THE TOPOGRAPHIC IMPACT OF TYPHOON DISTURBANCES ON VEGETATION DAMAGE

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Abstract: Taiwan is an island with active tectonic movements. Mountains over 3000 meter are distributed from north to south and the terrain are complex in features. The typhoons are common disturbance events for the forest in the mountain area during the summer season. Typhoons often cause damage to forests with strong wind and heavy rain which affect the structure and function. However, the mountains affect the destructive power of the typhoon, and resulting in the variation of damage in different regions. Taiwan was divided into 3 regions to explore the relationship between vegetation damage and topographic factors after strong typhoon disturbances in different geographical areas. The NDVI in low-altitude areas below 1,000 meters were reduced after the large disturbance in the northern watershed. The NDVI below 2,000 meters were obviously degraded after the disturbance of all types of vegetation in the central watershed. A similar result occurred in the south watershed while coniferous forest was increased in NDVI after disturbance. The regression between NDVI decrease and topographic factor was established. The R^2 value of the central watershed is 0.61, and the order of contributing factors is the altitude, the NDVI before the disturbance and the cosine of aspect. The R^2 value of the southern watershed is 0.42, and the main influencing factors are the NDVI before the disturbance, followed by the altitude and the cosine of aspect. However, the R^2 value in the north is close to 0, which means that the topographic factors have poor interpretation ability for disturbance damage. The north region was affected by the typhoon directly. In contrast, the influence of topography is insignificant. The main wind direction and scale were changed by the high mountain in the central and southern regions, which may increase the influence of topography on the typhoon's damage.

Keywords: Typhoon disturbance, Topography, Vegetation damage, NDVI

1. INTRODUCTION

Disturbance plays a key role in dictating patterns of forest structure and biodiversity. Cyclones are known to have a strong influence on forest structure and effects varying with topography (Tanner et al., 1991). The effects of topography on the climate and vegetation of any given region are powerful. Mountain ranges create barriers that alter wind and precipitation patterns. The windward sides of mountain ranges tend to be lush and rich with vegetation because of orographic precipitation.

Taiwan is an island that possesses complicated mesoscale topography. Its Central Mountain Range (CMR) has dimensions of about 200 km × 100 km and includes many peaks that exceed 3000 m. One feature of mountainous regions is vegetation zonation along gradients in altitude. Typhoon is an important disturbance factor affecting the growth of forests in Taiwan. In particular, mature and tall trees are more susceptible to typhoon and control the development of forest structures (Lin et al., 2017). The mountainous terrain in Taiwan is complex, and the interaction of typhoons and topography alters the exposed areas of disturbances, which in turn controls the development of biomass on forests (McEwan et al., 2011).

2. MATERIAL AND METHODS

Three watersheds in the middle and upper reaches of the rivers were selected as the study area. The Dahan, the Jyunda, and the Laonong were respectively representing the northern, central and southern region. The altitude of watershed ranges from 400 meters to more than 3,000 meters with feature varies greatly (Figure 1). As a result of sharp elevation gradients, Taiwan has very diverse forest ecosystems, including evergreen hardwood forests at lower altitudes, deciduous forests at mid-altitudes and evergreen conifer forests at higher altitudes.

2.1 Typhoon Events and Satellite Imagery

To understand the damage associated with typhoon, it is important to examine the path of typhoons. According to CWB, typhoon paths with wind field having physically affected the Taiwan are divided into ten categories. Fig. 2 illustrates the statistics of those categorized paths from 1989 to 2011 (Hsu et al 2014). To minimize the path effect, the Soulik, Haitang, and Matmo which follow the path 2 and 3 were included as the disturbance events in this study (Table1).

