Climatic Controls on Natural Forest Distribution and Predicting the Impact of Climate Warming: Especially referring to Buna (Fagus crenata) Forests

Nobuyuki TANAKA1*, Tetsuya MATSUI2, Tsutomo YAGIHASHI3 and Hirosi TAODA1

1Forestry and Forest Products Research Institute (FFPRI)
1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan
e-mail: ntanaka@ffpri.affrc.go.jp
2FFPRI, Hokkaido Research Center
7 Hitsujigaoka, Toyohira, Sapporo, Hokkaido 062-8516, Japan
3Japan International Research Center for Agricultural Sciences
1-1 Ohwashì, Tsukuba, Ibaraki 305-8686, Japan
*corresponding author

Abstract

This paper illustrates studies on impacts of climate change on buna (Fagus crenata) forests in Japan and discusses issues for further study. The occurrence probability of buna forests was predicted by tree-based models. In the models, the response variable was presence/absence data on actual distribution of buna forests derived from the Third Mesh Vegetation Database (MVDB). Predictor variables comprised four climatic ones, i.e., the Warmth Index (WI), the mean minimum daily temperature of the coldest month (TMC), the precipitation in the warm season (PRS) and that in the cold season (PRW); and five non-climatic variables, i.e., topography, surface geology, soil, slope aspect and inclination. According to the models developed, DWS values, which evaluate the contribution of each predictor variable to a model, were the highest for PRW, followed by WI and TMC. They were low for PRS as well as for the non-climatic variables. The models showed climatic conditions for varying occurrence probability for buna forests, indicating that the variables controlling buna forest distribution and their thresholds vary among regions. Suitable habitats for buna forests, defined as the areas with over 0.5 in occurrence probability, cover 26,220 km² under the current climate. The area of suitable habitats is predicted to decrease to 9% of the current area under the CCSR/NIES climate change scenario and 37% under the RCM20 scenario. Under both scenarios, suitable habitats disappear in Kyushu, Shikoku and the Pacific Ocean side of Honshu, and decline greatly even in the Tohoku area of northern Honshu with the most extensive suitable habitats. The vulnerability index, which indicates the degree to which climatic conditions become worse for buna with climate change, is defined as the reciprocal of the occurrence probability, and its map was depicted. Buna forests in the areas which become unsuitable after climate change may gradually decline along with the death of the buna trees. This method is useful for predicting distributions of plants and vegetation on large spatial and temporal scales. The MVDB provides distribution data for vegetation types but not for plant species. It is necessary to construct databases on plant species distributions in Japan in order to predict habitats for various plant species.

Key words: climate change scenario, potential distribution, suitable habitat, tree model, vulnerability index

1. Introduction

Global warming has been proceeding, according to an IPCC report (IPCC, 2001). The global average surface temperature has increased by 0.6°C over the 20th century. That was projected to increase by 1.4 to 5.8°C over the period from 1990 to 2100. Precipitation was projected to change along with the temperature. Assessing the impact of climate change on natural ecosystems is an important issue in the IPCC program (IPCC, 2001).

Much research on predicting the impact of climate change on potential distributions of wild plants has been conducted in Europe and the United States. For example, current and potential future distributions of 80 common trees of the Eastern United States were
predicted by bioclimatic models (Iverson et al., 1999). Those of 33 plants of England were predicted, and ecosystems vulnerable and/or sensitive to climate change were determined (Harrison et al., 2001; Berry et al., 2003). Those of 1,350 plants of the European continent were predicted under seven climate change scenarios (Thuiller et al., 2005).

Developing such bioclimatic models enables the prediction of potential distributions of wild plant species under current and future climates. As models provide qualitative predictions, the potential distribution can be classified in some areas with different magnitudes of suitability for plant species, such as “potential distribution areas,” where a plant species can occur, “suitable habitat,” where it can occur in high densities, and “optimum habitat,” where it can occur in the highest densities. This kind of research enables prediction of changes of habitat for a plant species after climate change, and determining the areas which will continue to be habitat for the species after climate change as well as those which become non-habitat. These results are useful to the preparation of management plans for conserving plants and plant communities in the age of climate change.

