Comparison of forest stand characteristics and species diversity indices under different human impacts along an altitudinal gradient

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Various disturbances and ecological successional processes shape the structure of forests and affect biodiversity. We examined the forests over a 7400 km^2 area in the Upper Min River watershed in Sichuan under different levels of human disturbance. This mountainous watershed represents a transitional landscape between the Qinghai-Tibet plateau and the Sichuan basin, with elevations ranging from 900 m to 5700 m. The watershed is degraded due to deforestation and soil degradation caused by natural and anthropogenic disturbances. According to different levels of human impact, the sample sites were divided into four classes: 1) near-natural forests, 2) selectively logged forests, 3) natural regeneration forests (after clear-cut), and 4) plantations. At different elevations, following quantitative characteristics were analysed: stand volume, basal area, weighted diameter, weighted height, and 7 biodiversity indices of tree species. The results showed that the structure of forest stands was characterized by a large number of seedlings and saplings. The near-natural forest had a significantly higher stand volume and basal area than the other managed stands. The four levels of human impact resulted in different abundance, evenness and richness of tree species along the altitudinal gradient. Explanatory variables, such as volume and weighted diameter, significantly contributed to the models for discrimination of stands under different human impacts. The result implies that near-natural forests, with their large stand volumes and biodiversity, can be used as references when developing strategies for forest restoration.

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Introduction

A comparison of stand structure between near-natural and managed forests can provide a reference for sustainable forest management and restoration of degraded forests. Vertical and horizontal forest structure characteristics that reveal the changes caused by disturbances have been studied in different ecosystems, ranging from tropical forests to boreal forests (Engelmark & Hytteborn 1999; Uuttera et al. 2000; Franklin et al. 2002; Kuuluvainen 2002; Lilja & Kuuluvainen 2005). According to different levels of human disturbances, forests are usually divided into different classes, such as near-natural forests, selectively logged forests, and managed forests (Lilja & Kuuluvainen 2005). Disturbances and structural development of natural forest ecosystems have been studied to meet the challenge of managing the forest stand structure for maintaining the biological diversity while sustaining the forest productivity (Franklin et al. 2002). Structure elements used to describe spatial patterns are the vertical canopy distribution, the horizontal structure distribution (forest texture, forest mosaic and patch patterns), and gaps and anti-gaps. Individual stand structure can be described by such variables as species, density, composition, volumes of living trees and dead wood, diameter, height, and tree species diversity (Franklin et al. 2002).

The Upper Min River (UMR) watershed is located in the upper Yangtze River basin with Subtropical, Temperate, Subalpine, Boreal, and Arctic zones. Anthropogenic impacts on forest stand have not been studied before in this watershed. Despite their limited accessibility, forests in this watershed have been utilized for a very long time. The utilization of natural forests began here already about 4000 years ago when the Qiang tribes moved into the basin from the northwest of China. However, most natural forests remained undisturbed by human activities until about 600 years ago when they still covered 50% of the land area (Wu 2000; Li et al. 2006). Since then, the forest cover has decreased gradually as a result of conversion to agricultural land, clear-cut harvesting and selectively logging (EPIGPA 1990; Winkler 1996; Wu et al. 2003; Wang et al. 2004b). Rehabilitation activities used included aerial seeding, limiting of access to mountain areas, and planting of seedlings. The forest structure is largely influenced by anthropogenic disturbances of clear-cutting, selective logging, afforestation, and other activities, during the last five decades.

Although there are increasing numbers of studies dealing with the structure of forests and biodiversity under different influences (Bradshaw & Hannon 1992; Attiwill 1994; Kuuluvainen et al. 1996; White & Walker 1997; Boncina 2000; Wirth et al. 2002), the emphasis has generally been put on natural processes, such as endogenous and natural exogenous disturbances in carefully selected forests. Studies are thus needed to deepen the knowledge of "naturalness". Huston (1994) regarded the patterns of species richness as being determined by the interaction of disturbance with environmental gradients and competitive exclusion. The spatial extent, intensity, frequency of human induced disturbance and its effect on species are highly variable (Wohlgemuth et al. 2002). Generally, species richness declines with increasing elevation (Stevens 1992). This study was based on a large number of sample sites in the UMR watershed that had a wide environmental gradient. The forest classes of human impact were recorded in the field, according to given criteria (Boncina 2000; Franklin et al. 2002; Lilja & Kuuluvainen 2005) and to the effect of local land-use history and forest management. The sample sites were also classified into four altitudinal ranges according to the recorded elevation and vegetation zones (Editorial Board of Sichuan Vegetation 1980).

The aim of research was to study whether the near-natural forest could be used as a reference when decided the strategies and objectives of forest restoration. The specific aim was to compare the volume, basal area, weighted diameter, weighted height, and biodiversity indices and evenness of the forests under different levels of human disturbances along an altitudinal gradient in the UMR watershed. In addition, an attempt was made to quantify the human impact on forest stand, and to test possible numerical indicators selected for detecting the human impact.

