USING TERRAIN-RELATED VARIABLES TO ASSESS THE NEGATIVE EFFECTS OF TOPOGRAPHIC OBSTACLES ON TAIWAN RED CYPRESS DISTRIBUTION

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ABSTRACT: From a mechanistic viewpoint, it is desirable to predict the distribution of species based on ecological parameters (e.g. rainfall or temperature) that are causal factors for their distribution. Data for such ecological factors are difficult or expensive to collect and are usually insufficient. Terrain-related variables are used as proxies of ecological factors in the study since data for them can be easily obtained by remote sensing. Taiwan red cypress (TRC) grow in fog-forest belt (FFB) with rich moisture brought by northeastern (NE) season wind but with lower solar radiation due to high moisture in fogs and clouds. TRCs grow on the north part of the study area, but almost do not grow in the Huisun Experimental Forest Station (HEFS), except Shou-Cheng Mountain, in the south part of the study area. The study attempted to determine if the NE wind blocked by topographic obstacles is a key to above-mentioned distribution by reversely thinking their positive effect with another case of Taiwan fir. Topographic sheltering index (TSI) thus was developed. The accuracy of ecological niche model (ENM) using MAXENT with elevation plus TSI was better than that of the ENM using MAXENT with elevation plus slope, NDVI, and PCT bands. Consequently, TSI was useful for explaining the above-mentioned distribution. Moreover, the greater the TSI, the fewer TRCs grow in the study area, especially in the HEFS due to the negative effect of topographic obstacles opposite to the case of Taiwan fir. This proxy therefore may be a critical predictor variable for ENMs. The rise in accuracy is relatively limited despite TSI improving the predictive ability of these ENMs. Hence, the more refined TSI, the proxy of solar radiation (SR), and high-resolution DEM will be included into ENMS so that their predictive ability can be greatly improved.

1. INTRODUCTION

Ecological niche modeling (ENM) is a powerful tool for many different ecological applications such as the identification or prediction of rare species, the estimation of species richness, the testing of ecological niche concepts for biogeographical hypotheses, the assessment of potential invasion risks or for nature reserve selection and conservation planning. Also, ecologists have recognized that understanding the influence of macroclimate on the growth and productivity of forests is required to project future growth patterns in the face of global climate change. By linking climate projections with the known physiological tolerances of many species, it is possible to model direct and indirect consequences of global change scenarios on species and ecological systems. However, such future projections require two important additional components. The first is the proper understanding of the species–environment relationship, often couched in terms of niche theory. The second is the ability to relate these species–environment relationships to structural habitat properties in the form of digital data layers in a geographic information system (GIS). Projections will thus rely ideally on the melding of basic life history information with current and evolving remote-sensing techniques (Zimmermann *et al*., 2007). As compared with climate and soil data, it is much easier to obtain topographic data through remote sensing technology, thereby saving much longer time originally needed for field surveys. The study thus focused on identifying the relationship between topographic variables and ecological features of species to characterize the ecological traits of species by topographic variables, the surrogates of climatic variables (wind or humidity), and to model its potential distribution.

Chamaecyparis formosensis (Taiwan red cypress, TRC) often forms pure forests and grows in the fog-forest belt (FFB) with rich humidity brought by northeastern season wind in winter at medium elevation range in Taiwan. Because of growing in this belt, humidity is a critical environmental factor to TRC forests. TRC tree was a valuable commercial timber in Taiwan (Liu *et al*., 1994). Our study area, encompassing the Huisun Experimental Forest Station (HEFS) also referred to as Huisun area, is situated in central Taiwan, and a large part of the entire area falls within fog-forest belt. TRCs grow on Chilung Mountain and Paiku Mountain in the study area, but do not grow in the areas of the HEFS with elevation less than 1,800 m (non-FFB) and the areas of the HEFS with elevation greater than 1,800 m (FFB), except in

Huisun's Shou-Cheng Mountain (FFB with elevation 2,400 m). Huang (2002) pointed out that topographic shelters formed by mountains protect *Abies kawakamii* (Taiwan fir, TF) from a high wind so that TFs can grow in gullies or depressions rather than near ridges or peaks. The study attempted to find out northeastern season wind blocked by topographic shelters is a key to the absence of TRC forests in Huisun area with elevation greater than 1,800 m (FFB) by reversely casting from the case study of Taiwan firs in Hohuan Mountains. Hence, the study developed ENMs by maximum entropy (MAXENT) algorithm for predicting the suitable habitat of TRC forests in the study area.

