***Taiwania*, 48**(4): 259-272, 2003

Possible Impacts of Climate Change on Potential Tree Plant Forms of a Mountain Region in Central Taiwan

Biing-T. Guan(1, 3), Zenn-Bor Huang(1) and Nien-June Chung(2)

(Manuscript received 26 September, 2003; accepted 20 November, 2003)

ABSTRACT: In this study we used Box's model, which is based on the equilibrium relationships between macroclimate and plant forms, to assess the possible impacts of climate change on the potential tree plant forms of a mountain region in central Taiwan. To account for the effects of uncertainty associated with the projected climatic conditions on the model's predictions, a Monte Carlo study was also carried out. For the temperature variables in the model, they varied between 0 and 5°C above the long-term average; for the precipitation related variables, the projected precipitation varied between ±30% of the long-term average. The responses of tree plant forms to temperature increases could be divided into three categories: (1) those that would not be influenced, (2) those that could disappear gradually, including summergreen tree species, which are more sensitive to temperature and require a lower temperature to exist, and (3) those that could appear gradually, including tropical tree species. Under the projected precipitation conditions, most of the tree plant forms currently present would not be influenced, except for rainforest and raingreen tree plant forms. The necessary data for Box's model could be obtained easily from usual climatic databases, and the results have a higher resolution than Holdridge Life Zone model. When detailed information necessary to run high-resolution models is not available, the approach used in this study could be used as an alternative.

KEY WORDS: Biogeographical model, Box's model, Climate-vegetation classification, Monte Carlo simulations.

INTRODUCTION

Assessing the likely impacts of anthropogenic-induced climate change on forest vegetation distributions is one of the core areas in global change research. The basic idea in that type of research is to couple a climatic model (e.g., a general circulation model, GCM) with a vegetation model of interest, and then assesses the changes in vegetation distributions under some projected climatic conditions. Currently, two categories of vegetation models are most often used in such a study. Models in the first category, known as biogeographical models, are based on the long-term equilibrium between macroclimate and vegetation physiognomy; models of this type could be correlative or mechanistic, static or dynamic (Peng, 2000). Models in the second category, known as successional or gap models, are based on the eco-physiological responses of individual species and are typically semi-mechanistic and dynamic in nature (Shugart and Smith, 1996). The main advantage for the first category of models resides in their minimal data requirements, especially those correlative static models. For this reason, the U. S. Country Studies Program (Benioff *et al*., 1996) recommended their usage for initial climate-vegetation interaction assessments to many countries. The advantages of the second category of models lie in their dynamic nature and high spatial and temporal resolutions, and therefore is suitable for assessing small regional vegetation dynamics. Their demands on data, however, hinder their uses in large-scale assessments or in regions where the required data are sparse.

---

1. School of Forestry and Resource Conservation, National Taiwan University, Taipei 106, Taiwan.
2. Experimental Forest, National Taiwan University, Zhushan, Nantou County 557, Taiwan.
3. Corresponding author. Email: btguan@ntu.edu.tw

Taiwan began its assessment of climate change on forest vegetation distributions about six years ago. The main focus currently is on the mountain vegetations since those are considered to be the most vulnerable under the projected climate change scenarios (Beniston *et al.*, 1997; Theurillat and Guisan, 2001). Because of lack of accurate data and detailed information on the dynamics of the mountain vegetations, previous assessments (e.g., Lo and Guan, 1999a, b) have been mainly based on Holdridge Life Zone model (Holdridge, 1947; 1959), which is a correlative static model from the first model category. The results were unsatisfactory due to that model's poor resolution and limitations. As an attempt to improve the resolution, this study used another model from the first category to assess the likely impacts of climate change on the potential vegetations of a mountain region in central Taiwan. To account for the uncertainties associated with the predicted climatic conditions used in this study, we also conducted a Monte Carlo sensitivity analysis to assess the likelihood of our predictions. Our results suggested that certain warmer climate vegetation components could appear in the assessed region, whereas some of the existing components might disappear, and together they could change the physiognomy of the vegetations.

METHODS

Study Area

The mountain region assessed is the Shalisen area in central Taiwan, which is a part of the National Taiwan University Experimental Forest. With elevation ranging from 750 to 3,950 m and a total area of more than 6,500 ha, the region is one of the best areas to study altitudinal differentiation of Taiwan's vegetation. From low to high elevation, the vegetation types in the study area include *Machilus-Castanopsis* (lower-montane) type, *Quercus* (montane) type, *Picea-Tsuga* (upper-montane) type, *Abies* (subalpine) type, and tundra-like alpine vegetation above the timber-line (Chung, 1994; Hsieh *et al.*, 1994). In this study, we focused on the area with elevation between 750 and 2,500 m since forests within this elevation range are more diverse in compositions and believed to be more sensitive to climate change. Within this elevation range, the lower elevation region (ca. 750~1,500 m) is known as the Her-Sher region (*Machilus-Castanopsis* type), and the higher elevation region is known as the Dui-Gao-Yue region (*Quercus* type).