Material and methods

Study area

The selected study area, with an area of 7432 km^2, is located in the UMR watershed, in the Upper Yangtze River basin, between 31º–34º N, 103º–104º E. The climate is characterized by the southeast and southwest monsoons. This mountainous watershed represents a transitional landscape between the Qinghai-Tibet plateau and the Sichuan basin, with elevations ranging from 900 m to 5700 m. The most common species in our study area at different elevations were: *Pinus armandii* and *Robinia pseudoacacia* (an introduced species) (1300–2200 m), *Quercus dentata* and *Picea asperata* (2200–2600 m), *Picea asperata* and *Betula pendula* (2600–3200 m), *Picea asperata*, *Betula pendula* and *Abies fabri* (3200–3600 m), *Picea likiangensis* var. *rubescens*, *Abies fabri* and *Picea asperata* (3600–5700 m) (Zhou et al. 2008). According to different levels of human impact, four classes of forests can be observed in the UMR watershed: 1) near-natural forests (forests that are characterized by lowest intervention and natural forest regeneration, without signs of management, cf. Fig. 1A); 2) selectively logged forests (with low number of large trees, and with usually visible stumps, Fig. 1B); 3) natural regeneration forests after clear-cut (forests that have been clear cut, leaving no large trees, Fig. 1C); and 4) plantations (planted trees in rows or arrays, Fig. 1D).

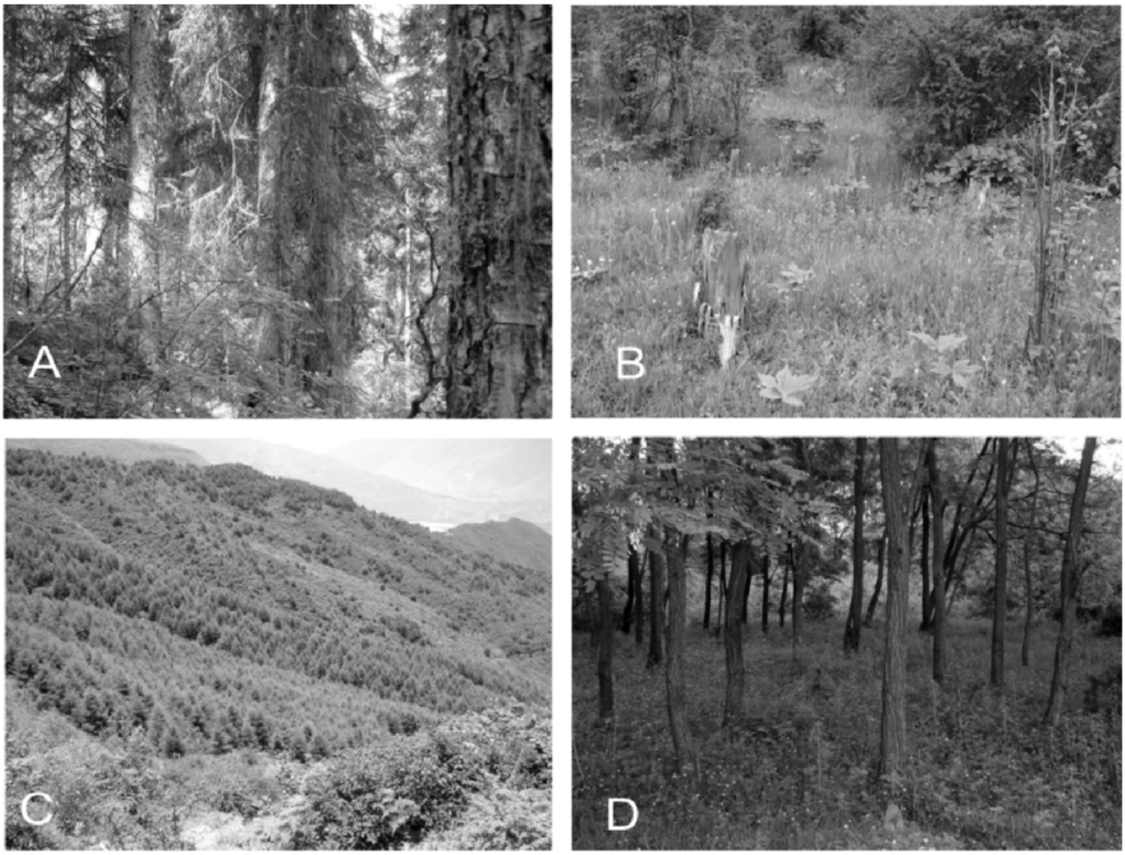

Fig. 1. Examples of four different levels of human impact: near natural forest (A), selectively logged forest (B), natural regeneration forest (after clear-cut) (C), and plantation (D). (Photo Ping Zhou, 2004).

The area has been inhabited for thousands of years by numerous ethnic groups, such as the Han, Tibetans, and Qiang. The total population of the area in 2000 was 385,300, giving a population density of 16 people per square kilometre. The main source of livelihood is agriculture (National Bureau of Statistics of China 2002). During the period of nomad immigration (A.D. 220–649), the upper limit of the subalpine forest moved downward and was replaced by the expanding subalpine meadows (Fan & Zhao 2003). With an increasing number of farmers, much forest has gradually been converted to farmland. Modern commercial logging started at the beginning of the 20th century; the first logging company in the UMR basin was founded in 1921 (Winkler 1996). The forest cover fell rapidly from 30% in the 1950s to around 15% in the 1970s. From the 1950s until 1998, the deforestation was severe due to commercial clear-cut harvesting (EPIGPA 1990) and the "Big Leap Forward" campaign in which massive areas of natural forests were logged for steel making (Wang et al. 2004b). However, the forest cover increased a little, to 18.8%, in the 1980s and to 21% by 2004, due to the national-scale reforestation and afforestation efforts in China that in many areas restored the forests from the 1970s up to the early 2000s (Wang et al. 2004b; Kauppi et al. 2006). In addition, other national programs have contributed to improving the state of the forests in the UMR watershed. These programs included the conservation of forests in the upper and middle reaches of the Yangtze River in 1989, a natural forest logging ban in 1998, and the "Grain for Green" program since 2000 which has converted farmlands either to forest or to grassland. Today, practically no natural forest untouched by human activity exists.

