Front. Biol. China 2007, 2(1): 62–68
DOI 10.1007/s11515-007-0011-9

RESEARCH ARTICLE

# Habitat fragmentation impacts on biodiversity of evergreen broadleaved forests in Jinyun Mountains, China

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**Abstract** The plant communities and their microclimates were surveyed and observed, and the soil fertilities were determined in six plots of evergreen broadleaved forests of different sizes and similar slope aspects on Jinyun Mountains of Chongqing in China from April to October, 2003. The relationships of biotic and abiotic factors were analyzed using the Simpson, Shannon—Wiener, and Hill diversity indices, and stepwise multilinear regression analyses techniques. The results showed that compared with continuous evergreen broadleaved forests, five fragmentations had a lower species diversity index, and different life forms showed differences in diversity index. With the decrease in patch areas, the daily differences in air temperature (ΔTa), ground surface temperature (ΔTs), daily differences in relative humidity (ΔRH), maximum wind velocity (Vmax), differences in photosynthetic available radiation (ΔPAR) (at noon) of both edges and interiors, all tended to increase. Maximum wind velocity (Vmax) and photo effective radiation in forest edges were higher than those in interior forest, which presented a stronger temperature-gained edge effect. In all the fragmentations of evergreen broadleaved forests, the depth of the edge effect was the nearest from interior forest in the biggest patch (about 15 meters away from interior forest), while the depth of the edge effect was the farthest from interior forest in the smallest patch (about 25 meters away from interior forest). With regard to the water conservation function, soil water content improved along with increasing species diversity. Some of the nutritional function substances of soil increased with increasing species diversity. The elements of microclimate, such as Ta, ΔTa, ΔTs, ΔRH, Vmax, and PAR, changed along with the extent of fragmented forest.

Translated from *Acta Ecologica Sinica*, 2005, 25(7): 1642−1648 [译自: 生态学报]

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**Keywords** evergreen broadleaved forest, edge effect, fragmentation, microclimate, biodiversity, regression

## 1 Introduction

Fragmentation implies that the original continuous habitat transforms into several isolated remnant patches, and the area of the original habitat decreases (András Báldi, 1999). The changes in microclimatic factors of forest edge over time and space is very important for further study on responses, distributions, and species diversity changes in plants in fragmented forests (Kapos, 1989). Forest edges are known to consist of microenvironments that may provide habitats for a different suite of species than forest interiors. Several abiotic attributes of the microenvironment may contribute to this change across the edge to the central gradient (light, air temperature, soil moisture, humidity) (Sophia et al., 2000). Fragmented forest ecosystems change through time as a result of isolation as well as other human and natural disturbances. A reduction of species may occur in fragments that are too small to support their original flora and fauna (Blake, 1983; Blake and Karr, 1984). While the reduction in species may result directly from a decrease in forest area, it is more likely due to the increased perimeter: area ratio that results from fragmentation and the modification of abiotic and biotic factors at the forest edges (Laurance and Yensen, 1991). Investigators have begun to carry out some work about edge effects in fragmented tropical forests since the 1980s (Camargo and Kapos, 1995). Forest fragmentation is especially severe in tropical and subtropical areas of South China (Qu et al., 2000). Investigations by Chinese scholars on forest fragmentation have mainly focused on tropical rainforest since 1990 (Xu et al., 1994; Zhu et al., 1997; Ma et al., 1998), while there are few investigations on the effects of fragmentation on subtropical evergreen broadleaved forests.

In this study for the first time we determined the relationships of biotic and abiotic variables and described how these variables varied with the distances from the edge of fragmentation in subtropical evergreen broadleaved forests. To understand these dynamics of forest edges, we can enrich the theory of how habitat fragmentation affects forest ecosystem, and provide scientific basis on the management and restoration of existing fragmented forests, as well as biodiversity conservation.

