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RESEARCH

Simplification of Pine Forests Due to Utilization by Tibetan Villages in Southwest China

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Abstract In China, many rural communities depend upon forests to provide wood, fuel, fertilizer, animal bedding, and valuable non-timber forest products (NTFP). However, the degree to which forest resource extraction is compatible with new conservation aims is unclear because there is little information on the specific ecological effects of traditional forest collecting practices. Therefore, we compared the structure and floristics of *Pinus densata* forests exposed to three levels of resource extraction by Tibetan villages in northwest Yunnan: (1) a forest site protected from wood and timber removal, (2) moderately utilized forest sites exposed to traditional collecting practices, and (3) patches of highly utilized forest from which timber extraction is high in response to recent development pressures. The results show that understorey and cryptogamic species are reduced in all the utilized forest sites by comparison with the protected forest. However, the moderately utilized pine forests still provide good NTFP habitats by maintaining relatively high canopy covers, litter covers, and understorey structural complexity; this suggests that traditional forest resource use, while simplifying the forest, does not pose an increasing threat to pine forest integrity. By comparison, the highly utilized forests are transformed into open, herb-rich environments in which canopy covers and understorey complexity are depleted, and NTFP habitats are degraded. In the future it may be practical to enhance biodiversity by proscribing forest resource collection, but the immediate priority is to monitor the sustainability of forest utilization using indicators such as understorey development, litter cover, and cryptogamic richness.

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Introduction

In recent times, the Chinese government has initiated a range of forest conservation measures, including large-scale reforestation programs and commercial logging bans. These policy changes are, in part, a response to past over logging which culminated in catastrophic downstream flooding in 1998 (Zhang and others 2000, Liu and Diamond 2005). In addition to promoting reforestation, China has also emphasized biodiversity conservation; consequently, the numbers of protected areas have more than doubled in the last decade and this expansion is set to continue (Jim and Xu 2004, López-Pujol and others 2006). Furthermore, a new 'Ecological Function Conservation Areas' approach aims to guide land use across large parts of rural China, including collective forests, settlements and areas that support a wide range of human activities (PATF 2004, López-Pujol and others 2006).

As well as closing down commercial logging operations, China's new forest conservation measures have limited the activities of traditional forest users. For generations, rural residents have used forest resources, such as wood, fodder, and fertilizers, but villagers are now increasingly constrained by forest collection permits and excluded from many protected areas (Xu and Ribot 2004). In fact, the unsustainable collection of forest products by local communities has been cited as a reason to expand and better police protected areas and/or conservation management zones (Harkness 1998, PATF 2004, Xu and Wilkes 2004, López-Pujol and others 2006). Together with biodiversity and water catchment concerns, a further reason to conserve forest integrity is that rural economies are becoming increasingly dependent on non-timber forest products (NTFP) (particularly high-value mushrooms), which require relatively undisturbed forest habitats (Liu and others 1999, Yang and others 2006). However, new development pressures, when combined with restricted forest access, can drive communities to overexploit local forest resources, an outcome that is counterproductive to the desired conservation aims (Winkler 2003; PATF 2004; Melick and others 2006).

The challenges of conserving forests in China are similar to those in other parts of the world where debate rages between the proponents of people-free zones (who contend that the presence of human communities within sensitive areas is incompatible with long-term conservation) (e.g., Redford and Sanderson 2000, Terborgh 2005) and those who believe that human habitation and use is viable within inclusive conservation areas (e.g., Andrade 2005). While there are conflicting views on conservation, and specific policy needs are affected by regional differences (such as the influence of new settlers and shifting patterns of resource use), there is a lack of information about the impacts of local collecting practices on forest ecology. Studies to monitor community forest use are expensive and logistically difficult since study areas may be broad ranging, collecting regimes variable, and local people are often guarded with outsiders. As a result of these problems, most estimates of the ecological effects of forest resource use are inferred from limited collection records augmented by household surveys; much more research is required to understand the ecological implications of forest resource use (Tietema 1993; Shahabuddin and Prasad 2004; Gavin and Anderson 2005).

Certainly, in China there is a dearth of quantitative and qualitative information about the effects of traditional livelihoods on forest ecosystems, so it is difficult to assess whether the current levels of forest utilization and the increased demands being imposed on collective forests are compatible with new conservation priorities (Harkness 1998; Ervin 2003; Xu and Wilkes 2004; PATF 2004). Moreover, there are concerns that the scientific arguments used to justify official policies to remove or reduce traditional land-use practices have often been simplistic or ill-conceived (Weyerhaeuser and others 2005; Xu and others 2004; 2005). In the absence of any meaningful ecological monitoring it is feared that many Chinese conservation policies produce little real on-the-ground protection (Harkness 1998; PATF 2004).

Despite the doubts over the effectiveness of current conservation policies, there is evidence that long-term traditional management has protected forests. Recently in southwest China, Salick and others (2007) showed that Tibetan sacred sites have conserved larger trees in old growth forests, primarily by excluding logging. However, the aforementioned study gave little indication of the effects of village forest-use because (excepting commercial logging history) their study sites were exposed to non-specified degrees of resource collection; therefore, the present study links differences in the structure and floristics of collective pine forests to the degrees of utilization by rural Tibetan communities in northwest Yunnan. Monitoring this detailed ecological information can help improve sustainable forest management within the very challenging and dynamic forest governance environment in China.

Forest Use and Governance in China

The governance of collective forests and the rights of local peoples to use forest resources are confusing and contentious issues in modern China. For generations the use and management of collective forests (also known as community forests or village forests) in rural China were determined by local community rules and mores (Xu and others 2005). This community system was usurped in recent decades by rapid changes to forest policy as China moved through the revolutionary era (in which all lands were effectively nationalized) into a period of modern economic expansion (Zhang and others 2000, Liu 2001, Miao and West 2004). In the late 1980s, the Chinese government started to devolve land titles back to traditional owners or villages, but the usufruct and transfer rights of collective forests are still effectively government controlled through the local Forest Bureau who assign forest classifications, from which villagers designate the forests from which material may be extracted (Jim and Xu 2004, Miao and West 2004).

