Risk assessment of spatiotemporal wind hazards in Japanese mountain forests: linking an air-flow model and the local yield table construction system

TOHRU NAKAJIMA (Research Fellow of the JSPS, The University of Tokyo)
TOSHIAKI OWARI (University Forest in Hokkaido, The University of Tokyo)
JUNG-SOO LEE (Kangwon National University)
MITSUO MATSUMOTO (Forestry and Forest Products Research Institute)
SATOSHI TATSUHARA, NORIHIKO SHIRAISHI (The University of Tokyo)

Introduction

In Japan, the most catastrophic forest disturbances are caused by severe typhoons. For example, the tree volume damaged by Typhoon No. 15 (1981) in the University Forest in Hokkaido, University of Tokyo, was about 0.81 million m^3 (*7*). Despite the extensive area of damage, forest managers are shifting to long rotations, which make forests more susceptible to the impact of typhoons. This applies to plantation forests, which comprise 40% of the forest area in Japan (*2*). A longer period without cutting leads to a greater probability of natural disturbance. Hence, it is important to analyze the patterns of natural wind disturbance caused by catastrophic typhoons.

Here we assessed the risk of wind disturbance in mountain terrain by combining air-flow simulations and historical records of wind disturbance to forests.

Materials and methods

1) Study site

The study was conducted in the University Forest in Hokkaido, which belongs to the University of Tokyo and is between 190 and 1,460 m above sea level. The forest was severely damaged by the Toyamaru and typhoon No. 15 which struck in 1954 and 1981, respectively. The wind damage caused by the typhoons was analyzed (*7*) using detailed information on the disturbance caused, wind conditions, and forest conditions.

2) Data sources

For analysis of wind conditions, Digital Surface Models (DSMs) and Digital Elevation Models (DEMs) with 10 × 10-m mesh data (GISMAP terrain, Hokkaido – chizu co., ltd.) were used. DSMs were constructed from aerial photographs taken in 1978 and 2007 and were produced using ERDAS IMAGINE (ESRI). In order to analyze wind disturbance, local records of the forest area disturbed by wind were incorporated. These records are based on field surveys and aerial photographs of the study area conducted after a typhoon in 1981. The data sources also include meteorological information, such as maximum wind speed and wind direction, and estimates of stand growth parameters obtained from ground survey records and yield tables in Hokkaido and the northern area of Japan (*3*,*5*,*8*).

3) Data analysis tool

The RIAM-COMPACT (*6*) simulator was used to calculate air-flow conditions. When a digital surface model (DSM), together with wind direction and wind speed for a site are input into RIAM-COMPACT, it provides output wind conditions in the local area in the form of raster data. The raster data, combined with GIS data for the University Forest, were analyzed using ArcGIS9.0 (ESRI).

4) Procedures

Estimation of wind conditions

In the University Forest in Hokkaido, wind hazards caused by typhoon No. 15 in 1981 were calculated and analyzed by considering wind speed reported by previous study (*7*).

Wind conditions were estimated using RIAM-COMPACT. First, meteorological data were entered, followed by local wind hazard records. The wind direction entered was from the south, because local records for the site indicate that the strongest winds (>19 $m•s^{-1}$) are from this direction. Therefore, 19 $m• s^{-1}$ and southerly winds were used as the maximum instantaneous

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Tohru Nakajima (Research Fellow of the Japan Society for the Promotion of Science, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku, Tokyo, 113-8657, Japan), Toshiaki Owari (University Forest in Hokkaido, The Univ. of Tokyo, Furano, Hokkaido 079-1561), Jung-Soo Lee (Kangwon National University, Chuncheon 200-701, Korea), Mitsuo Matsumoto (Forestry and Forest Products Research Institute, Tsukuba, Ibaraki 305-8687), Satoshi Tatsuhara, Norihiko Shiraishi (The University of Tokyo)

Risk assessment of spatiotemporal wind hazards in Japanese mountain forests: linking an air-flow model and the local yield table construction system wind speed and wind direction. In general, height above sea level is positively correlated with wind speed. Then, the location of the maximum wind speed corresponded to the highest part of the study area

Next, maximum wind speed by stand area was determined by overlaying a raster map of the wind speed distribution predicted by RIAM-COMPACT onto a vector map with a 50-m grid. For each grid square, the average maximum wind speed was determined, and the relationship between maximum wind speed and wind disturbance was analyzed.

Logistic analysis

A logistic analysis (*1*) technique was used to assess the probability of wind disturbance for disturbed stands (indicator for wind hazard: iwh = 1) and stands without hazards (iwh = 0). When using logistic analysis, the probability (p) of a stand being disturbed was modeled as a function of wind conditions and stand height (x1, x2). We estimated the stand height by subtracting DEM from DSM for 1978 data points. Using these factors, the probability of disturbance (*p*) was calculated from:

$$p = \frac{\exp(a_0 + a_1 x_1 + a_2 x_2)}{1 + \exp(a_0 + a_1 x_1 + a_2 x_2)} \quad (1)$$

where $x1$, $x2$ are maximum wind speed (m•s^{-1}) and stand height, and $a0$, $a1$, and $a2$ are constants.

The wind disturbance probability for the forest was predicted on the basis of this logistic analysis.

