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# Unintended Side Effects of Conservation: A Case Study of Changing Land Use in Jiuzhaigou, Sichuan, China

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*Toward the goals of returning the landscape of Jiuzhaigou National Nature Reserve to a perceived "natural" state and protecting the environment, the Reserve in 1998–2002 implemented forest preservation policies that included restrictions on forestry, agriculture, and animal herding practiced by resident Tibetans. To document the effects of these land use changes on landscape diversity and on human vulnerability to natural hazards, we mapped and characterized topographic parameters of anthropogenic treeless areas from 1973, 2004, and 2013 satellite images. Results showed that, in addition to a previously documented overall loss of cleared land, the distribution of treeless area elevation, aspect, and slope has changed. In 1973, treeless areas were distributed approximately uniformly across all elevations and a wide range of slopes, but now they are concentrated on relatively flat slopes in the valley bottoms (~2400 m) and high, subalpine elevations (~3800 m). These changes are decreasing the topographic diversity of landscapes people use and likely also decreasing the biodiversity of the Reserve, where plant communities are highly stratified based on both elevation and aspect. In addition, many 1973 treeless areas were located on deep-seated landslides, while many 2004 and 2013 treeless areas were located on landslide deposits and alluvial fans, suggesting that relocation may not be reducing the risk of natural hazards for residents. These effects combine with the previously documented decline in overall area of montane meadows and associated losses to cultural heritage, ecosystem services, and biodiversity.*

***Keywords:*** *Jiuzhaigou National Nature Reserve; Returning Farmland to Forest; biodiversity; Sichuan; China; Tibet; environmental hazards.*

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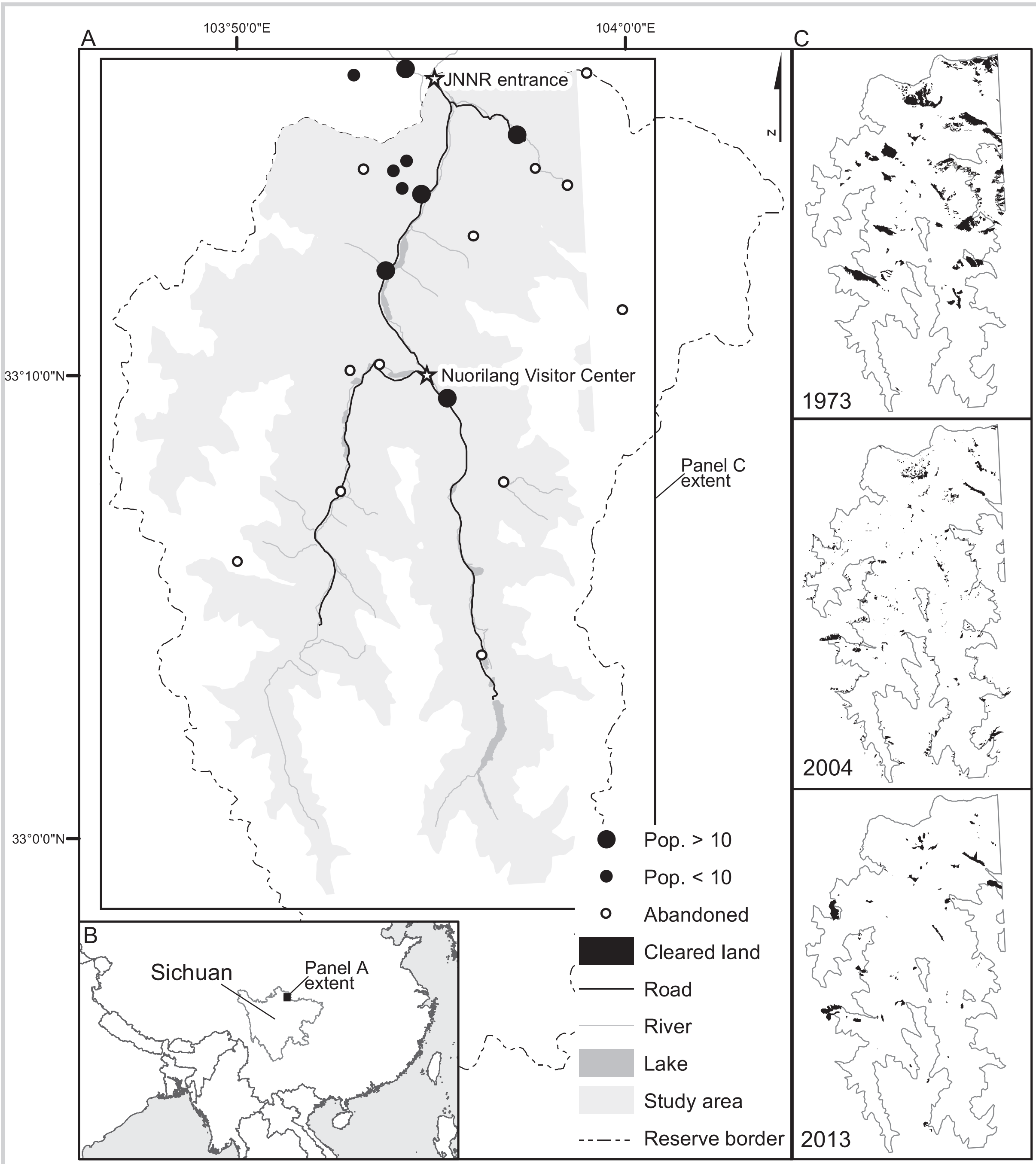
## Introduction

