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RELATIONSHIP BETWEEN OXIDANT-BASED AOT40 AND FOREST ENVIRONMENTAL CONDITIONS OF DAMAGED JAPANESE CEDARS IN THE KANTO PLAINS.

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Abstract

In recent years, photochemical oxidant concentration has increased continually in Japan. The current ozone level has a potentially adverse effect on plants. Forest health monitoring surveys have been carried out, but effects of air pollutants on plants have not been clarified. In this study, we analyzed observation data using a geographic information system (GIS) to evaluate, both regionally and visually, the relationship between air pollutants and plant decline, as represented by data of Japanese cedars (*Cryptomeria japonica* D. Don). Japanese cedar forests in the Kanto plains of central Japan were studied. Cumulative exposure over a threshold of 40 ppb (AOT40) based on photochemical oxidant concentrations at all air pollutant monitoring stations showed a gradual upward trend from 1982 after a rapid decrease from 1975. The AOT40 values vary annually to a great degree: high AOT40 values were observed in hot summer years. Distributions of AOT40 values were compared to plant decline information from Nashimoto (1990) and Matsumoto et al. (2002). Severely damaged Japanese cedars were distributed in regions of less than 100 m altitude, less than 1000 mm precipitation during April–September, less than 20% forest coverage, and a leaf area index (LAI) of less than 1.5. The distribution of severely damaged stands coincided approximately with the regions of average AOT40 equal to 10 000 ppb·hr.

KEYWORDS: Air pollutant, Forest decline, GIS, AOT40, Japanese cedar

1. Introduction

Forests are receptors of SOx, NOx and photochemical oxidants. In the United States, the US Environmental Protection Agency has regulated ambient ozone concentrations since the early 1970s (Jeremy, 2003). In Europe, critical levels of air pollutants were first discussed in the late 1980s; the first provisional critical levels of gaseous air pollutants for agricultural crops and forests were proposed in 1988 (Ashmore and Wilson, 1992; CLAG, 1994).

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Among Asian countries, efforts to establish critical levels of air pollutants for protecting Asian vegetation have been nonexistent, except for the RAPIDC (Emberson et al., 2003). Japan's ozone level might adversely impact plants. Moreover, forest health monitoring surveys have been conducted in Japan. Although no relationship between air pollutant concentrations and plant decline has been clarified, numerous reports have described the decline of Japanese cedars (*Cryptomeria japonica* D. Don) in the Kanto plains. The decline of Japanese cedars has been recognized and studied in suburban areas in Japan since the late 1960s (Yambe et al., 1978). Nashimoto (1990) examined the relationship between the decline of Japanese cedars and secondary air pollutants or precipitation during the warm season. The distribution of severely and mid-severely damaged stands occurred in regions with a high oxidant index and low total precipitation during the warm season. Moreover, Matsumoto et al. (2002) reported that high temperature stress and low moisture (drying) stress affected the decline of Japanese cedars in cities. Notwithstanding, the distribution of damaged Japanese cedars and the mechanisms of that damage have not been clarified.

This study is intended to evaluate the relationship between cumulative exposure over a threshold of 40 ppb (AOT40) based on photochemical oxidant concentrations and forest environmental conditions (elevation, precipitation, and land use) of damaged Japanese cedars in the Kanto plains using a geographic information system (GIS).

2. Materials and Methods

2.1 Description of GIS database

A GIS database was compiled for evaluation, both regionally and visually, of the relationship between air pollutants and forest decline and to propose critical-level mapping. Observation data, such as those of forest health and air pollutants, vegetation survey data and other environmental information were collected and stored in the GIS database. We used a commercial software program (ArcGIS; ESRI). Mesh climatic data file of the Japanese Meteorological Agency included data indicating monthly mean temperatures, precipitation, and snow depth of the 30 years during 1971–2000 (JMA, 2001). Digital national land information (elevation and land use) data were obtained from the Ministry of Land, Infrastructure and Transport of Japan (GSI, 1998). The vegetation survey mesh file is shown as a present vegetation map with 1-km^2 grid data (EA, 1993). Forest health monitoring data included plant decline information obtained from two survey results by Nashimoto (1990) and Matsumoto et al. (2002). Air pollutant data were measurements of 2200 air-pollutant surveillance stations. A monthly leaf area index (LAI) was produced using 1-km^2 digital data (vegetation type and land use) and seasonal changes in NOAA satellite data (Ishii, 1999, 2001).