## 2 Study area and methods

### 2.1 Study area

The environment and vegetation of Jinyun Mountain Reservation, China, have been reported (Liu et al., 1984). The study was conducted from April to October 2003 in subtropical evergreen broadleaved forests of Jinyun Mountain Reservation, located approximately 32.5 km north of Chongqing, China. We chose Luoyangqiao as a continuous plot for comparison with five fragmental plots, namely, Fuxingsi, Qinglongzhai, Gaoguanyin, Juyunfeng, and Yuanxiaofeng. The basic environmental and soil conditions of different evergreen broadleaved forest stands of Jinyun Mountain are described in Table 1.

### 2.2 Methods

#### 2.2.1 Investigation of plots

In the center of each plot, two transects of 160 m long and 10 m wide were established perpendicular to each other. One 10 m × 10 m quadrat was placed every 10 m on each transect, and one 5 m × 5 m quadrat was placed in each 10 m × 10 m quadrat, and one 1 m × 1 m quadrat was placed in each 5 m × 5 m quadrat. There were in all 12 transects, ninety-six 10 m × 10 m quadrats, ninety-six 5 m × 5 m quadrats, and ninety-six 1 m × 1 m quadrats. We regularly investigated the quadrats. Five quadrats were located in the intersect, and the two sides of two transects in each plot were chosen as sampling points. We took 50–30 cm deep soil samples at four corners and from the center of each 10 m × 10 m scale sampling point. In all, 150 soil samples were analyzed in the laboratory.

#### 2.2.2 Microclimate observation

We created a horizontal gradient pattern to place observation plots, and the principle was to set up some points of different distances from forest edges to the interior and open forest. Measurement of environmental variables were collected at 0 (forest edge), 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 m (interior forest), as well as 5, 10, 15, and 20 m (open forest) along each transect. Air temperature, relative humidity, temperature of ground surface, and temperature of 20 cm below ground surface were measured using a set of instruments including thermometer, hygrometer, and curved thermometer, which were placed at 25 m of open forest, forest edge, and at 50 m of interior forest. The wind velocity of 1.5 m above ground surface was measured using a portable anemometer (DEM6, meteorological and oceanographic instrument company, China). The photosynthetic active radiation was measured using a luminometer (FLUKE limited corporation, USA). The maximum temperature, minimum temperature, and relative humidity of ground surface as well as 1.5 m above ground surface were measured using high-low thermometer and hygrometer, respectively, which were placed every 5 m from 25 m of open forest to 50 m of interior forest. At the same time, photosynthetic available radiation (PAR) of 1.5 m above the ground surface was measured using a luminometer. This experiment was designed to: (1) compare the microclimatic factors of open forest, forest edge, and interior forest, which included the maximum temperature of open forest, forest edge, and interior forest ($T_{max}$), the daily differences of air temperature (T), minimum relative humidity (RH), maximum ground surface ($\Delta T_s$), and average value of wind velocity (V) (twice); (2) analyze the relationships between horizontal distances and microclimatic factors that included temperature, relative humidity, relative light intensity, and differences of air and ground temperatures. These

**Table 1** Environmental and soil conditions of different evergreen broadleaved forest stands of Jinyun Mountain, China

| Plots | Altitude /m | Area /hm$^2$ | Slope aspect /° | Slope /° | Soil water content /% | Soil organic matter /(g·kg$^{-1}$) | Soil total nitrogen /(g·kg$^{-1}$) | Soil available potassium phosphorus /(mg·kg$^{-1}$) | Soil available /(mg·kg$^{-1}$) | Soil pH | ΔTa /°C | ΔTs /°C | ΔRH /% /(m·s$^{-1}$) | $V_{max}$ | ΔPAR (14:00) /(μmol photons m$^{-2}$·s$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ | $X_{12}$ | $X_{13}$ | $X_{14}$ | $X_{15}$ |
| Luoyangqiao | 690 | 13.7 | 31 | 28 | 5.25 | 14.79 | 0.29 | 3.84 | 63.04 | 4.56 | 5.53 | 7.03 | 29.33 | 0.35 | 1 311.30 |
| Fuxingsi | 700 | 12.4 | 17 | 30 | 5.05 | 14.39 | 0..23 | 3.58 | 62.03 | 4.41 | 6.23 | 7.47 | 32.00 | 0.42 | 1 129.95 |
| Qinglongzhai | 810 | 11.6 | 47 | 25 | 4.93 | 13.71 | 0.24 | 3.35 | 57.09 | 4.34 | 6.77 | 7.80 | 33.67 | 0.47 | 1 189.47 |
| Gaoguanyin | 600 | 6.1 | 348 | 20 | 4.49 | 13.55 | 0.16 | 2.99 | 50.51 | 4.62 | 6.87 | 8.87 | 34.67 | 0.47 | 1 041.60 |
| Juyunfeng | 820 | 3.5 | 353 | 30 | 4.47 | 13.50 | 0.12 | 2.91 | 52.81 | 4.10 | 7.40 | 7.83 | 35.00 | 0.53 | 975.57 |
| Yuanxiaofeng | 810 | 3.0 | 33 | 20 | 2.60 | 13.08 | 0.11 | 2.84 | 50.31 | 4.46 | 8.13 | 9.73 | 37.17 | 0.56 | 1 012.77 |