In China, 2 national programs, the Restoring Farmland to Forest Program (also known as Grain for Green or the Sloping Land Conversion Program) and the Natural Forest Protection Program—which were designed to reduce erosion by converting agricultural land to forest, banning logging in natural forests, and reforesting logged areas—indirectly changed land use patterns in mountainous areas (Trac et al 2007, 2013; Urgenson et al 2014; Harrell et al 2016). We mapped changes to settlement patterns and the topographic characteristics of areas historically maintained as treeless meadows in Jiuzhaigou National Nature Reserve (JNNR), northern Sichuan Province (Figure 1), to show how changes to land cover and land use have adversely affected landscape biodiversity and may have increased exposure to landslide hazards.

After widespread flooding in 1998 that was perceived by the Chinese government to be the result of erosion caused by extensive deforestation (Winkler 1999), the government implemented these reforestation programs to reduce erosion (Shapiro 2001; Hyde et al 2003; Trac et al 2007). Case studies in Sichuan suggest that these programs are not as successful at increasing forest cover as government officials claim (Trac et al 2007, Trac et al 2013), though success varies widely depending on location, and JNNR is among the more successful reforestation areas (Trac et al 2013). However, in JNNR, where documented human habitation dates to at least 2100 years BP (Taylor et al 2008; Henck et al 2010; Lu et al 2010; Urgenson et al 2014; d'Alpoim Guedes et al 2015), these afforestation policies resulted in a 70% decrease in meadowland from 1973 to 2004, which has led to a decrease in biodiversity through declining numbers of meadow species, loss of ecosystem services such as access

**FIGURE 1** The study area. (A) location in Jiuzhaigou National Nature Reserve; (B) location within Sichuan Province and East Asia; (C) land cleared in 1973, 2004, and 2013. Note that the study area does not entirely encompass Jiuzhaigou National Nature Reserve because of the extent of the satellite images analyzed and the elevation range studied (below treeline). We use “study area” and Jiuzhaigou National Nature Reserve interchangeably. (Map by Amanda Schmidt)




to traditionally important plants, and loss of cultural heritage for JNNR residents (Urgenson et al 2014; Harrell et al 2016). Similarly, in northern Yunnan Province, bans on logging resulted in 40% of alpine meadows converted to woody shrubland between 1990 and 2006, significantly reducing biodiversity in the region (Brandt et al 2013).

In JNNR, most village sites are in or near meadows, and ethnographic and ecological evidence suggests that treeless areas below the 3800 m tree line are anthropogenic in origin (Winkler 1998a; Henck et al 2010; Urgenson et al 2014). Most meadows in mountainous regions of Sichuan are on south-facing slopes. Early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investigators interpreted these as natural meadows (Rock 1930; Hanson-Lowe 1940; Ku and Cheo 1941); however, more recent ecological evidence suggests that south-facing slopes in western and northern Sichuan can support trees but remain treeless due to human activity (Winkler 1998a). Regionally, this human influence may have begun in the mid-Holocene; paleoecological studies in southern Tibet attribute late Holocene forest loss to human activity (Kaiser et al 2009).

In southern Tibet, where large areas were previously forested, the role of humans in deforestation is less clear (Kaiser et al 2007; Miehe et al 2008). However, the presence of indicators of pastoralism, including plants commonly eaten by grazing animals, in sediment cores suggests a strong temporal coincidence between forest loss and human migration to northern Tibet (Miehe et al 2009); evidence for this coincident timing has also been found in Nepal (Byers 2005). Nearer to JNNR, palynological evidence in the Hengduan Mountains implicates human populations rather than climatic changes in bringing about rapid shifts in treeline elevation around 3400 years ago (Kramer et al 2010). Because treeless slopes and changes in treeline are attributed to human activity elsewhere in the region, below-treeline meadows in JNNR are likely anthropogenic in origin; archaeological evidence, including pottery, seeds, and animal bones, suggests that 2100 years ago people occupied sites and had land use habits similar to those of Tibetan residents of JNNR prior to 1998 (Taylor et al 2008; Henck et al 2010; Lu et al 2010; Urgenson et al 2014; d'Alpoim Guedes et al 2015). The montane meadows in JNNR are particularly rich in ecosystem services and provide biodiversity (Urgenson et al 2014) and cultural value to the landscape (Harrell et al 2016).

