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Factors Affecting the Snow and Wind Induced Damage of a Montane Secondary Forest in Northeastern China

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In order to understand the processes of snow and wind induced damage in a natural montane, secondary forest in northeastern China, we examined the impacts of site conditions on the snow and wind damage; analyzed if the dominant tree species differed in their susceptibilities to the damage; and established the relationships between the characteristics of tree and stand and the damage. The results indicated that in regard to the topography factors, slope steepness and soil depth played a relatively important role for the damage. Damage ratios of all types combined were positively related with the composition of dominant tree species. The stand density was also important in determining resistance to the damage, i.e., the densely populated stand exhibited less overall damage ratios; however, the dominant tree species were commonly damaged easily by the snow and wind. Four damage modes found (uprooting, stem breakage, canopy damage and bending) were closely related to the stem taper ($p<0.05$), and they could be ranked in following order: bending (92.0) > uprooting (85.3) > stem breakage (80.1) > canopy damage (65.0). In regard to differences in tree species' susceptibilities to the damage, *Betula costata* exhibited the most uprooting, bending and overall damage ratios; while *Quercus mongolica* showed the highest breakage (both stem breakage and canopy damage) ratio, and *Fraxinus mandshurica* exhibited the least damage ratio (overall). The major six tree species could also be divided into two groups according to the overall damage ratios, i.e., more susceptible ones (*B. costata*, *Ulmus laciniata* and *Q. mongolica*), and less susceptible ones (*F. mandshurica*, *Acer mono* and *Juglans mandshurica*) to the snow and wind damage.

Keywords snow and wind damages, secondary forests, stem breakage, uprooting, mixed forests, stand structure

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1 Introduction

Forest damage caused by snow and wind is an important and significant problem in boreal, temperate and mountainous forests (Nykänen et al. 1997, Valinger and Fridman 1997, Peltola et al. 2000, Schönenberger 2002), which not only leads to the timber losses through the reduction of timber quality and production, but leads to the disturbances to the ecological condition of the forest ecosystem as well (Veblen et al. 2001, Li et al. 2005). In Europe, the scales of the snow and wind damage problem lose hundreds of millions of European Currency Unit each year (Nykänen et al. 1997, Peltola et al. 1997, Valinger and Fridman 1997, Gardiner and Quine 2000, Bründl and Rickli 2002). The common tree damage is generally classified into stem damage and canopy damage (Everham 1995, Zhu et al. 2002). The stem damage comprises uprooting, stem breakage, and stem bending or leaning (Everham 1995). While, canopy damage may be quantified directly on the basis of branch loss, canopy defoliation and destruction (Zhu et al. 2002). Following the consequence of snow and wind damage, however, other sources of forest damage such as attacked by insects, fungi enhancing rate and rapidity of the destruction are increasing (Nykänen et al. 1997, Valinger and Fridman 1997, Schönenberger et al. 2002). Therefore, most studies concentrate their focuses on the development of methods to minimize the future damage by snow and wind, although it is very difficult to avoid these unexpected natural disturbances (Matsuzaki 1994, Chiba 2000, Zhu et al. 2003a).

During recent decades, many detailed investigations of forest damage induced by snow and wind have been contributed to the knowledge of the damage problems (Petty and Worrell 1981, Peltola and Kellomäki. 1993, Valinger et al. 1993, Solantie 1994, Quine 1995, Peltola et al. 2000, Baker et al. 2002). These studies have provided valuable information about the extent and causes of snow and wind damage, and how they can be avoided (Matsuzaki and Nakata 1993, Peltola et al. 1993, Valinger et al. 1993, Peltola 1996, Valinger and Pettersson 1996, Valinger and Fridman 1997, Quine et al. 1999, Lässig and Mocalov 2000, Schönenberger et al. 2002, Zhu et al. 2003b). However, most of these studies focused on the plantation or the influences of damage on timber losses, while information was poorly documented on natural forests damaged by wind and snow. Recently, the wind and snow damage has been reported in natural forests.

It is suspected that the climate changes may cause the extremes such as extreme temperatures, heavy snow, strong wind and flood, and alter the frequency and severity of the damage (Schönenberger et al. 2002). Therefore, it is necessary to focus the studies of snow and wind damage on the natural forests, too. Additionally, it is important and significant for the natural development of a forest ecosystem to have snow and wind disturbances because they influence the forest ecosystem from both timber and ecological aspects (Zhu and Liu 2004). Based on literature survey, however, the researches related to these aspects have been mostly conducted in Europe for plantations (Schönenberger et al. 2002, Quine 2003), while information is lacking in Asia and other regions for the natural forest ecosystems.

The process of snow interception by trees is complex and involves components of throughfall, adhesion, cohesion, wind removal, sliding, melting and vapor transportation (Nykänen et al. 1997), especially, the process is strongly dependent on temperature and wind speed because temperature influences the water content of snow, and the wind speed can not only cause snow to be shed but also lead to large accumulations of wet snow, rime or freezing rain (Nykänen et al. 1997). The most favorable conditions for snow accumulation are light winds, falling air temperature and no sunshine. Adhesion and cohesion of snow get the greatest at temperature just below freezing. If temperature exceeds 0.6 °C for a three-hour duration, it may reduce the damage or even prevent the damage because snow will become wet enough to slip off the trees. On the other hand, snow shedding can occur when snowfalls at low temperature, e.g. –5 °C, because snow is dry enough and does not adhere at such temperature (Solantie 1994, Nykänen et al. 1997, Pellikka and Järvenpää 2003).

Generally, snow and wind damage has occurred relatively less in forest ecosystems in northern China (Hao and Peng, 1995, Liang et al. 2002). In early spring of 2003 (29 March 2003), serious forest damage occurred in a natural secondary forest in Dasuhe District, Qinyuang County, Liaoning Province, Northeastern China (Fig. 1), in which present study is located. The total forest area of Dasuhe District is more than 1.0×10^4 ha, of which, about 1000 ha belongs to Qingyuan Experimental Forests (QEF) of Institute of Applied Ecology, Chinese Academy of Sciences. More than 15% of the total area in QEF was damaged (including both canopy damage and stem damage), of which, about 10% quantified as stem damage (bending, stem breakage, uprooting). Damage in the form of stem breakage and uprooting in Qingyuan County occurred first time since records began from 1958.