items were recorded every hour manually and the weather conditions were logged. Each plot was observed every 3 days from April 1 to May 1, 2003 and from September 1 to October 1, 2003, for in all 36 days.

2.2.3 Determination of species diversity

We chose the following common and effective formula to calculate diversity index:

Simpson index: $\lambda = \sum_{i=1}^{s} P_i^2$

Shannon–Wiener index: $H' = -\sum_{i=1}^{s} (P_i \ln P_i)$

Hill index: $N_A = \sum_{i=1}^{s} (P_i)^{1/(1-A)}$

when $A = 0$, $N_0 = S$; when $A = 1$, $N_1 = e^{H'}$; when $A = 2$, $N_2 = \lambda^{-1}$.

2.2.4 Stepwise multilinear regression analysis

Statistical analysis and stepwise multilinear regression analysis were carried out by using SPSS (11.5 Version). Prior to conducting stepwise multilinear regression analysis, let $X_1$ = altitude, $X_2$ = area, …, $X_{15}$ = Δ PAR (14:00) (Table 1), and $Y_1$ = Simpson index of tree layer, $Y_2$ = Shannon–Wiener index of shrub layer, …, $Y_{15}$ = Hill index of herb layer (Table 2). Then, the stepwise multilinear regression was carried out on all microclimate and diversity indexes that were quantified as described above.

## 3 Results

3.1 Comparison of species diversity in continuous and fragmented plots

The species diversity indexes of five fragmented evergreen broadleaved forests were lower than those of continuous evergreen broadleaved forests (Fig. 1). Different life forms had different exhibitions. Diversity indexes of trees decreased along with human disturbances; however, the diversity indexes of trees in Fuxingsi were lower than those in other plots, and it might be due to historic factors, fewer numbers of potential settlers, farther distances from source of settlers, and interaction of species in the community. Diversity indexes of saplings and shrubs tended to decrease along with the enhanced disturbances and with increasing time after isolation. Diversity indexes of herbaceous plants were higher in Fuxingsi, Juyunfeng, and Yuanxiaofeng, and were lower in other plots, which meant that diversity indexes of herb layers perhaps would increase after disturbances of some extent.

3.2 Comparison of microclimatic factors of interior forest, edge, and open forest in continuous and fragmented plots

3.2.1 Air temperature and ground temperature

The trend of air temperature (ΔTa) was open forest > edge > interior forest. ΔTa of interior forest in maximum plot No. 1 (Luoyangqiao) was the lowest, and ΔTa of interior forest in minimum plot No. 6 (Yuanxiaofeng) was the highest. ΔTa of edge was higher than that of open forest in plot No. 5 (Juyunfeng) and plot No. 6; however, ΔTa of edge was lower than that of open forest in plot No. 1, plot No. 2 (Fuxingsi), plot No. 3 (Qinglongzhai), and plot No. 4 (Gaoguanyin). ΔTa presented increasing trend with the decreasing area of fragment. At the same time, the standard error of ΔTa indicated that ΔTa of edge varied more widely than that of interior forest and open forest. In addition, we can also see from Fig. 2 that the trend of ΔTs was open forest > edge > interior forest, and the ΔTs of edge and interior forest tended to increase with the decreasing area of plots. The standard error of ΔTs indicated that the ΔTs of open forest varied more widely.