Specifically, the study aimed at: (1) confirming currently used predictor variables, except elevation, to be ineffectual for explaining the absence of TRCs in most of the Huisun area with elevation greater than 1,800 m (FFB), except Shou-Cheng Mountain; (2) constructing topographic sheltering index (TSI) to the hypothesis; (3) evaluating if the TSI can improve predictive performance of ENMs.

2. MATERIALS AND METHODS

2.1. Study Area

The entire study area is situated in central Taiwan, and it contains three main parts of TRCs including Huisun Experimental Forest Station (HEFS), Pahsien and Chilung Mountains, and Paiku Mountains, as shown in figure 1. The HEFS is one of four forest stations of the Chung-Hsing University and the elevation of the study area falls within 445–2,419 m, partially contained in the elevation range of fog-forest belt. Chilung Mountain elevation is about 2,938 m. It belongs to the southwest offshoot of Snow Mountains and also to the watershed of Tachia River. Pahsien forest station, along with Ali and Tai-ping-shan forest stations, had stopped logging for many years. Government planned to set the Pahsien forest recreation area in 1978, and it was open in 1986. Paiku Mountains belong to Snow Mountains originally. Tachia River divided them from Snow Mountains, and they became an independent system. Paiku Big Mountain is the highest peak of Paiku Mountains, with elevation about 3,341 m. The study adopted a rectangular region, which covers HEFS, Pahsien Mountain, and Paiku Big Mountain to correspond with the area covered by SPOT-5 satellite images (c SPOT Image Copyright 2004 and 2005 CNES).

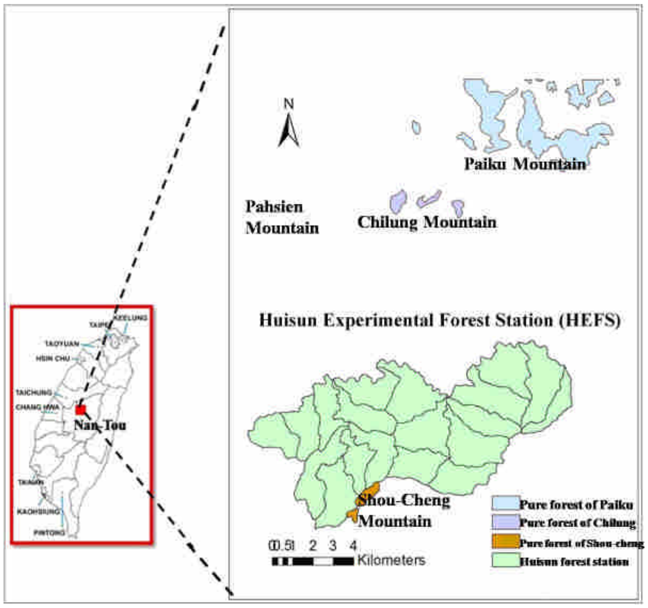

Figure 1 Location map of the study area.

2.2. Target Species

Taiwan red cypress (TRC) was valuable timber tree in Taiwan. TRCs grow in Central Mountains, Taiping Mountain and North Chatian Mountain, the natural distribution elevation ranges from 800 to 2,800 m and most fall within 1,500–2,150 m. They grow in the foggy and humid region, called fog-forest belt. TRCs only occur in Shou-Cheng Mountain in the HEFS (Liu *et al*., 1994).