Model Description

The model used in this study is developed by Box (1981). Unlike Holdridge Life Zone model, which is based on the equilibrium between vegetation physiognomy and macroclimate, the central idea of Box's model is based on the equilibrium between the so-called plant forms and certain macroclimatic (or ecoclimatic) factors. A plant form is a set of plant species (not necessarily phylogenetically related) with common physiognomic, morphological, physiological, and life history characteristics (Duckworth *et al.*, 2000). The use of plant form, rather than the actual species, as a response unit for studying impacts of climate change on formation distributions has been recommended by several studies (e.g., Bugmann, 1996; Duckworth *et al.*, 2000; Lavorel and Garnier, 2002). The characteristics in Box's model include structural type, relative plant size, leaf type, relative leaf size, leaf structure, and photosynthetic habit. With these six characteristics, Box grouped plant species into 77 major plant forms with 13 sub-types, a total of 90 plant forms.

The eight macroclimatic factors in Box's model are the mean monthly temperature of the warmest month (Tmax, °C), the mean monthly temperature of the coldest month (Tmin, °C), the annual range of the monthly mean temperature (DTY, °C), the average annual precipitation (PRCP, mm), the annual moisture index (MI), the highest average monthly precipitation (Pmax, mm), the lowest average monthly precipitation (Pmin, mm), and the average precipitation of the warmest month (PMTmax, mm). In the model, MI is defined as the ratio between PRCP and the potential evapotranspiration (PET) derived using the Thornthwaite method (Box 1981). All the macroclimatic factors in the model can be determined either directly from regular climatic records or indirectly by simple calculations.

In Box's model, each plant form has a lower and an upper limit with respect to each of the eight climatic factors, and each of the limits has its own ecological meaning. For instances, the lower limit of Tmax represents the minimum mean temperature that a given plant form could exist in a given region during the growing season, whereas the lower limit of Pmin represents the minimum mean precipitation required during the driest month for a plant form to exist. Together, those climatic limiting factors form the existence envelop of a plant form. To determine the potential plant forms of a given region, we need to input the values of the eight climatic factors, the model then "sieves" through all the plant forms and outputs all the possible ones for that region. Under Box's model, the physiognomy of a particular region is determined by the dominant plant forms of that region. Because we are only interested in the dominants of forest vegetations, only tree plant forms (23 altogether) were included in this study.

Since more climatic factors are involved and with a large number of possible plant form combinations, Box's model has a higher resolution and fewer limitations than Holdridge Life Zone model. However, the fundamental difference between Holdridge Life Zone and Box's models is a philosophical one. As Prentice *et al*. (1992) pointed out that Holdridge Life Zone model has a Clementsian ancestry since the basic modeling unit is a biome or formation. In contrast, Box's model has a Gleasonian ancestry because the basic modeling unit is a plant form, and a biome or formation is determined collectively by the dominant plant forms present. Under this paradigm, it is the individual plant form that will either persist or perish under climate change, and the cumulative effects of individual plant forms in turn determine the fate of a biome or formation. Available paleo-ecological data suggest that plants did respond in this individualistic fashion during the past climate changes (Prentice *et al*., 1992).

Box's model has been used to assess the interactions between plant formations and climate change on a global scale (Cramer and Leemans, 1993), and it also forms the basis of the BIOME1 model (Prentice *et al.*, 1992) and the subsequent BIOME family of models. The BIOME family models have added more phenologically related variables (e.g., Growing Degree-Days) and other eco-physiological variables (e.g., cold-tolerance) which give that family of models a more mechanistic flavor.

In this study, to integrate with the subsequent statistical analysis, we ported the model into a SAS programming environment, and all model runs were executed within SAS.

Climatic Data

The required basic climatic data are from two weather stations in the two regions. The Her-Sher station is located at 23°35' N 120°53' E with an elevation of 778 m, whereas the Dui-Gao-Yue station is located at 23°31' N 120°52' E with an elevation of 2,250 m. Both stations started operation since 1950, and the data used in this study were from the period between 1953 and 1992. To minimize the effects of major land-use changes between 1993 and 2002 on the regional climate, the climatic data from that period were excluded from this study. The average monthly temperature and precipitation data for the time period were summarized in Table 1. The precipitation data indicate that the regions have a distinct wet

Table 1. The average monthly temperature and precipitation data for the two weather stations in the study region between 1953 and 1992. The elevation of the Her-Sher station is 778 m, and the elevation of the Dui-Gao-Yue station is 2,250 m.

	Temperature (°C)		Precipitation (mm)	
	Her-Sher	Dui-Gao-Yue	Her-Sher	Dui-Gao-Yue
January	15.1	6.7	43	72
February	15.9	8.2	68	109
March	18.0	10.0	84	165
April	20.3	12.0	120	168
May	22.2	13.8	252	559
June	23.6	15.0	308	716
July	24.6	15.4	235	608
August	24.4	15.1	317	622
September	23.8	14.8	204	410
October	22.0	12.5	56	105
November	19.3	10.3	29	53
December	16.6	7.9	36	65
Ann. Mean	20.5	11.8		
Mean Ann. Total			1752	3752

season (from April to September) and a dry season (from October to March). The precipitation during the wet season is primarily orographic precipitation due to typhoons and southwestern monsoons. For the two weather stations, data required to execute Box's model were summarized in Table 2. As the values of MI indicated, the two regions are not water-stressed in general. Since the weather stations are close geographically, the differences in climatic patterns between the two regions are mainly due to elevation and topography.