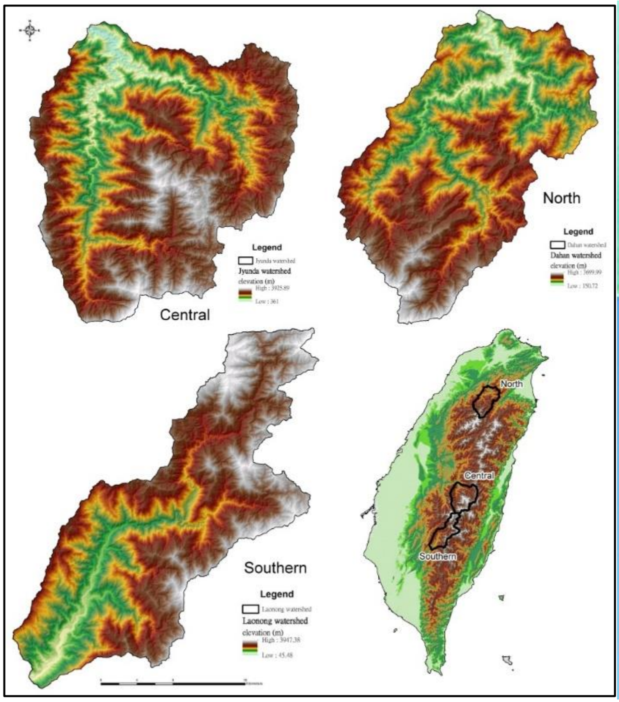


Figure 1 Study area

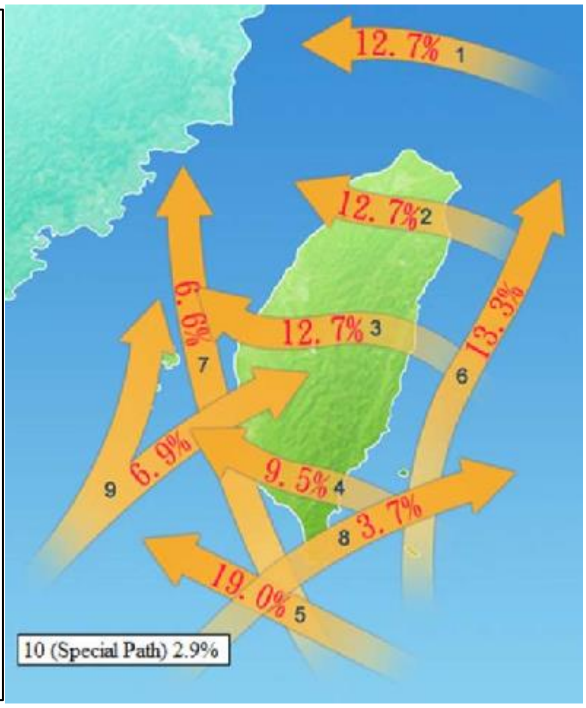
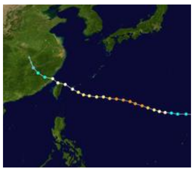
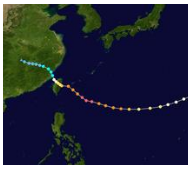


Figure 2 The categorized typhoon paths in Taiwan from 1989 to 2011 (Data source: adapted from CWB). Cite from HSU et al 2014.

The cloudless image before and after the major typhoon events in each region were used to determine the vegetation damage and the histogram matching method were used to perform relative radiation correction to achieve image homomorphism.

Table 1 Typhoon events and satellite imagery parameters

Region/Typhoon (level)	date	path		Satellite	Date	GSD(m)
North/Soulik (Severe)	2013 7/11-7/13		2	SPOT-5	2013/03/07	10
				SPOT-5	2013/08/09	10
Central/Haitang (Severe)	2005 7/16-7/20		3	SPOT-5	2005/07/09	10
				SPOT-5	2005/09/20	10
Southern/Matmo (Middle)	2014 7/21-7/23		3	SPOT-5	2014/6/28	10
				SPOT-5	2014/8/24	10

2.2 Vegetation Loss

Vegetation indices are designed to maximize sensitivity to the vegetation characteristics while minimizing confounding factors such as soil background reflectance, directional, or atmospheric effects. The Normalized Difference Vegetation Index (NDVI) is probably the most frequently used vegetation index which quantifies vegetation by measuring the difference between near-infrared and red light because it is a standardized way to measure healthy vegetation. Its formula was listed following:

$$\mathrm{NDVI} = \frac{(NIR-RED)}{(NIR+RED)} \quad \text{(Eq. 1).}$$

NDVI was used to calculate the changes of vegetation in the watershed area before and after the typhoon. To evaluate the damage of typhoon disturbance in each area, the forest type map was used to discover the disturbance difference of vegetation types. Meanwhile, 20-meter digital elevation model was used to investigate the vegetation loss at different altitudes, and the measurement interval was 500 meters.