2.3. Procedures and Rationale

The study generated elevation, slope and aspect from DEM by ERDAS Imagine software packages and derived terrain position from photo base map and DEM by ERDAS Imagine and ARC/INFO (Skidmore, 1990). The study also derived NDVI (Normalized Difference Vegetation Index) from SPOT-5 images of summer and fall (NDVI-summer and NDVI-fall). Besides, the study considered that the moisture content and structure within different plant's leaves would have different change between dry season (fall) and wet season (summer) (Hoffer, 1978). It also produced principal component transformation (PCT) images of summer and fall (PCT-summer and PCT-fall) by using ERDAS Imagine.
Furthermore, the study developed topographic sheltering index (TSI), the surrogate of wind (or humidity) and incorporated it into ENMs because we view it as a key variable. The TSI was derived from the concepts of permeable shelterbelt (windbreak) using a point-in-polygon operation in GIS (Kimmins, 1997; Aronoff, 1993). The index considers the downwind (or horizontal) distance protected by a "shelterbelt", i.e. impermeable topographic obstacle. The downwind distance protected by a topographic obstacle is roughly 15–20 times the relative height difference between the topographic obstacle and a certain point in the downwind direction.

The study chose 200 pixels from Shou-Cheng Mountain (containing 35,090 pixels), 270 pixels from Chilung Mountain and 2,815 pixels from Paiku Mountain, based on the ratio of area between Shou-Cheng Mountain, Chilung Mountain and Paiku Big Mountain. The number of background samples randomly selected was five times more than that of target samples (TRCs) in order to avoid spatial autocorrelation (Pereira and Itami, 1991; Sperduto and Congalton, 1996). Finally, the study built one-variable (elevation) model, two-variable model (elevation and TSI), and five-variable model (elevation plus slope, NDVI-summer, NDVI-fall, and PCT-fall) using MAXENT to predict the suitable habitat TRCs and evaluated them by the *Kappa* statistic (the coefficient of agreement) using an independent sample set (Cohen, 1960).

3. RESULTS AND DISCUSSION

Figure 2 shows the line graph of TSI statistics (mean, median, and mode) at the TRC forest sites and non-TRC forest sites (backgrounds) of the Huisun area and whole study area. The mean, median, and mode of TSI values were much lower at the TRC forests (blue line) than those at the backgrounds of the Huisun area and whole study area (red and light green lines) as varied with the number of samples. At a given location, the higher the TSI value, the greater the topographic sheltering effect is and the lower a TRC tree has the likelihood to grow at that location. Therefore, the TSI value is closely related to the occurrence of TRC tree at a given position. This outcome indicates why TRC forests can not grow in the areas of HEFS with elevation greater than 1,800 m (FFB), except its Shou-Cheng Mountain (2,400 m).

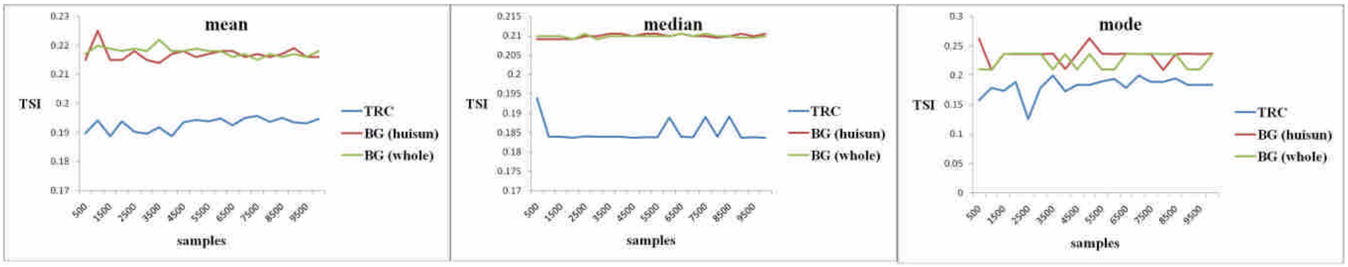

Figure 2 Statistics of TSI taken from the TRC forests and backgrounds (BG) of the Huisun and whole study area

Table 1 Accuracies of the models validated by independent sample dataset

Area for model calibration and validation	Huisun area (*1v)	Huisun area (**5v)	Entire study area (1v)	Entire study area (***2v)	Entire study area (5v)
	Kappa	*Kappa*	*Kappa*	*Kappa*	*Kappa*
MAXENT	0.94	0.91	0.51	0.56	0.54

*1v: one variable of elevation; **5v: five variables of elevation, slope, NDVI-summer, NDVI-fall, and PCT-fall, ***2v: two variable of elevation and topographic sheltering index (TSI).