Table 2. Climatic input values required to run Box's model for the assessed regions based on the data recorded between 1953 and 1992.

	Tmax	Tmin	DTY	PRCP	MI	Pmax	Pmin	PMTmax
Her-Sher	24.6	15.1	9.5	1752	3.97	317	29	235
Dui-Gao-Yue	15.4	6.7	8.7	3752	6.16	716	53	608

Tmax (°C): mean monthly temperature of the warmest month
Tmin (°C): mean monthly temperature of the coldest month
DTY (°C): annual range of the monthly mean temperature
PRCP (mm): average annual precipitation
MI: annual moisture index
Pmax (mm): highest average monthly precipitation
Pmin (mm): lowest average monthly precipitation
PMTmax (mm): average precipitation of the warmest month

When assessing the likely impacts of climate change on forests, most of the published studies projected the vegetation distributions under two climate conditions and then compared the differences. The baseline climate is when the atmospheric CO_2 concentration was about 280 p.p.m. (referred to as $1\times CO_2$), which was the pre-industrial atmospheric CO_2 concentration. The contrast climate is when the atmospheric CO_2 concentration reaches 560 p.p.m. (double CO_2 radiative forcing, referred to as $2\times CO_2$). Double CO_2 radiative forcing includes about 50% actual CO_2 forcing, with the remainder from other greenhouse gases (Bachelet and Neilson, 2000). In this study, the projected $2\times CO_2$ climatic conditions were from a localized version of the Fifth-generation Penn. State/NCAR Mesoscale Model (MM5) commissioned by Taiwan's Environmental Protection Administration (Chang, 1998) with a spatial resolution of 30 km × 30 km. At the time of this study, that localized MM5 model had the highest resolution. For the study region, the model predicted that under 2×CO_2 the average monthly temperature during the summer would be 3 °C higher than under 1×CO_2, and during the winter the average temperature could be as much as 5 °C higher than under 1×CO2. The model also predicted that the amount of annual precipitation would not change significantly from 1×CO_2 to 2×CO_2. In this study, we assumed that under 2×CO_2 situation the mean values of Tmax and Tmin would be 2.5 °C higher than the values listed in Table 1. For the precipitation related inputs (PRCP, Pmax, Pmin, and PMTmax), the mean values under 2×CO_2 situation remained unchanged.

Monte Carlo Analysis

To account for the effects of uncertainty associated with the projected climatic variables on Box model's predictions, a simple Monte Carlo analysis was also carried out. Following the suggestions given in Guan *et al.* (1997), we treated six of the eight climatic factors (Tmax, Tmin, PRCP, Pmax, Pmin, and PMTmax) as unimodal symmetric beta-distributed random variables. As a bounded distribution, this type of beta-distributions reflects our belief that, within the specified lower and the upper limits, the distribution's mean value is the one most likely to occur under the projected condition. For Tmax and Tmin, we assumed that under 2×CO_2 condition, the ranges of their distributions were (T+0, T+5) with a mean of T+2.5 °C, where T were the respective values listed in Table 2. For precipitation related variables, the ranges of their distributions were (0.7×P, 1.3×P) with a mean of 1.0×P, where P were the respective values listed in Table 2. Essentially, we assumed that the ranges of precipitation related variables were between ±30% of the respective long-term averages. Since DTY and MI are derived quantities, they would become random variables by default. For temperature related variables, the specified upper limit could be considered as the worst-case since in 1990's the atmospheric CO_2 concentration was already about 350 p.p.m., and the temperature differences from then to 2×CO_2 condition should be less than 5 °C.

We then assigned five levels of uncertainty (5%, 10%, 15%, 20%, and 25% of the distribution range) to each of the factors. Theoretically, the five distributions will have the same mean but with greater dispersion (more "spread-out") with increasing levels of uncertainty, that is, the higher the uncertainty, the more likely the presences of extreme values. For each level of uncertainty, 5,000 random variates with the prescribed beta distribution were generated using the gamma random variates generating function (RANGAM) of SAS. The uncertainty effects of each factor were assessed independently, and changes to values of DTY and MI were also recalculated when applicable. With this approach we not only could put likelihood (or probability) on our predictions with respect to each of the factors examined, and but also could examine how extreme values associated with the projected climatic conditions would affect the outcomes of Box's model.