In western Sichuan in general, and JNNR in particular, vegetation patterns are strongly dependent on both elevation and slope aspect (Winkler 1998b). Lower elevations are characterized by montane mixed forests on all aspects, but above 2200 m, moisture differences on north and south slopes result in different characteristic forests (Winkler 1998b). Hemlock and spruce–fir forests dominate between 2200 and 2700 m on north-facing slopes, while south-facing slopes have pine–oak and pine–spruce forests, although south-facing slopes at these elevations were historically cleared and used for agriculture (Winkler 1998b). Due to moisture from fog, between 2700 and 3200 m all slopes are characterized by bamboo–spruce–fir forests, though sunny (south-facing) slopes historically were cultivated or used for pasture (Winkler 1998b). At higher elevations, rhododendron–fir forests grow on north-facing slopes, and spruce and juniper grow on south-facing slopes; but historically, few south-facing slopes above 3000 m were forested due to human intervention, including burning once-forested areas to keep them tree and shrub free (Winkler 1998b), which was happening in JNNR as early as 2100 years ago (Taylor et al 2008; Henck et al 2010; Lu et al 2010; Urgenson et al 2014). Vegetation surveys of 2 JNNR meadows found at least 92 species of plants, 46% of which are either commonly used or culturally important (Urgenson et al 2014). However, Urgenson et al (2014) found that meadow area has been declining in JNNR since 1973 due to both natural succession and active reforestation.

Prior work in JNNR found that afforestation policies decreased the area of meadows (Urgenson et al 2014). We hypothesized that changing patterns of land use also changed the distribution of treeless areas with respect to elevation, slope, aspect, and risk of natural disasters such as landslides and debris flows. We tested this hypothesis by comparing the elevation, aspect, and slope distributions of treeless areas mapped from satellite imagery taken prior to Reserve formation (1973), immediately following bans on forestry, agriculture, and animal husbandry (2004), and a decade after the bans were implemented (2013).

We also hypothesized that recent relocation may have altered human exposure to natural hazards. To quantify this potential, we mapped the geologic materials underlying treeless areas in the study site and conducted field surveys of possible hazards around those areas.

## Study site

JNNR (33°13′N, 103°55′E), a World Heritage Site in the Minshan Mountains (Figure 1), encompasses a 640 $km^2$ watershed ranging in elevation from 1996 to 4764 m. It is famous for crystal-clear lakes formed behind tufa deposits on the main valley floors (Yamashita 2009). Bedrock geology of the Reserve is primarily limestone, mudstone, siltstone, and sandstone (Guo et al 2006). Quaternary deposits, primarily in and near valley bottoms, include alluvium, tufa, collapse deposits, landslide deposits, lake sediments, moraines, loess, alluvial fans, and colluvium (Figure 2D). Faulting is extensive in the Reserve; fault activity is constrained to 2 periods: 14 million years ago and 213,000–253,000 years ago (Guo et al 2006). JNNR is near the 2008 Wenchuan Earthquake zone; although damage from the earthquake itself was minimal, residents and JNNR staff reported to us that they have observed an increase in landslides since that time.

More than 1100 Amdo Tibetans still live in JNNR, but access by the 2–5 million annual tourists is restricted to valley bottoms and daytime hours (Gu et al 2013). Prior to Reserve development, the local population lived in small, mid-elevation villages in the northern part of what is now JNNR and subsisted on farming and raising sheep, goats, horses, and yaks; forest products were used for fuel and house construction (Urgenson et al 2014). To promote environmental conservation and allow the landscape to return to perceived natural conditions, the JNNR administration banned forestry, farming, and animal


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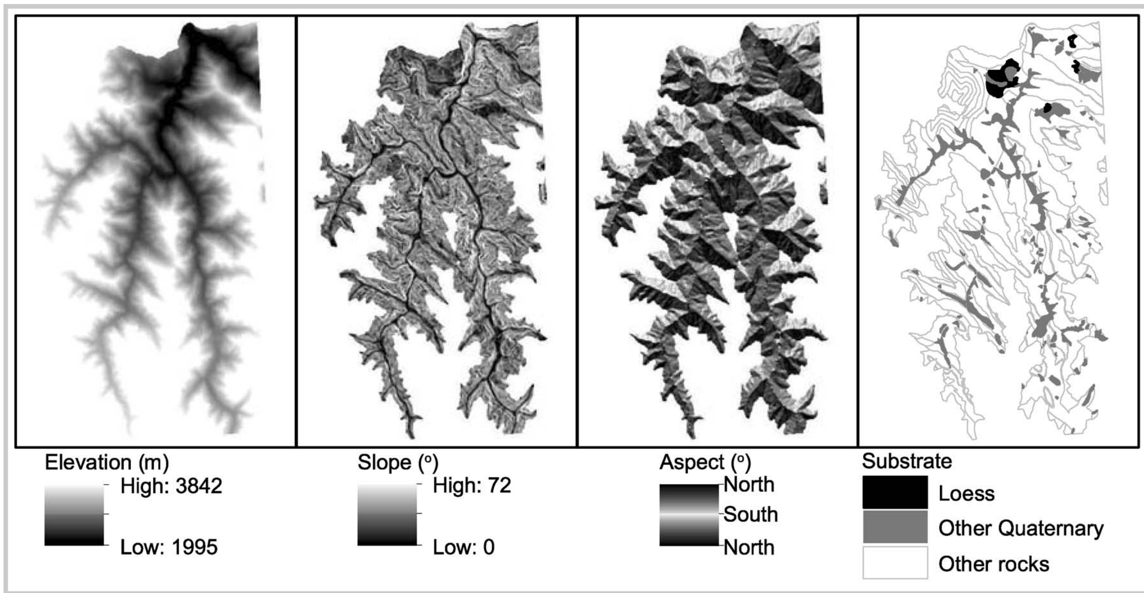
**FIGURE 2** Environmental parameters for the study area. From left to right, study area elevation, slope, aspect, and substrate.