Field work

A field inventory was done by stratified sampling with the aid of GPS to fix the field sample plots in 2004. The inventory plots were randomly located in the middle and upper reaches of the UMR watershed (Fig. 2). A clustered systematic eight-plot sampling method made it possible to measure at least eight plots in one cluster per day within certain walking distance (Tokola & Shrestha 1999). Each plot consisted of a maximum of five concentric rectangular subplots that were adjusted in size for each community. Zhou et al. (2008) have separately described the stratified subplots. The subplot sizes were:

- 2 m × 2 m for seedlings with height (H) ≤ 1.3 m
- 5 m × 5 m for saplings with H > 1.3 m, DBH ≤ 10 cm
- 10 m × 10 m for trees with 10 cm < DBH ≤ 20 cm
- 20 m × 20 m for trees with 20 cm < DBH ≤ 40 cm
- 30 m × 30 m for trees with DBH > 40 cm.

Within each plot, recordings were made on GPS coordinates, forest classes of human impact, tree species, diameters at breast height, sample tree heights, tree quality (healthy, damaged, dead), elevation and slope. Sample tree heights were measured with a clinometer. The missing tree heights were estimated using a height curve. The height curve was computed using a two-parameter regression model for each species by plot separately. Tree volumes were computed for each tree species using volume functions (Zhang 2003; Wang et al. 2004a).

Altogether, 271 of the total of 625 randomly placed plots had tree cover. Of the 271 sample plots, 59 located in the range of 1300–2200 m, 87 in 2200–2600 m, 61 in 2600–3200 m, and 64 in 3200–3600 m (Table 1). The vegetation spectrum extended from subtropical evergreen broadleaved forests to boreal forests. The sampled plots have slopes between 0 to 75 degrees. Table 1 also shows plots information on slope, canopy closure and maximum tree height at four different altitudinal gradients.

Data analysis

The forest stand was characterized by computing the volume including living stem volume and standing dead wood, basal area, weighted diameter and height (weighted by stratum area), and the tree species diversity indices (Tmi LTV Forest 2004). Volume, basal area, weighted diameter and height were calculated for each plot. The species diversity indices was described using the Shannon, Simpson, McIntosh and Berger-Parker's indices, and Evenness, Alpha, and Q-stat criteria (Peet 1974; Kempton & Taylor 1976; Magurran 1988). The Shannon index takes into account the evenness of the abundance of species, while Simpson's index is less sensitive to the species richness but more sensitive to the most abundant species. The McIntosh's index is a dominance measure, as is the Berger-Parker's index. Evenness measures the similarity of the abundances of different species. Q-stat is an index based on the slope of a cumulative species curve in the mid-range of abundance. Stand characteristics and biodiversity indices were compared under different levels of human impact along four altitudinal gradients using analysis of variance (ANOVA), and Tamhane's T2 was used for testing differences in means (Norusis 2005).

To test the possible numerical indicators to distinguish the forest classes affected by human dis-

Table 1. Information on sampled plots.

Altitude (m)	No. of plots	Mean slope (degree)	Mean canopy closure (%)	Maximum tree height (m)
1300–2200	59	25	31	34
2200–2600	87	33	41	26
2600–3200	61	31	32	32
3200–3600	64	26	39	42