2.2 Estimate of AOT40 using monthly photochemical oxidants

In Japan, the concentration of photochemical oxidants (Ox) is reported officially; the Ox data are presented as total excess hours over the Japanese standards. For several sites, both excess hours and hourly concentration data needed for the calculation of AOT40 are obtainable. Using those data, we developed an AOT40 estimation method using monthly Ox data. The AOT40 datum represents a dose (concentration × time). For that reason, it is expected to be related to total excess hours over a specific hourly concentration value. This assumption is valid for the use of Ox other than O_3. On the other hand, the monthly Ox data record the annual total number of hours during which oxidant levels are greater than the Japanese standards of 0.06 ppm or 0.12 ppm per hour. The AOT40 is estimated using monthly data with a regression relationship between AOT40 and total excess hours. Here, total excess hours are expressed as a sum of excess hours over 0.06 ppm and 0.12 ppm during April–September.

Based on measurements at sample points, two methods can be used for estimating values at unsampled locations: deterministic methods (e.g. inverse distance interpolation) and probabilistic methods (e.g. Kriging interpolation). Recently, Kriging is a popular technique for creation of ozone surfaces. Kriging estimates values at unsampled locations using weights that reflect the correlation between data at two sample locations or between a sample location and a location to be estimated (Myers, 1991). In this study, Kriging is used to predict AOT40 values for large areas.

2.3 Analysis of relationship between tree decline and AOT40

The study areas are Japanese cedar forests in the Kanto plains, central Japan. Nashimoto (1990) and Matsumoto et al. (2002) investigated the decline of Japanese cedars in this area. In those reports, a standard forest health monitoring method was used for estimating the state of damage of individual trees in a Japanese cedar stand. The health level is classified as one of four: healthy or minor damage, light damage, moderate damage, or severe damage based on needle loss and degree of dieback. This is equivalent to visual assessment of crown conditions in Europe (UNECE, 2004).

For this study, we extracted AOT40 values in degraded forest areas in two reports (Nashimoto, 1990, Matsumoto et al., 2002) and analyzed the relationship between climate, land use, and LAI data of the GIS database and AOT40 values.

3. Results and Discussion

3.1 Estimate of AOT40 using monthly Ox data

The monthly Ox data are presented as total excess hours over the Japanese standards (0.06 ppm and 0.12 ppm). AOT40 represents cumulative exposure (concentration × time) over a threshold of 0.04 ppm. Thus, total excess hours over the Japanese standards is expected to be related to AOT40. The relationship between total excess hours and observed AOT40 values is shown in Fig. 1. The total excess hours indicates the sum of the hours during which the values of photochemical oxidants exceeded 0.06 and 0.12 ppm during April–September. According to Fig. 1, the estimated values underestimated the actually measured values up to 400 h. Despite the estimation method's simplicity, the estimated values agreed well with measured AOT40 values. The observed AOT40 measurements were performed during daytime for 12 h. However, the sum of the hours during which the values of photochemical oxidants exceeded 0.06 and 0.12 ppm during April–September were performed during daytime for 15 h: from 5 a.m. to 8 p.m. The estimation accuracy might be improved if the definition of daytime were changed from 12 h to 15 h in AOT40 measurements. For preparation of whole-area maps shown below, the relationship between the total excess hours and observed AOT40 was used.

