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Short communication

Forest degradation deepens around and within protected areas in East Asia

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A B S T R A C T

Forest degradation in protected areas has been monitored around the world with remote sensing data, but degradation processes undetectable by widely used satellite sensors have been largely overlooked. Increased human pressures and socioeconomic development make forest protection more challenging, particularly for forest ecosystems that lie across national borders because of the differences in national socioeconomic policies and conditions within them. Here with Landsat data, Google Earth images, and field observations, we show that, in two adjacent biosphere reserves across the border of China and North Korea, over one half of primary forest landscapes have been deteriorated by exploitive uses, including seed harvesting and systematic logging. The combined effects of detectable and hidden degradation processes have further damaged forest ecosystems in the core areas in the two biosphere reserves, threatening sustainable biodiversity conservation in the region. It is urgent to develop cross-border collaborative conservation strategies that can help combat both detectable and hidden degradation processes at a regional scale.

1. Introduction

The management and protection of ecosystems that lie across national borders are more likely to be unbalanced due to the differences in national socioeconomic policies and conditions within them (Smith et al., 2003). Geographically adjacent protected areas should have synergistic effects on biodiversity conservation (Shao and Zhao, 1998; Rodrigues et al., 2004; Franklin and Lindenmayer, 2009; Wiens, 2009). As human population growth accelerates near and far away from protected areas (Wittemyer et al., 2008; Joppa et al., 2009), it is essential to closely monitor the integrity of the remaining intact protected forest landscapes (Mehring and Stoll-Kleemann, 2008). There were extensive studies of forest conservation in protected areas in tropics in the past (e.g., Skole and Tucker, 1993; Bruner et al., 2001; Joppa et al., 2008). For the first time, we systematically assessed the degradation of forests in two adjacent temperate zone biosphere reserves on the highest mountain in the northeastern Eurasian Continent, located along the border of China and North Korea (Stone, 2007).

Known as Changbaishan in Chinese and Baekdu-san in Korean (C/B Mountain hereafter), the area covered consists of contiguous primary forest landscapes and has the highest plant biodiversity in the cool temperate zone (Barnes et al., 1992). Due to an expansive elevation gradient that creates a wide range of climatic conditions, the diversified biomes range from temperate forest (<1100 m) to tundra at high elevations (>2000 m). There are two adjacent biosphere nature reserves with a combined area of 328 465 ha across the China-North Korea border (MAB of UNESCO, 2008) (Fig. 1a). The Changbaishan Biosphere Reserves (CBR) on the Chinese side was designated in 1979, and the Baekdu-san Biosphere Reserve (BBR) of North Korea was established in 1989 (MAB of UNESCO, 2008). The two biosphere reserves were designed to protect contiguous forest ecosystems on C/B Mountain as these forests are habitat for many wildlife species, such as the endangered Siberian tiger (*Panthera tigris altaica*). While there are no human residents living inside CBR, tens of thousands of people live inside BBR (MAB of UNESCO, 2008). Under the biosphere reserve program, the core area of a reserve is afforded a higher degree of legal protection by the participating country and serves as focal point for the conservation of biodiversity.

Recommendations have been made to develop cross-border protected areas between Far East Russia and northeast China (Marcot et al., 1997). The East Asian Steering Committee of the World Commission on Protected Areas has recently developed a conception plan for the establishment of a Baekdu-Daegan

