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Influence of Human Pressure on Forest Resources and Productivity at Stand and Tree Scales: The Case Study of Yunnan Pine in SW China

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Abstract: This paper examines human impact on stands and individual trees of *Pinus yunnanensis* growing near the small mountain villages of Pianshui and Yangjuan in southwestern Sichuan Province, China. In an effort to assess whether use of these forests was sustainable, we examined the effects of human use in two ways. First, we directly measured the effect of cutting branches, for fuel and fodder, on tree growth. We hypothesized that branch cutting would negatively impact tree growth. We established 12 plots on four hills and compared 14 pairs of trees, one tree in each pair with an apparently full crown and the other with a considerable portion of the crown removed. Second, we assessed stand and tree properties over a 500 m elevation gradient above the villages where we hypothesized that as elevation increases, stand and tree properties should show fewer human impacts. Although extensive branch cutting reduced the live crown, tree height and diameter, compensatory processes likely enabled trees to recover and to add basal area increments (BAIs) similar to those added by trees with full crowns. Trees and stands close to villages showed less growth and lower basal areas, respectively, than stands and trees at intermediate or distant elevations from villages. Areas relatively close to the villages showed considerable effects of human-related disturbances such as branch cutting, grazing, tree and shrub removal, losses of litter, and human and animal trails. Such areas had increased soil erosion and often loss of the 'A' horizon. Stands close to villages had younger trees, lower stand basal areas, smaller basal area increments, and more stumps. Our results suggest an increasingly vulnerable interface between occupants of these two villages and their surrounding forests.

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Keywords: *Pinus yunnanensis*; Tree growth; Stand basal areas; Basal area increment; Ring width

Introduction

Finding the right balance between human activities and the maintenance of both human and ecosystem well-being becomes increasingly problematic at both local and global levels as population, affluence, and the demand for natural resources increase (Corvalan et al. 2005; McMichael 2013). Globally and locally, the harvesting of forests for commercial use on public lands, the active management of forests, such as the use of fire or its suppression, or the cutting of trees and shrubs to meet the demands of local households, all generate frequent conflicts and their solutions are difficult (Thomas et al. 2006; He et al. 2009; Salerno et al. 2010; Swanson et al. 2011;

Pan et al. 2012). Efforts to achieve meaningful solutions involve the need to consider a broad array of issues. These include (1) possible conflicts between goals at different scales, (2) the role of incentives versus penalties, (3) whether long-term indigenous activities can be considered positive (i.e., increasing land fragmentation and corresponding structural and biological diversity) or negative (i.e., simplification of forest systems with resulting loss of species), (4) the value of local versus scientific knowledge, and indeed, (5) even how to assess ecological or ecosystem well-being (Gadgil et al. 1993; Feintrenie et al. 2010; McShane et al. 2011). How local people use forests and how historical and current local to national policies affect this use in China has dominated our recent research interests (Trac et al. 2007; Henck et al. 2010; Urgenson et al. 2010; Grub 2012; Trac et al. 2013). This paper explores how one might relatively rapidly assess the 'well-being' or sustainability of such forests and provide some potential management guidelines.

There is a substantial body of literature on the interaction between local people and their surrounding forests (Bhuyan et al. 2003; Kumar and Shahabuddin 2005; Sagar and Singh 2006; He et al. 2009; Clark and Covey 2012; Pan et al. 2012; Chetelat et al. 2013; Garbarino et al. 2013). This literature illustrates a strong relationship between human use and often its negative impacts on species diversity and conservation goals (Sharma et al. 2009; Thomas et al. 2011). However, there is increasing recognition that indigenous peoples have shaped the planet's ecosystems for thousands of years through land-clearing and the widespread use of fire, and that these impacts were much more extensive than previously believed. For example, historical human footprints due to land clearing for agriculture were much greater per unit of food produced than those associated with modern agriculture (Kaplan et al. 2011). As a consequence, there is currently an increasing emphasis on understanding and even integrating local land practices, particularly by indigenous populations, into conservation (Miller et al. 2001; Phillips 2003). However noble this emerging objective, it becomes difficult to implement when dramatic changes in policy, technology, and population continue to impact our assessment of both current and historical local practices.