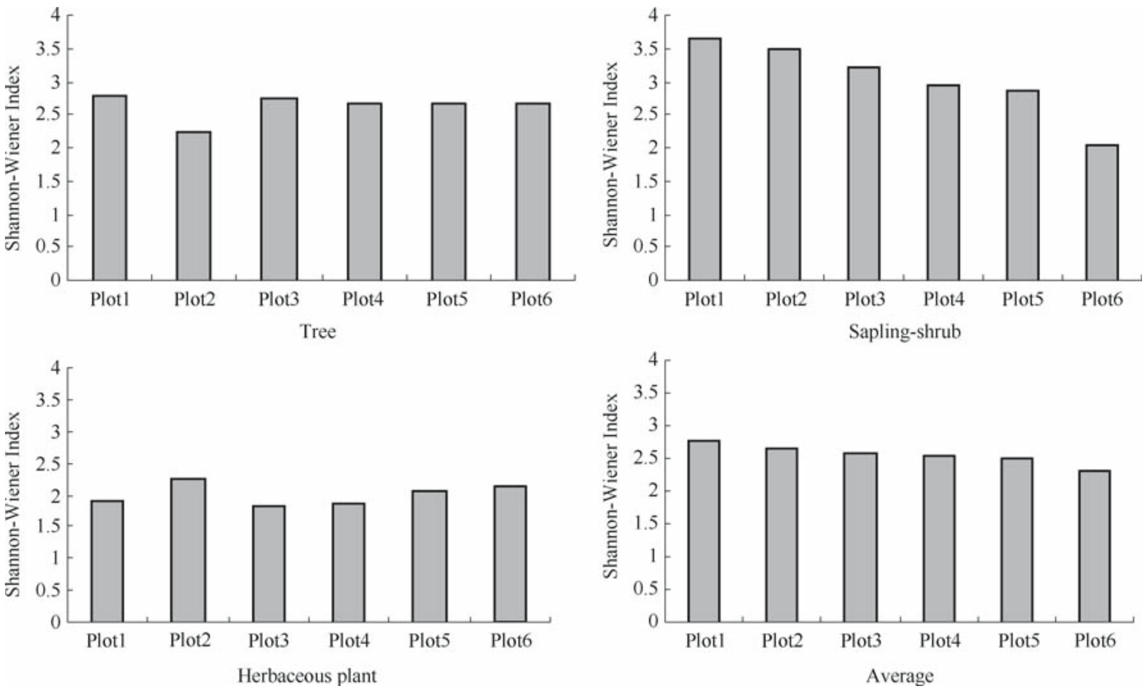
3.2.2 Relative humidity of air and wind velocity

The trend of ΔRH were open forest > edge > interior forest, and the decrease of ΔRH in plot No. 1 was more obvious. At the same time, the RH of edge in plot No. 4 and plot No. 5 varied less obviously. ΔRH of edge and interior tended to increase along with the decrease in area of fragments. Figure 2 also showed that the standard errors of $V_{max}$ were