In an attempt to codify forest use, Chinese forest law now defines five classes of forests: (1) protection forests (which aid in water storage, landscape stabilization and act as shelterbelts), (2) timber forests (for the provision of timber), (3) economic forests (includes orchards and other trees that produce foodstuffs, medicines and industrial raw products), (4) fuelwood forests (for the provision of fuelwood), and (5) forests for special uses (includes areas for national defence, experimental research, historical interest, environmental protection or aesthetic value) (Miao and West 2004). Under this classification system, local communities are entitled to an annual timber quota from some timber forests to meet building needs, together with

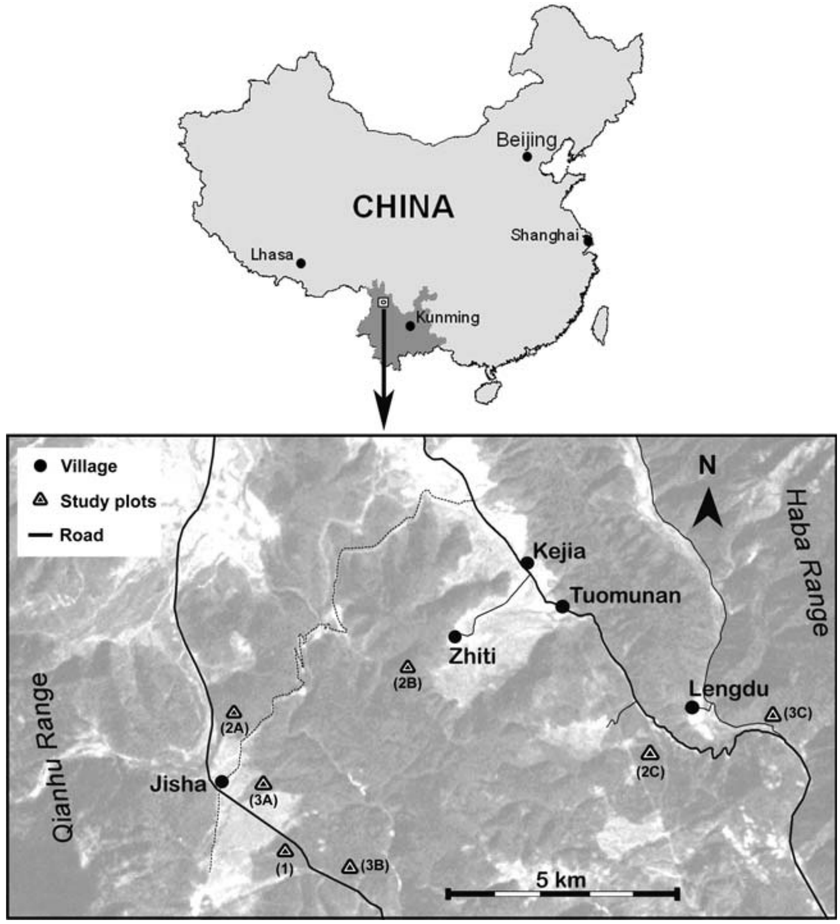

Fig. 1 Overview map of the study area; the shaded portion in the China map represents Yunnan Province. In the village map, the forested areas are shaded and the study sites are shown in parentheses

collecting rights from fuelwood forests (Xu and Ribot 2004, Xu and Wilkes 2004). However, the on-the-ground definitions of forest types remain inconsistent between and within levels of government and the mechanisms of policy enforcement are often unclear (Miao and West 2004, Weyerhaeuser and others 2005). To complicate matters even further, confusion reigns over tenure rights for NTFP; in some cases the presence of NTFP creates differentiation between forestland tenure and NTFP tenure on the same land (Yeh 2000).

Study Area

Regional Context

Northwest Yunnan lies on the Yunnan-Guizhou Plateau in southwest China. To the west the region merges into the Himalayan mountain ranges, and to the north onto the Tibetan plateau, while the south borders the temperate and subtropical lowlands of central and southern Yunnan. This mountainous area forms the upper reaches of three major river systems: the Nu Jiang (Salween), the Lancang (Mekong), and the Jinsha Jiang (the upper Yangtze). The wide altitudinal and microclimatic ranges support a diverse flora and fauna: numerous vegetation types exist including, grasslands, cushion-like alpine grasslands, evergreen broadleaf forest, mixed forest, alpine mosaic, deciduous broadleaf forest, and temperate conifer forest (Li 1994; López-Pujol and others 2006).

General Study Site Characteristics

This study incorporated forest areas in the Xiaozhongdian Valley, Shangri-La County, Diqing Prefecture (Fig. 1). This valley runs north–south and is bounded by the Qianhu and Haba ranges (which rise to over 5000 m); in the study area the valley is about 15 km wide. Study sites were near three villages: Jisha (centered 27°26’50” N: 99°48’50” E) on the western valley edge near the base of the Qianhu range, Zhiti (27°28’50” N: 99°51’28” E), which lies 5.2 km east of Jisha in the central valley, and Lengdu (27°28”08’ N: 99°53’55” E), which is a further 5 km southeast at the base of the Haba range. Jisha Village comprises two subvillages, Upper and Lower Jisha, which contain 83 households with a population of more than 400 people. Zhiti Village contains 24 households (population of about 130) and Lengdu Village has 15 households (population about 85). The two other local villages, Tuomunan and Kejia, contain a total of 46 households with a combined population of about 270. All villagers are Tibetan and dependent upon agriculture and animal husbandry (Li 2003). The villages are at elevations of 3100–3200 m and the climate is monsoon-influenced: clearly divided into a dry season (November to May) and a wet season (June to October). Data collected from Shangri-La County (30 km north,elevation 3200 m) shows an annual mean rainfall of 654 mm. Temperatures are generally mild, although winters are cold and snow may be persistent. The maximum monthly average of 13.5°C occurs in July, whereas monthly average temperatures are below zero from December through February.

The villages all lie in gently undulating cleared pasture and agricultural land set amid forestlands on the valley floor. Nearest to the villages and throughout the valley, the forest is dominated by *Pinus densata*, which is generally the only canopy species. This *P. densata* forest type is an important component of the lower mountain ecosystems (i.e., below 3400 m) in northwest Yunnan and Sichuan. For instance, in the Xiaozhongdian region *P. densata* forest accounts for about 40% of all forest cover (Willson 2006). Villagers commonly use the nearby *P. densata* forests as sources of firewood, timber, animal bedding, fertilizers, and NTFP. Pine is also used as a soft carving wood for lintels and feature work. The amounts of timber removed are very difficult to determine; for example, the estimates of annual per capita firewood demands for Tibetan communities in Sichuan and Yunnan range from 0.5 to 6.2 m^3 (Melick and others 2006).

On the valley side slopes above the villages, the pine forests merge into mixed spruce and oak forest (*Picea likiangenis*, *Quercus* spp.), eventually giving way to fir forest (*Abies georgei*), which dominates at elevations above 3600 m. Many of these higher elevation forests have been severely degraded by past commercial logging activities and also by insect pest attack (Willson 2006). Spruce, and to a lesser degree, fir are prized timber, oak was the first choice for firewood; thus, many merchantable timber trees have been removed from the higher elevation conifer forests.

Local Socioeconomics and Forest Use Changes

Recent forest policy changes have impinged upon the economy and lifestyles of local communities, and this has in turn affected the management of collective forests in Xiaozhongdian. When the commercial logging ban was imposed in 1998, the timber industry accounted for more than 80% of the regional income in this area (Hillman 2003). Although local communities did not log directly (the timber industry was monopolized by state-owned enterprises), villagers were employed in support services. Loss of revenue from the logging industry and the protection of high-value timber forests has increased pressure on local forest lands as rural communities attempt to find alternate income streams, such as increasing livestock herds and the harvesting of firewood and timber from collective forests, which is often (unofficially) used to supply township needs (Melick and others 2006). The harvesting of NTFP, in particular matsutake mushrooms, has also become a very important source of revenue for these communities in recent years (Yang and others 2006).