Over the last 60 years, China has undergone a series of socio-political changes that dramatically impacted the environment in both positive and negative ways (Shapiro 2001; Xu et al. 2006; Trac et al. 2007; Urgenson et al. 2010; Trac et al. 2013). How these changes have played out in various parts of China are of interest (Chen et al. 2009; Bullock and King 2011, Brandt et al. 2013).

Beginning 2002, a group of faculty and students from the University of Washington and Sichuan University initiated a series of studies in Baiwu Township, Yanyuan County, a mountainous area in Liangshan Yi Autonomous Prefecture in southern Sichuan Province, China (Figure 1; Chi 2004; Harrell and Hinckley 2011; Grub 2012). This paper explores two of Chi's (2004) observations: (1) *P. yunnanensis* trees closest to

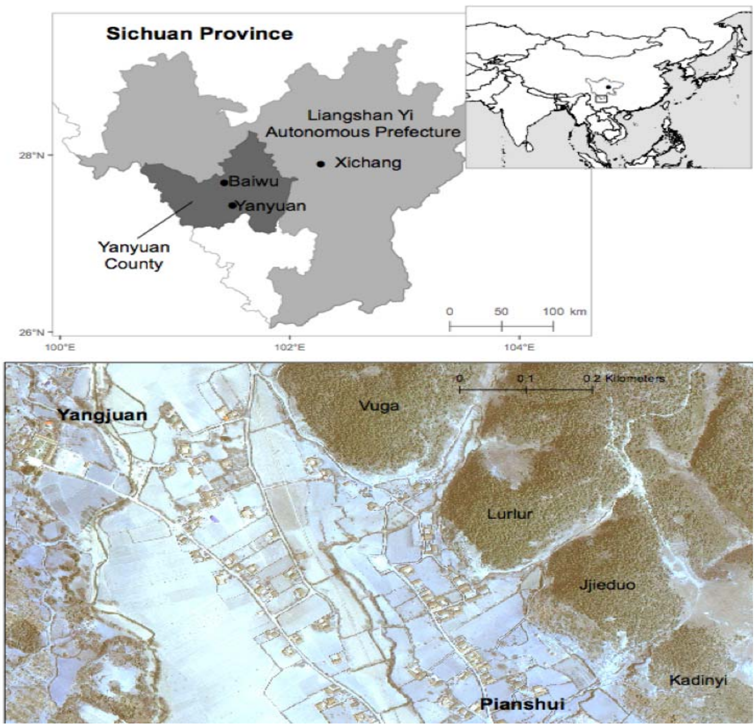

Figure 1 Study area. Top: Location of Baiwu Township in Yanyuan County, Liangshan Autonomous Prefecture, Sichuan. Yangjuan and Pianshui are slightly NW of Baiwu. Bottom: Location of the two villages and the four study hills. Vuga, Lurlur, and Jieduo were contracted to individual families in 1983; Kadinyi is used collectively by Pianshui villagers.

the villages had extensive cutting of their branches (Figure 2) for fodder and protection of mud walls from rain damage and (2) stands more remote in elevation from villages showed less evidence of human-related activities and had greater standing biomasses.

Figure 2 Pine trees with branches removed. Left: Thirty-two year old *Pinus yunnanensis* tree with branches completely removed from 15 whorls and another 2 whorls with partial cutting (photo by Tom Hinckley, July 4, 2002). Right: Twenty-two year old *P. yunnanensis* tree with branches completely removed from 15 whorls, 3 whorls (top) with live branches; branch stubs and scars indicate location of harvested whorls (photo by Keala Hagmann, August 26, 2008).