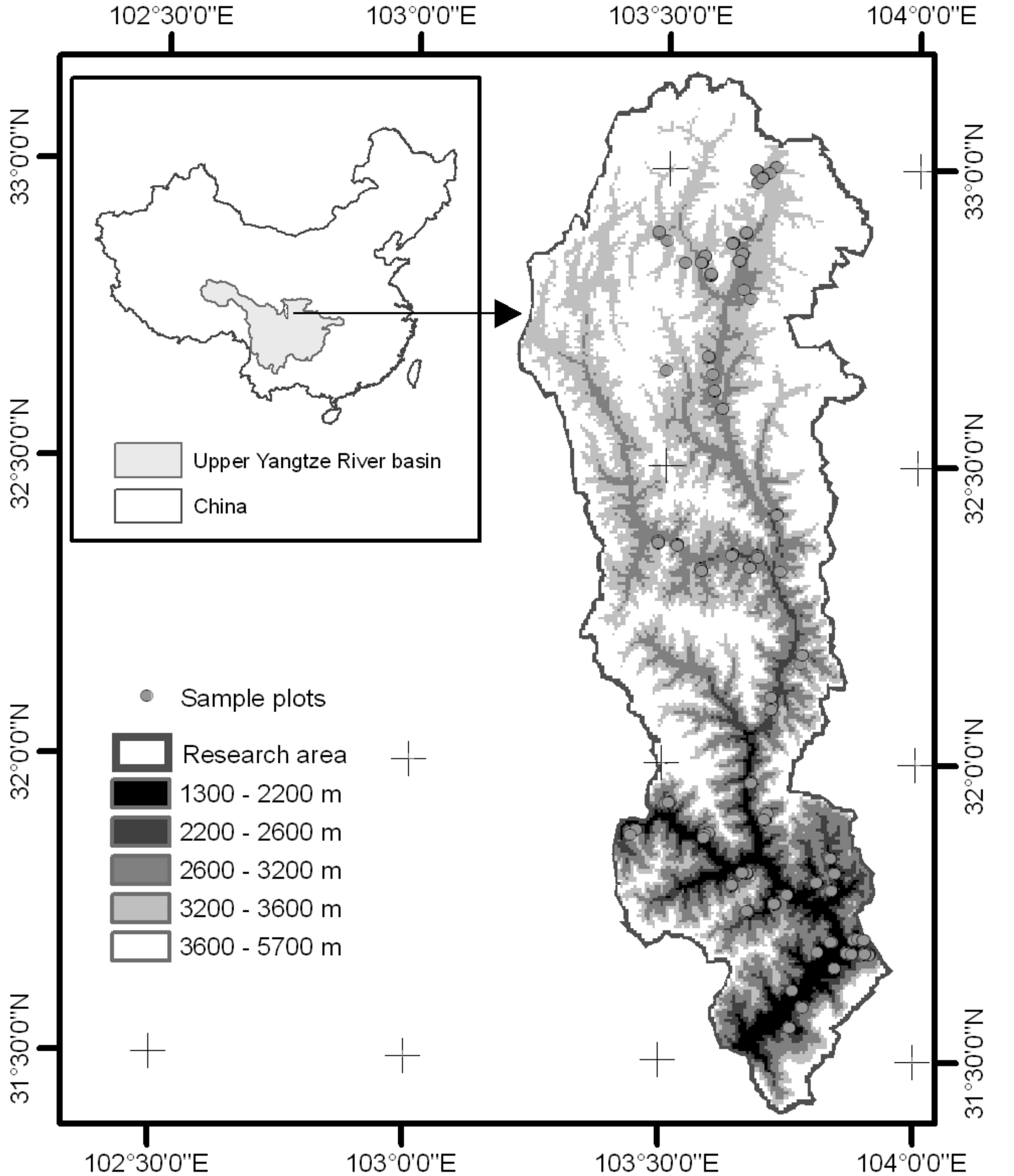

Fig. 2. Location of the research area in the Upper Yangtze River Basin, China and the sample plots.

turbances, Linear Discriminant Analysis (LDA) was performed to calculate the coefficient of the linear combination of variables in different human impact classes. For LDA classification, the pooled within-class covariance matrix and predictor variables from samples were used to build classification equations or discriminant functions for each class (Duda & Hart 1973; Tabachnick & Fidell

1989). The classification functions were created to classify cases into groups. A case is predicted as being a member of the group in which the value of its linear classification function is largest:

Y = f (Volume, basal area, weighted diameter, weighted height, Shannon index, McIntosh, Simpson, Berger-Parker, Evenness, Alpha, Q-stat).

The analysis was performed using SPSS 13 for windows statistical software. All of these eleven variables were selected as independents. Prior probabilities were computed from group sizes. Wilks's Lambda, which is a parameter for stepwise discriminant analysis, was used to choose variables for entry into the classification function. Only the variable that significantly minimized the overall Wilks's Lambda was entered to the model at each step. In addition, the statistical and classification results were generated for both selected and unselected cases with a random Bernoulli selection. With cross-validation, each case in the analysis was classified by the functions derived from all other cases.

Results

Frequencies of stand variables

The frequency distributions of stand volume, basal area, weighted diameter and weighted height showed a monotonic decrease pattern with an increasing value of the variable (Fig. 3). The standardized skewness and standardized kurtosis, with values far outside the range of –2 to +2, indicated that the stand variables significantly differed from normal distribution. Plots with a stand volume of less than 100 m^3 ha^{-1} dominated, counting for 84.1% of the total plots. This indicated that the most of the present forests had low biomass productivity. The plots with a basal area less than 20 m^2 ha^{-1} accounted for 87.1%, which indicated that gaps existed in the stands and the density of large trees in them was low. In addition, 61.3% of the plots had a weighted diameter less than 20 cm, and 67.5% of the plots had a weighted height less than 10 m. It implied that the present structure was characterized by a relatively large number of seedlings and saplings.

Stand variables as affected by human impact along altitudinal gradient

The mean of stand variables for each of the four levels of human impact were significantly different ($p < 0.01$). When near-natural forests was compared to plantations, natural regeneration forests, and selectively logged forests, more variation and significantly higher value showed in the volume and basal area of the former than those of the latter (Fig. 4). The near-natural forests had a mean stand volume of 203.5 m^3 ha^{-1}, and an average volume of standing dead trees (snags) of 37.8 m^3 ha^{-1}. Selectively logged forests reached a stand volume of 50.3 m^3 ha^{-1} (snags 1.5 m^3 ha^{-1}), regeneration forests after clear-cut 30.9 m^3 ha^{-1} (snags 0.4 m^3 ha^{-1}), and plantations 49.2 m^3 ha^{-1} (snags 2.4 m^3 ha^{-1}). The mean stand volume in near-natural forests was significantly larger than that in the other types of forests ($p < 0.05$). No significant differences in this volume could be found between selectively logged forests, plantations and natural regeneration forests after clear-cutting. The average basal area was significantly larger in near-natural forest than in the other forest classes ($p < 0.05$). No significant difference was found between near-natural forest and selectively logged forest in weighted diameter or weighted height.

Stand variables also varied significantly along four altitudinal gradients. The mean volume in RF showed an increasing trend with altitudinal gradient, for example 2.66 m^3 ha^{-1} (1300–2200 m), 22.08 m^3 ha^{-1} (2200–2600 m), 36.59 m^3 ha^{-1} (2600–3200 m), and 41.51 m^3 ha^{-1} (3200–3600 m) respectively at each altitudinal range. The volume in SF showed a similar trend. In contrast to it, the mean volume in PF decreased with the gradient, for instance 64.57 m^3 ha^{-1} at lower elevation, and 24.14 m^3 ha^{-1} and 6.06 m^3 ha^{-1} at higher elevation. Near natural forests with highest volume and basal area only remained in the remote areas of higher elevations (> 2600 m). The basal area, weighted diameter and weighted height also exhibited the similar pattern with volume along altitudinal gradient.