The purpose of the present study is to document the initial situations and to understand the processes of snow and wind damage in the natural secondary forests. The specific objectives of this study are 1) to examine the impacts of site conditions on the snow and wind induced damage; 2) to find out if the dominant tree species differ in their susceptibilities to the snow and wind damage; and 3) to establish the relationships between characteristics of tree and stand and snow and wind damage in the natural secondary forests.

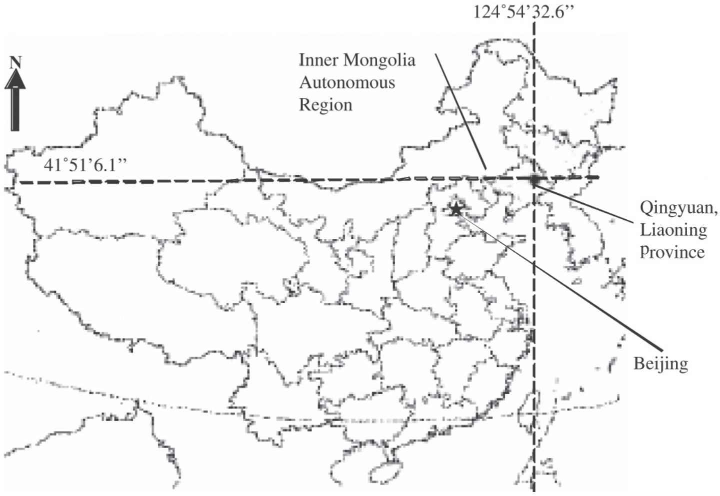
2 Materials and Methods

2.1 Site Description

The study area is located at Dasuhe District, Qingyuan County, Liaoning Province, the northeast of China (41º51'6.1''N, 124º54'32.6"E) (Fig. 1). Qingyuan County covers an area of more than 3.98×10^5 ha, in which forest covers 71.7%. The permanent sample plots were established within the QEF. Present research site was dominated with natural secondary forests, which were formed after the disturbance from the virgin forests or regional climax, i.e., the natural mixed-broadleaved Korean pine (*Pinus koraiensis* S. et Z) forest (MBKPF). MBKPF is the largest and the most important forest community in northeastern China, which provides large amounts of timber and ecological services (Chen et al. 1994, Zhu 2002, Chen et al. 2003). However, after a century of forest exploitation from both abroad and home (Huang and Wang 2000, Zhu 2002, Chen et al. 2003), the total area and productivity of the natural forests have been dramatically reduced. Currently, more than 70% of these excessively exploited MBKPFs have become the natural secondary forests, and the dominant species of Korean pine has become less and less. The current natural secondary forests in QEF are typical ones in northeastern China, which have not been exploited for about 50 years.

The climatic condition of the study area belongs to temperate monsoonal characters. The annual precipitation is 810.9 mm, annual average temperature is 4.7°C, the maximum and minimum temperatures are 36.5 °C and –37.6 °C, respectively. The frost-free period is 130 days. The topography belongs to Changbai Mountain (42º24'N, 128º28'E). The main land type of the secondary forests is mountainous land with slope between 10–30º, and elevation between 452–1116 m (Based on measurement by GPS, eTrex Vista, USA). Brown earth dominates the secondary forest soils, parent rock composed of granite and granite-gneiss.

On 29 March 2003, the local foresters and farmers witnessed the occurrence of the forest damage in study site, we got the meteorological information from Qingyuan Meteorological Station at Qingyuan County (41º50'47.7"N, 124º54'31.6"E, ASL: above sea level, 253 m), which is located at about 50 km north of the experimental forests (QEF). The meteorological information confirmed the occurrence of damaging event (storm). The low pressure system observed on the ground of 29 March 2003 (GMT+008) was showed in Fig. 1. The weather map showed that a low pressure system moved from N45º, E118º to the southeast into Liaoning Province toward Qingyuan. This low pressure system made the area of Liaoning Province fall in a warm front, which is described as: the leading edge of an advancing warm air mass that is replacing a retreating relatively colder air mass (Bründl and Rickli 2002). As typical, after the passage of a warm front, the temperature and humidity will increase, precipitation, in the form of rain, snow, or drizzle, is found ahead of the surface front heavily, as well as convective showers and thunderstorms. The process of precipitation on 29 March 2003 (GMT+008) showed that the precipitation of snow covered the areas of



