Research note

Forest damage and recovery resulting from 2015 typhoons in Lanyu island

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【Summary】

Lanyu is a small island located off southeastern Taiwan which experiences more frequent and intense typhoons than does Taiwan. Six surveys were conducted between 2015 and 2016 to study damages and recovery in natural and managed forests in response to three typhoons. The results indicate that the greatest canopy damage was not associated with the typhoon having the highest wind speed, suggesting that wind speed alone is not a good predictor of typhoon damage. Typhoon-induced tree mortality was less than 1%, and the gap fraction returned to the level before typhoon Soudelor in less than seven months, which highlights high resistance and resilience of the forests of Lanyu in response to typhoon disturbance and supports the hypothesis that there is a positive relationship between typhoon frequency and ecosystem resistance and resilience.

Keywords: Lanyu, typhoon, forest recovery, resistance, resilience.

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研究簡報

2015年颱風對蘭嶼森林的損傷與森林回復狀況

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摘 要

蘭嶼是位於臺灣東南海域的小島，遭受比臺灣本島更高頻率及更強烈的颱風侵襲。本研究於2015～2016年調查蘭嶼天然林與人工林受颱風的損害與回復情形。調查結果林冠最大的損害並非由風速最強烈颱風所造成，顯示單由風速並無法準確預測颱風對森林的損害。颱風造成的樹木死亡率低於1%，而森林孔隙率於七個月內即回復至蘇迪勒颱風前的狀況，顯示蘭嶼森林對對於高頻率颱風擾動地區森林會具有較高的抵抗力與恢復力，並支持颱風的頻率和生態系的抵抗力與回復力有正向關係的假說。

關鍵詞：蘭嶼、颱風、森林回復、抵抗力、回復力。

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The Northwest Pacific Ocean region has the highest frequency of typhoon disturbance globally (Lin et al. 2011). Between 1996 and 2015, 59 typhoons passed through or near within 100 km of Taiwan (Central Weather Bureau, http://rdc28.cwb.gov.tw/). The high winds and heavy rainfall associated with typhoons often lead to forest damages ranging from defoliation, tree snapping, uprooting, and landslides (Boose et al. 1994, Frangi and Lugo 1991, Harrington et al. 1997, Yih et al. 1991). Although Taiwan is a relatively small island, typhoon effects vary considerably spatially as a result of differences in topography and distance to the typhoon path among regions. Based on analyses of NDVI using satellite images, Lee et al. (2008) reported greater typhoon damage at Lienhuachi Experimental Forest of central-western Taiwan than Fushan Experimental Forest of northeastern Taiwan and attributed this difference to different typhoon frequencies between the two sites (0.7 typhoon/yr at Lienhuachi and 1.4 typhoon/yr, at Fushan) (Lee et al. 2008, Kang et al. 2005). Possibly, through long-term interactions, forests developed under frequent typhoon disturbance are more resistant to typhoons (Lin et al. 2011).

Lanyu (121°32″E, 22°03″N) is a small island (~46 km^2) located off southeastern Taiwan (Chen et al. 1982). Most of the island is less than 500 m above sea level. The mean monthly air temperature at Lanyu is 18.5℃ in January and 26.3℃ in July, and its mean annual precipitation is ~3000 mm (Central Weather Bureau, http://www.cwb.gov.tw/V7e/climate/monthlyMean/Precipitation.htm). Forests cover is about 80% of the island (Chen et al. 1982), some of which near the coastal village of the island are managed by aboriginal people, while the rest are unmanaged (Chen et al. 1982, Chen and Tso 2004). The most common tree species of the managed forests are *Artocarpus altilis* and *Pometia pinnata*. The dominant tree species in the natural forest are in the families Lauraceae, Leguminosae, Moraceae and Pandanaceae, with *F. formosana* being the most dominant species on hilltops (Chen et al. 2008).

Between 2000 and 2015, there are an

average of 1.75 typhoons that affected Lanyu (defined as typhoons with a minimum distance between the typhoon center and Lanyu < 100 km). With no high mountains nearby, Lanyu typically experiences much higher winds than locations in Taiwan during typhoon periods. Both intensity and frequency are important determinants of typhoon effects on ecosystems (Lee et al. 2008, Webb et al. 2011, Van Bloem et al. 2003, Van Bloem et al. 2006). It has been proposed that both resistance and resilience to typhoon disturbance are positively related to typhoon frequency (Lin et al. 2011). Therefore, as a result of the high frequency of typhoon disturbance at Lanyu, we hypothesized that forests at Lanyu have high resistance and resilience to even the most intense typhoons.