**Table 2** Species diversity indices of different evergreen broadleaved forest stands of Jinyun Mountain, China

| Plot | Tree layer | | | | | Shrub layer | | | | | Herb layer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\lambda$ $Y_1$ | $H'$ $Y_2$ | $N_0$ $Y_3$ | $NP$ $Y_4$ | $N_2$ $Y_5$ | $\lambda$ $Y_6$ | $H'$ $Y_7$ | $N_0$ $Y_8$ | $NP$ $Y_9$ | $N_2$ $Y_{10}$ | $\lambda$ $Y_{11}$ | $H'$ $Y_{12}$ | $N_0$ $Y_{13}$ | $NP$ $Y_{14}$ | $N_2$ $Y_{15}$ |
| Luoyangqiao | 0.114 | 2.781 | 26 | 261 | 8.772 | 0.071 | 3.658 | 52 | 182 | 14.085 | 0.149 | 1.919 | 14 | 62 | 6.711 |
| Fuxingsi | 0.175 | 2.245 | 17 | 268 | 5.714 | 0.074 | 3.496 | 65 | 195 | 13.514 | 0.134 | 2.245 | 19 | 85 | 7.463 |
| Qinglongzhai | 0.128 | 2.736 | 17 | 197 | 7.813 | 0.078 | 3.220 | 47 | 194 | 12.821 | 0.189 | 1.832 | 10 | 66 | 5.291 |
| Gaoguanyin | 0.158 | 2.678 | 23 | 198 | 6.329 | 0.085 | 2.945 | 38 | 286 | 11.765 | 0.162 | 1.881 | 9 | 91 | 6.173 |
| Juyunfeng | 0.171 | 2.651 | 28 | 169 | 5.848 | 0.090 | 2.868 | 37 | 207 | 11.111 | 0.140 | 2.056 | 9 | 51 | 7.143 |
| Yuanxiaofeng | 0.170 | 2.676 | 24 | 113 | 5.882 | 0.116 | 2.047 | 37 | 216 | 8.621 | 0.138 | 2.150 | 14 | 108 | 7.246 |

λ: Simpson index; *NP*: Number of plant; *H′*: Shannon–Wiener index; $N_2$: Hill index; $N_0$: Number of species




Plot1: Luoyangqiao; Plot2: Fuxingsi; Plot3: Qinglongzhai; Plot4: Gaoguanyin; Plot5: Juyunfeng; Plot6: Yuanxiaofeng