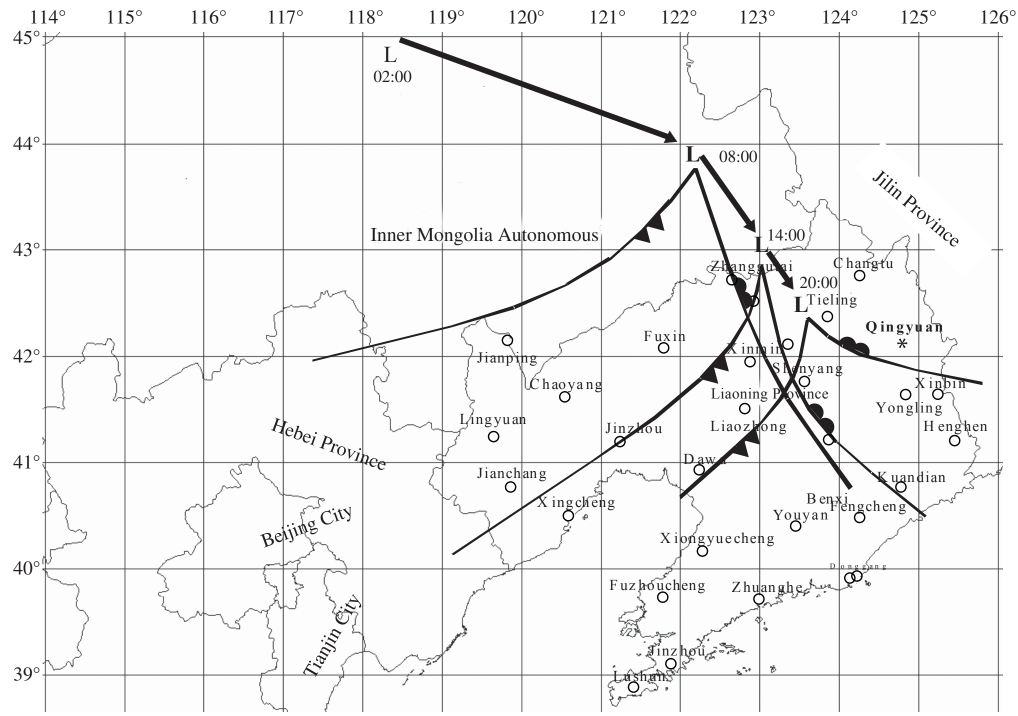


Fig. 1. Above: Location of the experimental site (Dasuhe, Qingyuan County, Liaoning Province, China, (41º51'6.1"N, 124º54'32.6"E); Below: The moving route of low pressure system on 29 March 2003 (GMT+008) on the ground, which showed the rapid movement of the storm.

eastern Liaoning Province (Liaodong mountainous areas). The precipitation of snow reached 10.5 mm in 12 hours at Qingyuan Meteorological Station. According to the National Criteria of Meteorology (China), snowfall of 10 mm in 24 hours is defined as a snow-storm, therefore, the precipitation of snow in the low pressure system at Qingyuan was classified as very heavy.

The temperature condition must have fit for snow accumulating on tree crown in the experimental forests. It was observed in the fact, that the twigs and branches in almost each damaged tree were bended by heavy snow load. According to the wind speed data from the Qingyuan Meteorological Station, wind speed of more than 10.0 m s^{-1} was observed every day after the heavy snow (from 29 March to 4 April 2003). It could be concluded that the wind speed should be much

Table 1. General characteristics of the stand and site used in this study (including the damaged trees) (Plot area = 1200 m^2).

Stand Plot no.	Age (years) Mean	Max.	Min.	Stand density (stems ha^{-1})	Stand averages DBH (cm)	Tree height (m)	Height at crown base (m)	Number of tree species	Site conditions Direction of slope	Slope (°)	Elevation (m)	Soil depth (cm)
QY2003A	33	82	6	717.0	19.3	16.0	10.8	11	Northwest	27	951	51
QY2003B	26	67	5	950.0	15.1	15.1	10.6	12	Southeast	25	959	35
QY2003C	41	85	6	908.0	16.9	14.6	10.0	13	Southeast	29	898	42
QY2003D	50	108	8	291.0	27.7	18.8	13.7	8	South	15	1015	50
QY2003E	36	67	6	1275.0	16.3	17.5	10.8	9	West	19	1042	42
QY2003F	38	68	6	1183.0	16.1	17.4	11.5	10	West	17	1037	40

Max.: maximum, Min.: minimum

stronger in the damaged forest (41º51'6.1"N, 124º54'32.6"E, ASL: 800–1116 m). This might aggravate the forest damage further.

2.2 Field Investigation

We first made a reconnaissance throughout on the damage induced by the snow and wind (March 29 2003) in Dasuhe District soon after the occurrence of the damage (14–23 April 2003). During the survey, for viewing the damage in general, forty 20 m × 20 m temporary sample plots, in which damage types, diameter at breast height (1.3 m, DBH, cm), tree height, amount of damage and the corresponding tree species were investigated. In order to examine more in details the damage in relation to site, tree species, tree and stand characteristics, we conducted intensive observations in May–August 2003 in the stands containing snow and wind damage. For this purpose, we selected six typical plots, which met the following criteria:

1) The damage area was big enough (generally, more than 100 m × 100 m).
2) Each plot should contain different damage types.

Each plot was set up as 40 m × 30 m. All trees within each plot were positioned using GPS for calculating relative frequency of tree species, and for assessing the damage status, i.e., whether the trees had uprooted, suffered from stem breakage, bending, canopy damage, or remained undamaged. Caliper measurements were made on all trees of at least 5 cm for DBH, and tree species were registered within each plot. For the broken trees, the sum of the height from ground to the point of stem breakage, and the diameter at the corresponding height, the height at crown base, and the diameter of the stem at crown base were all measured.

Stand age was determined by the mean values of each stem in the plot. Tree age at damaged trees was countable according to the growth ring in the base disk. The age of undamaged tree was estimated using increment borers by sample trees. Additionally, site conditions including slope, direction of slopes steepness, soil depth and topography etc. were also investigated (Table 1).

2.3 Data Analysis

Damage Ratios

Four damage types were identified as uprooting, stem breakage, canopy damage and bending. The damage ratio was defined as the ratio of number of damaged stems to total number of stems in a plot or for one tree species (Eq. 1).

$$Dri = Ndi / Nt \times 100\% \tag{1}$$

where Dri is the damage ratio according to each damage type, Ndi is the number of the damaged stems corresponding to the damage type in a plot or for one tree species, i presents different damage types, i.e., i can be replaced by u (uprooted), s (snapped), c (canopy damage), b (bended), and t (overall damage), Nt is the total number of stems in a plot or for one tree species.