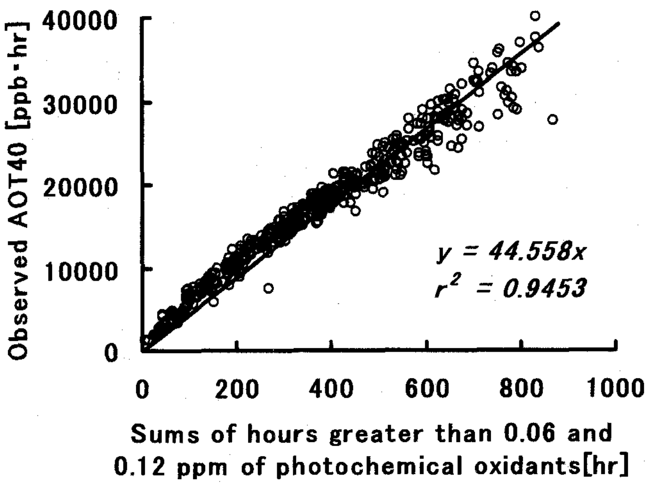

Fig. 1. Correlation between sums of hours greater than 0.06 and 0.12 ppm of photochemical oxidants and observed AOT40.

The horizontal axis shows the sum of hours greater than 0.06 and 0.12 ppm of photochemical oxidants based on the official monthly photochemical oxidant reports during April–September. The vertical axis is AOT40 calculated by the hourly photochemical oxidant data during April–September.

3.2 Tendency of AOT40 during 1975–2001

We calculated annual mean AOT40 values based on photochemical oxidant values obtained during 1975–2001 using the equation in Fig. 1. The AOT40 values in the Kanto district and nationwide showed a similar tendency: a gradual upward increase from 1982 after a rapid decrease from 1975 (Fig. 2). Recently, many monitoring stations have come to record their highest AOT40 values because of increasing oxidant concentrations (Fig. 3). But the plant influence of the highest value is not clear. The rise of ozone concentrations is inferred to result from complex effects including changes of solar radiation, changes in the concentration ratio of non-methane hydrocarbons to oxides of nitrogen, changes in non-methane hydrocarbon compositions, and long-range transport of ozone (Ohara, 2006 and Akimoto, 2003). Regarding meteorological condition changes, the average temperature of all air pollutant monitoring stations in the Kanto district increased 0.88°C during 1975–2001, solar radiation decreased 0.57 MJ/m^2, and AOT40 values increased 10 980 ppb·hr (Fig. 4). Temperature changes are inferred to result from the influence of global warming and heat-island phenomena. The AOT40 variation pattern apparently resembles trends of average temperature and solar radiation. For example, AOT40, average temperature and solar radiation tended to be high in hot summer (1994) and low in cool summers (1988 and 1993). Nevertheless, it remains unclear how changes in meteorological conditions influenced Japanese cedars.

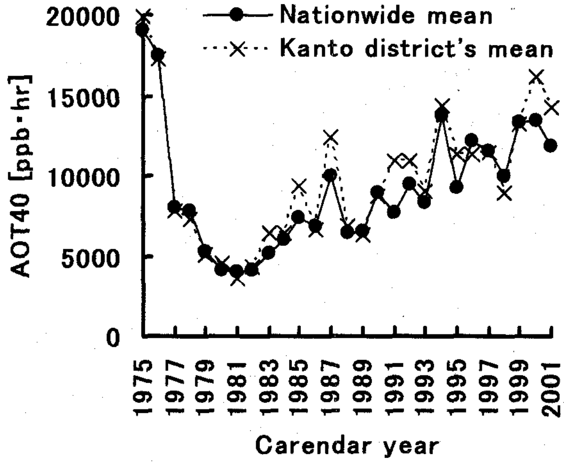

Fig. 2. Kanto district and nationwide tendency of AOT40 values during 1975–2001.

AOT40 was calculated from GIS data base transformed from nationwide air quality monitoring data during 1975–2001 using the equation in Fig. 1.