2.3 Multiple Regression

Regression analysis is a common method to discover a relationship between dependent and explanatory variables. Multiple regression is an extension of simple linear regression which generally explains the relationship between multiple independent or multiple predictor variables and one dependent. Therefore, the simultaneous multiple regression was applied to analyse the factors including altitude, slope, aspects of sine, aspects of cosine, typhoon rainfall and pre-disturbance NDVI which effects on vegetation loss. All of the explanatory variables were added to the equation on one step in simultaneous multiple regression. The power and contribution of the explanatory variable to the dependent variable could be clarified by the factor coefficients.

3. RESULTS

3.1 Vegetation Loss at Different Altitudes

The NDVI difference before and after the typhoons were calculated (Figure 3). The positive value indicated that the vegetation was less affected by disturbance and continued to grow; the negative value indicated that the typhoon disturbance was greatly affected, and the phytosanitary quantity was significantly degraded. The disturbance loss mostly occurred below 1,000m in the northern watershed, and the disturbance effect was much smaller at the mid-altitude area of 1,000-2,500m. The loss of mixed forest is relatively small than conifer, and the broad-leaved forest even showed a positive increase in mid-altitudes. The loss of coniferous forest and coniferous broad-leaved mixed forest were also quite obvious at high altitudes over 2,500 m.

The areas below 2,000m were obviously affected by typhoon disturbance in central watershed and the vegetation loss was decrease with the altitude. The damage decreased and NDVI even showed an increasing trend after typhoon over 2,000m, especially in coniferous forest. A similar result appeared in the southern watershed with significant impairment below 2,000 m, while the damage was unapparent in 2,000-3,000 m. The NDVI increased obviously over 3,000m. It was worth noting that the NDVI of coniferous forest in the southern watershed showed a positive increase in all altitudes, indicating that the southern coniferous forest was less affected in this typhoon event.

3.2 Multiple Regression of Vegetation Loss

30,000 samples were selected randomly to establish the multiple regression models for each watershed (Table 2) to clarify the relative contribution of these variables (Table 3). The Variance Inflation Factor (VIF) values of each variable are less than 10 and pass the significance test which indicates that the variables relationship is independent. However, the R^2 in the northern watershed was only 0.09 which means the independent variable on the NDVI variation is without explanatory power. Therefore, the topographic parameters, pre-disturbance NDVI and the rainfall could not explain the NDVI fluctuation in the northern watershed.

The R^2 of the NDVI variation model was 0.615 in the central and 0.438 in the southern watershed respectively, and both statistically significant, indicating that the variable composition had a acceptable explanatory power for the NDVI variation. The value of Standardized Coefficient Beta showed that the main explanatory variables in the central watershed are altitude, pre-disturbance NDVI and cosine of aspect. The beta of altitude was 0.528, indicating that the NDVI damage tends to be negative correlated with altitude. The beta value of pre-disturbance NDVI was -0.362 indicating that the impairment is positive relate to the vegetation condition before disturbance. In the case of southern watershed, the pre-disturbance NDVI Beta value is -0.472, which is the largest contribution factor. Followed by the altitude (0.315) and cosine of aspect (-0.204).