Statistical Analyses

To test the differences among tree species' susceptibility to types of the damage (canopy damage, snapped/breakage, uprooted and bending), Chi-square analysis of r×k (2×6) contingency tables was used to statistically evaluate the differences among the six major tree species, and separate analyses were conducted for each damage type (Eq. 2). In order to compare the difference between two tree species, Chi-square (χ^2) analysis of 2×2 contingency tables was used (Glover and Mitchell 2001). Tests were not conducted if the expected frequency in any cell of the contingency table was less than five (Veblen et al. 2001, Zhu et al. 2003b, 2004). The influences of taper and tree species composition on susceptibility to the damage were examined by comparing the mean values of taper for the four damage types (canopy damage, snapped/breakage, uprooted and bending).

$$\chi^2 = \sum_{i=1}^{k} \frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}} \qquad (2)$$

where O_{ij}, the sample number of the ith row and the jth column in the contingency table; E_{ij}, the theory number of the ith row and the jth column in the contingency table, degree of freedom, df = $(k-1)\times(r-1)$. Student's t-test was used to test the differences in taper among tree species and damage types.

In the above context, taper was calculated as Eq. 3.

$$T_{h-dbh} = H \,/\, DBH \qquad (3)$$

where H is tree height (m), DBH is diameter at breast height (cm).

The taper was calculated for individual trees and total stems in a sample plot, respectively.

3 Results

3.1 Qualitative Observations on Snow and Wind Damage

About 12% of the total area in Dasuhe District was affected by the damage (the total area of damaged stand was 1150 ha). Total of 3144 stems were visually investigated, of which, 58.4% damaged, and 41.6% undamaged. Based on the severity and qualitative characters of trees, four damage types could be identified, i.e., canopy damage (19.0%) (Canopy damage was defined as more than 30% crown damaged), breakage or snapping (16.4%), bending (18.5%) and uprooting (4.5%). Most of the damage occurred over ASL 800 m. The major damaged tree species included *Betula costata*, *Acer mono*, *Ulmus laciniata*, *Quercus mongolica*, *Carpinus cordtaa*, *Fraxinus mandshurica*, *Juglans mandshurica*, *Acer pseudosieboldianum*, *Acer tegmentosum*, and *Populus davidiana*.

3.2 Effects of Geographical Conditions on the Damage Ratio of Trees

We selected three factors to represent geographical conditions, which included height of ASL (Sla, m), slope steepness (Sl, degree), and soil depth (Sd, cm). The relationships between damage ratios (all types of damage, Drt) and the geographical factors were examined using the 6-sample data set. The multi-regression equation could be expressed as,

$$Drt = 0.0530Sla + 0.6636Sl - 0.5363Sd$$
$$(R^2 = 0.695,\ p < 0.01) \qquad (4)$$

Damage types changed with geographical conditions were plotted in Fig. 2. All of the four types of damage occurred at high elevation (above 1000 m), and no bending trees under 1000 m were observed (Fig. 2A). Snapped ratios increased with the slope steepness and soil depth, but the uprooted ratio decreased with increasing soil depth (Fig. 2B, C). Snapped ratios seemed to increase from southern slope to northwestern slope (Fig. 2D).

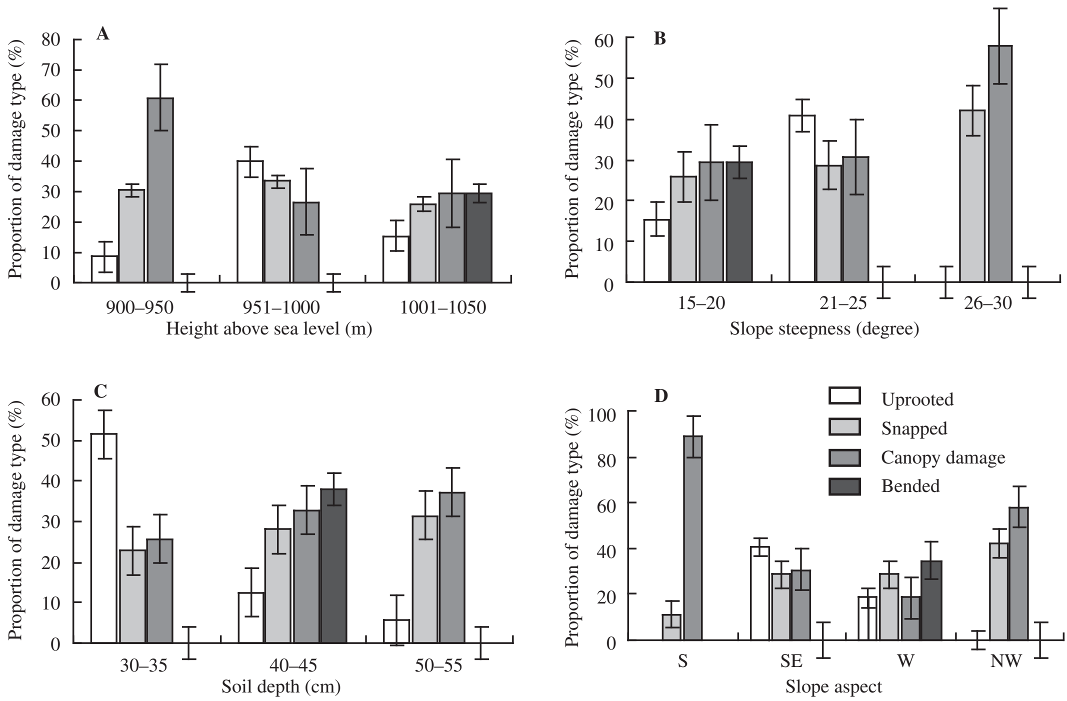


Fig. 2. Damage types with respect to geographical conditions at QEF. Bars are standard errors. A: elevation, B: slope steepness, C: soil depth, D: slope aspect, NE=Northeast, NW=Northwest, S=South and W=West.