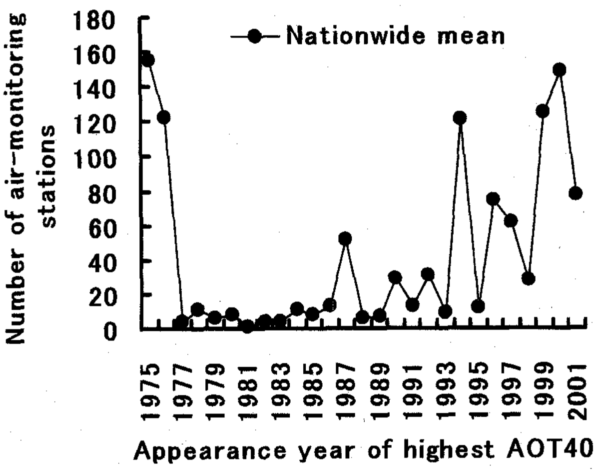

Fig. 3. Number of air-monitoring stations that recorded highest AOT40 values during 1975–2001.

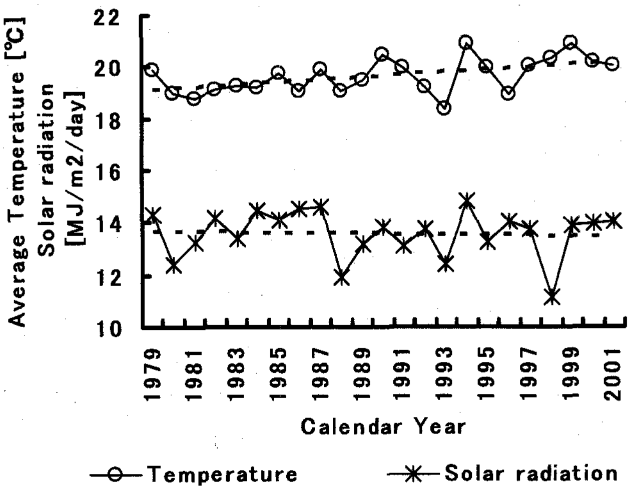

Fig. 4. Temperature and solar radiation in Kanto district during 1979–2001.

3.3 Zoning map for predicting a severe decline of Japanese cedar

The dot points shown in Fig. 5a represent the locations of monitoring stations. Figures 5b–5d depicts the distributions of averaged AOT40 values in Kanto district for nine years. The symbols + and □ show crown conditions, which were observed during each period of Japanese cedar damage surveys. The expanded areas of the severely damaged stands in Figs. 5c–5d coincide approximately with the regions in which the mean AOT40 value is 10 000 ppb·hr or higher. Wakamatsu et al. (1996) indicated that the daily maximum oxidant concentrations observed between 1978 and 1990 tended to move far from the emission areas in the Tokyo Bay area. In Figs. 5b–5d, it is apparent that the rising-AOT40 area during three periods originated in and expanded from the Tokyo Bay area. These trends agreed with Wakamatsu et al. (1996). Especially, the area of AOT40 increase was observed in northwest Kanto district.

Next, we extracted AOT40 values at various locations shown in Fig. 5 and analyzed the relationship between climate, land use, and LAI data in the GIS database and tree decline. The areas of severe damage of Japanese cedar were roughly distributed in regions with an altitude of less than 100 m and precipitation of less than 1000 mm during April–September (Fig. 6). Regarding precipitation, our results agreed well with those reported by Nashimoto (1990). The severely degraded stands are almost all located in areas where the forest coverage is less than 20% of the total area and where the LAI is less than 1.5 (Fig. 7). For such areas, the forest cover ratio was calculated for each 1-km grid using land use data (100-m resolution) obtained from Digital National Land Information. The areas of low forest cover ratio are mostly located inside cities, which concur with results of Takahashi et al. (1991) and Ito et al. (2002). Next, using an overlay technique, those zones were extracted of regions with less than 100 m altitude, less than 1000 mm precipitation, less than 20% forest coverage, and a LAI of less than 1.5 (Fig.8). The resultant zoning region suggests regions where the potential for severe damage of Japanese cedar can be predicted based on prevailing environmental conditions. If AOT40 values continue to increase, moderately damaged stands in the zoning area might become severely damaged stands. This overlay analysis of both AOT40 and forest environmental conditions of damaged Japanese cedars involve many uncertainties. Thus, there is a need for more statistical studies to develop appropriate methods to provide a more realistic assessment of ozone impacts on vegetation.