**Fig. 1** Comparison of plant diversity between the fragmented forests and continuous forests of Jinyun Mountain, China

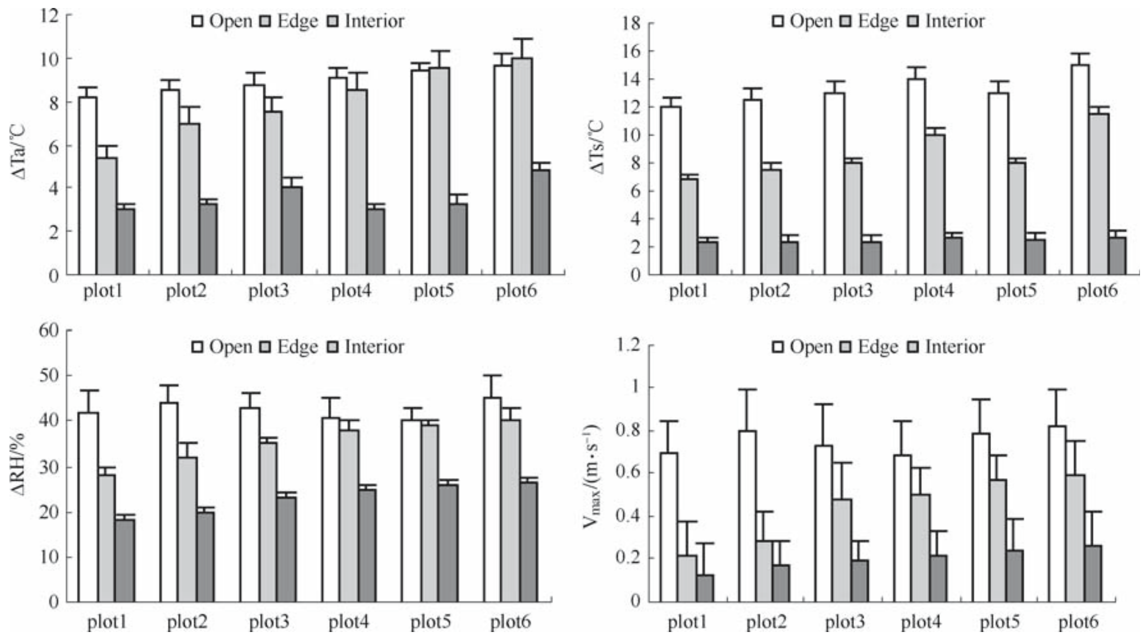
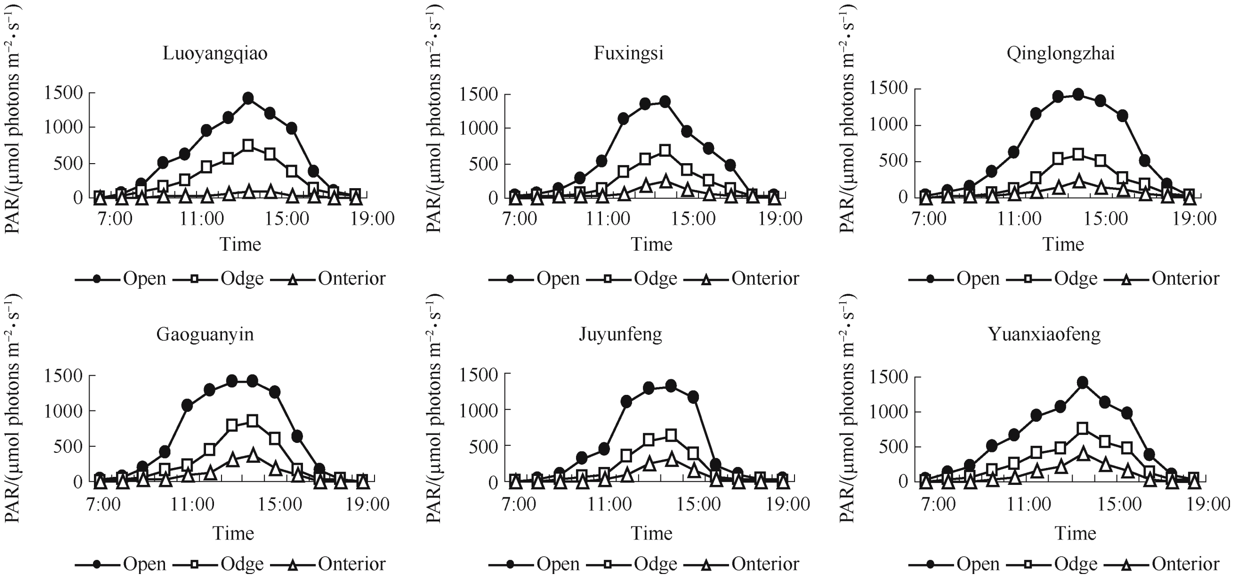



**Fig. 2** Daily differences of air temperature (ΔTa), ground surface temperature (ΔTs), relative humidity (ΔRH), and maximum wind velocity ($V_{max}$) and their standard errors in the open, edge, and interior forest over 18 days measurement period from 1 April to 1 May 2003

high, which indicated the change in wind velocity varied widely. However, the trends of $V_{max}$ were open forest > edge > interior forest. The $V_{max}$ of each fragment tended to decrease with the increasing area of fragment, i.e., it was a function of retarding wind reducing along with the decreased area of fragment.

### 3.2.3 Photosynthesis active radiation

The PAR from edge to interior forest in Luoyangqiao was diminished more significantly than those of any other plots (Fig. 3). ΔPAR in interior forest, edge, and open forest was larger in 12:00~15:00 than that in any other time. This




PAR: (mEinstein·m−2·s−1)

**Fig. 3** Variation of photosynthetic available radiation (PAR) in the open, edge, and interior forest by daylight under clear sky

phenomenon might result from the density of canopy of continuous evergreen broadleaved forests. The maximum total PAR of edge and interior were 51.84%, which is 7.24% of that of open forest in continuous evergreen broadleaved forests. The maximum total PAR of edge and interior were 50.06%, which is 22.76% of that of open forest in fragmented evergreen broadleaved forests.

It could be concluded that the changes of ΔTa, ΔTs, ΔRH, Vmax, and PAR of forest edge were due to the decrease of buffering function of forest, which resulted from the increased fragmentation.