There has been a little research on the impact of climate change on distributions of plants and vegetation in East Asia including Japan. The research started in the 1990s in Japan. Potential distributions of six forest types, i.e., Picea jezoensis forests, Quercus crispula forests, Zelkova serrata forests, Quercus acuta forests and Castanopsis cuspidata forests (Uchijima et al., 1992), and those of natural vegetation zones (Tsunekawa et al., 1993) were predicted to shift northward as the climate warmed. These studies used only the index of accumulated temperature, the Warmth Index (Kira, 1977), as the predictor variable. We reviewed the research on climate and forests in Japan (Ohsawa et al., 1998; Omasa et al., 2003; Tanaka et al., 2003), developed models predicting distributions of buna (Fagus crenata) forests and Quercus crispula forests, using environmental predictor variables (Yagihashi et al., 2005; Matsui et al., 2004a; Matsui et al., 2004c; Matsui et al., 2005), and assessed the impact of climate change on buna forests (Matsui et al., 2004b; Matsui et al., in press).

The buna forest is one of the main climax forest types in Japan, covering 23,000 km² (17% of the total natural forest area). The forests are important as water sources and habitats for wild plants and animals. The Shirakami Mountains located in northern Honshu are designated as a World Natural Heritage Area for the largest area of primeval buna forests (Fig. 1). Buna ranges from southern Hokkaido (42°38’ N in latitude) in the north to Mt. Takakuma, Kagoshima Prefecture (31°29’ N) in the south. Buna forests cover extensive areas in southern Hokkaido, Tohoku and the Sea of Japan side of Honshu, whereas they are limited to upper parts of mountains on the Pacific Ocean side of Honshu, Shikoku and Kyushu.

This paper illustrates our researches on the impact of climate change on buna forest distribution and refers to issues for further study.

2. Predicting the Impact of Climate Warming on Buna Forests

2.1 Current climatic data and climate change scenarios

Current climatic data for all the 345,175 Third Standard Area Grid cells were extracted from the current climatic database generated by the Japan Meteorological Agency (1996). The Third Standard Area Grid is a framework of cells of 30” in latitude by 45” in longitude (ca. 1 km × 1 km) with ID numbers, covering all of Japan (Japan Map Center, 1998). The original dataset was obtained from weather stations established nationwide, and the dataset was interpolated into the cells by multiple regression analysis (Okamura et al., 1989). The averaged period for temperature is from 1953 to 1982 and for precipitation, from 1953 to 1976.

From this current climatic database, the present studies extracted the following four climatic variables for every cell and used them as predictor variables for predictive distribution models. They were considered likely to be major factors critically affecting the survival and growth of plants in Japan. (A) The Warmth Index (Kira, 1977), defined as the annual sum of positive differences between monthly means and +5°C, is a measure of effective heat for plants. Isopleths of WI correspond well with boundaries of forest zones in Japan since precipitation is sufficient for plant growth (Kira, 1977). WI has often been used for forest zonation studies in East Asia rather than mean annual temperature (Kira, 1977; Box 1995). (B) The monthly mean daily minimum temperature for the coldest month (TMC) is an index of the cold extreme. Northern limits of plant distributions coincide with their tolerance to cold (Sakai, 1995). Absolute minimum temperature may have a more di-
rect effect on survival, but suitable data were unavai-
lable. (C) Winter (December-March) precipitation
(PRW) is an index of dryness and snowfall. The Sea
of Japan side of Honshu has one of the heaviest snow-
falls in the world. There are many plants whose
distributions correspond well to snow cover (Sakai,
1995; Ohsawa et al., 1998). Snow cover is advanta-
geous and disadvantageous for various plant species to
different degrees. (D) Summer (May-September)
precipitation (PRS) is an index of water supply during
the growing season. The summer precipitation is
generally considered to be sufficient for plants in
Japan. However, it may be critical for some plant
species in some regions. For example, it is suggested
to be critical for buna in southern Hokkaido (Tsukada,
1982) and inland areas of Honshu (Yagihashi et al.,
2005).