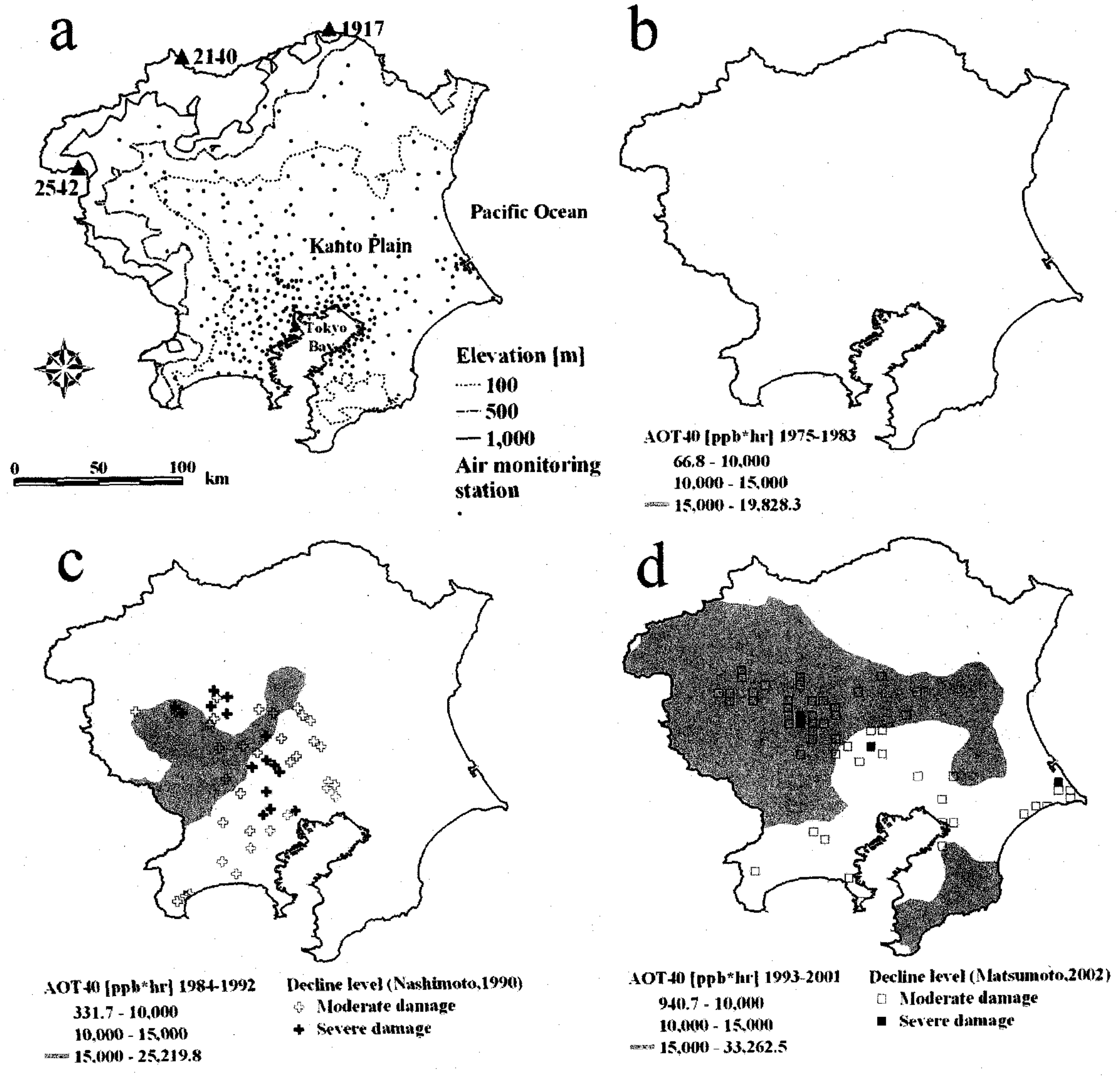

Fig. 5. Averaged AOT40 values for nine years for three periods in the Kanto district
Averaged AOT40 values for nine years were calculated using the regression equation in Fig. 1. Severely and mid-severely damaged plots are based on plant decline information obtained from results of two surveys by Nashimoto (1990) and Matsumoto et al. (2002).

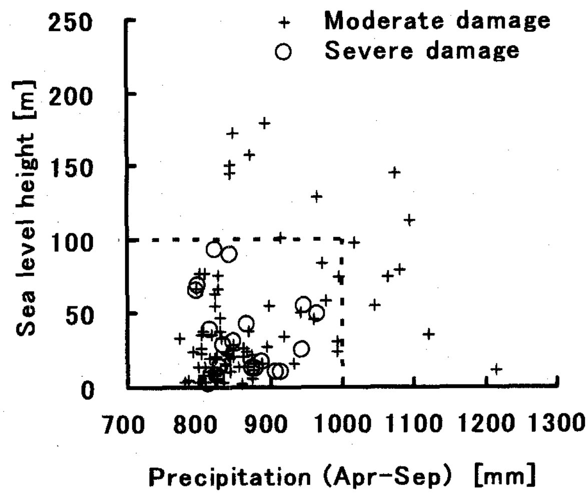

Fig. 6. Relationship between precipitation (April–September) and elevation of Japanese cedar decline area. Precipitation data indicate mean precipitation during April–September of 30 years (1971–2000). Severely and mid-severely damaged plots