### 3.3 Horizontal distance changes of microclimatic factors from open forest to interior forest

The $Ta_{max}$ from interior forest to open forest tended to decrease basically (Fig. 4). $Ta_{max}$ of edge was larger than that of the open forest in medium fragments (Gaoguanyin) and small fragments (Yuanxiaofeng). In contrast, it was not significant in large fragments (Fuxingsi). $Ta_{max}$ of every fragment from edge to interior forest increasingly decreased and tended to level off. The large fragments decreased most rapidly (the stable point was about 15 m from the forest edge) and the small fragments decreased most slowly (the stable point was about 25 m from the forest edge), and the medium fragments tended to stabilize at approximately 20 m from the forest edge. It could also be found from Fig. 4 that $RH_{min}$ tended to increase. This trend was more obvious in large fragments than in small fragments. The $RH_{min}$ in medium fragments varied similarly as that in large fragments (the value t stable at 15 m of interior forest), and the $RH_{min}$ in small fragments was stable at 25 m of interior forest.

The trend in horizontal distance changes of rPAR increasingly decreased from open forest to interior forest in every fragment (Fig. 3). The rPAR decreased most rapidly in large fragments, and the rPAR decreased most slowly in small fragments. The distances of stabilization of rPAR were 15 m in forest interior of large fragments and 25 m in forest interior of small fragments.

### 3.4 Effects of environmental factors on biodiversity

We obtained the regression equations by calculation:

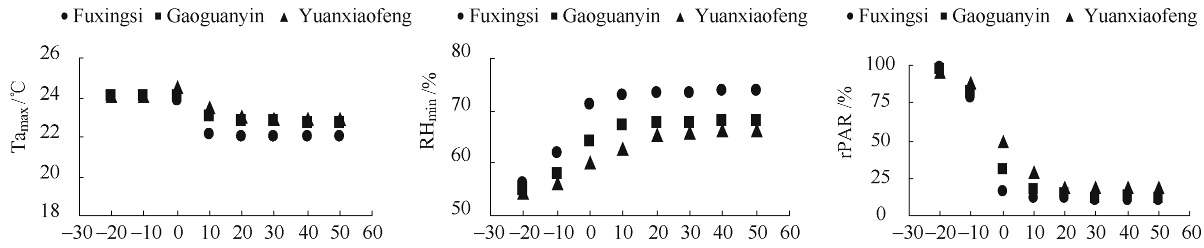



**Fig. 4** Variation of mean maximum air temperature ($Ta_{max}$), minimum relative humidity ($RH_{min}$), and relative PAR (rPAR) with distance from the forest edge

(1) $Y_1 = 0.346 - 1.74 \times 10^{-4} X_{15}$ (partial correlation coefficient: $r_{1,15} = -0.857$, $F = 11.100$, $P \leqslant 0.05$)

(2) $Y_4 = 621.261 - 61.607 X_{11}$ (partial correlation coefficient: $r_{4,11} = -0.957$, $F = 43.027$; $P \leqslant 0.01$)

(3) $Y_5 = -3.129 + 8.877 \times 10^{-3} X_{15}$ (partial correlation coefficient: $r_{5,15} = 0.883$, $F = 14.152$, $P \leqslant 0.05$)

(4) $Y_6 = 0.161 - 1.69 \times 10^{-2} X_5$ (partial correlation coefficient: $r_{6,5} = -0.990$, $F = 202.469$, $P \leqslant 0.01$)

(5) $Y_7 = -3.584 + 0.394 X_5 + 0.351 X_6$ (partial correlation coefficient: $r_{7,5} = 0.988$, $r_{7,6} = 0.966$, $F = 376.794$, $P \leqslant 0.01$)

(6) $Y_8 = -52.673 + 1.763 X_9$ (partial correlation coefficient: $r_{8,9} = 0.892$, $F = 15.614$, $P \leqslant 0.05$)

(7) $Y_{10} = -0.313 + 1.387 X_5 + 1.877 X_8$ (partial correlation coefficient: $r_{10,5} = 0.984$, $r_{10,8} = 0.952$, $F = 220.704$, $P \leqslant 0.01$)

Linear relations were found in ΔPAR, ΔTa, soil water content, soil organic matter, available phosphorus in soil, and available potassium in soil. The fluctuation of microclimate was strengthened, and some factors, such as temperature and humidity, changed largely in community. Some species that could not adapt to the environment were eliminated along with increasingly heavy fragmentation. Simultaneously, the functions of ecosystem, such as conserving soil and water as well as supplying water resource, were impaired, and contributed to the drier and warmer environment of the community than before. In addition, nutritional elements were lost, and subsequently the species diversities of tree layers and shrub layers were reduced.