3.3 Tree Species and Damage Types

Differences in tree species' susceptibility to damage were examined for the major six tree species in the secondary forest, i.e., in *B. costata*, *A. mono*, *U. laciniata*, *Q. mongolica*, *F. mandshurica*, *J. mandshurica*. Amount of uprooting trees were too low (total 123 trees, for example, only 4 trees for *Q. mongolica*) for statistical evaluation of differences among the tree species (Fig. 3A). Significant differences among species' susceptibility to bending, snapping and canopy damage were found ($\chi^2=31.6$, 19.6 and 24.9 for bending, snapping and canopy damage, respectively, which were more than $\chi^2_{(df=5,\ \alpha=0.005)}=16.7$, $p<0.005$; Fig. 3B–D). For the overall types of damage, significant difference among species' susceptibility to damage was also observed ($\chi^2=78.9>\chi^2_{(df=5,\ \alpha=0.005)}=16.7$, $p<0.005$, Fig. 3E).

B. costata was the most susceptible to uprooting among the six species ($\chi^2=7.0>\chi^2_{(df=1,\ \alpha=0.01)}=6.63$, $p<0.01$, Table 2). The significant differences to those of *F. mandshurica* ($\chi^2=5.8$, $p<0.05$) and *A. mono* ($\chi^2=11.2$, $p<0.005$) were found, while other species did not show significant difference (Table 2). Although *Q. mongolica* was somewhat less frequently uprooted (significant tests were not performed because of the small sample number of uprooted *Q. mongolica* trees), it was most susceptible to snapping and canopy damage, while it was not significantly different as compared with *U. laciniata* and *J. mandshurica* ($p<0.05$). *A. mono* was the least susceptible to snapping and canopy damage, but no significant differences when compared with *F. mandshurica* and *J. mandshurica* ($p<0.05$) were found (Table 2). *B. costata*, *A. mono* and *U. laciniata* (group 1) were more susceptible to bending than *Q. mongolica*, *F. mandshurica* and *J. mandshurica* (group 2), and significant differences were observed between these two groups ($p < 0.05$) (Table 2).

As for the total damage (all types), *B. costata*, *Q. mongolica* and *U. laciniata* were more susceptible to total damage than those of *A. mono*, *F. mandshurica* and *J. mandshurica* ($\chi^2\geq 9.7$, $p<0.005$) (Table 2).

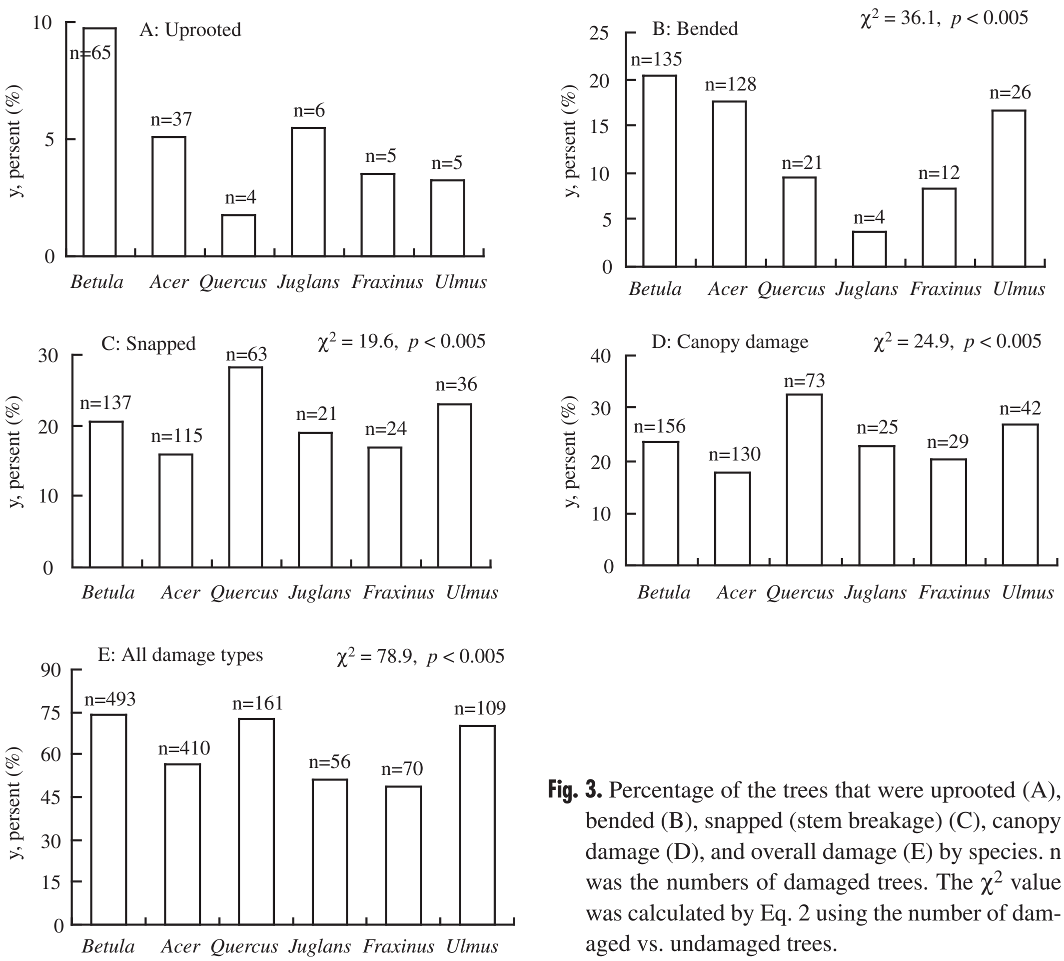


Fig. 3. Percentage of the trees that were uprooted (A), bended (B), snapped (stem breakage) (C), canopy damage (D), and overall damage (E) by species. n was the numbers of damaged trees. The χ^2 value was calculated by Eq. 2 using the number of damaged vs. undamaged trees.

3.4 Influence of Tree and Stand Characteristics on Forest Damage

We selected stem taper (H/DBH) and stand density to represent the tree and stand characteristics in analyses (the indexes were determined by all of the trees in the plots, including the damaged ones). Four damage types of uprooting, snapping, canopy damage and bending were closely related to mean value of stem taper. When damage types were compared independently of tree species, the order of weighted mean taper values of the four-type damage ranked as: bending (92.0, n = 605) > uprooting (85.3, n = 141) > stem breakage (80.1, n = 813) > canopy damage (65.0, n = 380) (Table 3) (*t*-test, $p < 0.05$). This rank also fit to the tree species of *B. costata*, *A. mono* and *U. laciniata*. The bended trees with the largest tapers and the canopy damage trees with the least tapers for all of the tree species are listed in Table 3 except for *J. mandshurica* (Table 3).