Four typhoons affected Lanyu in 2015: Noul, Soudelor, Goni, and Dujuan, all of which caused high winds at Lanyu (Table 1). We took this opportunity to study forest responses to typhoons by established five transect lines just before Typhoon Soudelor, and six measurements were made between August 2015 and July 2016. Three of the transect lines (100, 120 and 140 m) were in the natural forest, and the other two (both 140 m) were in the managed forest (Figure 1). We took hemispherical photographs at 10 m intervals along each transection line using a 24-megapixel Nikon D610 digital camera (Nikon, Tokyo, Japan) equipped with a Sigma fisheye lens (with a combined focal length equivalent to 8 mm and combined F number f/3.5). We set the camera on a tripod at 1 m above the ground and used an air-bubble level to ensure that the camera lens was leveled. The top of the camera pointed to magnetic north using a compass, and the camera was set in aperture priority mode with ISO of 800 and F of 3.5 while taking the photographs. All photographs were taken early in the morning before sunrise or after sunset but prior to dusk or on overcast days. Gap fraction was analyzed using HemiView 2.1 (Delta-T, 2000), with the threshold value that classified an image into canopy (black) and sky (white) elements determined manually through the comparison between the original and classified images. We also recorded the identity of all trees and identified typhoon-induced tree damages within 3 m from each transect line. Damage comprised two categories: uprooted and bole-snapped. The survey was conducted five times, following typhoons Soudelor, Goni and Dujuan (all within two weeks), 28 November 2015, and 6 July 2016. Analysis of variable with repeated measurements and Student t test was used to detect differences in gap fractions among the surveys using JMP (version 10; SAS Institute Inc, North Carolina, USA).

Gap fraction of the natural forest increased gradually from 0.053 in 6 August 2015 to 0.096 in 28 November 2015, but decreased to 0.057 in 6 July 2016, which was not significantly different from the value of 6 August 2015 (Figure 2). A similar pattern was

Table 1. Basic information of 2015 typhoons in Lanyu weather station. (Central Weather Bureau, Typhoon Database: http://rdc28.cwb.gov.tw/)

Typhoon	Warning period	Mean Maximum wind (m/s)	Maximum gust wind (m/s)	Total rainfall (mm)
Noul	10-11 May 2015	22.9	49.3	37.5
Soudelor	6-9 August 2015	30.6	52.6	34.8
Goni	20-23 August 2015	20.6	41.8	282.3
Dujuan	27-29 September 2015	28.4	44.5	3.2

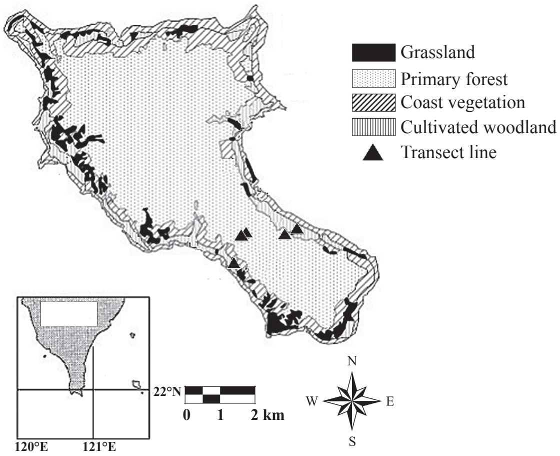

Fig. 1. Location and vegetation distribution map of Lanyu. The figure is modified from Chen et al. 1982 and Chen and Tso 2004.

observed in the managed forest: gap fraction increased gradually from 0.070 in 6 August, 2015, to 0.113 following Typhoon Goni and then decreased to 0.076 in 6 July, 2016, which was not significantly different from the value of 6 August 2015 (Figure 2). In other words, regardless of the multiple typhoon influences, the forest canopies were able to recover in less than seven months, highlighting the resilience of forests in Lanyu to frequent typhoon disturbance. These results support the inference that forest recovery from typhoon disturbance is positively related to typhoon frequency (Lin et al. 2011).