Various climate change scenarios (Global Climate
Model scenarios) based on emissions scenarios for
greenhouse gases such as CO₂ and N₂O have been
proposed by different institutes. Because of the steep
and complex topography of Japan, it is apparently
necessary to analyze the distribution of plants and
forests in as small spatial resolutions as 0.1, 1 or
10 km for accurate and useful prediction. The two
climate change scenarios, i.e., the CCSR/NIES
scenario (spatial resolution: 5° latitude × 7.5° longitude,
ca. 10 km × 10 km), (Yokozawa et al., 2003), based
on greenhouse gas emission scenario IS92a (IPCC,
1992), and the RCM20 scenario (spatial resolution:
20 km × 20 km; Japan Meteorological Agency, 2004)
based on emission scenario SRES-A2 (IPCC, 2001),
were referred to for constructing databases of future
climates with a resolution of ca. 1 km (the Third Stan-
dard Area Grid) by means of spatial interpolation
(Matsui et al., 2004b).

Comparing the current climate with the CCSR/
NIES (2091-2100) and the RCM20 (2081-2100)
scenarios shows larger difference in temperature than
in precipitation (Fig. 2). The average annual tempera-
ture for all of Japan increases by 4.9°C in the CCSR/
NIES scenario and by 2.9°C in the RCM20 scenario.
WI and TMC increase by 42°C·month and 5.1°C in
the CCSR/NIES scenario, and by 23°C·month and

![Fig. 2 Maps of four climatic variables under the current climate and future climate scenarios, i.e., the CCSR/NIES scenario of 2091-2100 and the RCM20 scenario of 2081-2100. WI: Warmth Index, TMC: monthly mean daily minimum temperature for the coldest month, PRW: winter (December-March) precipitation, PRS: summer (May-September) precipitation.](image_url)
4.1°C in the RCM20 scenario, respectively. While PRS increases for both scenarios, PRW changes little for both.

The averaging period differs between the two scenarios. In this paper, the CCSR/NIES scenario for 2091-2100 and the RCM20 scenario for 2081-2100 are expressed by those for 2100.

2.2 Environmental data other than climatic data

The distributional frequency and dominance of plants are affected not only by climatic factors but also by land factors such as geology, topography and soil. The five non-climatic factors, i.e., topography, surface geology, soil, slope aspect and inclination, were used as predictor variables in predicting buna forest distribution (Matsui et al., 2004b). The data sets of topography, surface geology and soil were extracted from Digital National Land Information (Japan Map Center, 1979), based on 1:200,000 maps covering the entire nation (National Land Agency, 1970-1978). In these data sets, classification categories for factors sometimes differed among prefectures, necessitating standardization of the classification categories over the nation. After that was done, 15 topography, 21 surface geology and 18 soil types were classified (Yoshinaga et al., 1994). The data on slope aspect and inclination were calculated from 1.5° × 2.25” (ca. 50 m × 50 m) data from the Digital Elevation Model (Geographical Survey Institute, 2000).

2.3 Vegetation data

A statistical model incorporating vegetation distribution as a response variable and environment factors as predictor variables enable prediction of habitats for the vegetation analyzed. Information on the geographical distribution of buna forests was obtained from the Third Mesh Vegetation Database (MVDB), which includes data on vegetation types in every Third Standard Area Grid cell. The MVDB was made from the 1:50,000 vegetation maps of the entire nation produced under the Third National Survey on the Natural Environment (NSNE) conducted by the Ministry of the Environment, Japan (Asia Air Survey, 1988).