Table 1 shows the accuracies of one-var0able, two-variable, and five-variable models over the Huisun area and the entire study area. The accuracy of one-variable model (0.94) for the Huisun area was slightly greater than that of five-variable model of the same area (0.91), and the opposite was true for the entire study area (0.51 and 0.54). Furthermore, the accuracies sharply declined from 0.94 to 0.52 for one-variable model and from 0.91 to 0.54 for five-variable model as we expanded the study area (43,460 ha) from the smaller HEFS (7,477 ha). The outcome indicates that currently used predictor variables mentioned in section 2.3 except elevation did not provide substantial contribution for explaining the absence of TRCs in most FFB areas of the HEFS and also suggests that topographic sheltering index should be included into the ENMs. On the other hand, the accuracy (o.56) of two-variable model (elevation and TSI) was substantially better than that (0.51) of one-variable model, and slightly better than that (0.54) of five-variable model for the entire study area. This indicates that the TSI was an important predictor variable for the ENMs, only second to elevation. However, TSI cannot greatly improve the predictive ability of ENMs as expected partly because the index does not consider progressive lessening of the NE season wind with latitude as the latitude decreases from northern Taiwan to central Taiwan and partly because the index does not consider topographic sheltering effects of multiple terrain obstacles at a given position. These two reasons combined may account for a decline in the moisture brought by the NE season wind, in turn a drop in the duration of cloud and fog, and intensification in sunlight as well as prolongation in sunshine duration over most FFB areas in the HEFS. This situation eventually may benefit the competition of broad-leaf trees with TRC trees (needle-leaf) under stronger and longer sunshine.

Here are two points of view suggested from the visual analysis of main ridges in the study area, as shown in figure 3. First of all, there are several main ridges in the northeast of the study area. Lack of rich humidity in the FFB areas of the HEFS is chiefly because the NE season wind laden with moisture has become weak as it reaches the HEFS in central Taiwan from northern Taiwan and is also blocked by these main ridges. Secondly, pure forests of TRCs are usually located at or near main ridges shown in figure 3 (left). This represents that TRCs can only grow at or near ridges where TRC trees can access more moisture; namely, where topographic sheltering effects are relatively lower. Consequently, the greater the TSI, the lower a TRC tree has the probability to grow at a given position in the study area. Two maps generated from MAXENT model with elevation (center in figure 3) and MAXENT model with elevation and TSI (right in figure 3) show the distribution of TRC forests, respectively, and the area of the latter is less than that of the former, particularly at top-left side. This indicates that TSI has the capability of limiting the distribution of TRCs.

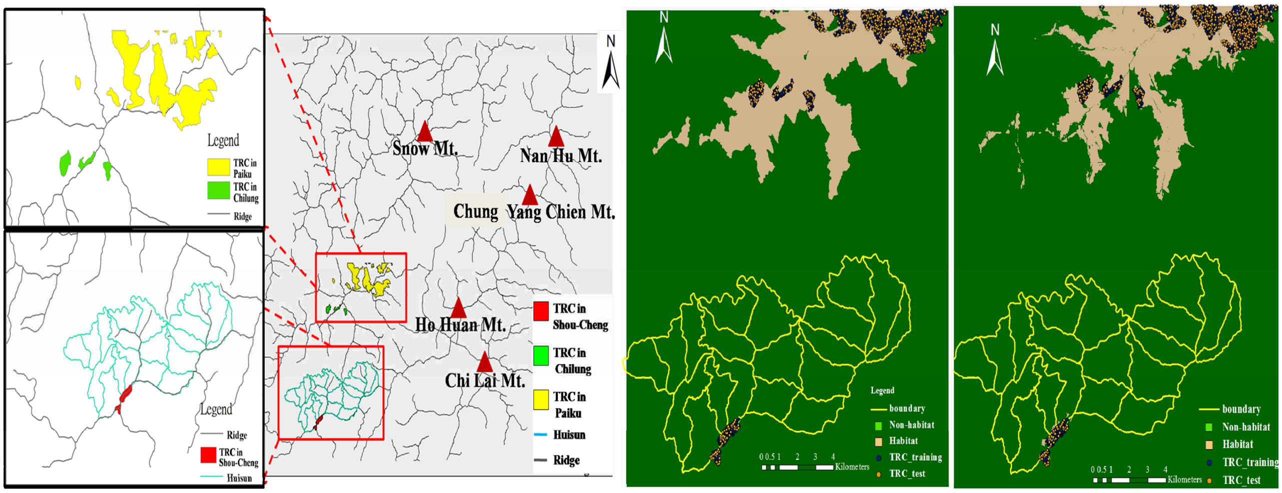

Figure 3 Distribution of main ridges and pure forest polygons of TRCs (left), as well as two maps generated from MAXENT with elevation (center) and MAXENT with elevation and TSI (right), respectively.