Differences in mean taper values between damage types and tree species were examined by *t*-test (Appendices 1 and 2). For the overall damage, *Q. mongolica* and *J. mandshurica* exhibited the lowest taper (59.6 and 61.0, respectively). *A. mono* exhibited the highest taper value (85.7), but was not significantly different with *B. costata* (82.4) and *F. mandshurica* (81.9) ($p < 0.05$). In the uprooting type, *Q. mongolica* also showed the lowest taper, but significance tests (*t*-test) could not conducted because the uprooted *Q. mongolica*

Table 2. Summary of Chi-square results between tree species and damage types.

Damage type / Tree species	*Q. mongolica*	*U. laciniata*	*F. mandshurica*	*J. mandshurica*	*A. mono*
Uprooted					
B. costata		7.00[b]	5.80[a]	2.10	11.20[c]
Q. mongolica[d]					
U. laciniata			0.00	0.80	1.00
F. mandshurica				0.60	0.70
J. mandshurica					0.00
Snapped					
B. costata	5.70[a]	0.50	1.10	0.10	5.40[a]
Q. mongolica		1.30	6.30[a]	3.30	17.40[c]
U. laciniata			1.80	0.60	4.80[a]
F. mandshurica				0.20	0.10
J. mandshurica					0.80
Bended					
B. costata	13.60[c]	1.00	11.20[c]		1.60
Q. mongolica		4.40[a]	0.10		8.60[c]
U. laciniata			4.60[a]		0.10
F. mandshurica					7.50[b]
J. mandshurica [d]					
Canopy damage					
B. costata	7.60[b]	0.80	0.70	0.00	6.60[a]
Q. mongolica		1.50	6.70[b]	3.60	22.50[c]
U. laciniata			1.80	0.60	6.70[b]
F. mandshurica				0.20	0.50
J. mandshurica					1.50
Total					
B. costata	0.30	1.10	35.00[c]	24.40[c]	47.80[c]
Q. mongolica		0.20	20.20[c]	14.70[c]	17.90[c]
U. laciniata			13.60[c]	9.80[c]	9.70[c]
F. mandshurica				0.10	2.60
J. mandshurica					1.10

$\chi^2_{(df=1,\ \alpha=0.05)} = 3.84$, $\chi^2_{(df=1,\ \alpha=0.01)} = 6.63$, $\chi^2_{(df=1,\ \alpha=0.005)} = 7.88$.
[a]: significant difference at $p < 0.05$, [b]: significant difference at $p < 0.01$, [c]: significant difference at $p < 0.005$, [d]:sample number was less than 5.

Table 3. Relationships between stem taper (H/DBH) and damage types.

Tree species	Uprooting		Bending		Damage types Stem breakage		Canopy damage		Undamaged	
	Damaged stem no.	Mean taper	Damaged stem no.	Mean taper	Damaged stem no.	Mean taper	Damaged stem no.	Mean taper	Undamaged stem no.	Mean taper
A. mono[a]	37	91.4	128	95.0	203	85.8	64	63.4	296	85.9
A. pseudosieboldianum	7	98.8	195	92.0	93	89.4	25	78.6	418	91.3
A. tegmentosum	7	97.5	63	89.6	39	85.2	72	71.1	21	90.4
B. costata[a]	66	80.8	135	95.5	229	82.0	86	64.2	150	88.5
Q. mongolica[a]	4	51.7	21	76.2	95	61.1	47	50.0	56	65.9
Phellodendron amurense							6	78.5	5	94.4
P. davidiana							7	78.5	5	104.0
F. mandshurica[a]	5	82.4	12	84.0	31	89.2	29	73.1	66	84.3
Tilia amurensis					4	96.7	3	78.3	6	96.6
U. laciniata[a]	5	85.6	24	85.8	62	67.0	24	57.5	41	78.4
C. cordtaa	4	99.3	23	92.4	32	89.8	11	79.8	38	84.3
J. mandshurica[a]	6	81.8	5	49.6	29	59.3	22	59.8	49	63.4
Total/average	141	85.3	605	92.0	813	80.1	380	65.0	1135	85.9

[a]: the six tree species were used to test the difference of taper between damage types and tree species (see Appendices 1 and 2).

trees were less than five individuals. The highest taper of uprooting was found in *A. mono*, but the value was insignificant with other species ($p<0.05$). For the snapping and canopy damage types, the tapers exhibited the same tendency, i.e., the tapers of *B. costata*, *A. mono* and *F. mandshurica* (group 1) were higher than those of *U. laciniata*, *Q. mongolica*, and *J. mandshurica* (group 2), and significant differences between the two groups ($p<0.05$) (Appendix 2).

The relationship between overall damage ratios of tree species in each plot was also examined. The relationship between stand density and damage ratios showed a decreasing tendency for the overall damage ratios and the canopy damage ratios (Fig. 4). However, the damage ratios for other damage types did not show any trend.

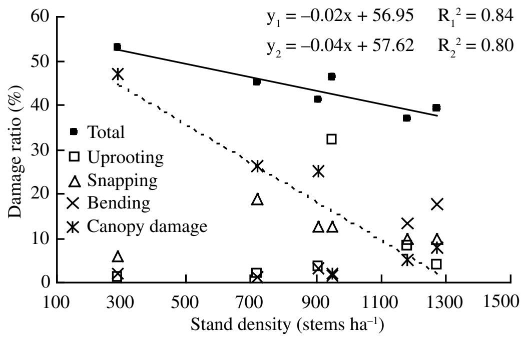


Fig. 4. Relationships between stand density and damage ratios (all types of damage), x: stand density, y_1: overall damage ratio, y_2: canopy damage.