Not only is the provision of wood to nearby town markets applying pressure on collective forests, but the demand for pine wood in the villages has risen in response to the decline of bamboo. Bamboo was a traditional fencing material, but commercial logging and replanting destroyed the bamboo understorey in the upper forests. Villagers now attempt to meet new demands for wood, while also trying to maintain a supply of wood for their fuel, building, and other needs. Moreover, improved road access (part of a national program to modernize and open up poor rural areas – the so-called "Develop the West" policy) has inadvertently facilitated an expansion of wood and timber collection into nearby pine forests, both by locals and outsiders. The impacts of road development are graphically illustrated in the study area, where a new highway, National Highway 214, now runs straight through Jisha Village and allows easy public access to forested areas to the south (see Fig. 2). All these recent changes mean that the total amounts of wood removed from village collective forests are almost certainly higher than the current estimates based upon average wood consumption and Forest Bureau quotas (Xu and Ribot 2004, Melick and others 2006).

Therefore, in what is now supposed to be a more tightly regulated forest use system, new economic pressures have conspired to actually increase the resource extraction from collective forests. In addition, uncertainty over forest definitions and user rights further hinders effective forest management. In the Xiaozhongdian area, for example, the villagers consider the surrounding pine and lower valley slope forests to be "fuelwood forests" for use as the community sees fit; however, some sections of these village forests are demarcated as "protection forests" and "timber forests" by provincial authorities (L. Guo, Xioazhongdian Forest Bureau, personal communication). Similarly, although a cemetery forest in the study area was demarcated as a "forest for special use" by the Forest Bureau, this protection status was overridden by the

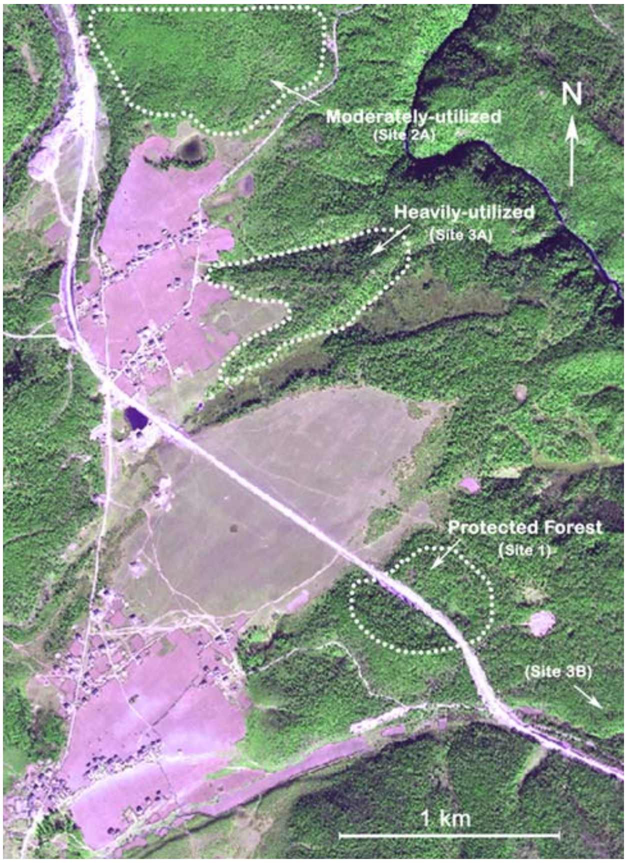

Fig. 2 A section of a QuickBird image (November 2003) showing the locations of the study sites in the collective forests near Jisha Village. The northern margin of the area into which heavy logging activities have recently expanded in the southeast (Site 3B), is also marked

Ministry of Construction when the aforementioned new national highway was bulldozed straight through the middle of the sacred forest – this exemplifies the ministerial overlap that further complicates forest governance in China (Liu 2001, Jim and Xu 2004). All these administrative problems and uncertainties illustrate the importance of trying to monitor the human impacts on forests with direct and repeatable ecological indictors.

Forest Site Selection

The aim of this study was to try and elucidate ecological changes to the pine forests resulting from human utilization; to that end we selected seven forest sites that were geographically separated across the Xiaozhongdian Valley, but (excepting local collecting practices) as similar as possible (Fig. 1; Table 1). The seven forest sites comprised three replicated sites within each of two use-regimes (i.e., moderately and heavily utilized) and one control site (i.e., protected forest). The first step was to broadly stratify the valley into zones of similar aspect, slope, and forest type by overlaying a digital elevation model and land cover map derived from Landsat satellite data (Willson 2006). Within this stratification, we selected sites exposed to similar collecting regimes as well as the protected cemetery forest control site. Determining the extent of collecting at specific forest sites is difficult; in reality local forest use varies depending upon seasonality, local demand, proximity, and ease of access. However, we endeavored to ensure sites within a given use-regime were consistent in terms of the degree of firewood, timber, and fodder collection, and quality of NTFP habitat (i.e., whether or not the sites were considered as viable wild mushroom habitat). These subjective assessments were based upon previous participatory mapping and collecting surveys, performed with members of the village communities, augmented with high-resolution satellite imagery of the area (QuickBird: pixel size 60 cm, pass date November 2003) (Fig. 2). According to Chinese forest law, all of our forest study sites were classified as "fuelwood forests," with the exception of the cemetery forest that was designated as a "forest for special use."

The forests in the study sites were relatively simple. *Pinus densata* was the sole canopy species and all sites occurred on yellow–brown silty clay–loams on flat to gentle slopes (≤ 8°) of south to southwesterly aspects (Table 1). Detailed forest surveys were conducted in the summers of 2005 and 2006 over a central 3–4 ha area within each site, but additional information on the broader extent of forest types were recorded throughout the field surveys using a GPS connected to a palm pad computer running ArcPad software, on which we accessed the QuickBird image.

Specific Forest Study Sites

The locations of the sites are shown in Figs. 1 and 2, and details of all sites are given below.