The purpose of this paper is to examine interactions between two villages and their neighboring forests. We studied human-related pressures in two ways (1) directly measuring the specific impact of branch cutting on the subsequent growth of *P. yunnanensis* trees and (2) assessing the general role of human activity on tree growth and forest productivity, using proximity to villages as a proxy. Our initial observations suggested that more than 50% of the green crown had been cut from many of the *Pinus yunnanensis* trees closest to the villages (Figure 2). The silvicultural literature suggests that 25 to 45% of the lower, green crown can be pruned (i.e., cut at the stem – branch interface) from both deciduous and evergreen tree species without affecting subsequent growth (Bandara et al. 1999; Dahm 1954; Montagu et al. 2003); however, the branch cuttings we observed resulted in greater green crown loss. Thus, we hypothesized that branch cutting would negatively impact tree growth and thereby affect the potential for such trees to serve other human needs. Second, we examined the growth of trees and the general condition of stands at increasing horizontal and vertical distances from the two villages. We hypothesized that a combination of direct forest use for products and impacts due to grazing would negatively affect stand condition and potential stand and tree productivity and that these impacts would decrease with horizontal and vertical distance from the two villages. Others have noted similar patterns (He et al. 2009; Cheletat et al. 2013; Garbarino et al. 2013).

1 Methods

1.1 Study area

The study was conducted near the villages of Pianshui (elevation 2,550 m) and Yangjuan (2,560 m) in Baiwu Township, Yanyuan County, Liangshan Yi Autonomous Prefecture in southwestern Sichuan province (27°41'N and 101°25'E; Figure 1). Baiwu Township lies at elevations ranging from 2,400 to 3,900 m. Total current population of the two villages is about 1,100 people, all of whom belong to the Nuosu ethnic group, which is part of China's Yi *minzu,* or "nationality" (Harrell et al. 2000; Harrell 2001). Alluvial plains and dry uplands are either farmed or grazed intensively, and mountain areas are given over to a combination of rotational-fallow farming, grazing, and low- to medium-intensity forestry. The nationwide, policy-driven Three Great Cuttings during the latter half of the twentieth century greatly reduced forest cover and forest diversity in this region of rural Sichuan. There is also some evidence that the previous swidden-agricultural practices (Dove 1983) of local people may have significantly impacted the lower elevation forests prior to the Communist revolution (Collins et al. 2011).

Pinus yunnanensis (Yunnan pine) is a dominant species in Baiwu Township. Regionally it often forms extensive, pure stands between 1,800 and 2,700 meters, especially on drier sites (Fang and Yoda 1989, Chi 2004). We focused on this species because of its wide distribution and its critical importance to the well-being of local people. Following our earlier student-led studies, village leaders specifically requested our assistance in understanding the status of their pine forests.

1.3 Study design

Our study sites fell into three distance and elevational zones (Close: 2,570 – 2,650, Intermediate: 2,695 – 2,930, and Distant: 2,950 – 3,050 m elevation) and these were used to address our two objectives (Table 1). Our study on the effects of branch cutting focused on sites close to the villages: four west-facing hills located east and south of Yangjuan and east and north of Pianshui (Figure 1 [bottom]). We established a total of 12 plots and measured at least one pair of *P. yunnanensis* trees per plot (n = 28). An additional 10 study sites (4 and 6, see Table 1) were established in forest stands that were intermediate or distant from either village.

1.3.1 Tree-scale method

Pairs of dominant trees located within 50 m of each other on the NW, W, and SW parts of each of the four hills were chosen for further study (n = 12 sites and 28 trees, Table 1). Paired trees were selected for similarity in estimated age and crown exposure to light (i.e., dominant crown class). One tree in each pair had an almost full crown and the other a greatly reduced crown. We measured the height, base of live crown, and diameter at breast height of each tree, and took one increment core from each tree near breast height (avoiding branch scars and pitch pockets) and re-cored if necessary (missing center). Annual ring widths were measured to the nearest 0.5 mm using a head-lamp and a hand lens.

We also took an additional 10 increment cores from dominant trees in 10 additional study stands (see Table 1). From increment core data, we determined age, ring width, and annual basal area increment.