4 Discussion and Conclusions

The snow and wind damage destroyed small percentages (12% of the total area in Dasuhe District affected) of the trees in the natural secondary forest; it was the first time since recorded began from 1958. The overall pattern of the damage was significantly influenced by topography factors. The amount of damage increased with the height of ASL (over 800 m) and the slope steepness, and decreased with the increment of soil depth in each plot. Slope steepness and the soil depth played a relatively important role, the height of ASL played a relatively minor role, as suggested earlier also by Solantie (1994), Nykänen et al. (1997) and Ruel et al. (1998), for example. The forest damage was identified as canopy damage, snapping/stem breakage, bending and uprooting, of which, more than 60% were breakage (canopy damage and stem breakage). The damage ratios of all types of the snow and wind damage decreased with the increment of stand density (Fig. 4). The damage ratios for individual damage types of uprooting, snapping and bending were not correlated with the stand density, while canopy damage ratio was closely related with the stand density (Fig. 4). This might be explained from two aspects, on one hand, the stand with lower stand density (sparse stand) might load less snow than that of the stand with greater stand density (dense stand), but the snow quantity on individual trees in the smaller density stand might be more than that in the greater density stand. On the other hand, 60% of the damage belonged to breakage (canopy damage and stem breakage), the lower the stand density was, the bigger the individual trees were, especially the tree crown, therefore, more snow loaded on the individual trees within the lower density stand.

Without considering of tree species, the bending damage exhibited the highest weighted mean taper (92.0), but the canopy damage showed the lowest weighted mean taper (65.0) (Table 3). This result might be explained as follows: the smaller the taper was, the bigger the crown was, i.e., the stems with smaller taper loaded heavier snow than those with bigger taper. Therefore, the canopy damage and stem breakage of the stems with smaller taper occurred easily (Petty and Worrell 1981, Dobbertin 2002, Pellikka and Järvenpää 2003). The same principle as above-mentioned, the bigger the taper was, the easier the bending occurred, correspondingly

Evidently, the dominant tree species within the stand were commonly damaged by the snow and wind. The result might indicate that the composition of tree species in a stand influenced the extent of the snow and wind damage (Matsuzaki 1994, Nykänen et al. 1997, Veblen et al. 2001). The snow and wind damage was also significantly influenced by the tree species composition and forest structure at the time of the damage occurred. Tree species differed not only in the amount of snow and wind damage but in the type of damage as well. Among the major tree species, when the individual tree species were compared independently of site and stand characteristics, we found that *B. costata* exhibited much more uprooting than other species (Fig. 3). This may be due to the origin of the *B. costata* with much denser fine branches in the crown (Ren 1997, Li et al. 2004), which results in much more snow accumulation on the tree crown. This explanation can be confirmed by viewing the curved branches in the field investigation, i.e., most of *B. costata* branches were curved in the uprooted trees. Other contributing factors may be the thin soil depth and the taller stature of *B. costata*, which would have increased the wind force in the canopy. Not only this, *B. costata*, together with *A. mono* and *U. laciniata*, also exhibited significantly higher bending ratio than *Q. mongolica*, *J. mandshurica* and *F. mandshurica* ($p<0.05$) (Table 2). This is because the stems of the three species (*B. costata* and *A. mono* and *U. laciniata*) have pliable stems (Ren 1997). *Q. mongolica* showed the highest breakage damage ratios (both stem breakage and canopy damage) because of the frangible branches of *Q. mongolica* (Ren 1997); but not significantly different from *U. laciniata* and *J. mandshurica* ($p < 0.05$).

As for the overall damage ratios, *B. costata*, *Q. mongolica* and *U. laciniata* exhibited relatively high overall damage ratios (Fig. 3E, Table 2), but they displayed different proportions of damage types. For example, the proportion of the four damage types of *B. costata* was about 13 (uprooting): 60 (breakage: canopy and stem): 27 (bending), but for tree species *Q. mongolica* and *U. laciniata* were 3 (uprooting): 84 (breakage: canopy and stem): 13 (bending) and 5 (uprooting): 72 (breakage: canopy and stem): 23 (bending), respectively. This result indicated that the canopy and stem breakage were the major types of *Q. mongolica* and *U. laciniata*, But uprooting was the major type of *B. costata*. *F. mandshurica* exhibited the least overall damage than other species (Fig. 3E). This may be due to the origin of most branches of *F. mandshurica* distributing sparsely in the crown (Ren 1997), which resulted in less snow loading, and therefore increased the resistance to snow and wind damage. There were no significant differences between the overall damage ratios of *F. mandshurica*, *A. mono* and *J. mandshurica*, this result may attribute to their canopy sizes were relatively smaller.

Reported studies showed that intermediate-size trees are more susceptible to snow and wind damage than sub-canopy or very large trees (Petty and Worrell 1981, Cremer et al. 1982, Peterson 2004), and this has been explained by sheltering of smaller trees from the wind and preconditioning of the largest trees because of their greater exposure to wind (Everham and Brokaw 1996). In our study, even snow accumulation played a major role in the snow and wind damage; the tapers of uprooted and snapped trees for all tree species were almost the same as the mean tapers (Table 3). However, the bending damage and canopy damage occurred in the trees with higher (a partial exception was for *J. mandshurica* because of less sample trees) and lower tapers, respectively; not the intermediate-size trees. For the overall damaged trees, the tapers for all tree species were similar to the mean tapers of sample plots (Appendix 1). The analyses of influences of tapers led to the expectation that tree species with lower taper would be less susceptible to uprooting damage. On the other way round, the tree species with higher mean tapers would be more susceptible to uprooting damage (Veblen et al. 2001). This is supported by the result obtained in this study, i.e., *U. laciniata*, *Q. mongolica* and *F. mandshurica* with lower taper (61–72) were less susceptible to uprooting damage, *B. costata*, *A. mono* and *J. mandshurica* with higher mean tapers (83–86) were more susceptible to uprooting damage (Tables 2, 3, Appendices 1, 2).