(1) Protected cemetery forest (27°26'50" N: 99°49'20" E): this area, located 1.5 km south of central Jisha Village, was used as a long-term control site. The total area (both sides of the road) is about 15 ha. This forest has been protected for its sacred significance as a traditional Tibetan sky burial site. For generations, no tree removal, timber cutting or firewood collection has been permitted. In recent years the new highway was unceremoniously carved through this forest (see Fig. 2), but nonetheless, despite some edge effect, parts of this forest are relatively untouched. Collection of NTFP (primarily mushrooms) is permitted as

Table 1 Summary of the criteria used to stratify the study sites in Xiaozhongdian Valley

Criterion	Site characteristics	Applicable study sites
Vegetation	*Pinus densata* forest	All sites
Soil	Yellow-brown silty clay-loams	All sites
Slope	≤8	All sites
Aspect	S-SW	All sites
Altitude	3100–3200 m	All sites
Firewood/fodder collection permitted?	Yes	Sites 2A, 2B, 2C, 3A, 3B, 3C
	No	Site 1
Trees commonly felled for fencing and/or firewood markets?	Yes	Sites 3A, 3B, 3C
	No	Sites 1, 2A, 2B, 2C
Quality of NTFP habitat?	Good mushroom habitat	Sites 1, 2A, 2B, 2C
	Poor mushroom habitat	Sites 3A, 3B, 3C

is animal grazing, although there was not much evidence of grazing during the study.

(2) Moderately utilized forest. This forest-use type covers the undulating floor of the valley and the lower slopes of the surrounding ranges; it comprised the majority of forest in the study area. We examined three sites:
   - (2A) Jisha (27°27′30″ N: 99°49′15″ E) is a site within the forest about 1 km north of Upper Jisha Village. This forest ranges around the valley floor covering an area of about 100 ha and is utilized moderately by local people. Timber extraction is permitted, but tree removal is generally light; however, firewood is collected regularly and understorey shrubs (primarily *Quercus monimotricha*) are pruned and used for animal bedding and fertilizer. This site is also used for NTFP harvesting – primarily mushrooms such as matsutake and morels. Animal grazing is permitted, but at the time of the study this was relatively light.
   - (2B) Zhiti (27°28′36″ N: 99°50′50″ E) lies about 1 km southwest of Zhiti Village on undulating terrain on a predominately southern aspect. As for Site 2A, this forest site supports the collection of NTFP, firewood and some animal bedding.
   - (2C) Lengdu (27°27′50″ N: 99°53′30″ E) is a forested area that is used similarly to Sites 2A and 2B; this multi-use forest lies about 1 km southwest of Lengdu Village on the gentle south–southwesterly slopes.

(3) Heavily utilized forest. These were all sites in which heavy tree felling and wood removal were apparent. For all these sites, the intensity of wood removal had escalated recently, since imagery from 2003, showed much less evidence of severe canopy disturbance. We compared three sites:
   - (3A) Jisha (27°27′10″ N: 99°48′20″ E) is in a patch of forest on the flats that start about 500 m southeast of Jisha Village and covers approximately 20 ha. Due to its proximity to the village, this forest is subjected to intensive local logging activity. Large canopy gaps were apparent and cattle and yak grazing was much more severe than in the other forest-use types. Recent logging activity was very evident, including large numbers of fallen trees and trimmed limbs. As for the moderately utilized sites, shrubs are cut and collected for animal bedding and fertilizer, but in these high-use sites the cutting is more intensive. Toward the edges of open gaps, understorey trees (mainly *Betula* sp.) are also cut (and allowed to re-coppice) for firewood. NTFP collection is permitted, but yields are so poor that villagers no longer bother to collect in this forest type.
   - (3B) South of Jisha (27°24′50″ N: 99°49′40″ E) is a forest site covering about 40 ha on flat to gently undulating terrain about 3.5 km south-southeast of Jisha center. Timber extraction appears to be increasing, due to the access permitted by the new highway. Many trails fan out from the highway into the forest leading to a patchwork of variously disturbed sites and locals claim that outsiders now access this area (illegally) for wood. Livestock grazing was evident through the area.
   - (3C) Lengdu (27°27′50″ N: 99°54′20″ E) occurs about 1 km south east of Lengdu Village on the gentle south–southwesterly slopes near the eastern edge of the valley. The tree felling was quite intense over an area of about 8 ha. As for the other high-utilization sites, gaps were prominent, shrub trimming common and there was evidence of ongoing livestock grazing.

Table 2 The basal areas and the average canopy covers ($n = 52$ replicates) ± SD for *Pinus densata* in the forest study sites in the Xiaozhongdian Valley

Study site	Forest-use regime	Basal area (m^2ha^{-1})	Canopy cover (%)
Jisha (1)	Protected	$31.4^a \pm 3.0$	$32.0^c \pm 3.9$
Jisha (2A)	Moderate	$34.7^a \pm 3.9$	$30.1^c \pm 4.1$
Zhiti (2B)	Moderate	$36.9^a \pm 4.1$	$28.1^c \pm 4.5$
Lengdu (2C)	Moderate	$31.0^a \pm 4.4$	$27.5^c \pm 3.7$
Jisha (3A)	Heavy	$16.0^b \pm 4.9$	$15.3^d \pm 5.1$
South of Jisha	Heavy	$14.9^b \pm 4.8$	$14.2^d \pm 4.4$
Lengdu (3C)	Heavy	$17.4^b \pm 5.1$	$19.8^e \pm 5.2$

Means denoted with different superscripted letters within the same column are significantly different ($p < 0.05$) according to Tukey's test

Methods

Data Collection

For each of the seven forest sites, stand structures were assessed using a closest individual plot method in which 52 plots were randomly selected; this method is considered to give good approximation of overall forest stand characteristics for areas of up to 100 ha (Cottam and Curtis 1956). For each of these plots, the distance and size (diameter at breast height [dbh], measured at 1.3 m on the uphill side) of the nearest canopy trees were recorded for each of the diameter classes: 1–10 cm, 11–20 cm, 21–30 cm, and >30 cm. When tree distance exceeded 10 m from the random plot origin point, the plot was considered to be empty (i.e., a nil plot). At each plot origin location, tree heights, and distances were recorded with a digital hypsometer; these data were used to calculate tree density and basal areas. In addition, for each plot, overstorey canopy cover was estimated from a grid analysis of digital canopy images, which had been photographed vertically from forest floor. Litter cover depth (pine needles, leaves, sticks <5 mm diameter) was also measured at the randomized origin point of each plot.

Understorey characteristics at each forest site were sampled in 25 quadrats (5 × 5 m), placed 10 m apart along five parallel transects starting at randomly selected points within the forest site. In sloped sites, transects were laid across the slope. Within quadrats, the understorey percentage covers of species were visually assessed in each of the following strata: 0–0.25 m, 0.25–0.5 m, 0.5–1 m, 1–2 m, and 2–5 m. Ground cover vegetation was visually estimated within nested 2 × 2 m quadrats.

Woody debris was measured with a line intersect method along each of the transects using the method of Van Wagner (1968). All diameters of debris were measured at the point of intersection. Large woody debris was considered to be any piece ≥10 cm in diameter.

Diversity Calculations

Species and structural diversity were analyzed using Shannon's diversity index (H) and equitability or evenness (E_H) (Magurran 1988). Contributions of each species were determined from cover values or crown projection estimates as appropriate. For understorey structural diversity, we followed the method of Sullivan and others (2001), where each stratum was considered a separate species and indices were calculated accordingly.