We recognized 345,167 cells, 23,432 of which were buna forests (Fig. 6a). The presence/absence datum of the buna forest for every cell was the response variable for the models. For development of the model, we excluded 188,363 cells of anthropogenic vegetation types, such as plantation forests, agricultural lands and urban areas, to avoid having anthropogenic effects excessively affecting the model. The model was developed using the remaining 156,804 cells, and used to calculate the probability of buna forest occurring in each of the 345,167 cells, producing a complete map of occurrence probability of buna forests for the entire nation.

2.4 Comparison of models

The predictive models examined were statistical models to determine the potential distribution of a given species (Guisan & Zimmermann, 2000). Three popular predictive distribution models (MathSoft Inc., 2000), i.e., Generalized Linear Models (GLMs), Generalized Additive Models (GAMs) and Tree-based Models (TMs), were used to determine the potential distribution of buna forests and their performance was compared (Matsui et al., 2004c). For GLMs, two sets of predictor variables were applied, one of which was based solely on the four climatic terms (GLM-Simple), while the other included two-level interaction terms and quadratic polynomial terms (GLM-Complex). The models’ performance was compared with AIC (Akaike’s information criterion), residual deviance, and accuracy measures, including Kohen’s kappa statistic and overall prediction success, which are often used in predictive modelling studies. The resulting values all indicated that TMs performed best, followed by GAMs, GLM-Complex, and GLM-Simple. The superiority of TMs may be due to their binary recursive partitioning approach to split a data set into subsets based on a single predictor variable chosen to minimize the deviance in the response variables in each of the resulting subsets until each subset becomes homogeneous. TMs incorporate possible interactions among predictor variables to form prediction rules. TMs have a high capacity to model relationships between the buna forest distribution and the non-homogeneous Japanese climatic patterns nationwide. In addition, TMs have another advantage that the predictor variables and their threshold values in partitioning can be interpreted ecologically.

2.5 Variables and threshold values relevant to buna forest distribution

The ranges for all buna forest cells are between 30.5 and 109.4°C-month in WI, between −15.5 and 0.0°C in TMC, between 440 and 2,750 mm in PRS, and between 165 and 1,593 mm in PRW (Fig. 3). Along the PRS axis, buna forest cells occurred

---

**Fig. 3** Distributions of buna forests in climate spaces defined by the axes of four climatic variables (WI, TMC, PRW and PRS). Black and gray circles respectively indicate Standard Area Grid cells of buna forests and those of other vegetation. Abbreviations of climatic variables are as in Fig. 2.
throughout the whole range of available cells. Along the PRW axis, buna forest cells occurred up to the maximum value but did not occur under 165 mm. Ninety-nine percent of buna forest cells occurred between 42.9 and 92.6°C-month in WI, between −13.0 and −2.6°C in TMC, between 552 and 2,256 mm in PRS, and between 251 and 1,485 mm in PRW in the climate space.

Potential distributions of buna forests were predicted by three TMAs, i.e., TM CLIMATE, which incorporated only the four climatic variables; TM SPATIAL, which incorporated spatial variables (latitude and longitude) as well as the four climatic variables; and TM ENVI, which incorporated five land variables as well as the four climatic ones (Matsui et al., 2004a, b). There was little difference in prediction accuracy between TM SPATIAL and TM CLIMATE. Deviance Weight Score (DWS) values, defined as the sum of the reduction of deviance between the parent nodes and the respective children nodes generated by each predictor variable (Matsui et al., 2004a), were low for both latitude and longitude, which contributed only locally to TM SPATIAL. This indicates that the four climatic variables are able to explain the actual buna forest distributions, and suggests that buna forests are distributed in almost all areas which are suitable for them.

The DWS values of TM ENVI were highest for PRW, followed by WI and TMC, and lowest for PRS among the four climatic variables, while the DWS values for the land variables were all low (Matsui et al., 2004b). This result indicates that the three climatic variables with high DWS values greatly influence buna forest distributions on the condition of modelling the whole range of buna forests on a 1-km spatial resolution.