1.3.2 Stand-scale methods

We surveyed the condition of forest stands by evaluating site characteristics (elevation, slope, slope position, aspect, dominant overstory and understory species, litter depth) and indicators of human use (branch cutting, slashing, partial tree cutting, bare ground, trails, tree stumps, coarse woody debris) of the 12 study sites on hills near the villages as well as the 10 additional study sites located at greater distances and elevations (Table 1). For each stand, we also measured stand basal area with a keyhole prism and took the average of two measurements, measured the diameter at breast height of one to five of the dominant trees, and collected one increment core from one of the dominant trees.

2 Analysis

Our interpretation of differences and patterns in growth is based upon either simple differences in measured growth (i.e., height or diameter) or patterns of growth over time (i.e., ring widths or basal area increments). Graphs of ring width and basal area increment (where BAI in year i = $[\{RW_1 + RW_2 \ldots RW_i\}^2 - \{RW_1 + RW_2 \ldots RW_{i-1}\}^2] \times 3.14$) against year of ring formation were constructed for both individual trees and the average of all trees from an elevational zone. For the lowest elevational zone, we both averaged (n = 28) and separated the branch cut (n = 14) from the control trees (n = 14). In addition, we calculated average annual BAI for the last five years and used these data to compare the trees from each of the three elevational zones. This five-year average was used as it smoothed year-to-year differences and has been used to evaluate differences in growth rates between

Table 1 Summary of the three types of tree/stand studies

Proximity to villages	Elevation range (m)	# of sites	# of plots/site	Stand factors measured	Tree factors measured
Close	2,570 – 2,650	4	3	Elevation, Aspect, Slope, Slope Position, Evidence of Disturbance, Litter Depth, Tree Species Present, Stand Basal Area	Paired Dominant Trees Selected: Tree height, diameter, percentage live crown, age and ring widths via increment cores (n = 28)
Intermediate	2,695 – 2,930	4	2	Same	Dominant Tree Selected: Tree diameter, age & ring widths (n = 4)
Distant	2950 –3,050	6	2	Same	Same (n = 6)

species (Pokharel and Dech 2011) and sites (Pokharel and Froese 2009).

For trees with relatively full crowns (defined as 'control', n = 14) versus those with greatly reduced crowns due to branch cutting (n = 14), we performed an F-test on the two series of data to determine whether the variances were equal or not. A non-parametric paired Wilcoxon Signed Rank test was performed on age, diameter, height, percentage live crown and 5-year average BAI.

We evaluated stand and dominant tree productivities in three different elevational zones (2,560 – 2,650 m [close and within 90 vertical meters of the two villages], 2,695 – 2,930 m [intermediate and within 135 to 370 m], and ≥ 2,950 m [distant or ≥390 m]). Increasing elevation is assumed to encompass both horizontal distance and physical difficulty of access from villages. Results include (1) averaged stand basal areas (a metric of stand carrying capacity or productivity), (2) 5-year average BAI (a metric of tree productivity), and (3) tree ages within the three elevational zones.

3 Results

3.1 Impact of branch cutting

For 28 study trees (14 pairs) the average age was 32.0 (ranging from 22 to 40) for the branch-cut trees (see Figure 2 for examples) and 32.5 (ranging from 19 to 45) for the 'uncut' or 'control' trees. Analysis of average annual basal area increment over the last five years suggested that there was no statistically significant difference between trees with extensive branch cutting and control trees (p = 0.27), in spite of large and statistically significant differences in percent live crown (p = 0.002) (Table 2). Live crown represented an average of 36.5 and 53.9% of the height for branch cut and 'control' trees, respectively. Crowns on trees with visible branch cutting averaged 3.17 m in length; in contrast, crowns on the 'control' trees were 5.53 m in length. Diameters (p = 0.017) and heights (p = 0.017) were significantly different and slightly larger in the control versus branch–cut trees (21.0 and 17.7 cm and 10.5 and 8.7 m, respectively).

Examining average ring widths for the 14 'control' trees (solid line, solid circles) versus ring widths for the 14 trees with reduced live crowns (dashed line, open circles), it is difficult to see a pattern or a difference. However, when one compares the yearly basal area increments of the average branch cut and 'control' tree, both types of trees appear similar until 1990 when average ring widths and BAIs in the control trees increased and remained greater than in the trees with cut branches until 2004. For the last five years, both cut and control trees have added similar ring widths and basal areas.