husbandry starting in 1998–2002 (Urgenson et al 2014). To compensate for the loss of income resulting from these restrictions, the JNNR administration shares profits from park operations with residents. Residents now subsist on dividends from sales of Reserve tickets and food at the main visitor center and income from selling souvenirs, water, and photographs to visitors; some residents are also employed by the JNNR Administrative Bureau (Gu et al 2013).

As income sources changed, many residents relocated from mid-mountain to valley-bottom villages. Current management policies provide financial incentives for villagers to relocate outside JNNR, but, as in Sichuan's Wolong Nature Reserve (Xu et al 2006), few residents are moving outside the Reserve, where they would lose the income from both dividends and souvenir sales. The increased income associated with JNNR dividends and sales to tourists has resulted in rapid modernization of JNNR villages, primarily through the building of homes with running water and electricity located closer to roads. Older homes in traditional locations were less likely to be renovated than abandoned as families moved closer to roads and access to new jobs, although some families occupy older homes in the winter (tourist off-season) because the locations are sunnier and warmer. Local people consider the treeless areas, both meadows and farmland, to be important cultural resources that are fundamental parts of their landscape (Urgenson et al 2014; Harrell et al 2016).

## Modeling landscape characteristics

In order to understand how distribution of treeless areas has changed over time, we analyzed the distribution of treeless areas for 3 periods—before Reserve development (1973), immediately after the forestry, farming, and grazing bans (2004), and a decade after the bans went into effect (2013). We defined treeless areas as places without visible forest cover on satellite images, including pasture, agricultural, and developed areas; we identified rocky areas in order not to map them as treeless areas, as we wanted to reserve the category "treeless" for areas people likely cleared. For 1973 and 2004 treeless areas, we used the datasets described by Urgenson et al (2014): treeless areas mapped from KH-9 and Quickbird satellite images taken on 31 December 1973 and 27 November 2004, respectively. We mapped 2013 treeless areas using a Google Earth image taken on 12 August 2013. It is possible that treeless areas were under-mapped in 2013 because of the late summer (after leaf-out) timing of the satellite image, but forests in JNNR are predominately conifer (Winkler 1998a), so this bias was likely to have been minimal. Our study site encompassed 328 $km^2$ of land below 3800 m elevation located within JNNR and visible in all 3 satellite images. In July 2011, we examined mapped treeless areas from 1973 and 2004 for evidence of prior human land use (such as stone walls or remains of houses) and potential for natural hazards.

To characterize the topographic and geologic characteristics of treeless areas, we mapped elevation, slope, aspect, and underlying geological materials following methods described by Henck et al (2010). We calculated slope and aspect using the 1 arc-second ($\sim$30 m) resolution Advanced Spaceborne Thermal Emission and Reflection (ASTER) Global Digital Elevation Model (GDEM) (NASA 2009). For each period, we converted treeless area polygons into raster datasets with the same cell size as the GDEM. We used ArcGIS to determine the


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**TABLE 1** Summary of environmental parameters of the entire study area and land cleared in each period.

| Parameter | Entire study area | 1973 clearings | 2004 clearings | 2013 clearings |
|---|---|---|---|---|
| Area ($km^2$) | 328.11 | 20.97 | 6.38 | 4.97 |
| Elevation (m)[a)] | 3406 | 3184 | 2393, 3647 | 2355, 3647 |
| Mode aspect (degrees) | 57.6 | 187.2 | 165.6 | 158.4 |
| Median slope (degrees) | 32.99 | 33.02 | 27.68 | 22.30 |
| Median June sunlight (hours) | 323.02 | 327.36 | 331.15 | 339.29 |
| Median December sunlight (hours) | 176.31 | 228.50 | 223.56 | 215.59 |

[a)]Median reported for entire study area and 1973, mode for each peak reported for 2004 and 2013.

elevation, slope, and aspect for each pixel of treeless area during each period.