Species diversity indices and evenness

Species diversity, which considers two aspects, richness and evenness, is commonly used as a measure for forest structure. Shannon's index, Simpson's index, Alpha, Q-stat, Berger-Parker's index, McIntosh's index and Evenness showed sig-

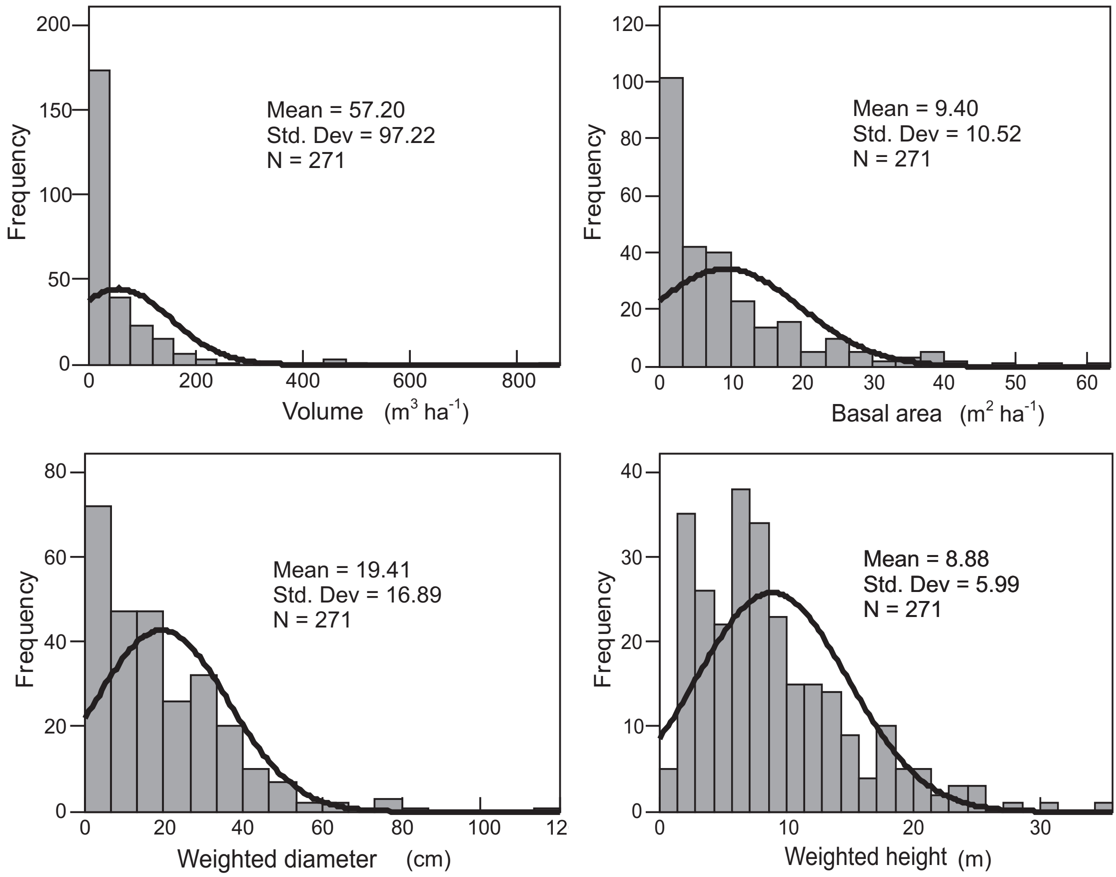

Fig. 3. Frequency distributions for volume, basal area, weighted diameter and weighted height. Columns in each graph show the number of data values in each interval. The normal curve is also displayed in each chart.

nificant differences among the four human impact classes of forests especially when studied at different elevations (Table 2). This result also suggests that the four levels of human impact resulted in different abundance, degree of evenness and richness of tree species. Below 2200 m, SF showed a significantly lower evenness and richness of tree species than RF indicated by the Shannon index, evenness, and Alpha. Between 2200 m and 2600 m, a similar result showed by the Shannon index, evenness, and Q-stat. NF showed a higher species dominance than the other managed forests indicated by the McIntosh index at elevations higher than 2600 m. At the highest elevation (3200–3600 m), only McIntosh's index was significantly higher for the near-natural forests than that for the other classes ($p < 0.001$), while the other indices showed little variation. This indicated that different degrees of human impact did not have much effect on the species biodiversity, except for the number of big trees at elevations higher than 3200 m. The latter result was influenced by the fact that McIntosh's index was sensitive to sample size and the plot size in stratified sampling.

Biodiversity showed different patterns along the altitudinal gradient. With the increasing elevation, the tree species dominance tended to increase both in the near-natural forests and in the naturally regenerated forests. In contrast, with increasing elevation, the species richness tended to decrease in the near-natural forests (Table 2). This is probably due to the combined effect of human impact and