3.2 Impact of Elevation on Tree Growth

The above analysis of tree growth examined trees (n = 28) growing in stands between 2,560 and 2,650 m and close to the two villages. Growth data for trees and stands at greater elevations (and distances) are now presented (n = 4 and 6, see Table 1). Plots of average basal area increments and ring widths are shown in Figure 3A and 3B, respectively. In addition, average and range of age and stand basal area and average 5-year BAI, calculated two ways, are summarized for each elevation zone in Table 3.

The average age of study trees increased with elevation: from 32.3 to 33.0 and then to 43.3 years old (Table 3). The greatest range of ages was found at both the lower and upper elevation zones. It is important to note that no *P. yunnanensis* trees older than 52 years at breast height were found. Averaged stand basal areas increased even more dramatically with elevation, from 8.7 to 42.1 m² per

Table 2 Average values for the 14 (branches removed) and 14 (uncut or control) trees for the average annual basal area increment (BAI) over the last five years (Avg BAI), height (in meters), diameter at breast height (dbh in centimeters), and percentage live crown. P values are from a non-parametric paired Wilcoxon Signed Rank test.

Treatment	# of trees	Average age	Avg BAI (mm²)	Height (m)	dbh (cm)	% live crown
Branch cut	14	32.0	844.64	8.69	17.71	36.50
Uncut or control	14	32.5	868.81	10.51	21.14	52.77
P (T≤ t)			0.27	0.017	0.017	0.002

hectare, indicating that there were either more or larger trees per hectare. Similar to stand basal areas, the average basal area increment over the last five years (from 2004 to 2008) for dominant trees doubled from approximately 840 to 1,630 and almost doubled again to 2,850 mm²/y between elevational zones.

Average BAIs (Figure 3A) and average ring widths (Figure 3B) are much greater in the six cored dominant pine trees found above 2,950 m than in trees sampled from lower elevations. Initial average ring widths approached 6 mm, remained high and only declined slowly. Averaged BAIs rapidly increased from 1967/1968 until 1990 when the increase slowed. The period from 1990 until the present shows increased year-to-year variation, but still an increasing pattern. Trees from the intermediate elevation band were younger (Table 3) and showed an initial rapid increase in BAI from 1977 that ended in 1985 and did not recover until 1996. Except for a two-year pause, BAI values continued to increase until the last reading in 2008.

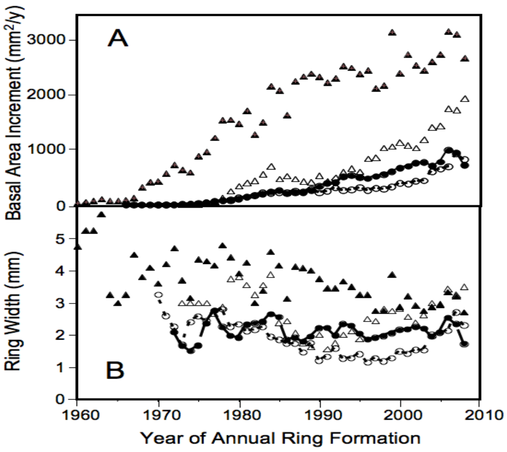

Figure 3 Pooled chronologies (ring width or basal area increment versus year of formation) for cored *Pinus yunnanensis* trees from the three elevational zones relative to the two villages. Solid circles with a solid line and open circles with a dashed line are the paired (n = 14 pairs) control and branch cut trees, respectively, from the four study hills described in the text and in Table 1. All of these trees are from sites less than 2,650 m. Trees (n = 4) located between 2,695 and 2,930 m) are indicated by open triangles. Trees (n – 6) located above 2,950 m are indicated by solid circles. Panel A = ring widths; panel B = annual basal area increments.