Statistical Analyses

For each of the seven forest sites, canopy cover, basal area and litter cover figures were calculated for all quadrats ($n = 52$) and woody debris for each transect ($n = 5$). These data were then tested for normality and equal variance using the Kolmogorov–Smirnov test (SPSS Vers. 13), and where necessary, arcsine transformations were applied. Standard single factor ANOVA were used with normal and equal variance data. Post-hoc tests of differences between site means were performed using Tukey's multiple comparisons.

The Shannon indices, and species-richness figures were calculated for each site independently (i.e., using data from 25 quadrats at each site), while the combined diversities for forest-use types were calculated using all pooled data (75 quadrats) for each forest-use regime (with the exception of the protected control site [Site 1] where only 25 quadrats were available).

Results

Stand Structure, Canopy Cover, and Basal Areas

There was some variation in stand structure for *Pinus densata*. Although the basal areas of the protected and moderately utilized forest were similar (Table 2), the latter contained a greater proportion of younger trees, suggesting a denser regenerating forest (Fig. 3). This combined stand data also shows that the heavily utilized forest contained a preponderance of medium sized stems; however, overall tree numbers were greatly depleted. The maximum heights of *Pinus densata* were similar for all forest types: the

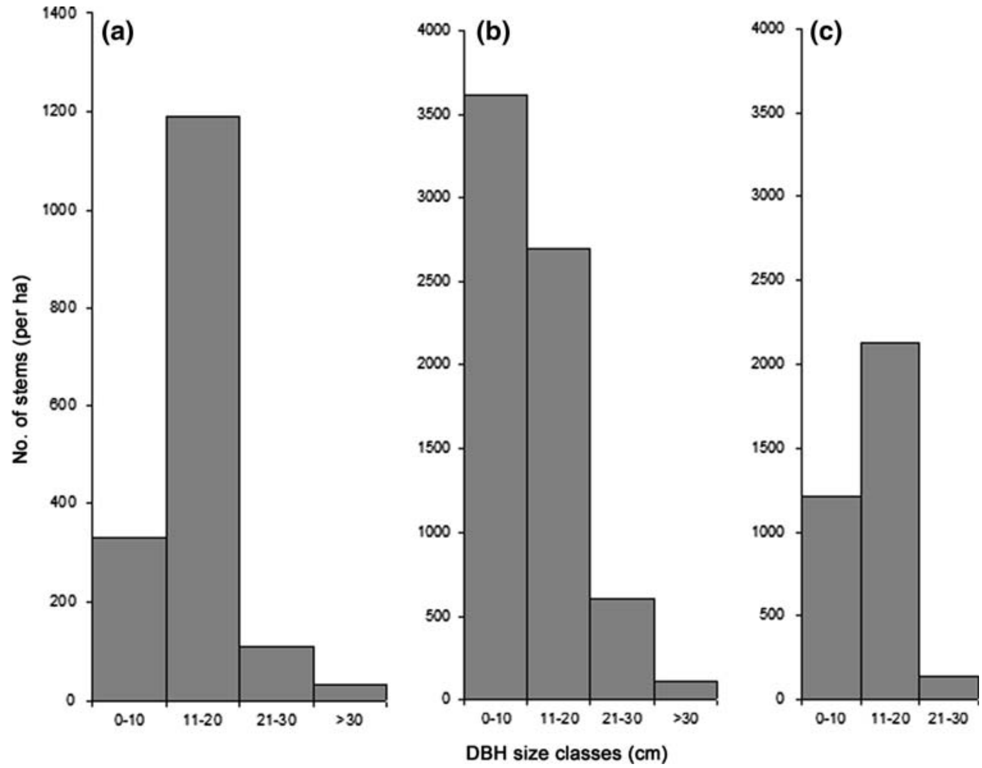

Fig. 3 The calculated size-class distributions of *Pinus densata* in Xiaozhongdian Valley for (a) protected forest, (b) moderately utilized forest, and (c) heavily-utilized forest. Note that the vertical scales are corrected for comparison of protected forest (n = 52 plots) with the other forest-use types (n = 156 plots)

average heights of the tallest individuals (15 tallest sightings for each forest site) were 18.5 m, 18.0 m, and 17.4 m for the protected, moderately utilized and heavily utilized forest types, respectively. For the heavily utilized sites the combined average basal areas (16 m^2ha^{-1}) and canopy covers (16.3 %) were reduced by about 50% by comparison with the protected forest (31.4 m^2ha^{-1}; 32.0%) and moderately utilized forest sites (34.2 m^2ha^{-1}; 27.4%). Within similar forest-use sites the only significant difference observed for stand characteristics was for canopy covers in the highly utilized forest type, where the average cover at Lengdu (Site 3C) (19.8%) was higher (p = 0.03) than the average canopy covers at Sites 3A and 3B (15.3% and 14.2%, respectively) (Table 2).

Table 3 Shannon diversity indices of the understorey strata for the variously utilized forest sites across Xiaozhongdian Valley

Study site(s)	Forest-use regime	Understorey structural diversity
Jisha (1A)	**Protected**	**1.49**
Jisha (2A)	Moderate	1.45
Zhiti (2B)	Moderate	1.42
Lengdu (2C)	Moderate	1.35
Combined (2A-2C)	**Moderate**	**1.44**
Jisha (3A)	Heavy	1.00
South of Jisha (3B)	Heavy	1.11
Lengdu (3C)	Heavy	1.13
Combined (3A-3C)	**Heavy**	**1.10**

Understorey Structural Diversity

Understorey structural diversity was greatest in the protected forest (H = 1.49) and moderately utilized forest (combined H = 1.44), and lowest in the heavily utilized forest (combined H = 1.10). Lower understorey diversities were apparent in all the heavily utilized sites (Table 3).

Litter and Woody Debris

The amounts of woody debris were relatively low in all sites; but woody debris was most common in the high-utilization forest sites and lowest in the moderately utilized forest sites (averaging 24.4 and 6.1 m^3ha^{-1}, respectively). Within the heavy utilized forest sites, there was a higher (p = 0.03) amount of woody debris in the site south of Jisha (3B) than the site at Lengdu (Site 3C). The highest proportion of large woody debris (LWD) (≥10 cm diameter) was found in the protected forest; none was found in any of the moderately utilized forest sites. Again, there was some variation in the amounts of LWD within the heavily utilized sites; slightly higher amounts (p = 0.04) were recorded in the site south of Jisha (Site 3B) compared with the site closer to Jisha Village (Site 3A). Litter depths (predominantly pine needles) were much greater in the

Table 4 Summary of mean (n = 5 replicates) volume of woody debris, percentage large woody debris (LWD), and litter depths (n = 52 replicates) ± SD for the forest study sites