RESULTS AND DISCUSSION

Potential plant forms based on long-term averages

For Her-Sher and Dui-Gao-Yue regions, the potential plant forms based on the data in Table 2 and their respective Tmax and Tmin limits as given in Box (1981) were given in Table 3. We also listed some of the native species found in the regions that we considered should belong to a particular plant form. We found at least one species for each of the

Table 3. Potential plant forms, their respective Tmax and Tmin limits as listed in Box (1981), and some of their representative native species in Her-Sher and Dui-Gao-Yue regions based on the data in Table 2.

Region	Code[a]	Plant Form	Representative Species
Her-Sher	4	Tropical evergreen microphyll-trees Tmax max. 32 °C, min. 15 °C Tmin max. 30 °C, min. 7 °C	*Evodia meliaefolia* *Lindera communis* *Murraya euchrestifolia* *Syzygium buxifolium* *Syzygium formosanum*
	5	Warm-temperate broad-evergreen trees* Tmax max. 32 °C, min. 20 °C Tmin max. 20 °C, min. 7 °C	*Cyclobalanopsis glauca* *Cyclobalanopsis stenophylla* var. *stenophylloides* *Lithocarpus lepidocarpus* *Machilus zuihoensis* *Michelia compressa*
	9	Montane broad-raingreen trees Tmax max. 25 °C, min. 15 °C Tmin max. 22 °C, min. 8 °C	*Albizia julibrissin* *Melia azedarach* *Sapindus mukorossi*
	11	Summergreen broad-leaved trees Tmax max. 30 °C, min. 15 °C Tmin max. 17 °C, min. -20 °C	*Acer kawakamii* *Acer serrulatum* *Aluns formosana* *Zelkova serrata*
	13	Tropical linear-leaved trees Tmax max. 28 °C, min. 15 °C Tmin max. 25 °C, min. 5 °C	*Dodonaea viscosa*
	20	Swamp summergreen needle-trees Tmax max. 28 °C, min. 20 °C Tmin max. 22 °C, min. 3 °C	*N/A*
Dui-Gao-Yue	7	Temperate broad-rainforest trees* Tmax max. 28 °C, min. 13 °C Tmin max. 18 °C, min. 5 °C	*Castanopsis carlesii* *Cyclobalanopsis morii* *Lithocarpus amygdalifolius* *Machilus japonica* *Machilus thunbergii* *Pasania kawakamii* *Trochodendron aralioides*
	11	Summergreen broad-leaved trees	Same as Her-Sher region
	13	Tropical linear-leaved trees	Same as Her-Sher region
	17	Temperate rainforest needle-trees* Tmax max. 25 °C, min. 12 °C Tmin max. 15 °C, min. -2 °C	*Cephalotaxus wilsoniana* *Chamaecyparis formosensis* *Chamaecyparis obtusa* var. *formosana* *Cunninghamia konishii* *Picea morrisonicola* *Pseudotsuga wilsoniana* *Taiwania cryptomerioides* *Taxus mairei* *Tsuga chinensis* var. *formosana*

[a] The assignment of plant form codes are based on the orders of plant forms listed in Box (1981, pp. 38-39).
*Indicates the dominant component(s) of the region.

potential plant forms, with the exception of hydrophilic (swamp) summergreen needle-trees (plant form 20), which Box (1981) listed *Taxodium* and *Metasequoia* as the two representative genera. Though in the study region we do have species from those two genera, those are introduced species, which again stresses the fact that the plant forms output by Box's model are the "potential" ones. Table 3 also suggested that the existing formation for

Her-Sher region should be a warm temperate evergreen broad-leaved one, and for Dui-Gao-Yue region it should be a temperate mixed rainforest one; both predictions matched the real situations well.

Potential plant forms under 2×CO_2

Based on the Monte Carlo runs, we could distinguish eight presence probability types for the fates of all plant forms involved. The first four types concern with the upper limit (the maximum) of each climatic factor, whereas the last four types concern with the lower limit (the minimum) of each climatic factor. We summarized the meaning of each probability type below:

Type I: The upper limit of a plant form with respect to a given factor is above the projected upper limit of that factor. Thus, that plant form will definitely be present under the projected conditions.

Type II: The upper limit of a plant form with respect to a given factor is between the projected mean and the projected upper limit of that factor. Thus, the presence probability for that plant form will be between 0.5 and 1, and the closer the plant form's upper limit to the projected mean, the lower the probability of presence. A higher projection uncertainty (more extreme events) would also decrease the probability of presence.

Type III: The upper limit of a plant form with respect to a given factor is between the projected mean and the projected lower limit of that factor. Thus, the presence probability for that plant form will be between 0 and 0.5, and the closer the plant form's upper limit to the projected mean, the higher the probability of presence. A higher projection uncertainty would also increase the probability of presence.

Type IV: The upper limit of a plant form with respect to a given factor is below the projected lower limit of that factor. Thus, that plant form will definitely not be present under the projected conditions, and therefore not our concern.

Type V: The lower limit of a plant form with respect to a given factor is above the projected upper limit of that factor. Thus, that plant form will definitely not be present under the projected conditions, and therefore not our concern.