Figure 4 shows the diagram for TM CLIMATE based on the four climatic variables. The intermediate node above the terminal nodes from 47 to 68 with high occurrence probability indicates a main area of suitable habitats located on the Sea of Japan side of Honshu and southern Hokkaido. This node showed 0.667 in probability and was defined by a climate with high precipitation both in winter and summer (564 < PRW, 731 < PRS) and intermediate temperatures (48.9 < WI < 77.2, −12.3 < TMC). Among the suitable habitat areas, the optimum habitat area with the highest probability, 0.857, (terminal node 51) was located in areas from Toyama Prefecture northward, being defined by a climate with 564 < PR < 1,059, 916 < PS < 1,151, 52.6 < WI < 65.2, −12.3 < TMC. Most of the buna forest areas in southwestern Japan such as Kyushu, Shikoku and the Kii Peninsula were included in terminal nodes 25 and 46, both of which showed 0.45 in probability. Terminal node 25 was defined by 331 < PRW < 494, 1,789 < PRS, WI < 74.0, −10.0 < TMC; and node 46, by 494 < PRW < 564, 1,941 < PRS, 48.9 < WI < 77.2, −12.3 < TMC. The variables apparently limiting buna forest distributions and their threshold values are indicated.

![Fig. 4 Diagram of the Tree-based Model (TM) CLIMATE. (Matsui et al., 2004a)](image-url)

If the condition shown at the top of a branch is met, follow the left branch, otherwise follow the right branch. The length of the vertical line below each yes-no split corresponds to the change in magnitude of deviance between parent and children nodes. The identification numbers for some of the 85 terminal nodes are shown in parentheses. Values following the terminal node identification numbers indicate the probability of occurrence of buna forests. Abbreviations of climatic variables are as in Fig. 2.
by the climatic conditions for the areas with low probability as shown in the TM (Fig. 5). The low probability for the majority of Hokkaido (Fig. 5(A)) is due to coldness and drought in winter (TMC < −12.5, PRW < 494); that for the inland areas of Honshu, and Abukuma and Kitakami mountains in northern Honshu (Fig. 5(B)) is due to drought in both winter and summer (PRW < 331, PRS < 795); that for the area southward from Miyagi Prefecture along the Pacific side of Honshu, Shikoku and Kyushu (Fig. 5(C)) is due to summer heat and winter drought (89.6 < WI, PRW < 494), and that for the area southward from Niigata Prefecture along the Sea of Japan side (Fig. 5(D)) is due to summer heat (95.2 < WI). These results indicate that the climatic variables limiting buna forest distributions and their threshold values vary among regions. Iverson and Prasad (1998) obtained similar results with environmental variables related to range boundaries of a tree species differing geographically in the Eastern US.

2.6 Impact of climate change on buna forest distribution

Three maps showing actual distribution and probability distribution under two future climates in 2100 for buna forests are shown in Fig. 6. When the threshold value of probability was set from 0.3 to 0.5, the Kappa value as an index of prediction accuracy was maximized (more than 0.6), indicating a good agreement. Assuming that suitable habitats for buna forests are areas with more than 0.5 in probability, the total area of suitable habitats is 26,220 km² under the current climate. The total area of suitable habitats decreases into 9% of that under the CCSR/NIES scenario (Matsui et al., 2004b), and 37% under the RCM20 scenario. Under both scenarios, the area of suitable habitats almost vanishes in Kyushu, Shikoku and the Pacific side of Honshu, and greatly decreases even in northern Honshu, which has extensive suitable habitats at present. The Shirakami Mountains, designated as the World Natural Heritage Area for the largest buna forest reserve are, unfortunately, no exception (Matsui et al., in press). In Honshu, suitable habitats are predicted to shift to higher elevations on high mountains with sub-alpine coniferous forests.