Additionally, as a conclusion, we would like to conclude that the occurrence of the damage in the secondary forests depended mostly on the heavy snow accumulation on trees with the moderate winds. This result was consistent with the conclusions obtained by Valinger et al. (1993) and Nykänen et al. (1997), i.e., wet snow occurred most likely in early spring and later autumn. When moderate winds came, the trees heavily loaded by snow would be broken easily (Peltola et al. 1997, Pellikka and Järvenpää 2003). Peltola et al. (1997) suggest that wind speed of 9.0 m s^{-1} over the canopy can increase the stem breakage of trees with heavy snow load.

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Appendix 1. Table of *t*-test on the difference of taper between tree species.

	Acer	*Quercus*	*Juglans*	*Fraxinus*	*Ulmus*
1) The overall damage (all types)					
Betula	[a]1.978 (948)	[c]10.679 (683)	[c]6.622 (577)	0.186 (593)	[c]5.004 (631)
Acer		[c]11.43 (599)	[c]7.179 (493)	1.206 (509)	[c]5.894 (547)
Quercus			0.439 (228)	[c]7.264 (244)	[c]3.578 (282)
Juglans				[c]5.985 (138)	[a]2.440 (115)
Fraxinus					1.456 (192)
2) Uprooting					
Betula	[a]2.497 (103)		0.146 (72)	0.178 (71)	0.602 (71)
Acer			0.875 (43)	0.681 (42)	0.486 (42)
Juglans				0.032 (11)	0.362 (11)
Fraxinus					0.167 (10)
3) Bending					
Betula	0.168 (263)	[c]3.290 (156)	[c]3.716 (139)	1.597 (147)	1.829 (159)
Acer		[c]3.403 (149)	[c]3.973 (132)	1.649 (140)	1.856 (152)
Quercus			1.917 (25)	0.937 (33)	1.370 (45)
Juglans				[c]5.038 (16)	[b]3.644 (28)
Fraxinus					0.291 (36)
4) Snapping					
Betula	1.685 (432)	[c]7.980 (324)	[c]5.428 (258)	1.671 (260)	[c]4.696 (291)
Acer		[c]8.717 (298)	[c]5.830 (232)	0.733 (234)	[c]5.431 (265)
Quercus			0.473 (124)	[c]6.538 (126)	1.694 (157)
Juglans				[c]6.116 (60)	1.676 (91)
Fraxinus					[c]4.327 (93)
5) Canopy damage					
Betula	0.216 (150)	[c]3.621 (133)	0.839 (108)	1.927 (115)	1.242 (110)
Acer		[b]3.088 (111)	0.622 (86)	1.930 (93)	0.986 (88)
Quercus			1.922 (69)	[c]5.309 (76)	1.400 (71)
Juglans				[a]2.575 (51)	0.328 (46)
Fraxinus					[b]2.695 (53)
6) Un-damage					
Betula	1.130 (446)	[c]6.353 (206)	[c]7.185 (199)	1.244 (216)	[a]2.358 (191)
Acer		[c] 5.722 (352)	[c]6.287 (345)	0.483 (362)	1.791 (337)
Quercus			0.665 (105)	[c]4.342 (122)	[a]2.426 (97)
Juglans				[c]5.342 (115)	[c]3.703 (90)
Fraxinus					1.126 (107)

[a]: $p<0.05$; [b]: $p<0.01$; [c]: $p<0.005$ (According to Student's *t* Table); Data in bracket is degree of freedom (df) for *t*-test, it is determined as: $df = n_1 + n_2 - 2$, n_1, n_2: the numbers of the damaged trees.

Appendix 2. Table of *t*-test on the difference of taper between damage types.

	Bended	Snapped	Canopy damage	Undamaged
1) *Betula costata*				
Uprooted	[c]4.379 (201)	0.427 (295)	[c]4.918 (152)	[a]2.347 (216)
Bended		[c]5.383 (364)	[c]9.464 (221)	[a]2.471 (285)
Snapped			[c]6.296 (315)	[b]2.765 (379)
Canopy damage				[c]7.843 (236)
2) *Acer mono*				
Uprooted	0.820 (165)	1.298 (203)	[c]5.379 (101)	1.306 (333)
Bended		[c]3.483 (331)	[c]8.816 (192)	[c]3.644 (424)
Snapped			[c]6.453 (267)	0.039 (499)
Canopy damage				[c]6.705 (360)
3) *Quercus mongolica*				
Bended		[b]2.93 (116)	[c]4.50 (68)	1.70 (77)
Snapped			[b]3.17 (142)	1.38 (151)
Canopy damage				[c]3.85 (103)
4) *Juglans mandshurica*				
Uprooted	3.623 (10)	[b]3.827 (35)	[a]2.472 (28)	[b]2.854 (55)
Bended		1.476 (33)	0.979 (26)	1.837 (53)
Snapped			0.107 (51)	1.279 (78)
Canopy damage				0.863 (71)
5) *Fraxinus mandshurica*				
Uprooted	0.134 (17)	0.541 (36)	0.890 (34)	0.161 (71)
Bended		0.721 (43)	[a]2.031 (41)	0.032 (78)
Snapped			[b]3.032 (69)	0.940 (97)
Canopy damage				[a]2.256 (95)
6) *Ulmus laciniata*				
Uprooted	0.028 (29)	1.742 (67)	[a]2.367 (29)	0.541 (46)
Bended		[b]3.521 (86)	[c]4.365 (48)	1.118 (65)
Snapped			1.651 (86)	[a]2.230 (103)
Canopy damage				[b]2.968 (65)

[a]: $p<0.05$; [b]: $p<0.01$; [c]: $p<0.005$ (According to Student's *t* Table); Data in bracket is degree of freedom (df) for *t*-test, it is determined as: $df = n_1 + n_2 - 2$; n_1, n_2: the numbers of the damaged trees.