Predictions of forest resources and wind hazard probability

We applied the Local Yield Table Construction System (LYCS) to *Abies sachalinensis* (todomatsu), *Cryptomeria japonica* (sugi) plantations using the parameter estimation method (*4*). The growth model consisted of the following four formulas:

Height growth curve:

$$H = M[1 - L\exp(-kt)] \quad (2)$$

H: stand height (m), *t*: stand age (year)

M, *L*, *k*: parameters

Relationship between stand density and mean DBH:

$$\log N + a \log D = K \quad (3)$$

where *N* is the stand density (trees/ha), *D* is the DBH in cm, and *a* and *K* are the parameters.

Increment rate of mean DBH:

$$r = m\exp(-n\,t) \quad (4)$$

where *r* is the increment rate of the mean DBH (%/year), *m* and *n* are the parameters, and t is stand age.

The growth model for diameter increment used the results from formulae (3) and (4) to give:

$$r = m\exp(-n\,t) + p\,(K - \log N - a\log D) \quad (5)$$

where *p* is the parameter.

We also predicted the expected stand volume to demonstrate how the forest would be affected during the sweep of a storm. Multiplying the wind hazard probability by the stand volume predicted by LYCS, we can estimate the expected stand volume that would be affected by this wind hazard:

$$P_i = V_i \ (1 - A_i) \quad (6)$$

where P_i is the expected stand volume in year *i* (m^3);

A_i is the wind hazard probability in year *i* (%); and

V_i is the volume in year *i* (m^3).

Results and discussion

The logistic analysis produced the following probability assessment model (7):

$$p = \frac{\exp(-8.664 + 0.498Ws)}{1 + \exp(-8.664 + 0.498Ws)} \times 100 \quad (7)$$

where *p* is the percentage wind hazard (%), and *Ws* is maximum wind speed (m·s^{-1}).

The *P* values for wind speed were less than 0.01. However, the variable ‘stand height’ was not significant ($P > 0.10$). Table 1 shows the estimated parameters.

Comparing tree height growth parameters of Hokkaido and Yamagata Shounai (heavy snowfall area) for *C. japonica*, it is evident that growth in Hokkaido is lower than that in Yamagata. Using the parameters in this table, we introduced differences in stand density that varied with district and tree species into the LYCS.

Figure 1 shows the wind hazard probability calculated by the logistic regression model with a changing time series of meteorological data based on the DSM in 2007. The observed maximum southerly wind speeds from June through September 1979, 1980, and 1981 were 7, 9, and 19 m•s^{-1}, respectively.

There were no significant changes in the wind hazard probability of the central area based on the time series data. This suggests that the wind hazard probability for the safety of the area subject toeases over time. Thus, we were able to quantify future risk by southerly wind disturbances was relatively stable. However, the northern area was significantly changed depending on the time series data used.

Figure 2 shows the expected stand volume for trees damaged by wind at various wind speeds. The timber volume increased in relation to length of growing time. This means that the growing stand volume that will potentially be damaged by typhoons incr using logistic regression models and the local yield table construction system.

Conclusion

We have elucidated the relationship between wind hazard probability and wind speed in plantation forest stands. Moreover, we have estimated the differences in expected stand volume damage by wind hazard probability and, using RIAM-COMPACT and the local yield table construction system, we have shown that it is possible to simulate wind hazard risk based on wind speed for the University Forests in Hokkaido.

Acknowledgement

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Table 1 Estimated model parameters for todomatsu and sugi stands.

$H = M\,(1 - L\,\exp(-k\,t))$

	Abies sachalinensis	*Chryptomeria japonica*	
		Hokkaido	Yamagata
M	49.00 − 6.16*S*	38.65 − 6.27*S*	45.14 − 8.72*S*
L	1.08	1.05	1.28
k	0.01	0.02	0.03

S: site class (1−3)

$r = m\exp(-nt) + p\,(K - \log N - a\log D)$

	Abies sachalinensis	*Chryptomeria japonica*	
		Hokkaido	Yamagata
m	8.03	7.44	5.57
n	0.04	0.04	0.04
K	5.25	4.89	4.07
a	1.73	1.40	0.74
p	5.30	2.00	2.00

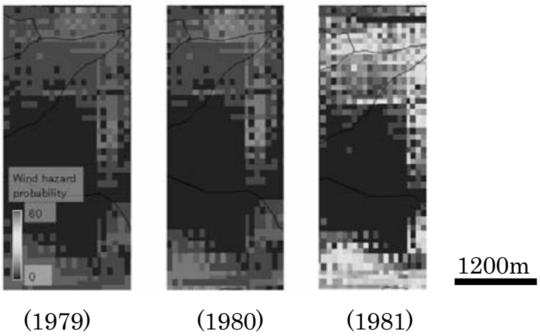

Fig. 1. Wind hazard probability time series meteorological data.

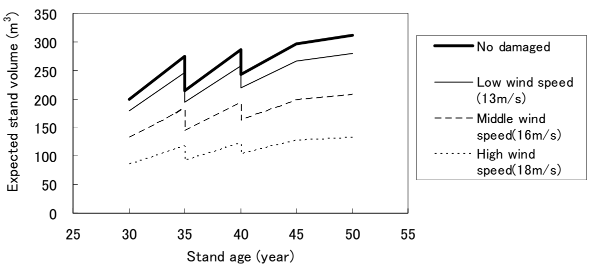

Fig. 2. Expected stand volume for trees damaged by wind at various wind speeds.