4. CONCLUSIONS

The study confirmed that topographic variables currently used, except elevation, in ENMs were useless for explaining the absence of TRCs in most FFB areas of the HEFS with elevation grater than 1,800 m. Even worse than that, models containing either elevation or elevation plus other four variables calibrated by TRC samples from three aforementioned mountains erroneously assigned non-TRC pixels far from Shou-Cheng Mountain in Huisun area to be TRC pixels. This outcome indicated that the ENMs could have left out certain critical predictor variables. Through reverse casting from the case study of TFs in Hohuan Mountains, the study thus herein confirmed that the absence of TRC forests in most FFB areas of the HEFS is attributable to the negative effects of topographic sheltering formed by mountain ranges (outside Huisun area) in the northeast of the entire study area. The accuracy of MAXENT with elevation plus TSI was better than that of MAXENT with elevation plus four other variables. Consequently, TSI incorporated into the predictive models was useful for explaining the above-mentioned distribution. Moreover, the greater the TSI, the fewer TRCs grow in the study area, especially in the HEFS due to the negative effect of topographic obstacles opposite to the case of Taiwan fir. This proxy therefore may be a critical predictor variable for ENMs and an alternative of the other four variables. The rise in accuracy is relatively limited despite TSI improving the predictive ability of these ENMs. Hence, more refined TSI (progressive lessening of the NE season wind as the latitude decreases from northern Taiwan to central Taiwan and multiple topographic sheltering effects), the proxy of solar radiation (SR), and high-resolution DEM will be included into ENMS so that their predictive ability can be greatly improved.

5. REFERENCES

Aronoff, S., 1993. Geographic Information System: A Management Perspective (Ottawa: WDL Publications).

Cohen, J., 1960. A coefficient of agreement for nominal scales. Educational and Psychological Measurement, 20 (1): pp. 37–46.

Hoffer, R. M., 1978. Biological and physical considerations in applying computer-aided analysis techniques to remote sensor data. Remote sensing: The quantitative approach, (P.H. Swain, and S.M. Davis, editors). McGraw-Hill, Inc. New York, pp. 227 – 289.

Huang, K. Y., 2002. Evaluation of the topographic sheltering effects on the spatial pattern of Taiwan fir using aerial photography and GIS, Int. J. remote sensing, 23(10): pp. 2051–2069.

Kimmins, J. P., 1997. Forest Ecology—A Foundation for Sustainable Management (Englewood CliVs, NJ: Prentice Hall).

Liu, Y. C., Lu, F. Y., and Ou, C. H., 1994. Trees of Taiwan. Taichung, Taiwan: College of Agriculture, National Chung-Shing University, pp. 440.

Pereira, J. M. C., and Itami, R. M., 1991. GIs-based habitat modeling using logistic multiple regression: A study of the Mt. Graham red squirrel, Photogrammetric Engineering & Remote Sensing, 57(11): pp. 1475 – 1486.

Skidmore, A. K., 1990. Terrain position as mapped from a gridded digital elevation model. International Journal of Geographical Information Science, 4: pp. 33–49.

Sperduto, M. B. and Congalton, R. G., 1996. Predicting rare orchid (S Using species distribution models to predict new occurrences for rare plants. mall Whorled Pogonia) habitat using GIS. Photogrammetric Engineering and Remote Sensing, 62 (11): pp. 1269–1279.

Zimmermann, N. E., Edwards, T. C., Moisen, G. G., Frescino, T. S. & Blackard, J. A., 2007. Remote sensing-based predictors improve distribution models of rare, early successional and broadleaf tree species in Utah. Journal of Applied Ecology, 44(5), pp. 1057–1067.