are determined according to plant decline information obtained from two survey results by Nashimoto (1990) and Matsumoto et al. (2002).

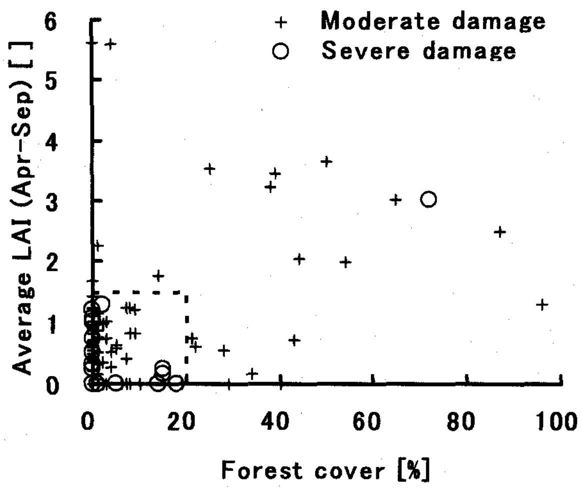

Fig. 7. Relationship between forest coverage and LAI (April–September) of Japanese cedar decline areas. The LAI data are calculated using vegetation type, land use, and satellite data during April–September (Ishii, 1999, 2001). The forest coverage ratio is calculated using land use data of digital national land information. Severely and mid-severely damaged plots are based on the plant decline information obtained from two survey results by Nashimoto (1990) and Matsumoto et al. (2002).