We then used a Monte Carlo simulation to determine whether the parameters for each period were a random subset of the aspect, slope, and elevation for the entire study area. There were 23,869, 7405, and 3631 pixels of data for 1973, 2004, and 2013 cleared areas, respectively, and 372,515 pixels of data for the entire study area. For each period, we ran a Monte Carlo simulation 1000 times, which generated a random list of numbers as long as the number of pixels for that period (eg 23,869 pixels for 1973) from a uniform distribution between 0 and 372,515 (the number of pixels of data for the entire study area). We used this list to generate 1000 possible random samples of pixels. For each parameter at each period we then generated the probability density function for the actual cleared land and the Monte Carlo results. If the treeless area distribution for the parameter was contained within the Monte Carlo results, the treeless areas for that period were considered a random selection of sites at that time. If the probability density function for the treeless areas at that time was different from the Monte Carlo results, the treeless areas were not considered a random selection of points from the study area. We used a Wilcoxon rank sum test to determine whether treeless areas for each period were statistically distinct for each parameter.

We determined geologic materials from the JNNR geologic map (Guo et al 2006) and field observations made in summer 2010 and 2011. The Monte Carlo experiments were conducted similarly except that instead of producing probability density functions, we produced bar plots showing the range of results for the Monte Carlo simulation compared to the distribution for clearings at each period.

## Characteristics of treeless areas

In 1973, Jiuzhaigou treeless areas occupied 6.4% of the study area (20.97 $km^2$), were evenly distributed across elevations, had southerly aspects (mode of 187° compared to 58° for the study area), and had a distribution of slopes that was indistinguishable from that of the JNNR as a whole (median 33°; Table 1; Figure 3). These treeless areas were disproportionately on loess and landslide deposits compared to the distribution of geologic units in JNNR as a whole (Figure 4). Field evidence suggested that the landslide deposits are deep-seated landslide complexes, some of which are still active. For example, in a valley with extensive 1973 treeless areas, portions of a road completed in 2005 could not be used in 2011 because of downhill slope movement of parts of the road surface (Figure 5).

By 2004, Jiuzhaigou treeless areas occupied 1.9% of the study area (6.38 $km^2$), were bimodally distributed around low (mode 2393 m) and high (mode 3647 m) elevations, were on slopes generally less steep than average (median 27°), and had southerly aspects (mode 166°). Treeless areas tended to be on surficial deposits, especially loess; in addition, landslide deposits, alluvial fans, and alluvium more frequently underlay 2004 treeless areas than landslide deposits, alluvial fans, and alluvium underlay Quaternary deposits in JNNR as a whole. Field surveys indicated that many of these 2004 treeless areas were located on the deep-seated landslides associated with the 1973 treeless areas. In addition, although it is not clear whether all of the landslides and alluvial fans were still active, some of the newer treeless areas also had debris dams and other mass-wasting control structures built to protect houses.

In 2013, treeless areas in JNNR occupied only 1.5% of the study area (4.97 $km^2$). The bimodal distribution of elevations seen in 2004 data persisted (peaks with modes of 2355 m and 3647 m). Median slopes became lower (median 22.3°), and aspects, while generally southerly (mode 158°), were less dominantly south-facing. Treeless areas still tended to be on surficial deposits; loess, landslide deposits, alluvial fans, and alluvium all frequently underlay treeless areas.

## Changes in the distribution of treeless areas

Although the location of some treeless areas changed over the study period, some areas remained treeless. Of the