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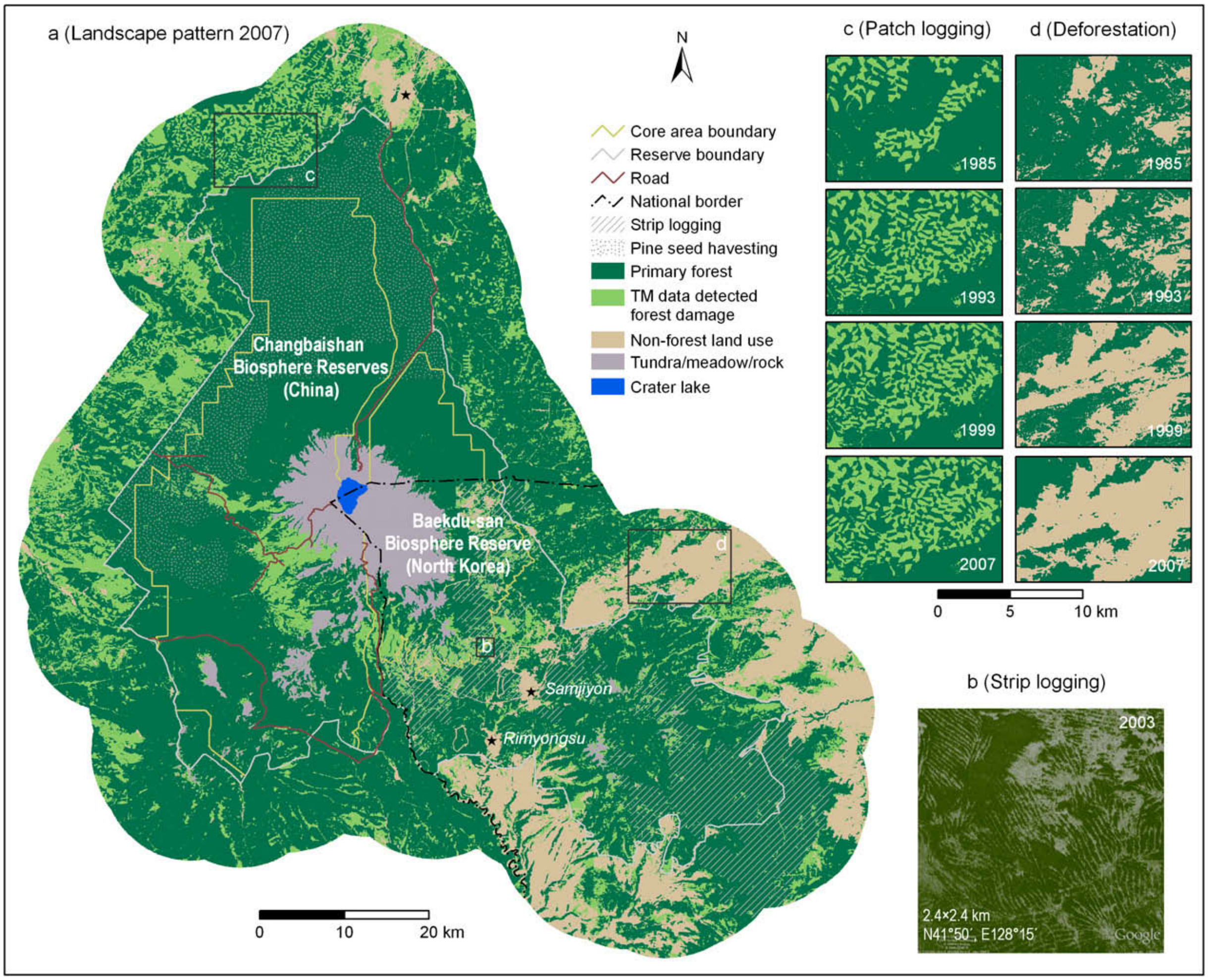

Fig. 1. Forest degradation has intensified over time and across space on C/B Mountain: (a) forest landscapes were degraded inside and outside the biosphere reserves by various human activities; (b) primary forests were structurally altered by widespread strip logging on the Korean side; (c) primary forests were fragmented by intensive patched logging on the Chinese side; (d) deforestation resulted in primary forest loss through conversion to agriculture on the Korean side.

ecological corridor to connect protected areas along the entire Korean Peninsula (MacKinnon, 2007). C/B Mountain forms the natural node of such a proposed corridor. Although cross-border conservation activities are critically important, there is no governmental attention that has been paid specifically to promote cross-border ecological conservation on C/B Mountain between China and North Korea.

2. Materials and methods

2.1. Remote sensing methods

In order to map primary forest distributions in the two biosphere reserves and their surrounding areas, 30-m-resolution Landsat TM data in 1985, 1993, 1999, and 2007 were used for the two nature reserves and a 10-km buffer around each of them. We performed the ISODATA unsupervised classifications to obtain four classification results using 40, 50, 60, and 70 spectral classes, respectively, and recoded the spectral classes into two information classes: primary forest and non-forest. For the 1985 classifications, we identified primary forest by referring to the 1987 forest cover data by the method from Shao et al. (1996) and Shao and Zhao (1998). We merged secondary and damaged forests into the non-forest class. We derived a single forest cover map from the four thematic maps by performing spatial overlay and the majority rule: if agreement of the four maps is $\geqslant$75%, the output map will received the majority value; if agreement is 50%, the pixel value will equal to its adjacent pixel value. The integration of multiple unsupervised classifications is intended to optimize the spectral discrimination power of the data (Lang et al., 2008). For the 1993 data, we classified newly cleared and damaged forestlands between 1985 and 1993 as non-forest and combined undamaged primary forest and restored forest into the forest class. Following the same procedure, we created the 1999 and 2007 forest cover maps. We extracted primary forest in 1993, 1999, or 2007 by overlaying the forest cover map in 1993, 1999, or 2007 with the map(s) from the previous mapping year(s).