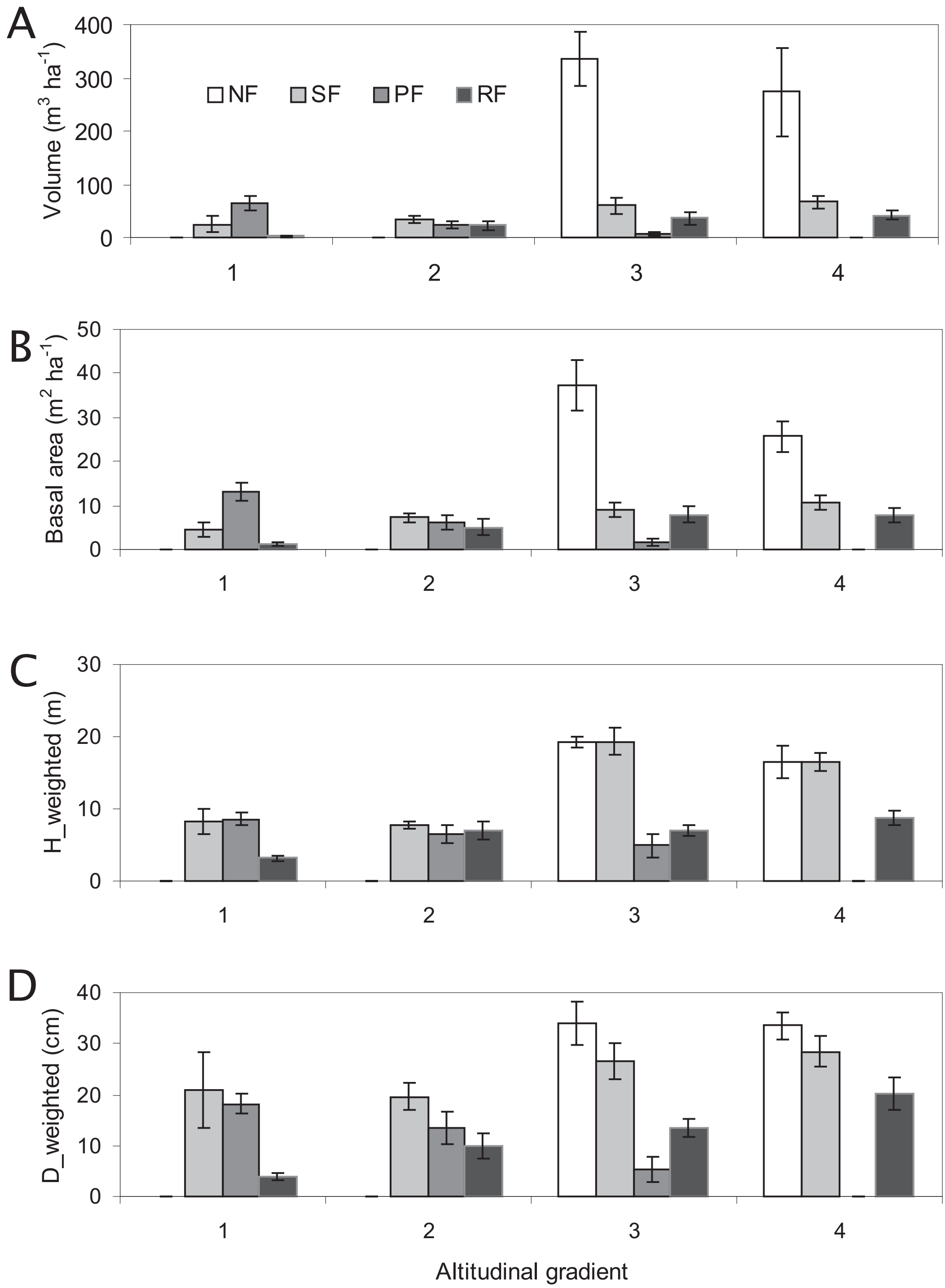

Fig. 4. Comparison of forest characteristics (volume, basal area, weighted diameter and weighted height) for different types of forests as related to human impact along four altitudinal gradients. NF: near-natural forest, PF: plantation, RF: natural regeneration forest (after clear-cut), SF: selectively logged forest. 1: 1300–2200 m, 2: 2200–2600 m, 3: 2600–3200 m, 4: 3200–3600 m.

Table 2. Biodiversity indices for trees in four classes of forest as determined by human impact. (Mean ± SE).

Elevation	Indices	NF (n = 24)	SF (n = 111)	PF (n = 56)	RF (n = 80)	Sig.†
1300–2200 m	Shannon	–	0.12 ± 0.06	0.36 ± 0.06	0.74 ± 0.13	0.001
	McIntosh	–	5.34 ± 0.84	8.2 ± 1.3	3.9 ± 0.9	0.212
	Simpson	–	0.93 ± 0.04	0.78 ± 0.04	0.57 ± 0.07	0.004
	Evenness	–	0.15 ± 0.08	0.43 ± 0.07	0.64 ± 0.10	0.011
	Berger-Parker	–	0.96 ± 0.02	0.83 ± 0.03	0.65 ± 0.07	0.004
	Alpha	–	0.80 ± 0.17	0.90 ± 0.10	2.72 ± 0.88	0.001
	Q-stat	–	0.46 ± 0.29	1.01 ± 0.21	1.69 ± 0.31	0.129
2200–2600 m	Shannon	–	0.37 ± 0.05	0.52 ± 0.10	0.73 ± 0.15	0.021
	McIntosh	–	3.88 ± 0.50	4.7 ± 0.8	4.6 ± 0.4	0.865
	Simpson	–	0.75 ± 0.03	0.67 ± 0.06	0.58 ± 0.08	0.118
	Evenness	–	0.39 ± 0.05	0.62 ± 0.11	0.67 ± 0.10	0.046
	Berger-Parker	–	0.80 ± 0.03	0.73 ± 0.06	0.64 ± 0.08	0.132
	Alpha	–	1.67 ± 0.24	1.58 ± 0.25	1.85 ± 0.44	0.980
	Q-stat	–	0.83 ± 0.14	0.97 ± 0.24	2.01 ± 0.63	0.017
2600–3200 m	Shannon	0.22 ± 0.14	0.70 ± 0.10	–	0.34 ± 0.07	0.001
	McIntosh	22.9 ± 3.8	5.3 ± 0.9	3.20 ± 0.73	5.8 ± 0.9	0.001
	Simpson	0.86 ± 0.09	0.59 ± 0.06	–	0.79 ± 0.04	0.002
	Evenness	0.25 ± 0.18	0.65 ± 0.08	–	0.36 ± 0.07	0.002
	Berger-Parker	0.9 ± 0.07	0.67 ± 0.05	–	0.84 ± 0.04	0.002
	Alpha	0.46 ± 0.29	1.89 ± 0.26	0.63 ± 0.10	1.07 ± 0.15	0.001
	Q-stat	1.04 ± 0.91	1.40 ± 0.23	–	1.32 ± 0.34	0.340
3200–3600 m	Shannon	0.39 ± 0.14	0.26 ± 0.07	–	0.18 ± 0.07	0.293
	McIntosh	13.5 ± 2.0	5.8 ± 0.8	–	5.1 ± 1.0	0.001
	Simpson	0.78 ± 0.76	0.85 ± 0.04	–	0.89 ± 0.04	0.438
	Evenness	0.36 ± 0.11	0.27 ± 0.07	–	0.18 ± 0.07	0.390
	Berger-Parker	0.85 ± 0.05	0.89 ± 0.32	–	0.91 ± 0.37	0.712
	Alpha	0.77 ± 0.24	1.01 ± 0.22	–	0.96 ± 0.24	0.823
	Q-stat	1.72 ± 0.59	0.95 ± 0.36	–	0.38 ± 0.16	0.059