Study site	Forest-use regime	Woody debris (m^3ha^{-1})	LWD (%)	Litter depth (mm)
Jisha (1)	Protected	15.9^a	43.4^e	$46.7^i \pm 6.2$
Jisha (2A)	Moderate	5.5^b	0.0^f	$50.2^i \pm 6.7$
Zhiti (2B)	Moderate	5.9^b	0.0^f	$44.8^i \pm 5.3$
Lengdu (2C)	Moderate	6.9^b	0.0^f	$49.9^i \pm 7.0$
Jisha (3A)	Heavy	23.9^{cd}	22.5^g	$10.6^j \pm 2.1$
South of Jisha (3B)	Heavy	27.8^d	29.9^h	$12.4^j \pm 3.0$
Lengdu (3C)	Heavy	21.7^c	26.9^{gh}	$13.6^j \pm 3.6$

Means within columns that are denoted with different superscripted letters are significantly different according to Tukey's test ($p < 0.05$)

Table 5 Shannon species diversity indices and the equitability or evenness of distribution (numbers in parenthesis) for various strata within the *Pinus densata* forest study sites in Xiaozhongdian Valley

Study site(s)	Forest-use regime	Understorey	Herb layer	Cryptogams	Total
Jisha (1)	**Protected**	**1.98 (0.80)**	**2.73 (0.91)**	**1.93 (0.73)**	**2.56 (0.66)**
Jisha (2A)	Moderate	1.33 (0.69)	2.77 (0.82)	1.33 (0.69)	2.23 (0.59)
Zhiti (2B)	Moderate	1.25 (0.77)	2.62 (0.82)	1.33 (0.69)	2.19 (0.61)
Lengdu (2C)	Moderate	1.38 (0.71)	1.96 (0.64)	1.31 (0.73)	2.19 (0.62)
Combined (2A-2C)	**Moderate**	**1.35 (0.68)**	**2.74 (0.77)**	**1.33 (0.68)**	**2.22 (0.59)**
Jisha (3A)	Heavy	0.98 (0.49)	3.19 (0.89)	1.00 (0.49)	2.23 (0.59)
South of Jisha (3B)	Heavy	1.05 (0.53)	3.44 (0.92)	1.03 (0.49)	2.39 (0.61)
Lengdu (3C)	Heavy	1.03 (0.60)	3.50 (0.89)	1.03 (0.52)	2.49 (0.62)
Combined (3A-3C)	**Heavy**	**1.02 (0.55)**	**3.36 (0.90)**	**1.03 (0.51)**	**2.44 (0.60)**

protected and moderately utilized forest sites than in the heavily-utilized forest (Table 4).

Species Richness and Diversity

According to Shannon's Index (H) and Evenness (E_H), overall species diversity was highest in the protected forest site (H = 2.56; E_H = 0.66), closely followed by the heavily utilized forest sites (combined H = 2.44; E_H = 0.60), and lowest in the moderately utilized forest sites (combined H = 2.22; E_H = 0.59) (Table 5). The protected forest also had the highest species diversity for all strata except the herb layer. Species richness, however, was greatest in the heavily utilized forest sites (a total of 55 species), followed by the protected forest (47 species) and moderately utilized forest sites (45 species) (Table 6). The relatively high species richness of the heavily utilized forest sites was due entirely to a higher number of herb species – this is reflected in the intra-strata diversity indices (Table 5).

Unique Species Distribution

The distribution of unique species further emphasizes the species diversity and richness data. The heavily utilized forest sites have the highest number of unique species (14), all of which are herbs. By comparison, the protected forest has 13 unique species evenly distributed between the understorey and the relatively rich cryptogamic flora. There are only three unique species in the moderately utilized forest sites (Table 7). For each forest-use type, a number of unique species were identified:

- Protected forest: (understorey) - *Elaeagnus* sp. *Ribes* sp., *Caragana franchetiana*, *Hydrangea* sp., *Sorbus* sp., *Smilax stans*; (cryptogams) - *Actinothuidium hookeri*, *Hypnum* sp. *Rhytidiadelphus triquetrus*, *Buellia* sp., *Lobaria* sp.
- Moderately utilized forest: (herb layer) - *Hemiphragma heterophyllum*, *Ixeris* sp., *Senecio* sp.
- Highly utilized forest: (herb layer) - *Anaphalis margaritacea*, *Anaphalis* sp., *Bupleurum* sp., *Gentiana* spp., *Kyllinga* sp., *Oxytropis* sp., *Thalictrum alpinum*, *Viola delavayi*, *Polygonum hookeri*.

Discussion

Human Impacts on the Pine Forests

In Tibetan areas of northwest Yunnan, Salick and others (2007) found that the long-term protection of sacred forests

Table 6 Species richness of the vegetation strata within each forest-use regime for the pine forest sites in the Xiaozhongdian Valley

Species richness				
Forest-use regime	Understorey	Herb layer	Cryptogams	Total
Protected (Site 1)	12	20	14	47
Moderate (Sites 2A, 2B, 2C)	8	27	9	45
Heavy (Sites 3A, 3B, 3C)	6	41	7	55

Note: species totals include the *Pinus densata* overstorey

Table 7 The number of species unique to each stratum within each forest-use regime for the pine forest sites in the Xiaozhongdian Valley

Unique species				
Forest-use regime	Understorey	Herb layer	Cryptogams	Total
Protected (Site 1)	6	1	6	13
Moderate (Sites 2A- 2C)	–	3	–	3
Heavy (Sites 3A- 3C)	–	14	–	14

Note: there were a total of 78 species recorded of which 25 were common to all three forest-use types

has preserved larger old growth trees, but has had no effect on understorey richness. It seems significant, however, that all the sites studied by Salick and others (2007) were exposed to some degree of resource extraction by local communities; as a result, the authors concluded that understorey plants in sacred and nonsacred areas do not differ ecologically since they are subject to similar anthropogenic and biotic pressures. Moreover, the authors speculated that results could be colored because the selection of sacred sites may inherently favor more complex, valuable or unusual forest types and regions. By contrast, in the Xiaozhongdian Valley we obtained a snapshot of some forest sites across a continuum of forest-use regimes within a single, simple forest type, which was exposed to distinctly differing degrees of resource extraction. While our data are limited, uniformity between forest-use sites shows that the intensity of human use affects the structure and floristics, not only of the canopy trees, but of all strata within the pine forests in the study sites.

The influence of wood harvesting on forests is often reflected in changes to structure rather than biomass (Tietema 1993), and this seems to be the case for the moderately utilized forest sites. The moderately utilized forests have similar basal areas and canopy covers to the protected forest, but their stand structures comprise smaller denser trees (see Fig. 3). By contrast, the reduction of biomass is obvious in the heavily utilized forest sites (3A, 3B, and 3C), which show classic signs of intensive cutting and disturbance, namely, the loss of basal area, simplification of the understorey, and loss of canopy cover (see Table 2). There was some variation within the heavily utilized sites in terms of canopy cover and amounts of woody debris (see Tables 2 and 3), but these differences were minor compared with the overall differences between forest-use types.