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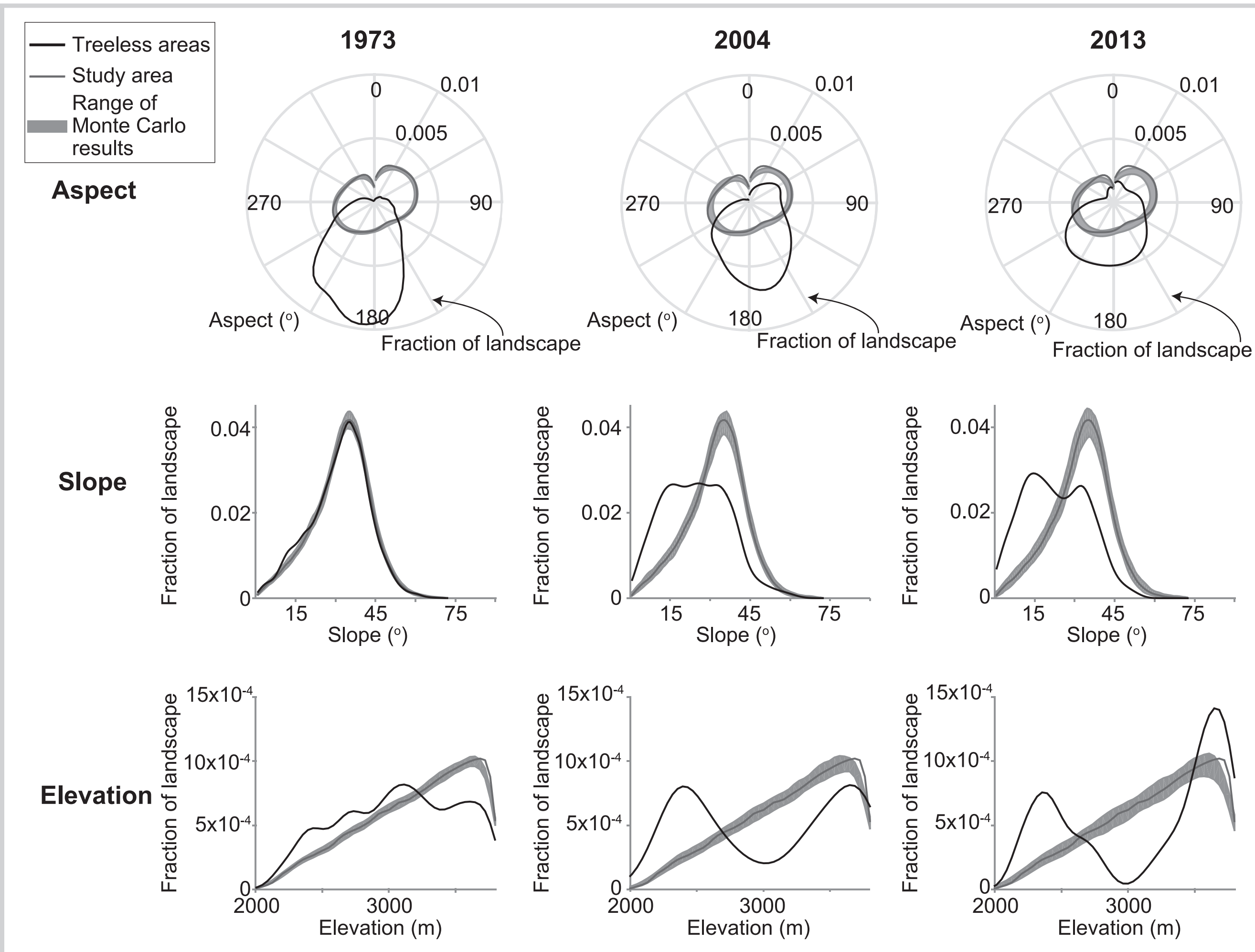
**FIGURE 3** Monte Carlo simulation results; distribution of topographic parameters for the entire study area and of environmental parameters for land cleared during 1973, 2004, and 2013. From left to right, data from 1973, 2004, and 2013. From top to bottom, aspect, slope, and elevation data.




20.97 km$^2$ of treeless areas in 1973, 1.16 km$^2$ (5.5%) were treeless in both 2004 and 2013 (18.2% and 23.3% of the 2004 and 2013 treeless areas, respectively). We found that 2.42 km$^2$ of the 1973 treeless areas (11.5%) were still treeless in 2004 (38.0% of these areas), and 2.07 km$^2$ of 2004 sites (32.4%) were still treeless in 2013 (41.6% of these sites). As previously described, when not maintained, treeless areas in the region revegetate naturally with shrubs or are reforested by local residents (Trac et al 2013; Urgenson et al 2014; Harrell et al 2016).

Many 2013 treeless areas were in different topographic and geologic settings than the 2004 treeless areas and had been newly cleared since 1993; this was confirmed with statistical tests of differences between the distributions of parameters for treeless areas at each period. The distributions of elevation and slope for treeless areas at each period were distinct from each other (Wilcoxon rank sum test $P < 0.005$; Table 2). However, although the distribution of aspects for the 1973 treeless areas was statistically distinct from that for the 2004 and 2013 areas ($P < 0.005$), the distributions of aspects for the latter 2 areas were statistically indistinguishable ($P = 0.43$).

The transition from a uniform to bimodal distribution of elevations was due to preferential loss of treeless areas at mid-elevations, although the few treeless areas added in 2013 were at high and low elevations. One possible explanation is that because JNNR is a protected watershed, but is unfenced, people herding animals outside JNNR could have been using high-elevation treeless areas to graze their animals, thus reducing forest growth at those elevations. Field observations and satellite images suggested that recently cleared treeless areas at low elevations were for village or tourist-related land uses. Satellite images suggested that at high elevations, new treeless areas were a result of either landslides or anthropogenic clearing.

Over time, the average slope of treeless areas has decreased. It was indistinguishable from the distribution of slopes in JNNR as a whole in 1973 and became increasingly negatively skewed over time (Figure 3). This is