† t test.

environmental gradients. The severity of human disturbance showed to be higher at lower elevations, because no near-natural forests were observed in areas below 2600 m, while plantations were mainly found at elevations below 2600 m.

Estimation of human impact using linear discriminant analysis

The constructed discriminant function contained estimates of the coefficients and a constant for each forest impact class (Table 3). A case was predicted as being a member of the class in which the value of its function was the highest. When a stepwise inclusion of independent variables was applied, all diversity indices were found insignificant. As far as the four levels of human impact were considered, the volume and weighted diameter variables significantly minimized Wilks's Lambda ($p < 0.001$) and thus constructed the function. However, only 47.8% of the selected original grouped cases, 46.5% of the unselected original grouped cases, and 47.4% of the selected cross-validated grouped cases were correctly classified. After reclassifying the selectively logged forests and natural regeneration stands as one class, and thus taking only three classes into consideration, the volume alone could be significantly entered to construct the function ($p < 0.01$). It now showed that 71.1% of the selected original grouped cases, 76.7% of the unselected original grouped cases, and 71.1% the selected cross-validated grouped cases were correctly classified. Finally, when we only took two classes – the near-natural forests and the other forests as one combined class – into consideration, the volume could be significantly entered to construct the discriminant function ($p < 0.001$). A classification test now showed that 90.4% of the selected original grouped cases, 95.3% of the unselected original grouped cases, and 90.4% of the selected cross-validated grouped cases were correctly classified.

Discussion

The pattern of stand variables

Most of the forests were subjected to heavy human impact. Near natural forests with least human disturbances were only remaining on the remote areas above 2600 m. Stand variables such as volume, basal area, weighted diameter and weighted height increased with altitudinal gradient in selectively logged forests and naturally regenerated forests after clear-cut, while those variables in plantations decreased along altitudinal gradient. This was probably due to the heavier human disturbances at lower elevation.

The frequency distribution of stand volume confirmed that most of the forests had a low volume. The average stand volume in selectively logged forests was only 50.3 m^3 ha^{-1}, which was much smaller than the 232 m^3 ha^{-1} found in selectively logged forest in Kuhmo, Finland, used as comparison (Lilja & Kuuluvainen 2005). This was explained by the fact that forests in the UMR watershed were heavily logged and silviculture measures such as seedlings planting or forest tending were lacking (EPIGPA 1990). In comparison, the average stem volume in living trees of the near-natural forests in the study area was 203.5 m^3 ha^{-1}, which was at the same level as that in the middle boreal vegetation zone of NW Europe. For example, Uotila et al. (2001) found 198–223 m^3 ha^{-1} of stem volume in living trees in semi-natural stands in eastern Fennoscandia. Lilja and Kuuluvainen (2005) also found a volume of 210 m^3 ha^{-1} in living trees in near-natural boreal forests in Kuhmo, Finland.

Meanwhile, near-natural forests in the study area showed a significantly higher volume of snags than the other types of managed forests. The dead wood succession and a continuum of volumes and decay stages are probably among the most essential characteristics of near-natural forests (Lilja et al. 2006). A lack of dead wood in managed forests

Table 3. Linear discriminate functions for classification of stands with different human impact.

Human impact classes	Classification functions	Proportion of correct classification (%)		
		S[a]	U[b]	V[c]
1. NF	$Y_1 = 0.019 \times \text{Volume} + 0.68 \times \text{Weighted Diameter} - 5.326$	47.8	46.5	47.4
2. SF	$Y_2 = -0.002 \times \text{Volume} + 0.117 \times \text{Weighted Diameter} - 2.338$			
3. PF	$Y_3 = 0.001 \times \text{Volume} + 0.071 \times \text{Weighted Diameter} - 2.000$			
4. RF	$Y_4 = -0.001 \times \text{Volume} + 0.071 \times \text{Weighted Diameter} - 1.875$			
a. NF	$Y_a = 0.024 \times \text{Volume} - 4.824$	71.1	76.7	71.1
b. SF+RF	$Y_b = 0.006 \times \text{Volume} - 0.591$			
c. PF	$Y_c = 0.006 \times \text{Volume} - 1.562$			
β. NF	$Y_\beta = 0.024 \times \text{Volume} - 4.873$	90.4	95.3	90.4
δ. SF+RF+PF	$Y_\delta = 0.006 \times \text{Volume} - 0.271$			