We identified the locations of disturbed forest, including forestland altered by human and natural disturbances, and non-forest land use, including "permanently" damaged forestland from 1985 to 2007. We obtained unchanged non-forest areas by overlaying the four temporal forest cover maps. If a non-forest polygon in 2007 contained the unchanged non-forest pixels, it would belong to the category of non-forest land use. We delineated the crater lake and tundra/meadow/rock out of the non-forest land use by referring to the elevation data.

We randomly selected 30 1×1 km^2 areas within the strip logging polygons delineated based on the high-resolution imagery from Google Earth (earth.google.com). We created 100 random points within the sample area and superimposed the 100 circular dots over each sampled image. We counted the number of points that were located in the logged strips for each sample area. We then computed the mean and standard deviation of logging intensity.

2.2. Field methods

At each harvesting season, we randomly selected 100 Korean pine trees ⩾30 cm in DBH from forests where pine seed harvesting took place in CBR and recorded seed production from each sample tree within the pine seed harvesting area. We then estimated the average seed production by each pine tree. The total pine seed yield within the reserve was then computed by multiplying the average seed production per pine tree with the total number of pine trees (1.1 million pine trees with DBH of 30 cm or above). The per-pine seed production estimation had to be convincing because it was used by the reserve administration to charge the seed collectors each year.

3. Results and discussion

The area of primary forest declined both inside and outside the biosphere reserves (Fig. 1). Although the two biosphere reserves contain similar forest ecosystems and their purposes were both to protect the contiguous forest systems on C/B Mountain, there were fundamental differences in the forest degradation processes between the two protected areas on either side of the national border.

3.1. Forest degradation on the Chinese side

CBR is a national-level nature reserve in China, and logging is strictly prohibited within the reserve, including the buffer and transition zones defined under the biosphere reserve system. The forest reduction inside CBR was mainly a result of wind damage on the west and south-facing slopes in 1987 (Shao et al., 1996) (Fig. 1a). The damaged forest area in the western slope has regrown into forest, but the damaged forests in the southern slope were further damaged by wind in later years and have remained non-forested. The loss of primary forest inside CBR was only 6% in total between 1985 and 2007.

Although logging was prevented within CBR, poaching was difficult to prevent, similar to protected areas in the tropics (Bruner et al., 2001). Some medicinal plant species, such as *Panax ginseng*, have disappeared from CBR (Bai et al., 2008). The border of CBR extends to lower elevations on northern and western slopes where the cool temperate mixed forest dominated by Korean pine (*Pinus korainsis*) occurs. The mixed forest is ecologically and economically important in northeast China, the Korean Peninsula, and Far East Russia but has suffered excessive exploitation for decades (Shao and Zhao, 1998). The seeds of Korean pine are an important food source for at least 22 species of forest wildlife, including the Eurasian red squirrel (*Sciurus vulgaris*) and spotted nutcracker (*Nucifraga caryocatactes*) which are key seed predators for Korean pine (Hutchins et al., 1996). The pine seeds are also highly desired in food markets and have become an important source of revenue for local communities. Harvesting pine seeds within CBR was prohibited until 2000. Our field data between 2000 and 2006 show that pine seed yields were high in the first 2 years but declined tremendously in the following years (Fig. 2). Nearly all pine seeds were removed from the forests, and every mature pine tree trunk was wounded by climbing spurs and lost twigs/branches. Although pine seed harvesting inside CBR was banned in 2007, the sharp decline in pine seed yield suggests a possible decline in the health of damaged pine trees. The pine seed harvesting area accounted for 47% of primary forest area in CBR and 43% of primary forest in the core area (Fig. 1a). The intensive pine seed harvesting may have contributed to population declines in Korean pine within CBR (Bai et al., 2008).

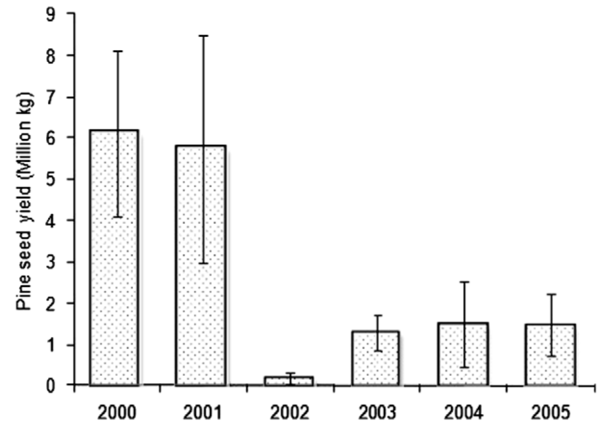

Fig. 2. Pine seed yield declined over time after destructive pine seed harvesting.