Type VI: The lower limit of a plant form with respect to a given factor is between the projected mean and the projected upper limit of that factor. Thus, the presence probability for that plant form will be between 0 and 0.5, and the closer the plant form's lower limit to the projected mean, the higher the probability of presence. A higher projection uncertainty would also increase the probability of presence.

Type VII: The lower limit of a plant form with respect to a given factor is between the projected mean and the projected lower limit of that factor. Thus, the presence probability for that plant form will be between 0.5 and 1, and the closer the plant form's lower limit to the projected mean, the lower the probability of presence. A higher projection uncertainty would also decrease the probability of presence.

Type VIII: The lower limit of a plant form with respect to a given factor is below the projected lower limit of that factor. Thus, that plant form will definitely be present under the projected conditions. Actually, we cannot distinguish between this type and Type I.

We also summarized the ecological meaning of the eight presence probability types with respect to the temperature and precipitation related factors in Table 4. With this information, we can now determine the impacts of the projected climate change scenarios on the potential plant forms of the two regions.

Table 4. The ecological meaning of the eight probability types.

	Ecological Meaning	
Prob. Type	Temperature Factors	Precipitation Factors
I	A projected 0~5 °C increase would not affect the plant form currently present	A projected ±30% change would not affect the plant form currently present
II	A projected 2.5~5 °C increase is approaching the plant form's upper limit, the plant form might disappear; further increase would likely cause the plant form to disappear	A projected +30% change would approach the plant form's upper limit, the plant form might disappear; further increase would likely cause the plant form to disappear
III	A projected 0~2.5 °C increase is approaching the plant form's upper limit, the plant form is likely to disappear; further increase would very likely cause the plant form to disappear	A projected -30% change would approach the plant form's upper limit, the plant form is likely to disappear; further decrease would very likely cause the plant form to disappear
IV	The plant form would not be present	The plant form would not be present
V	The plant form would not be present	The plant form would not be present
VI	A projected 2.5~5 °C increase would cause the plant form to appear, but with low probability	A projected +30% change would cause the plant form to appear, but with low probability
VII	A projected 0~2.5 °C increase would cause the plant form to appear with high probability	A projected -30% change would cause the plant form to appear with high probability
VIII	A projected 0~5 °C increase would not affect the plant form currently present	A projected ±30% change would not affect the plant form currently present

Effects of increasing Tmax and Tmin on Her-Sher Region

The results for this region were summarized in Table 5. In general, the effects of increasing Tmax generated four types of responses. For some there would be no effect (plant forms 4, 5, and 11), plant form 13 would have a 50% chance of being present, and plant form 9 would most likely disappear. For plant form 9 (montane broad-raingreen trees), its Tmax upper limit is 25 °C, and the long-term average in Her-Sher region was 24.6 °C. Thus, a slight increase in Tmax would very likely displace that plant form. For the projected Tmin increases, three plant forms would not be affected (plant forms 4, 9, and 13), plant forms 5 and 20 would have a 50% chance of being displaced, plant form 11 probably would likely disappear, and plant form 1 could appear. The upper limit of Tmin for plant form 11 (summergreen broad-leaved trees) is 17 °C, which is close to the averaged Tmin value of Her-Sher region (15.1 °C). Thus, an increase of about 2 °C would probably force the plant form out. The lower limit of Tmin for plant form 1 (tropical rainforest trees) is 18 °C, so if the increase is above 3 °C, then the plant form would have a good chance to appear in the region. From Table 5 we can infer that the status of some of the existing potential plant forms in Her-Sher region will be controlled by whether the temperature during the summer increases above their upper limits (plant forms 9 and 13), and some will be controlled by whether the temperature during the winter increases above their lower limits (plant forms 5 and 11). Overall, we can say that the physiognomy under the projected conditions would be similar to the present one, but could have a more tropical rainforest appearance. However, if the temperature during the winter increases more than 2.5 °C, then the physiognomy of this region could change.

Table 5. Effects of the projected increases in Tmax and Tmin on the potential plant forms of Her-Sher region.

Tmax	Plant Form				
	4	5*	9	11	13
Present Currently	Yes	Yes	Yes	Yes	Yes
Present at +2.5 °C	Yes	Yes	No	Yes	Yes
5% Uncertainty	1[a]	1	0	1	0.501
10% Uncertainty	1	1	0	1	0.501
15% Uncertainty	1	1	0.001	1	0.499
20% Uncertainty	1	1	0.008	1	0.500
25% Uncertainty	1	1	0.035	1	0.490
Prob. Type	I or VIII	I or VIII	III	I or VIII	II

Table 5. Continued.

Tmin	Plant Form					
	1[b]	4	5*	9	11	13
Present Currently	No	Yes	Yes	Yes	Yes	Yes
Present at +2.5 °C	No	Yes	Yes	Yes	No	Yes
5% Uncertainty	0	1	0.494	1	0	1
10% Uncertainty	0.219	1	0.508	1	0.021	1
15% Uncertainty	0.309	1	0.501	1	0.103	1
20% Uncertainty	0.352	1	0.508	1	0.181	1
25% Uncertainty	0.396	1	0.510	1	0.257	1
Prob. Type	VII	I or VIII	II	I or VIII	III	I or VIII

[a] Presence Probability

[b] Plant form 1 is tropical rainforest trees. Its listed Tmax max. is 30 °C and min. is 20 °C; its Tmin max. is 28 °C and min. is 18 °C.