[a] Selected original cases correctly classified.
[b] Unselected original cases correctly classified.
[c] Selected cross-validated cases correctly classified.

is often a major problem for maintaining biodiversity (Siitonen 2001). Our results suggested that the near-natural forest in the UMR watershed has greater volumes of both living trees and dead wood than the other classes of managed forests. The near-natural forest could thus be used as a benchmark for forest restoration and management, especially in a case like UMR watershed where forests undisturbed by man are absent. Specific restoration and management action could create similar near-natural structures by planting suitable successional tree species and killing some living trees to create snags. Reforested plantation stands in the present case had a higher volume than the natural regeneration stands after clear-cutting, which demonstrated that plantations can accelerate stand biomass accumulation. Furthermore, planting diverse species can accelerate the restoration of biodiversity and increase ecosystem stability (Ren et al. 2007).

The pattern in weighted diameter distribution showed that around half of the forests in the UMR watershed had an abundant occurrence of small trees. This was due to measures of reforestation and conservation that had been carried out recently (Ye et al. 2003; Wang et al. 2004b). Constantly with the growth of trees and stand development the forest structure changes from one dominated by young trees to another dominated by mature trees. As a result, the stocking volume will have a tendency to increase. This pattern has already been documented in natural or near-natural pine-dominated stands in NW Europe (Rouvinen & Kuuluvainen 2005) and in primary tropical forests (UNESCO/UNEP/FAO 1978). In the UMR watershed, natural regeneration and tree planting could be solutions to achieve an efficient restoration. To achieve a better and sustainable situation, methods combining social, economic and ecological aspects must also be considered and utilised.

The pattern of biodiversity indices

At certain soil and climatic conditions, species diversity are usually affected by the biological events such as gap dynamics, natural hazards such as landslides, fire, and human induced disturbances such as clear cutting or selective cutting (Wohlgemuth et al. 2002). As far as anthropogenic disturbance at different elevation range was analyzed, four levels of human impact resulted in different patterns of species diversity along an altitudinal gradient. Many of the features generally related to disturbance can be addressed as dominance, evenness and richness change. In the present study, the dominance of tree species in the near-natural forests, calculated as McIntosh's index, was significantly higher than that in the other classes of forests. Wohlgemuth et al. (2002) also concluded that "the dominance of a few species may be high with low disturbance rates". We found that the forests naturally regenerated after clear cutting showed a higher species richness below 2600 m. The reason for such a situation is probably a recruitment of seedlings in large gaps after clear-cut. In addition to the human impact, the altitudinal factor also showed a strong effect on tree species richness and dominance. The tree species richness exhibited a declining trend with an increasing altitude in the near-natural forests. This is in agreement with results obtained from many studies (reviewed by Stevens 1992; Ren et al. 2006). In the present study, the human impact had little effect on tree species diversity indices at high elevations, as indicated by the fact that most diversity indices showed no significant difference above 3200 m elevation. The result indicated that the forest tended to be more resilient at higher elevations. It also implied that the severity of disturbances was higher at lower elevations.

Indicators of stand classification

Results of the discriminant analysis confirmed that the human impact can be estimated by variables describing forest structure. However, it is difficult to distinguish all stand conditions under different degrees of human impact by discriminant functions alone, because the different classes of forests, such as the selectively logged, naturally regenerated or planted forests, also have similarities in structure and species diversity indices. Nevertheless, the stand volume can be used as an indicator for classifying a stand as near-natural forest, plantation, or other types of managed forest in this study. In the UMR watershed, the stand volume could alone be used to distinguish whether a stand belongs to near-natural forests or managed forests. Our study on classification of forests by stand structure indicated that the near-natural forest was clearly distinguishable by its volume in the UMR watershed. It implied that earlier silvicultural systems have commonly lacked the aim of maintaining the natural stand dynamics and structure of forests (Wu 2000; Wu et al. 2003). For comparison, in Fennoscandia the use of natural undisturbed forest as a benchmark for biodiversity restoration and management has been widely accepted (Kuuluvainen 2002).

Conclusions

This study explored the properties of near-natural forests, selectively logged forests, forests naturally regenerated after clear-cut, and plantations in the UMR watershed in Sichuan, China. The 271 studied sites represented a comprehensive environmental gradient. Their comparison offered a potential to illustrate the effects of human impact on forest stand and species diversity indices along altitudinal gradient. Near natural forests with little human intervention had high volume consisting of living trees and dead wood, and a high density of large trees. Traditional forest management affected negatively the stand production. Reforestation by tree plantations can accelerate the build-up of the stand volume. Of all the indicators used to describe the stand structure or biodiversity, volume gave the best distinction between near-natural forests and the other types of managed forests. However, the forest stand is not static. The present stand is shaped by exogenous factors (natural and human disturbances), as well as by endogenous processes in the forest stand. With the growth of trees and stand development, the stocking volume in the UMR watershed will have a tendency to increase.

Current forest land in the study area is still owned by state and collectives. After realizing the previous forest harvesting usually resulting in deforestation and a negative effect on environment, the forests are protected from any kind of management. The recent afforestation activities are mainly programme oriented through attracting various input: capital from government, land from degraded bare land or farmland on steep slopes, and labour from the local village. If we attempt to improve and restore the natural stand dynamics of forest ecosystems degraded by human activities, concerted efforts should be taken to enhance the speed and efficiency of regeneration and growth in disturbed natural forests. Special care should be given to the degraded forests at lower elevations. Natural regeneration and tree planting should be combined in an efficient way to achieve a better restoration.

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