4 Discussion

4.1 Impact of branch cutting

Plots of ring width from the average of all 14 branch cut and 14 'control' trees (Figure 3B) showed differences over time; however, these differences were difficult to interpret. Indeed, all of the averaged ring widths shown in these Figures did not demonstrate either a clear pattern or synchronized changes potentially associated with an abiotic or biotic disturbance. When each individual tree's ring width data were inspected (data not shown), it was clear that branches had probably been removed at some time from all trees. When sampled in 2008, the crowns of the 'control' trees were larger and no visible external evidence of branch removal was evident. Had all the trees been of the same age (or cored at different heights so that the total number of rings measured were equal), averaged ring width data might have been clearer. However, if branch cutting occurred at different times and with different intensities (highly likely), any clarity gained by having similarly aged trees would have been likely lost. The confounding effects of differences in age and differences in the timing and extent of branch removal on ring width were lessened when the area of each annual ring or BAI was plotted for the

Table 3 Data on cored dominant *Pinus yunnanensis* trees from three different elevation zones. Five-year average basal area increment (Avg BAI) for each elevation band was calculated two different ways. Calculation method A: from each tree's ring width data, that tree's basal area increment was calculated and then averaged for all trees in that study zone. Or, Calculation method B: ring width data for each tree were averaged (e.g., Figure 3B) and then that average was used to calculate basal area increments (e.g., Figure 3A). In addition, the averaged stand basal areas (and ranges) for stands from each elevational zone are given.

Study areas	Elevation range (m)	# of trees	Average age (range)	5-yr Avg BAI (method A)	5-yr Avg BAI (method B)	Stand basal area (m²/ha) (range)
Close	2,570 – 2,650	28	32.3 (17 –46)	856.7	823.1	8.7 (1.5 -20.1)
Intermediate	2,695 – 2930	4	33.0 (31 –36)	1,622.4	1,639.2	23.2 (13.2 – 29.8)
Distant	2,950 – 3,050	6	43.3 (35 – 52)	2,862.5	2,827.5	41.1 (37.7 – 48.2)

average of all trees (Figure 3A). A combination of the timing and intensity of human impacts (i.e., branch cutting or removal of competing trees), year-to-year differences in weather, and the inherent patterns of growth of trees of different ages (the range in age was from 17 to 46 years old in 2008) likely led to the variation and differences in ring width and BAI observed.

Trees in our study with smaller crowns produced in the last five years as much basal or ring area as trees with larger crowns. As noted in the silviculture literature, light to moderate pruning of green branches frequently does not affect diameter and height growth because of compensatory responses by the remaining green branches (Bandara et al. 1999; Montagu et al. 2003). Data from this study suggested that trees with severe branch cutting histories eventually recovered and were capable of diameter growth similar to the control tree. As previously suggested, some branches were likely removed from the control trees. Based on these results, branch cutting did significantly affect height and diameter, but does not appear to have harmed long-term diameter growth. However, the small but significant differences in height and diameter between the paired trees suggest that the removal of fewer branches might not lead to reductions in height and diameter.

4.2 Effect of elevation on trees and stand productivities

Data presented in Table 3 and Figure 3A strongly point to increased individual *P. yunnanensis* tree age and growth, and stand basal areas as elevation above (or distance from) the two villages increased. Over all our study sites, stand basal area ranged from 1.5 to 48.2 m² per hectare. Although ranges in stand basal areas might overlap, the increase in mean from 8.7 to 41.1 m² per hectare over the range of elevations studied was considerable. One might expect to see basal area increments of individual dominant trees to decrease with increases in stand basal area (greater site occupancy and thus greater tree-to-tree competition), but instead the opposite occurred. Decreases in site occupancy as inferred from decreases in stand basal areas reflected increased human use and associated negative impacts when compared to a more traditional silvicultural response due to density control. As stand basal areas increased from less than 10 to over 40 m² per hectare, the number of stumps per hectare decreased from over 2,000 to fewer than 50 (Urgenson et al. 2010). Our written field notes associated with these higher elevation stands indicated a more pronounced litter layer, an appearance of and then an increased depth of an A-horizon, less evidence of grazing, fewer trees with cut branches, fewer slashed shrubs and trees, fewer stumps, and fewer and less traveled paths (either by humans or livestock). In this study, the best growth was noted in a *P. yunnanensis* found at 2,985 m; it was growing in a mixed stand of about 80% pine and 20% alder (*Alnus ferdinani-obergii*) with a total stand basal area of 45.9 m² per hectare. This tree was 46 years old and had an average BAI for the last five years of almost 6,500 mm²/y (data not shown).