With climate warming, buna trees in low elevation areas will be replaced by tree species which occur in lower elevation areas under the current climate. The candidate species for replacement are Quercus serrata, Q. crispula and Castanea crenata in low elevation areas along the Sea of Japan side of Honshu; and additionally evergreen oak species (Cyclobalanopsis spp.), Fagus japonica and Abies firma in Kyushu, Shikoku and the Pacific side of Honshu. It will take about 100 years for trees of other species to replace buna trees by growing in canopy gaps formed by the death of buna trees.

With climate warming, buna forests surrounded by artificial forests may be succeeded by thickets of shrub and dwarf-bamboo species after the death of buna trees since there are few seed sources of succeeding tree species. With climate warming, the extinction of buna may occur most easily in buna forests isolated on summits of low mountains which are under marginal climate conditions with high temperatures and low precipitation (Fig. 7). In the marginal sites, buna may regenerate poorly after the death of the mother trees. On the other hand, in subalpine zones on high mountains, buna may colonize gaps formed after the death of coniferous trees, resulting in a gradual increase of buna.

2.7 Movement of the northern limit

The current northern limit of buna distribution is located in the Kuromatsunai lowland in southern Hokkaido. Under both climate change scenarios (CCSR/NIES and RCM20) in 2100, suitable habitat will expand into central and northern Hokkaido beyond Kuromatsunai. This suggests that buna will colonize the new regions with climate warming. The
northward migration of buna after the last glacial period was estimated to be 233 m/yr (Tsukada, 1982), 20 m/yr (Igarashi, 1994) and 11 m/yr (Takiya & Hagiwara, 1997). Isopleths for the TMC, which is an important variable relevant to the northern limit of buna forests, will shift northward or eastward 10 to 50 km in Hokkaido over the next 100 years according to both climate change scenarios. Assuming the migration speed to be 11 to 233 m/yr, the migration distance becomes 1.1 to 23.3 km in 100 years. This suggests that buna cannot keep pace with the speed of climate change projected by either scenario in many places in Hokkaido.

There need to be continuous natural forests from south to north in order for smooth migration of tree species to occur. Since natural forests are fragmented by artificial land-use areas such as plantation forests, agricultural fields and cities, it is not easy for buna to migrate. Northward migration of buna will be interrupted, especially by the extensive Ishikari lowland including many cities and agricultural fields. This lowland is also unsuitable for buna, due to too low values in TMC, PRW and PRS under the current climate, and due to both high values in WI and low values in PRW and PRS under the future climate scenarios.

2.8 Vulnerability map

The IPCC report of 2001 pointed out the importance of assessing vulnerability to climate change. In
order to prevent the decline of forest ecosystems, it is important to predict the location of forests vulnerable to climate change and to monitor the forests so that adaptive measures can be taken if necessary. Therefore a map showing the location of vulnerable forests would be useful.

Low occurrence probabilities indicate inferior habitat conditions for buna. The vulnerability index (VI), which is the reciprocal of the occurrence probability, was devised for assessing inferiority of habitat conditions for buna, and was calculated for every cell of the actual buna forest distribution under the current and future climate conditions (Fig. 8). Buna forests in Kyushu, Shikoku and the Pacific Ocean side of Honshu showed high VI values under both climate change scenarios in 2100. Buna forests in southern Hokkaido showed high VI values under the CCSR/NIES scenario and low VI values under the RCM20 scenario.

2.9 Adaptation

Climate change induces changes in species composition in forest communities through extinction and invasion of plant species. With climate warming, human society has to decide whether to accept the changes in forests or to take some adaptive measures to conserve declining species. In either case, conservation management plans incorporating possible impacts of climate change will be important for every region in the future. For example, adaptations relevant to buna could include (1) controlling evergreen tree species invading buna forests occurring at the upper limit of evergreen lucidophyll forests in western Japan, (2) constructing ecological corridors as migration paths for buna in mountainous areas in central and northern Honshu, and (3) controlling buna invasion into boreal forests beyond the northern limit of the current buna distribution in Hokkaido.