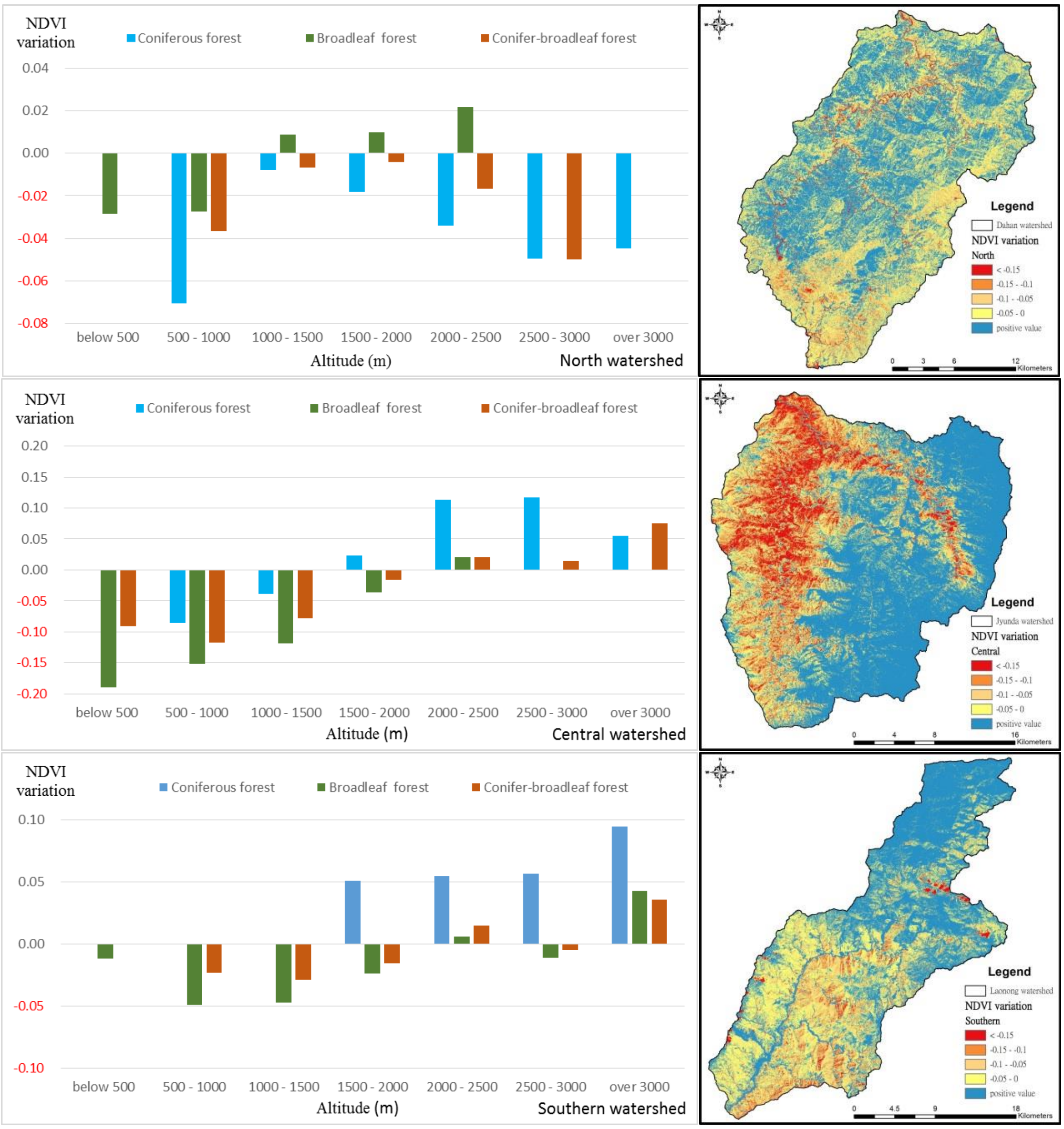


Figure 3 The result of NDVI variation after typhoon disturbance.

Overall, the results show that the altitude, aspect and pre-disturbance NDVI were common factors contributed to the typhoon disturbance in the central and southern watershed. However, the explanatory variables selected in this study did not have explanatory power in the northern watershed. Although the slope and typhoon rainfall were statistically significant, the contribution of explanatory power was small, may because the NDVI variation was not linearly related to both.

Table 2 Model Summary

Model	R	R Square	Adjusted R Square	Durbin-Watson	Sig.
North watershed	.299	.090	.089	1.789	.000**
Central watershed	.784	.615	.615	1.575	.000**
Southern watershed	.662	.438	.438	1.720	.000**