Much greater understanding of the impact of policy, human proximity, and socio-cultural requirements for natural resources on local land-use practices and patterns can be forthcoming with greater and more extensive spatial sampling as well as superior access to written and photographic (both remote and proximate) evidence (e.g., He et al. 2009; Chetelat et al. 2013; Garbarino et al. 2013). Following intense forest use in Switzerland during the Second World War, Chetelat et al. (2013) noted recovery followed different paths depending upon human proximity, policies, and weather events. Our data, and associated, but somewhat disjointed stories by village leaders and elders, begins to suggest different times of impacts at different elevations. Having a more spatially extensive set of data or clearer convergence of stories would greatly assist in clarifying potential human impacts and their spatial and temporal extent. The work by Garbarino et al. (2013) provides additional compelling evidence as to the importance of greater spatial sampling and better historical records in studies of socio-ecosystems. In contrast, our approach provides a model for an initial assessment of condition and pattern and, most importantly, for providing local people with an assessment of forest management options to maintain and even enhance existing forest conditions.

As a result of collectivization, growth of the villages, and continued, sustained demand for forest resources, including extensive use of understory plants by humans and livestock, stands and sites near these two villages had much lower stand and tree growth than more remote stands and sites at greater elevations. Without changes in population, demand or patterns of use, it is anticipated that sites near the villages will not recover and spreading pressures will likely impact stand, tree, and site productivity further from each village. Given the need for village members to utilize these forests for multiple goods and services, it is difficult for us to find meaningful solutions appropriate to the situations for these two villages that would lead to forest recovery. Clearly reducing the demand for wood (branches, trees, or shrubs) and the impact of grazing animals on loss of top-soil and soil compaction would be beneficial in reducing impacts. Opportunities to manage access, forest composition, and forest structure exist that would also be beneficial.

5 Conclusions

Although heavy branch pruning of *Pinus yunnanensis* marginally reduced height and diameter, trees eventually recover and are able to add ring areas similar to control trees. The fact that these trees had significantly smaller crowns than the control trees suggested that the smaller crowns had either greater foliage densities or more productive foliage per unit leaf area. Both would represent compensatory responses. Although branch cutting has a significant impact on the size of a tree, its impact is small in comparison to the much greater impact of stand condition and site degradation.

Stand condition and site quality played a large role in the poor growth exhibited on almost all of the study areas. Study areas at lower elevations and relatively close to the two villages showed considerable evidence of human-related disturbance, which was associated with decreases in both basal area increment for dominant trees and stand basal area. Stand condition and site quality likely represent a combination of the innate biophysical features of a given site as well as the nature, duration, and intensity of human pressures on both the stand and site. A combination of extensive forest harvesting, branch and shrub gathering for fuel and fodder, and considerable grazing pressure with associated erosional losses of litter and A-horizon have all combined to negatively impact site quality and tree and stand productivity.

Site degradation appears negatively correlated with elevation or access. This degradation, when coupled with the increased reliance on livestock until very recently, strongly suggests an increasingly vulnerable linkage between these people and their surrounding forests. Finally, the tree and stand assessment techniques used in this study, although not spatially sufficient, did provide an adequate assessment of tree and stand potential growth conditions.

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This journal pays particular attention to the relationships between mountain environment changes and human activities, including the processes, characteristics and restoration of mountain ecosystem degradation; dynamic processes, and the theory and methods of controlling mountain hazards, such as debris, landslides and soil erosion; the protection and development of special mountain resources; culture diversity and local economic development in mountain regions; and ethnic issues and social welfare in mountain areas.

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