* Indicates the dominant plant form

Effects of increasing Tmax and Tmin on Dui-Gao-Yue Region

From Table 6 we can infer that under the projected conditions, all the existing plant forms would still be present. However, with a slight increase in winter temperature, two new plant forms could appear (plant forms 2 and 4). The lower limits of Tmin for plant forms 2 and 4 are 8 °C and 7 °C, respectively, whereas the averaged Dui-Gao-Yue Tmin value was 6.7 °C. Thus, the two new plant forms would very likely appear in Dui-Gao-Yue region. The physiognomy of the region would thus change from a temperate rainforest forest type toward a warmer mixed rainforest one. We initially hypothesized that the dominant plant form of Her-Sher region, plant form 5, would appear in Dui-Gao-Yue region under the projected temperature conditions. The model, however, did not support our conjecture. The lower Tmax limit of plant form 5 is 20 °C, which is 4.6 °C higher than the averaged Tmax of Dui-Gao-Yue region. Plant form 5 would appear in Dui-Gao-Yue region if the temperature during the growing season is about 5 °C higher than the averaged value, an event which we consider to be rather unlikely to occur. The model predicted that it would be a less important plant form (plant form 4) of Her-Sher region that could have a good chance to migrate upward under the projected scenarios.

Effects of changing precipitation regimes

Among the four precipitation factors examined, only Pmin (the amount of precipitation during the driest month) had slight effects on the plant forms of the two regions. For Her-Sher region, an increase in Pmin would decrease the likelihood of having plant form 9 in the region since more water would be available during the dry season. For Dui-Gao-Yue, a decrease in

Pmin could decrease the likelihood of having plant form 7 in the region. The model suggests that the precipitation regimes of the two regions are not the limiting factors of the current plant forms, and this is reasonable since the amount of precipitation for both regions is abundant, especially for Dui-Gao-Yue region.

Table 6. Effects of the projected increases in Tmax and Tmin on the potential plant forms of Dui-Gao-Yue region.

Tmax	Plant Form			
	7*	11	13	17*
Present Currently	Yes	Yes	Yes	Yes
Present at +2.5 °C	Yes	Yes	Yes	Yes
5% Uncertainty	1[a]	1	1	1
10% Uncertainty	1	1	0.944	1
15% Uncertainty	1	1	0.846	1
20% Uncertainty	1	1	0.765	1
25% Uncertainty	1	1	0.706	1
Prob. Type	I or VIII	I or VIII	II	I or VIII

Table 6. Continued.

Tmin	Plant Form					
	2[b]	4	7*	11	13	17*
Present Currently	No	No	Yes	Yes	Yes	Yes
Present at +2.5 °C	Yes	Yes	Yes	Yes	Yes	Yes
5% Uncertainty	1	1	1	1	1	1
10% Uncertainty	0.995	1	1	1	0.944	1
15% Uncertainty	0.939	1	1	1	0.846	1
20% Uncertainty	0.869	0.994	1	1	0.765	1
25% Uncertainty	0.794	0.974	1	1	0.706	1
Prob. Type	VII	VII	I or VIII	I or VIII	II	I or VIII

[a] Presence Probability

[b] Plant form 2 is tropical montane rainforest trees. Its listed Tmax max. is 24 °C and min. is 15 °C; its Tmin max. is 23 °C and min. is 8 °C.

* Indicated the dominant plant forms

Our results agreed with the findings of Lo and Guan (1999b) in general. They concluded that a warmer formation probably could develop for the same regions under similar projected conditions. However, they also concluded that Holdridge Life Zone model probably is not suitable for Taiwan’s mountain regions since Holdridge Life Zone model did not handle the combinations of low temperature and high annual precipitation well. The study region, especially the upper elevation region, was considered as an area sensitive to clime change as we have stated earlier. This conjecture was mainly based on educated guess or reasoning. As a worst-case assessment, our study did not support the conjecture and actually suggested that most of the current forest plant forms in the study region are robust against the predicted climate change scenarios.

It was a surprise to find tropical linear-leaved trees (plant form 13) as a potential plant form for both regions, and we did indeed find the species *Dodonaea viscose* that belongs to this plant form. That species is a small-sized tree usually found in low elevation and along the shoreline or riverbed areas, and within the study regions, the population of that species is small and restricted to only certain areas. This indicates that Box’s model does have the capability to predict potential plant forms. Under the projected temperature conditions, that particular plant form would likely persist in both regions, which we consider to be a reasonable prediction.