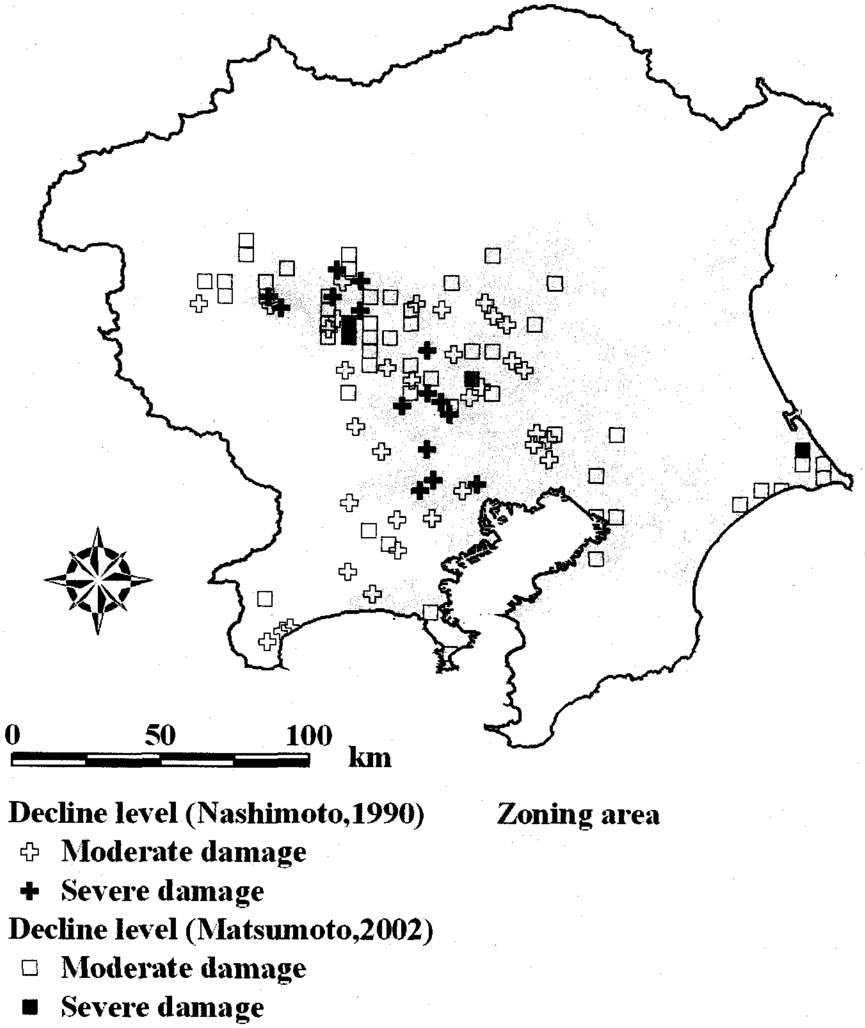

Fig. 8. Zoning map of severely damaged area prepared using elevation, precipitation, forest cover, and LAI.

4. Conclusion

Present critical levels for ozone for protecting vegetation against adverse effects are based on exposure-response relationships mainly derived from open-top chamber experiments and are expressed as an AOT40. They are based on a relatively small number of experiments and a very limited number of plant species. Thus, several important limitations and uncertainties of the AOT40 approach have been recognized. A critical level has been proposed as a precautionary indicator of Japanese cedar stand degradation. Ozone's effects on plants vary greatly among species and depend on environmental conditions. Pollutants that are present in concentrations that exceed the critical level indicate the risk of damage to vegetation. Furthermore, it has been considered that the critical pollution level is not related directly to the actual level of damage to vegetation. In this study, we analyzed observation data using a geographic information system (GIS) to evaluate, both regionally and visually, the relationship between air pollutants and plant decline in terms of Japanese cedars. The distributions of AOT40 values were compared to plant degradation information obtained from two survey results by Nashimoto (1990) and Matsumoto et al. (2002). Severely damaged Japanese cedars were roughly distributed in regions of less than 100 m altitude, less than 1000 mm precipitation during April–September, less than 20%, forest coverage, and a LAI of less than 1.5. The distribution of severely damaged stands coincided approximately with regions of average AOT40 equal to 10 000 ppb·hr. Therefore, if the AOT40 values continue to increase, moderately damaged stands in the zoning area might become severely damaged stands. AOT40 is a potential indicator for evaluation of ozone's effects on vegetation. The GIS databases created in this study are useful as basic tools for mapping critical levels for plant sensitivity evaluation of air pollutants using data obtained through exposure experiments.

Acknowledgements

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