3. Issues for Further Study

3.1 Significance and issues regarding predicting habitats

Changes in potential distribution areas of wild plant species due to climate change have been intensively studied in the US (Iverson & Prasad, 1998; Iverson et al., 1999), Europe (Huntley et al., 1996; Sykes et al., 1996; Kienast et al., 1998; Harrison et al., 2001; Berry et al., 2003; Thuiller et al., 2005) and New Zealand (Leathwick et al., 1996). These studies developed statistical models predicting habitats for plant species using data on actual distributions of the species and current climate, and predicted habitat distributions under future climate scenarios both on large scales (e.g., the eastern US, England and Europe) and on long time scales (e.g., 50 and 100 years). The predictions are useful for nature conservation. Assessments of vulnerability of ecosystems and species to climate change should be taken into account in planning conservation management. Predicted shifts in habitats are useful information when selecting monitoring sites for detecting the impact of climate change.

Few studies on the impact of climate change on plant distributions have been done in East Asia. Since Japan and other East Asian countries share floristic regions, such as the Sino-Japanese floral region, distributions of many species cover more than two countries. It would be desirable to conduct a collaborative study covering East Asia.

There are time lags between shifts in habitats and plant migration. It is necessary to develop dynamic models predicting plant migration. Models predicting shifts of plant species under climate change have been developed, incorporating data on potential migration rates, approximate time to reproductive maturity and potential migration paths on fragmented landscape (Iverson et al., 2005). No individual-based models of plant community dynamics which predict shifts in plant species on such a large scale have been developed yet.

3.2 Constraints in predicting distribution due to data

Among the data necessary for making a predictive model, it is most difficult to obtain accurate data on the distribution of wild plant species. Fortunately, data on buna forest distribution are available in the MVDB, which was made from vegetation maps covering Japan. Since buna is a typical dominant species in natural forests, buna forests were con-
sciously identified when making vegetation maps. However, since buna forests have been replaced by secondary forests dominated by other tree species including pioneers after frequent logging in the past, the cells occupied by these secondary forests are not identified as buna forests. The area of buna forests has apparently decreased in low elevation areas, where human impacts such as logging were more intensive. Therefore the statistical models, which were based on the actual distribution of buna forests, inherently underestimated the potential distribution in low elevation areas.

The MVDB, which provides information on the distribution of vegetation types in 1-km resolution covering all of Japan, is useful for predicting the distribution of some vegetation types. Since the MVDB provides no distributional information on plant species, it is not useful for predicting distributions of plant species. Distributions of plant species have been predicted in the US and Europe, based on digital information on plant distributions (Huntley et al., 1995; Iversen & Prasad, 1998; Thompson et al., 1999; Bakkenes et al., 2002; Thuiller et al., 2005). In Japan, we are constructing a Phytosociological Relevé Database (PRDB) in order to predict the distribution of many plant species (Tanaka et al., 2005). The PRDB includes standardized relevé data collected using a consistent survey method (Braun-Blanquet, 1964) for various types of vegetation throughout Japan for the last 50 years. Each relevé includes data on location (Standard Area Grid Code), environmental conditions, community stratification, and the name and dominance of each plant. When the PRDB is ready for analysis, it will enable us to parameterize models predicting distributions of a variety of plant species under current and future climates. Predicting changes in potential distribution for plant species is expected to provide a warning to human societies about risks and be a useful tool for conservation of plants and vegetation in the age of global warming.

Acknowledgement

This study was funded by the Global Environmental Research of Japan (B-11 and S-4) program of the Ministry of the Environment, and the Cooperative System in Supporting Priority Research Program of the Japan Science and Technology Corporation.

References


Matsui, T., T. Yagihashi, T. Nakaya, H. Taoda, S. Yoshinaga, H.


(Received 4 October 2006, Accepted 7 December 2006)