Although Typhoon Goni had the lowest wind speed among the three typhoons, it caused the largest increases both in absolute term (0.019) and in percentage (100 x (after-before)/before = 30.4%) of gap fraction in the natural forest. Gap fraction following Typhoon Goni also increased in absolute term 0.024 in the managed forest, and the percent change of 27% was slightly smaller than following Typhoon Soudelor (28%) (Figure 2). Although Typhoon Dujuan also brought strong wind to Lanyu (Table 1), it did not cause a significant change in gap fraction (Figure 2). The same was found following Typhoon Dujuan (i.e. between 6 september and 28 November, 2016) although it also brought strong wind to Lanyu (Table 1). These results indicate that wind speed is not a reliable predictor of typhoon-induced canopy damage (Chang et al. 2013). Factors such as rainfall quantity and intensity and topography likely also result in typhoon damages to forests in Lanyu.

Regardless of the lack of significant change in response to Typhoon Dujuan, the gap fraction increased in the natural forest but decreased in the managed forest. Currently, we have no data to infer whether such a difference resulted from differences in topography-typhoon interaction or management-induced alternation of ecosystem characteristics in the managed forest; however, differences in responses to typhoon disturbance between natural and managed forests have also been reported for forests in northeastern Taiwan (greater damage in forest plantations, Kang et al. 2005) and central Taiwan (greater damage in natural forests, Lee et al. 2008).

Typhoon-induced tree mortality on Lanyu was low. Only four trees were uprooted in the natural forest (total tree number was 959), and only one tree (out of 156) was

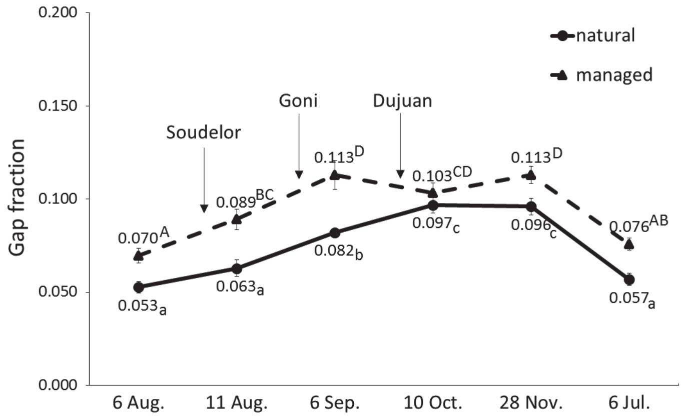

Fig. 2. Gap fraction of natural forest and managed forest in Lanyu between August 2015 and July 2016. Error bar: 1 standard error. Values of the same line with different letters are statistically different at α = 0.05 based on analysis of variance of repeated measurements and Student's t test for each pair comparison.

uprooted in the managed forest. Only six and three trees were bole-snapped in the natural and managed forest, respectively, following Typhoon Soudelor. The other two typhoons did not cause any tree mortality in our line transects. The low tree mortality indicated high resistance in response to multiple typhoon disturbance and support the positive relationship between forest resistance and frequency of typhoon disturbance (Lin et al. 2011). In regions with a high frequency of typhoons (or tropical cyclones in general), there would be few trees left, if tree mortality is high. Heavy defoliation is a good adaptation to strong winds, especially if it occurs early in a typhoon, as it lowers the exposure of trees to strong winds, and, as a result, protects the tree from lethal damage. This phenomenon has been reported for the Fushan Experimental Forest of northeastern Taiwan (Lin et al. 2003, Lin et al. 2011).

Due to the limited data for forests in Taiwan, we cannot make other direct comparisons of forest damage and recovery between Taiwan and Lanyu; however, because Lanyu experiences a greater frequency of and more intense typhoons than forests in Taiwan, the striking recovery of forests at Lanyu supports the hypothesis of a positive relationship between ecosystem resilience and resistance and frequency of typhoon disturbance (Lin et al. 2011). On the other hand, it is important to recognize that the high resilience and resistance of forests in Lanyu may also result from the frequent gusty winds that occur during the Northeast Monsoon season, as well as the stress from sea salt spray on this small island. In other words, both typhoons and high winds associated with Northeast Monsoon may contribute to the observed high resistance and resilience, and our results highlight the role of high winds on characterizing ecosystem structure and function.

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