On the other hand, under the projected winter temperature conditions, two new plant forms (plant form 2 tropical montane rainforest trees and plant form 4 tropical evergreen microphyll-trees) could appear with almost certainty in Dui-Gao-Yue region. According to Box (1981), the representative families of plant form 2 include *Anacardiaceae, Moraceae, Sapindaceae*, and *Meliaceae*, etc. Some of the species in those families can already be found in both regions. For examples, five species from *Moraceae* and three species from *Anacardiaceae* can be found in both regions. Also, plant form 2 is not a potential one for Her-Sher region both currently and under the projected conditions. Such a prediction does not fit well with our current understandings on species dispersal. Why plant form 2 is not a potential plant form of Her-Sher region? Because the averaged Tmax value of Her-Sher region (24.6 °C) is above the Tmax upper limit for plant form 2 (24 °C), so it is not considered as a potential plant form currently, and for the same reason plant form 2 would not be considered as a potential plant form under the projected conditions. Finally, according to Chung (1994) there are more than 200 tree species in the two regions. During our investigation, sometimes it was difficult to determine to which plant form certain species should belong. Sometimes we could not find a suitable plant form to assign a species to, while sometimes one species could belong to two plant forms (especially species from *Fagaceae* and *Lauraceae*), a dilemma that Box (1981) also encountered. Thus, in these respects, Box's model does have its limitations.

In this study, some of the disagreements between the predictions and reality are due to the model's assumptions, whereas some are due to the fact that we used the model to assess a mountain region. In Box's model, plant forms respond to the limits of the climatic factors independently and simultaneously (i.e., the limits are multiplicative or orthogonal; Botkin 1993). However, the actual presences of some plant forms not predicted by the model suggest that plant forms may respond to those limits in an additive manner (e.g., following Liebig's law of the minimum), or factors might compensate for each other. Box (1981) also pointed out that the macroclimatic approach might not produce satisfactory results for mountainous regions because the true controlling factors (e.g., soil water level) might not be directly considered in the model. One possibility is to localize the model so relevant factors will be included. We are currently in the process of developing a localized version of Box's model by incorporating other temperature factors, redefining the limits of each factor, and changing the way plant forms responding to those limits.

In this study, we focused only on tree plant forms while ignoring the rest, since our focus was on forest formations. It is possible that non-tree species (or plant forms) might be more sensitive to climate change than tree species and could be used as indicators (e.g. Debinski *et al*., 2000), or we may be interested in assessing the impact of climate change on biodiversity based on plant forms (Duckworth *et al*., 2000). The flexibility Box's model may provide useful insights into the impacts of climate responses on non-tree species.

CONCLUSIONS

In this study, we used a simple biogeographical model to assess the possible impacts of climate change (i.e., when the atmospheric CO_2 concentration reaches 560 p.p.m.) on the potential tree plant forms of a mountain region in central Taiwan. To account for the uncertainties associated with the projected climate change scenarios, we also employed a Monte Carlo approach to examine the likelihoods of our assessments.

Our results suggested that temperature would be the controlling factor in shaping the plant form compositions and thus the physiognomy of the study area under the projected climate change scenarios. The responses of existing plant forms to temperature increases could be divided into three categories: (1) those that would not be influenced, (2) those that could disappear gradually, including summergreen tree species, which are more sensitive to temperature and require a lower temperature to exist, and (3) those that could appear gradually, including tropical tree species. Overall, this study indicated that under the projected precipitation conditions, the plant form compositions and the physiognomies of the study region would be similar to the present ones, but with a warmer appearance.

Even though in Taiwan we currently lack the deep knowledge necessarily to use mechanistic models or gap models for assessing the likely impacts of climate change on the vegetation distributions, this study demonstrated that we can still answer some of the basic questions with good resolution by using correlative biogeographical models. By combining a biogeographical model with simple statistical tools, we can improve the resolution of a simple biogeographical model. When detailed information necessarily to run high-resolution models is not available, the approach used in this study could be used as an alternative.

ACKNOWLEDGEMENTS

Funding support from the Council of Agriculture, R. O. C. under the grant contracts COA89-2101-22-01-09-01(2) and COA90-2101-10-01-0403-R1(2) is greatly appreciated.

LITERATURE CITED

Bachelet, D. and R. P. Neilson. 2000. Biome redistribution under climate change. In: Joyce, L. A. and R. Birdsey (tech. eds.) The impact of climate change on America’s forests: A technical document supporting the 2000 USDA Forest Service RPA assessments, pp. 18-44. Gen. Tech. Rep. RMRS-GTR-59. USDA, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Benioff, R., S. Guill and J. Lee. 1996. Vulnerability and adaptation assessment: an international handbook. Kluwer Academic Publishers, Dordrecht, Netherlands.

Beniston, M., H. F. Diaz and R. S. Bradley. 1997. Climatic change at high elevation sites: an overview. Clim. Change **36**: 233-251.

Botkin, D. B. 1993. Forest dynamics: an ecological approach. Oxford Univ. Press, NY.

Box, E. O. 1981. Macroclimate and plant forms: an introduction to predictive modeling in phytogeography. Dr. W. Junk Publishers, The Hague, Netherlands.

Bugmann, H. 1996. Functional types of trees in temperate and boreal forests: classification and testing. J. Veg. Sci. **7**: 359-370.