Extensive clearcutting and deforestation outside CBR make the boundaries of reserve easily distinguishable from their surroundings (Fig. 1a). The CBR is surrounded by state-owned forest industries. Excessive logging near CBR did not begin until the 1980s. The patch logging patterns result from a government regulation called small-area clearcutting, which restricts the size of harvests up to 15 ha (Shao and Zhao, 1998). The size of actual harvests ranged from 5 to 20 ha. Although the logging patch size met or was close to the governmental requirement, the remaining small fraction of primary forest was highly fragmented after continuous small-area clearcutting within an area (Fig. 1c). The logged primary forests were replaced mainly with secondary birch (*Betula platyphylla*)-aspen (*Populus davidiana*) forests, which are simpler in composition and structure than the primary forests (Shao et al., 1994).

3.2. Forest degradation on the Korean side

The primary forests in North Korean were extensively harvested with long and thin logging strips (Fig. 1b). We estimated that by 2007, 50% of the total primary forest area within BBR and 75% of primary forest landscape in the core area of BBR had been logged (Fig. 1a). The average logging intensity across all logged areas was 23.8 ± 7.0%. The width of logging strips was about 10 m, much smaller than a 30 m pixel size of Landsat TM data. Such logging is mostly undetectable by the Landsat and similar resolution satellites (Asner et al., 2005). In our study, we were only able to detect high-intensity large-scale logging with Landsat TM data. The strip logging directly altered the properties of the primary forest because it created numerous artificially shaped canopy gaps that greatly increased forest edges within BBR.

Primary forests outside BBR were cleared mainly for farming, resulting in the constant expansion of non-forest areas over time on the North Korean side (Fig. 1d). Approximately, 39% of primary forests were lost between 1985 and 2007 (1.8% per year) in the buffer surrounding BBR, equivalent to the 1.9% deforestation rate across the entire country from 1990 to 2005 (FAO, 2009). North Korea's long-term food shortage has resulted in continued logging and conversion of forestland into cropland (Bhatia and Thome-Lyman, 2002; Zheng et al., 1997).

3.3. Implications of "unseen" forest degradation

Using the Landsat satellite data alone, the primary forest cover was determined to be 85% in CBR and 69% in BBR in 2007. Such remotely sensed primary forests could contain forests that were damaged by degradation processes hidden from Landsat satellite imagery. Pine nut harvesting on the Chinese side and strip logging on the Korean side could not be detected with Landsat TM data, and forest damage induced by those two types of disturbance was included in the remotely sensed primary forests above. By subtracting those damaged primary forests from the total primary forests, the truly well-protected primary forest covered only 44.9% of the reserve area in CBR and 34.6% in BBR. In other words, about one half of the remaining primary forest landscapes have been deteriorated from the exploitive uses of primary forests within the biosphere reserves.

The crater-formed lake (locally called Heaven Lake) on the mountain top is among the most scenic locations in East Asia. Tourists visit the lake from both China and North Korea. Tourism on the Chinese side has accelerated from around 30,000 visitors in early 1980s to nearly a million in 2007/2008. The sharp increase in visitation started in 2006 after the administrative supervision of CBR was shifted from the Forestry Bureau to the Tourism Bureau of Jilin Province. Since then, tourism development has become the most important mission within CBR. The Tourism Bureau built an airport on the western slope and opened up all the three roads within CBR for transporting tourists in 2007 (Fig. 1a). The tourism season is concentrated in only 2–3 summer months and as many as 10,000 tourists per day visited CBR during the summer of 2008. The number of tourists on the Korean side was 200,000 in 2001 (MAB of UNESCO, 2008), more than half the number of tourist visits on the Chinese side during the same year. The increased tourism can have positive and/or negative impacts on forest conservation depending on how the tourism is managed (Buckley, 2004; Yuan et al., 2008).

All these findings support that the two biosphere reserves have become structurally and functionally more isolated as logging and deforestation continued on either side of the boundary between China and North Korea. This indicates that staff and personnel of various government conservation agencies did not have the required capacity and vision to implement international protocols and treaties (McNeely, 2009). Different conservation and land-use policies and lack of cooperation between the two nature reserves and exploitive uses of primary forests in each reserve have defeated the goal of biosphere reserves, resulting in worsened forest degradation at the mountain scale. By integrating both visible and invisible forest degradation processes through combined two-resolution remote sensing and field observations, it was revealed that both reserves have become highly isolated and their truly protected areas have become rather small. The increasing rate of exploitive uses of forest resources around and within these reserves poses an alarming threat to sustainable biodiversity conservation in these protected areas and East Eurasian Continent.

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