Table 3 Factor Coefficients

Model		Unstandardized Coefficient B	Unstandardized Coefficient Std. Error	Standardized Coefficient Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
North watershed	(Constant)	.104	.005		22.639	.000**		
	Altitude	.000	.000	-.212	-27.606	.000**	.515	1.943
	Slope	.000	.000	.052	9.308 .	000**	.991	1.009
	Sin_aspect	.012	.001	.094	16.526 .	000**	.942	1.061
	Cos_aspect	.013	.001	.108	18.679	.000**	.905	1.105
	Pre-NDVI	-.166	.005	-.199	-34.498	.000**	.915	1.093
	Rainfall	.000	.000	.008	1.093	.275	.530	1.886
Central watershed	(Constant)	-.244	.067		-3.646	.000**		
	Altitude	.000	.000	**.528**	95.877	.000**	.423	2.363
	Slope	-.001	.000	-.087	-24.012	.000**	.980	1.021
	Sin_aspect	-.015	.001	-.080	-21.932	.000**	.964	1.037
	Cos_aspect	-.031	.001	**-.175**	-48.390	.000**	.983	1.017
	Pre-NDVI	-.216	.002	**-.362**	-93.440	.000**	.856	1.168
	Rainfall	.000	.000	.012	2.297	.022**	.437	2.289
Southern watershed	(Constant)	-.056	.005		-10.302	.000**		
	Altitude	.000	.000	**.315**	64.359	.000**	.779	1.283
	Slope	.000	.000	-.032	-7.191	.000**	.943	1.061
	Sin_aspect	.015	.001	.121	27.640	.000**	.983	1.018
	Cos_aspect	-.026	.001	**-.204**	-46.435	.000**	.968	1.033
	Pre-NDVI	-.168	.002	**-.472**	-105.709	.000**	.938	1.066
	Rainfall	.000	.000	.086	17.829	.000**	.800	1.250

4. CONCLUSION AND DISCUSSION

This paper investigates the impacts of Taiwan's topography in typhoon disturbances and leads to the following conclusions.

1. The relationship between typhoons and vegetation damage is complex and region varying. There is no simple relationship between topographic factor and vegetation loss.
2. The northern watershed had obvious vegetation decrease after typhoon disturbance, but the influence of topography was insignificant.
3. The high-altitude areas above 2,000 meters were less-affected area of typhoons in central and southern of Taiwan while the damage was relatively serious in the low-altitude areas.

The most important finding from this study suggests that there is no single model that can describe the NDVI impairment after a single large disturbance. But altitude difference is obvious in the mountainous area, and the low altitude area is more vulnerable to typhoon threatening. The similar results can be found in the previous research which pointed out that typhoon disturbances limit the growth of low-altitude forests (Chi et al., 2015). The forests in the northern mountainous areas had obvious vegetative degeneration after typhoon disturbance, but the relationship with the topography was not significant. The results from the regression model showed that the disturbance loss affects by the characteristics of regions.

More typhoon events or other influencing parameters are needed in future study to investigate the correlation of typhoon disturbance and topographic effect for understanding the complex process of natural disturbance.

References

Chi, C. H., McEwan, R. W., Chang, C. T., Zheng, C., Yang, Z., Chiang, J. M., Lin, T. C. 2015. Typhoon disturbance mediates elevational patterns of forest structure, but not species diversity, in humid monsoon Asia. Ecosystems, 18(8), pp. 1410-1423.

Hsu, T. W., Usman, M., Lan, Y. J., Lee, Y. P., 2014. A Study of Extreme Value Analysis on Typhoon Wave. Coastal Engineering Proceedings, 1(34), 38.

Lillesand, T. M. and Kiefer R. W., 2000. Remote Sensing and Image Interpretation, Fourth Edition. John Wiley & Sons, Inc.

Lin, K. C., Hamburg, S. P., Wang, L., Duh, C. T., Huang, C. M., Chang, C. T., Lin, T. C. 2017. Impacts of increasing typhoons on the structure and function of a subtropical forest: reflections of a changing climate. Scientific reports, 7(1), pp. 4911.

McEwan, R. W., Lin, Y. C., Sun, I. F., Hsieh, C. F., Su, S. H., Chang, L. W., & Yang, K. C. 2011. Topographic and biotic regulation of aboveground carbon storage in subtropical broad-leaved forests of Taiwan. Forest Ecology and Management, 262(9), pp. 1817-1825.

Tanner, E. V. J., Kapos, V., Healey, J. R. 1991. Hurricane effects on forest ecosystems in the Caribbean. Biotropica, pp. 513-521.

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