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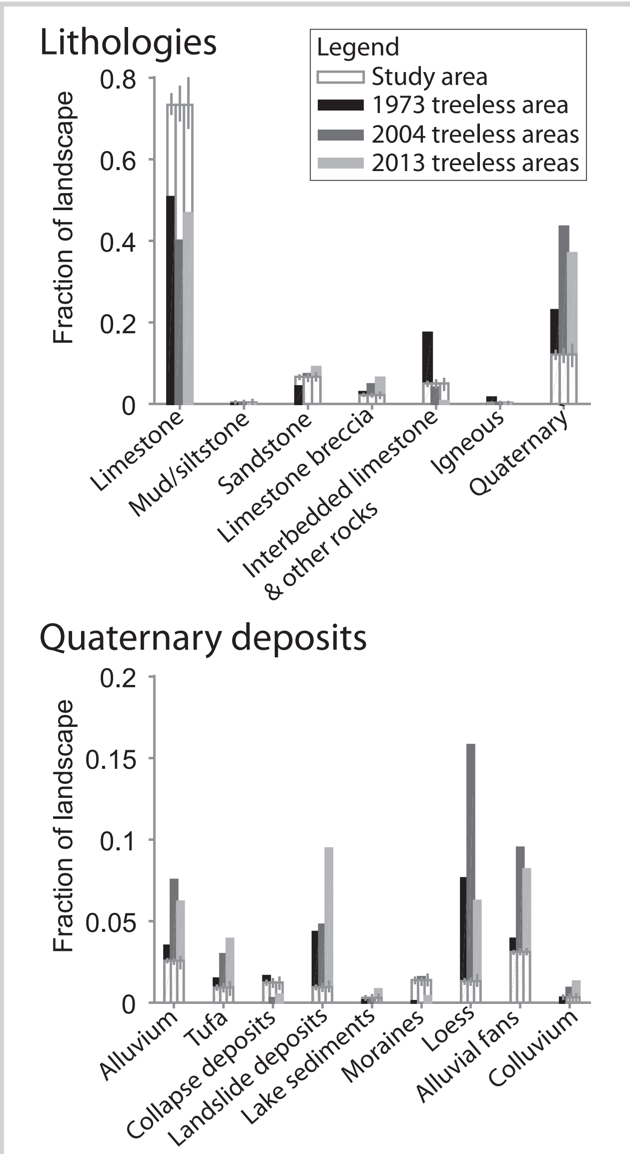
**FIGURE 4** Distribution of lithologies and Quaternary deposits for the entire study area and for land cleared in each period. Error bars on study area data show the range of possible values from the Monte Carlo simulation results.




likely related to the increase in frequency of treeless areas at low elevations; valley bottoms in JNNR tended to be low-angle slopes (<10°).

Throughout Sichuan, forest composition is strongly controlled by elevation (Tang and Ohsawa 1997; Winkler 1998b; Shen et al 2003). Meadow composition likely varies as well; there is some evidence for this from prior work in Jiuzhaigou (Urgenson et al 2014). Urgenson et al (2014) conducted plot surveys at 2 meadows (elevations 2290 m and 2570 m) in 2007 and found a total of 92 meadow species, with 57 at one meadow and 58 at the other. Thus, only 23 species were present in both meadows, even though they were only separated by 280 m in elevation. We speculate that beyond the overall loss of biodiversity due to decreasing areas of meadows that has previously been reported (Urgenson et al 2014; Harrell et al 2016), the preferential loss of meadows at particular elevations may result in an additional loss of biodiversity because of the elevational gradients in vegetation in the region.

Known archaeological sites in JNNR are all located in loess deposits, and ethnographic work suggests that loess soils are considered to be the best for farming (Guo et al 2006; Henck et al 2010; Urgenson et al 2014). Our data confirmed that loess commonly underlay treeless areas at all periods, and that as much as 36.9% of the loess deposits in the study area were underneath treeless areas. In all 3 periods, loess was a more common underlying soil in treeless areas than in JNNR as a whole (Figure 4).

It is unclear whether people sought out sunny (south-facing), low-angle slopes to build houses on, loess soils to farm, or places that had both of these desirable characteristics. Most JNNR loess was at mid-elevation (mean 2555.74 m, standard deviation 137 m), with a low slope angle (mean 20.97°, standard deviation 7.65°), and south facing (mode 173°), which are characteristics similar to the treeless areas. In contrast, JNNR in general has higher elevations (mean = 3300 m), steep slopes (mean = 30°), and a uniform distribution of aspects. Therefore, we wonder why loess was primarily located on south-facing low-angle slopes at moderate elevations.

The distribution of loess in JNNR suggests a possible relationship between loess deposits and natural hazards. Although the loess in JNNR has not well been described and the source is unclear, it likely came from the west or northwest (Derbyshire et al 1998; Yang, Fang, Shi, et al 2010; Yang, Fang, Yan, et al 2010). If this is true, then given the large scale of the topographic barriers (ie ridges), the conceptual model of loess deposition on the windward side of topographic barriers (Goossens 1988; Pye 1995) suggests that the loess should have been the thickest on northwest and/or west faces, near the bottom of slopes. However, although we saw loess on slopes of all aspects of our study area, it was most common on south-facing slopes. We suggest that loess was disproportionately eroded off other slopes because they were too steep (Vreeken 1975; Mason and Knox 1997) or otherwise more prone to mass wasting. Because we observed loess on slopes that are sunnier in addition to being less steep, we assumed that it was more stable on sunnier, drier (southerly) slopes than on wetter slopes. However, the reasons for loess distribution in JNNR still need to be explored.