## 4 Discussion

The microclimate of the interior of forests will turn from wet and cool to dry and warm after forest fragmentations, which will lead to the invasion of herbaceous plants. These changes described as above are related to not only biological and ecological characteristics but also the isolated status of fragments, which constitute the microenvironment of species. "Effects of dry and warm", on the one hand, contribute to the invasion of a great deal of pioneer plants and common plants rapidly into interior forest. On the other hand, original species that grew in shrub layers and herb layers lose their "wet and cool" environments; simultaneously, these population types of original species degenerate rapidly and lose some species because of the confrontation with invading species.

The edge effects of evergreen broadleaved forest fragments are confirmed to exist by measuring the microclimate of fragmental forest edge, i.e., the forest edges receive more radiation so that temperature rises, daily differences of temperature increases (air and ground surface), and relative humidity falls. Furthermore, the edge effects as well as the involved depth of edge effects are strengthened and increased along with the decreased fragment areas. These are correlated with the aspect and topography of plots. In general, microclimatic conditions of forest edges lead to the changes in biological features, for example, acceleration of litter decomposition and increase in components of pioneer plants. Biological feature changes affect the microclimatic conditions in turn. Therefore, biotic and abiotic effects of forest edges do not exist independently, but affect and control each other. The former is the precondition and drive of the latter; the latter also affects the former in turn. Finally, these procedures will change the structure and functions of the ecosystem of fragmented evergreen broadleaved forests by affecting plants, animals, and microbes. The restoration and rebuilding of the ecosystem will be extremely difficult because of the increasingly severe fragmentation.

Microclimate-vegetation and soil-vegetation are two kinds of different factors depending on each other in microclimate-vegetation-soil system. Microclimate affects vegetation, and vegetation alters microclimate in turn. Similarly, vegetation affects soil, and in turn soil restricts vegetation. As far as two different systems are concerned, the factors of microclimate and soil affect each other, and are not independent. The phenomenon affects the validity of regression; however, the factors of complete independence do not exist in nature. Further more, ecological factors cannot replace each other. Therefore, multilinear regression is still used extensively (An et al., 1997). The fragmentation of evergreen broadleaved forests in Jinyun Mountain contributes to the alteration of local habitat, and subsequently the decrease of species diversity as well as the impairment of buffering functions of the forest.

Fragmentation affects the biotic factors by altering the abiotic factors. The differences in the extent of fragmentation result in the differences of microclimate and soil conditions, and subsequently the differences of distributions and types in fragmented forest in different places. Therefore, forest fragmentation is the most important and basic reason for decreasing biodiversity. Our study results indicate that the functions of ecosystem in different fragmented forests are not completely the same. The species diversity will increase with the increasing soil water content. A part of species diversity also increases with the improved factors of soil nutrition function (for example, organic matter). The factors of microclimate, such as air temperature, also vary correspondingly with the changes in the extent of forest fragmentation, and accordingly affect the biodiversity. However, other factors of environment do not affect the diversity index largely. There are no linear relations between them. In our study, the correlated relation between species diversity and environment factors of evergreen broadleaved forests is only a statistical analysis on the data of quadrats in evergreen broadleaved forests in Jinyun Mountain, and hence the results have statistical meaning only in a special environment. We still need to use experimental methods to test the extent and mechanism of effects of environmental factors on species diversity of the community in fragmented forests.

**Acknowledgements** This study was supported by the National Natural Science Foundation of China (Grant No. 30370279).

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