due to insect infestation or fire (e.g., Willson, 2006), whether a harvest was carried out for commercial or subsistence reasons, or quantify the impact of forest cover change on Diqing's ecosystem service provisioning (Fremier et al., 2013; Xu, 2011). Finally, the respective impacts of the NFPP and SLCP and the potential interactions between policy implementations (e.g., Liu et al., 2008) cannot be discriminated in this study, nor can forest cover changes temporally coincident with state forest policy implementation be definitively ascribed to policy implementation.

Conclusions

This study shows the value of adopting a cross spatiotemporal scale approach in evaluating forest policy implementation effectiveness. By having multiple perspectives with which to measure forest cover change, the spatial variability of forest cover change during policy implementation, the persistence of illicit commercial logging and small-scale harvesting, and the spatial redistribution of forest cover change were illuminated. This cross-scale complexity supports a robust interpretation of policy implementation effectiveness and aids in understanding the indirect impacts of tourism development on regional forest cover change patterns. Though tourism is often heralded as the solution to rural development challenges in China's southwest, this research shows the unintended consequences that may result from inconsistent participation at the township-level, consequences which merely redirect, not necessarily reduce, forest use pressures, and that are contrary to the goals of policy implementation. Looking ahead, local institutional capacity for sustainable forest harvesting must be improved in parallel with tourism development lest Diqing's forests dwindle as tourism revenue rises.

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