The structural changes observed in the heavily utilized forests are not particularly surprising given the heavy tree removal in these sites. However, the loss of canopy trees and understorey species also caused a reduction of ground litter cover (primarily pine needles) (Table 2), and this together with the high-light environment has stimulated the development of herbs on the forest floor in heavily utilized sites. Indeed, due to this species-rich herb layer, the ground strata of the highly utilized forest sites had the highest species diversities and richnesses of all our forest study sites (see Tables 5, 6, and 7).

In addition to greater light penetration, herb richness in the highly utilized forest sites was enhanced by animal grazing disturbance: of all the sites examined, grazing was most intense in these highly utilized areas. Species unique to the highly utilized forest patches included perennials well adapted to colonizing disturbed sites (e.g., *Anaphalis* spp., *Aster* spp., *Gentiana* spp., and *Polygonum hookeri*). The highly utilized forests are transforming into de facto grazing patches, but, local farmers expressed concern at the rise in nonpalatable plant species; therefore, doubts linger as to the long-term usefulness and diversity of these disturbed areas. For example, species such as *Potentilla fulgens* and *Euphorbia stracheyi* (which are of poor fodder value and characteristic of ruderal habitats and overgrazed pastures [Shen and others 2006]) were far more prolific in the highly utilized forest than in any of the other forest sites. The longevity of this herb-rich flora is uncertain, but, even in the absence of further disturbances, an increase in herb species for at least 4 to 7 years after logging has been noted in temperate conifer forests (Dyrness 1973, Sullivan and others 2001).

Despite having the highest overall species richness, it is significant that the highly utilized forest sites had the least understorey structural diversity, and the lowest species richness and diversity for both the understorey and cryptogams. Although definitive measures of forest health are elusive, understorey structural complexity and diversity are good indicators of forest ecosystem diversity – particularly in less species-rich environments (Neumann and Starlinger 2001, Sullivan and others 2001). Similarly, cryptogamic diversity is often positively correlated with high forest diversity and low disturbance (Jonsson and Jonsell 1999, Zechmeister and Moser 2001). Given these findings, our results suggest that cryptogamic richness and understorey complexity could be useful indicators for monitoring the impacts of collecting practices and resource use on the integrity of *Pinus densata* forests.

Woody debris also enhances both animal and cryptogamic diversity in many forest ecosystems (Jonsson and Jonsell 1999, Lindenmayer and others 2000). In the *Pinus densata* forests, the amounts of woody debris were generally low; the greatest amount found in our study (27.8 m^3ha^{-1} in the highly utilized forest Site 3B) is still an order of magnitude lower than the amounts found in temperate coniferous forests in North America (cf. Sullivan and others 2001). Moreover, in deference to the generally dry nature of the environment, virtually no soft or rotten wood debris was found. But, in the highly utilized sites, heavy logging activity did produce – at least in the short term – a relatively high amount of debris, due to the presence of trimmed limbs from felled trees. By comparison, the total amounts of debris (and in particular larger debris) were much reduced in the moderately utilized forest sites – in these sites tree felling was not extensive and villagers regularly collected fallen firewood. The low amounts of woody debris could in part explain the relatively low cryptogamic diversity in the moderately utilized forest sites, since fallen logs were seen to provide good cryptogam habitats in the protected cemetery forest.

The absence of woody debris may also affect animal distribution. Despite the lack of faunal studies in this region, anecdotal evidence suggests that the loss of woody debris and structural simplification of the forest is reducing the habitat for at least one animal – the Asian black bear (*Selenarctos thibetanus*). Certainly, our field observations show that the bears use woody debris and understorey species to construct dens and larders; thus, even the moderate use of forest could impact upon bear habitats.

Relevance for Local Village Forest Management

Chinese government policies have advocated the reduction or abolition of traditional forest collecting practices, claiming these activities reduce biodiversity and threaten water catchment integrity (Xu and Wilkes 2004, Xu and others 2004, 2005, Weyerhaeuser and others 2005). Our results support these concerns to the extent that species diversity is reduced in the moderately utilized forest (i.e., traditionally used forest) and, moreover, the reduction of woody debris can deleteriously affect the habitats of animals and less obvious lower plants. However, in terms of watershed integrity, the structural changes in the moderately utilized forest sites are relatively minor. While there were fewer large trees, these forests still maintained high canopy covers, litter covers, basal areas, and relatively well-developed understorey structures (see Tables 2 and 3); characteristics that are conducive to healthy forest watersheds (PATF 2004).

Similarly, the possible impacts of moderate forest use on the resources important to local communities appear to be relatively subtle. Importantly, while there is some simplification of the moderately utilized pine forests (by comparison with the protected forest), these sites still support NTFP, which are valuable to the local economy. Therefore – provided that the intensity of local collecting does not increase – it seems that traditional forest use does not represent an increasing threat to forest integrity in terms of sustainable village livelihoods. In the long-term, the Chinese government may look to enhance biodiversity by reducing rural collecting pressures on forests by consolidating rural populations into serviced towns. But for now, pragmatism dictates that rather than worrying about traditional forest activities (which have been undertaken for generations), the immediate conservation aim should be to reduce unsustainable practices, such as increased localized overcollection and tree removal.

For the local villages in Xiaozhongdian an immediate cause for concern is the increasing high-intensity use of collective forests. Although the species richness of the highly utilized patches was actually the highest observed, this was due to the high numbers of herbs and ruderal species: this high species diversity can, therefore, be superficially misleading. Indeed, the nature of the forest ecosystems in these highly utilized sites has been altered, degrading their value as future timber resources and NTFP habitats. In fact, according to current Chinese definitions, these patches of heavily used forest are no longer technically "forest" as the average tree cover has dropped below 20% (Miao and West 2004) (see Table 2). The floristics of these forest patches could regenerate within several decades, but a restoration of structural complexity – with its associated better quality timber, NTFP and wildlife habitat – will take much longer. How long this restoration may take is unknown, but valuable mushrooms like matsutake are very sensitive to habitat disturbance such as the loss of litter cover (Liu and others 1999), as was observed in the highly utilized sites. The loss of understorey shrubs may also be significant in long-term, since pruning of these (especially *Quercus* and *Betula* spp.) provide renewable sources of animal bedding and fertilizer for villages.

According to local villagers, the increased tree removal from the pine forests in the valley is recent. Indeed, image analysis suggests that the pine forest cover over the valley floor remained relatively stable from 1981 to 1999, with most forest degradation occurring in the commercially logged areas of the upper valley margins (Willson 2006). The recent increase of clearing activity in the fuelwood forest patches is confirmed by QuickBird satellite imagery showing only about 6 ha of highly utilized forest near Jisha (Site 3A) in November 2003 (see Fig. 2). Three years later, we observed that the area of high utilization in this site had increased to about 20 ha.