Chang, L.-N. 1998. Assessments of climate change of Taiwan (II). Final Report EPA-87-FA44-03-46. The Center for Environmental Studies, National Central University, Chun-li, Taiwan. (*in Chinese*).

Chung, N.-J. 1994. Studies on the vegetation ecology and the conservation characteristics of Salisen area, central Taiwan. Ph. D. Dissertation, Department of Forestry, National

Taiwan University, Taipei, Taiwan. (*in Chinese* with English abstract).

Cramer, W. P., and R. Leemans. 1993. Assessing impacts of climate change on vegetation using climate classification system. In: Solomon, A. M. and H. H. Shugart (eds.) Vegetation dynamics and global change, pp. 190-217. Chapman & Hall, NY.

Debinski, D. M., M. E. Jakubauskas and K. Kindscher. 2000. Montane meadows as indicators of environmental change. Environ. Monit. Assess. **64**: 213-225.

Duckworth, J. C., M. Kent, and P.M. Ramsay. 2000. Plant functional types: an alternative to taxonomic plant community description in biogeography? Prog. Phys. Geogr. **24**: 515-542.

Guan, B. T., G. Z. Gertner and P. Parysow. 1997. A framework for uncertainty assessment of mechanistic forest growth models: A neural network example. Ecol. Model. **95**: 47-58.

Holdridge, L. R. 1947. Determination of world plant formations from simple climate data. Science **105**: 367-368.

Holdridge, L. R. 1959. Simple method for determining potential evapotranspiration from temperature data. Science **130**: 572.

Hsieh, C.-F., C.-F. Shen, and K.-C. Yang. 1994. Introduction to the flora of Taiwan, 3: floristics, phytogeography, and vegetations. In: Huang, T.-C. *et al*. (eds.). Flora of Taiwan, 2nd ed. 1: 7-18. Editorial Committee, Dept. Bot., NTU, Taipei.

Lavorel, S., and E. Garnier. 2002. Predicting changes in community composition and ecosystem functioning from plant traits: revisiting the Holy Grail. Funct. Ecol. **16**: 545-556.

Lo, Y.-H. and B.-T. Guan. 1999a. Impacts of climate change on the montane vegetation formations of central Taiwan (I): assessment based on Holdridge Life Zone model. J. Exp. For. Nat. Taiwan Univ. **13**: 241-253. (*in Chinese* with English abstract).

Lo, Y.-H. and B.-T. Guan. 1999b. Impacts of climate change on the montane vegetation formations of central Taiwan (II): an uncertainty analysis. J. Exp. For. Nat. Taiwan Univ. **13**: 265-278. (*in Chinese* with English abstract).

Peng, C. 2000. From static biogeographical model to dynamic global vegetation model: a global perspective on modeling vegetation dynamics. Ecol. Model. **135**: 33-54.

Prentice, I. C., W. Cramer, S. P. Harrison, R. Leemans, R. A. Monserud and A. M. Solomon. 1992. A global biome model base on plant physiology and dominance, soil properties and climate. J. Biogeogr. **19**: 117-134.

Shugart, H. H. and T. M. Smith. 1996. A review of forest patch models and their application to global change research. Clim. Change **34**: 131-153.

Theurillat, J. P. and A. Guisan. 2001. Potential impact of climate change on vegetation in the European Alps: a review. Clim. Change **50**: 77-109.

氣候變遷對台灣中部山區潛在植物型之可能影響

關秉宗[1, 3]、黃任伯[1]、鍾年鈞[2]

(收稿日期：2003 年 9 月 26 日；接受日期：2003 年 11 月 20 日)

摘　　要

本文利用 Box’s 模式探討在不同情境下氣候變遷對台灣中部和社與對高岳山區潛在林木植物型之影響。本文亦利用 Monte Carlo 模擬方法探討氣候變遷之不確定性對預測結果所可能產生之影響。在模擬研究中，氣候因子增溫的範圍為迄今長期平均溫度加 0 至 5 °C，而降水因子其變動範圍則為迄今長期平均降水之±30%。研究結果顯示，研究地區潛在林木植物型於所設定的變動範圍內受降水因子之影響頗小，主要影響將源自於溫度因子之改變。在所設定的氣候變遷情境下，研究地區現今出現之林木植物型其反應可分成：(1)不受影響，(2)逐漸消失(如夏綠型)，與(3)逐漸出現(如熱帶樹種)等三大類，而研究地區現今出現之林木植物型大多數屬於第一類。本文所用之方法在缺乏高解析度資料時，仍可有效地用以探討氣候變遷對森林植群相對組成之可能影響。

關鍵詞：生物地理模式、Box 模式、氣候-植群分類、Monte Carlo 模擬。

1.台灣大學森林環境暨資源學系，台北市 106，羅斯福路四段一號，台灣。
2.台灣大學實驗林管理處，南投縣 557，竹山鎮前山路 12 號，台灣。
3.通信作者。Email: btguan@ntu.edu.tw