Similarly, many treeless areas were colocated with hillslope terraces, which were also colocated with loess deposits. JNNR hillslope terraces have previously been described as forming as a result of local agricultural practices (Henck et al 2010), but recent field surveys suggested the terraces could reflect a more complex causality that combines natural slope instability and destabilizing effects of human occupation (Schmidt et al


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**FIGURE 5** Photos taken from Jiuzhaigou National Nature Reserve treeless areas at (A) high elevation with yaks in 2011; (B) mid-elevation with historic village sites on a deep-seated landslide in 2010; the road is partly no longer passable near the village in the center of the image because of landslide activity under it; (C) valley bottom in 2006. (Photos by Amanda Schmidt)


2011, 2012; Fiallo et al 2015). Terraces may have been disproportionately located on and largely formed by slumps, earthflows, and mass movement features, and settlements in these locations were thus in danger of mass wasting. The trend we observed toward treeless areas being on landslide deposits and alluvial fans poses a different natural hazard—burial by material moved by upslope mass-wasting processes. It is not clear whether


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**TABLE 2** *P* values from the Wilcoxon rank sum test of statistical difference between distributions of elevation, slope, and aspect at each period. For example, the first column in the first row has the *P* value for the likelihood that the distribution of elevations for treeless areas in 1973 is the same as the distribution of elevations for treeless areas in 2004.

| Parameter | 1973 and 2004 | 1973 and 2013 | 2004 and 2013 |
|---|---|---|---|
| Elevation | $3.93 \times 10^{-320}$* | $4.94 \times 10^{-204}$* | $2.46 \times 10^{-3}$* |
| Aspect | 0* | $1.86 \times 10^{-135}$* | 0.433 |
| Slope | 0* | 0* | $5.62 \times 10^{-105}$* |

*Significant difference at the $P < 0.005$ level.

and how the transition from mid-slope locations with deep-seated landslides to valley-bottom locations on mass-wasting deposits changed the hazard risk for residents, but the type of hazard changed from source areas of deep-seated landslides to being in the runout zone for mass-wasting events. In short, as Hewitt (2010) asked in relation to Pakistan's Nanga Parbat region, do people living in mountainous areas live in hazardous locations, such as landslide deposits, because those are the only places with gentle enough slopes?

## Implications

According to previous studies (Trac et al 2013; Urgenson et al 2014; Harrell et al 2016), the decrease in treeless area in JNNR has led to loss of biodiversity and ecosystem services as well as erosion of cultural heritage. Also of concern, besides the overall loss of area, is the change in distribution of treeless areas—from an approximately uniform distribution across all JNNR elevations to a bimodal distribution concentrated around low and high elevations. The plant and animal communities at different elevations in JNNR are distinct (Winkler 1998b). Concentrating treeless areas in a few elevations rather than spreading them across a broad range may increase the loss of biodiversity beyond that due to loss of meadows. It seems likely that over time treeless areas in JNNR, and the associated ecosystem services (eg Urgenson et al 2014), will continue to decline. The current national-level emphasis on forest ecosystems, and the monoculture implementation of those policies, makes it challenging for land managers to promote ecosystem diversity (eg Trac et al 2013; Urgenson et al 2014; Harrell et al 2016), even if that is the approach they wish to take.

An additional concern is that restricting people's livelihoods to tourism and Reserve-related activities encourages them to move their residences closer to valley bottoms. Field evidence suggests that 1973 treeless areas were often colocated with deep-seated landslide features that appear to still be active, while 2004 and 2013 treeless areas were increasingly on alluvial fans and landslide deposits. The JNNR administration has built mass-wasting control structures—including debris dams, channels to route debris flows, and nets to catch falling rocks—suggesting that mass wasting is still a hazard to these sites. Thus, residents seem to be trading one hazard for another, and relocation may not have reduced their risk. Ultimately the effectiveness of JNNR management's interventions will determine the viability of the new valley-bottom communities.

These 2 consequences of changing land use patterns could be reduced, both in JNNR and in other mountainous areas, with careful management strategies. For example, if loss of meadows in general, and at certain elevations in particular, is a result of restricting local land use practices, then location-specific policies based on historical land use patterns will be more effective than top-down blanket policies. As argued in prior studies in JNNR (Trac et al 2013; Urgenson et al 2014; Harrell et al 2016), we suggest that land managers carefully consider the baseline conditions to which they are trying to restore landscapes. If, as is the case in JNNR, landscapes have been altered by human activity for millennia (eg d'Alpoim Guedes et al 2015), it may not make sense to aim for restoration to a "natural" landscape that does not include people. Likewise, if management policies and changing economic conditions result in people relocating from traditional villages, complete assessments of natural hazards would enable those making relocation decisions to make informed choices about where to situate new developments. As economic development and restoration continue in protected areas, policy-makers can take these 2 lessons from JNNR and consider the baseline conditions they plan to restore to as well as potential hazards associated with resident relocation.

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