A reason to be somewhat pessimistic about the structural recovery of the highly disturbed forest patches is that even in the moderately utilized forest it is evident that stand structure is tending toward smaller denser trees (see Fig. 3). Another very significant factor is that the immediate pressures driving increased forest use are not likely to ease any time soon. The commercial logging ban has seen the rise of unofficial sales of poor quality firewood (Melick and others 2006), while the improved road access together with the ample supply of transport and power tools (in part a legacy from past logging activities), further mitigates more widespread timber removal from collective forests, both by locals and outsiders. Moreover, as noted earlier, the unavailability of traditional bamboo fencing materials has necessitated the use of more pine wood for village fencing. The fencing timber use problem is exacerbated by the fact that pine fencing is far less durable than bamboo (lasting 4–5 years as opposed to 10 years). At Jisha, these new fencing demands are estimated to have increased local pine wood removal as much as 35 fold in recent years (Melick and others 2006).

In terms of practical conservation management, the results of this study show the need to revert to more restrained community forestry practices in the high-utilization areas. Obvious management changes include reconsidering fencing materials and better policing of illegal wood extraction by outsiders. Eco-forestry and fencing alternative projects have been initiated and hopefully they will be encouraged and expanded. Other management changes may include allowing local communities to selectively log areas of protected higher quality timber forest to reduce pressure on the pine fuelwood forests (since revenue from a few good quality trees would equal that obtained from a large amount of pine wood) – it is important to remember that the local communities were never responsible for the logging industries, but are now paying the price for past over-exploitation by state interests. However, the lack of clear forest usufruct and tenure rights for local communities and the general administrative confusion continue to hinder coordinated on-the-ground forest management (Miao and West 2004, Xu and Ribot 2004).

Broader Considerations for Forest Monitoring and Management

While there is evidence that tree cover is increasing in China, there are concerns that the quality of forests may be decreasing (Sayer and Sun 2003, López-Pujol and others 2006, Willson 2006). In order to monitor the integrity of multiple-use forests our results suggest that it is important to consider subtle indicators, such as understorey development and cryptogamic diversity, rather than focusing solely on forest cover and species richness. At present, Chinese forest policies are driven largely by factors such as biomass and cover estimates rather than habitat diversity (Luo and others 2002, Weyerhaeuser and others 2005). This obsession with tree cover is understandable given the recent past, but forest quality is equally as important as forest cover, particularly for the local communities who depend heavily on forest products. For instance, we found that although the *Pinus densata* forests are not particularly rich, overuse can simplify and threaten NTFP habitats. Moreover, as alluded to earlier, the relatively high species richness of the utilized forests belies the fact that the structure and ecosystem functions of these areas may have been degraded.

Similar to our findings, other authors have recently noted the increasing pressures on collective forests, and queried the effectiveness of forest conservation policies in southwest China; however, these studies have generally been social and/or policy commentaries with little specific ecological monitoring data (e.g., Harkness 1998, Long and Zhou 2001, Winkler 2003, Xu and Ribot 2004, Weyerhaeuser and others 2005). The reasons for the lack of detailed ecological forest data are clear: many forest use studies rely on image interpretation and landscape modeling, but the effectiveness of these techniques are limited because the effects of forest harvesting are normally too fine scale to detect with satellite imagery (Tietema 1993, Shahabuddin and Prasad 2004). Even armed with the best imagery available it is impossible to delineate forest habitat complexity with much subtlety. For example, we found it extremely difficult trying to separate the moderately utilized and protected cemetery forest in Xiaozhongdian Valley using the detailed QuickBird satellite images, which have a resolution as fine as 60 cm (see Fig. 2). In a similar vein, when using remote-sensed imagery to assess land-use change in this region, Willson (2006) could not confidently classify large areas of transitional forest/shrub communities, despite their probable acceptance as “forest” in regular broader image analyses. These larger forest use studies could be bolstered with targeted ground truthing using the sort of forest quality indicators we have examined in the *Pinus densata* forests.

Study Limitations

While we detected significant ecological changes linked to the degree of forest use, the *Pinus densata* forests we studied are relatively simple. Moreover, we limited our study to a narrow topographic range; therefore, the effects of resource extraction from more diverse forest types would be expected to be more ecologically complex. The other major weakness for this sort of comparative analysis is the lack of good controls: there are simply not many forests in China that have not been affected by humans to some degree. For this study we were fortunate that the cemetery forest had – largely – survived the turbulent past. By the same token, however, the dearth of pristine forest sites shows that large tracts of relatively stable forests must have coexisted with generations of human use in rural China.

Since this study covered only 2 years we can only speculate about the speed and degree of forest changes. However, our speculation is supported by several sources. For example, the QuickBird image taken in 2003 (2.5 years before our initial field work) shows that the highly utilized forest patches were much smaller (i.e., Site 3A) or not evident at all (i.e., Sites 3B and 3C); this corroborates anecdotal reports of a recent rise in intensive forest use in response to increasing cash needs and improved road access. Similarly, for moderately used forests, village elders were able to identify sites which had a long history as traditional sources of mushrooms and/or sustainable firewood collection.

Despite the limitations, our findings have implications for other forest areas in southwest China. As is the case for Xiaozhongdian Valley, most rural communities in the mountain areas have been affected by the logging ban and are being targeted by new polices to improve road access and develop market opportunities (Hillman 2003, Xu and Wilkes 2004, Ma and others 2006). Moreover, forest utilization practices are broadly similar within the Tibetan communities in southwest China (Xu and Wilkes 2004) and a comparable trend of degraded local forests has also been noted in poor rural parts of Sichuan, which have faced similar problems from the loss of timber revenues (Winkler 2003). Thus, it seems likely that even in some of the most remote and least populated parts of China a significant number of collective forests are being subjected to the same pressures that we observed in this study.

Conclusions

Although there is growing pressure to protect forests in China, traditional collecting of forest resources remains important to poor rural communities. In fact, the collection of NTFP are becoming more important to many villagers, so conservation policies must balance biodiversity targets and the demarcation of protected areas against sustainable livelihoods. This study shows that attributes such as understorey complexity, litter cover and cryptogamic diversity are potentially useful indicators of forest ecosystem integrity in northwest Yunnan. Given that the effects of traditional human use on forests are difficult to monitor accurately, this sort of structural and qualitative ecological information should be considered when planning and implementing forest management policies.

While we have observed that small patches of collective forest are being logged unsustainably, our results suggest that the ongoing traditional collecting of forest resources by Tibetan villages in northwest Yunnan does not pose an increasing threat to forest integrity in terms of catchment and NTFP habitat health. However, until recently village forests only supported the resource demands of local communities, but now, as the markets for forest products are commercialized, forest managers need ways to monitor the possible over-exploitation of these forest ecosystems. This ongoing monitoring is even more important given the confusion and uncertainty surrounding forest governance and usufruct rights in China. With changed socio-economic conditions in the future, it may be possible to enhance biodiversity by reducing rural collecting practices, but for now we suggest that rather than trying, ineffectively, to lock forests away from local users, a more pragmatic conservation strategy is to ensure that traditional forest collecting practices remain sustainable.

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