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The Synergistic Effects of Typhoon and Earthquake Disturbances on Forest Ecosystems: Lessons from Taiwan for Ecological Restoration and Sustainable Management

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ABSTRACT

Taiwan is a mountainous island in which 58.5% covered by subtropical and monsoon rain forests. Degradations of forestlands and resources often occur due to fragile geological formations and by frequent major typhoons and earthquakes. We summarized the impacts of typhoons and earthquake as natural disturbance events on forest ecosystems from various perspectives, including vegetation changes, nutrient dynamics, and watershed protection. Considering the unique environmental conditions of Taiwan, we address the synergistic effects of multiple natural disturbances. We also discuss the basic principles and framework related to post- major disturbance forest restoration and sustainable management. Moreover, we examine the potential issues of current management practices and provide insights for future directions and research needs.

Keywords: defoliations, gap dynamics, island ecosystem, natural disturbance, regeneration, subtropical forest, vegetation recovery

CONTENTS

INTRODUCTION

Natural disturbance events, such as wildfires, tropical cyclones or typhoons (i.e., hurricanes in the Atlantic Ocean, Caribbean and eastern Pacific Ocean), earthquakes and landslides have been characterized by a large amount of energy changes and may propagate from/to various directions in diverse forms (Forman 1995; Lin *et al.* 2006; Xi and Peet 2008, 2011). These widespread natural disturbance agents are discrete events in particular time that not only alter species population dynamics, landscape structure and ecosystem functions, but also affect the arrangements and availabilities of resources in the physical environments (White and Pickett 1985). For both tropical and subtropical forest ecosystems, typhoons are one of the most important natural disturbances, which often cause increased variations of forest structure, diversity and functions (Lee *et al.* 2008). For example, studies on effects of Caribbean hurricanes indicated that strong wind and storm surge play an important role altering forest composition and forest structures, as well as certain key environmental conditions of forest ecosystems such as understory light regimes and nutrient cycling (Tanner *et al.* 1991; McDowell 2000; Vandermeer *et al.* 2000; Lin *et al.* 2003). Earthquakes often lead to steep topography or weak geological formations that may trigger landslides (Jibson 1996). Landslides triggered may lead to a tremendous loss in forest habitats (Lin *et al.* 2003; Chen

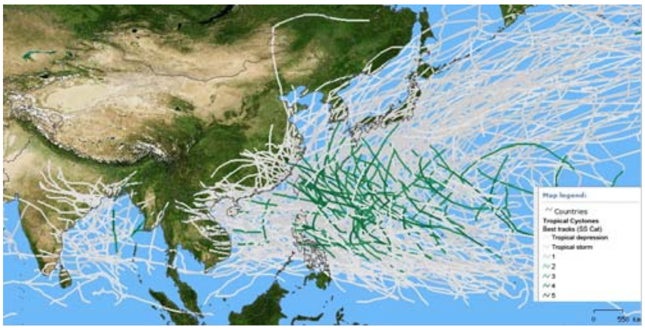

Fig. 1 The track map of tropical cyclones at various Saffir–Simpson scales in the Northwest Pacific regions between 2000 and 2010. Data source: Global Risk Data Platform (http://preview.grid.unep.ch/index3.php?preview=data&lang=eng).

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2005; Lin *et al.* 2006). Forests are not only the home of various plant species but also a host for many animal species. Altering the structure of forest ecosystems is a major factor on biodiversity. Therefore, understanding the impacts of the natural disturbances on the forested landscapes becomes an essential task for managing and restoring disturbed forests.

Taiwan is a mountainous island (i.e., 74% approximately; Lu *et al.* 2001) located on the Philippine plate and the junction of the Euro-Asian Plate (DeMets *et al.* 1990; Lin *et al.* 2010). Because of plate convergence, the tectonic activities not only lead to a weak geological formations but also cause frequent disastrous earthquakes. Coincidentally, the region is located in the northwestern Pacific Ocean as well, where the highest frequency of typhoons in the world (Berz *et al.* 2001, **Fig. 1**). A typhoon of originating in the western Pacific Ocean off the Philippines usually strikes Taiwan at least once a year since the last hundred years. From 1987 to 2008, typhoons averaged 3.8 events annually in Taiwan (Central Weather Bureau 2009). Nearly 80% of annual precipitation falls throughout the May-October typhoon season. The synergistic effects of fragile geological conditions and heavy rainstorms can cause soil erosion, landslides, debris floods, and forestland losses (Lu *et al.* 2001; Cheng *et al.* 2002). Forestlands cover about 58.5% of the total area of Taiwan (Taiwan Forestry Bureau (TFB) 1995). Given the high annual rate of typhoons and frequent earthquakes, few places in the world encounter the similar environmental extremes and face the tough challenges of forest management as Taiwan. However, these particular conditions also make the region a unique example for studying the interactions among natural disturbances and forest ecosystems.

This review examines the impacts of typhoons and earthquakes on forest ecosystems from different perspectives, including composition changes, nutrient cycling, and forested watershed protection. Considering the unique environmental conditions of Taiwan, we also discuss the synergistic effects of typhoons and earthquakes, in addition to the implications of forest management and restoration after those natural disturbance events. Moreover, we provide insights to highlight the development of management techniques and future needs.

OWNERSHIPS AND STEWARDSHIPS OF FOREST RESOURCES

It is essential to understand Taiwan's forest types with the ownerships and stewardships of its resources before discussing how the natural disturbances affect forest ecosystems. The scenic landscapes of Taiwan have earned the reputation of being '*llha Formosa*', meaning 'beautiful island'. The forests have been a nursery for diverse flora and fauna in Taiwan for long time. Currently, forestland occupied 2,102,400 ha, which is relatively 58.3% of the overall island area (TFB 1995). Both topographic complexities of Taiwan's terrains and climatic variability contribute to form a relative warm and humid environment, as well as give rise to species diversity. In general, forests in Taiwan consist of hardwood, conifer, mixed conifer and bamboo forest types (**Table 1**). Total forest growing stock volume is 358,209,000 m^3, of which 125,835,000 m^3 is contributed by conifers, 13,973,000 m^3 by hardwood forests, and 99,401,000 m^3 by mixed forests (TFB 1997). The average forest volume per hectare is 287 m^3 for conifers, 119 m^3 for hardwoods, and 254 m^3 for mixed forests (**Table 1**). Based on various climatic and environmental conditions, diversity retained in the tree species. More than 3,800 species of vascular plants species from tropical to temperate regions can be found in Taiwan's forest, such as Formosa michelia (*Michelia compressa*), camphor tree (*Cinnamomum micranthum*), Formosan ash (*Fraxinus formosana*), Formosan red cypress (*Chamaecyparis formosensis*), Taiwan cypress (*Chamaecyparis obtus*a) and Taiwan hemlock (*Tsuga chinensis*) (Eu 1986; TFB 2009).

Table 1 Forest resources of Taiwan (TFB 1995 1997).

Forest type	Area (ha)	Percent of forest land	Growing stock volume (100 m^3)	Average forest stock volume per ha
Hardwood	1,120,400	53.29	125,835	287
Conifer	438,500	20.86	132,973	119
Mixed forest	391,200	18.61	99,401	254
Bamboo	152,300	7.24		
Total	2,102,400	100	358,209	

The stewardships of forest land and its natural resources, as in many countries of the world, involve numerous agencies (**Table 2**). Among the forestland in Taiwan, approximately 77% is classified as national forests. The Council of Agriculture (COA) holds the ownerships for overall natural resources. However, the TFB actually takes charge of managing those lands, which contain more than 35 natural protected areas and nature preserves, totaling around 1,643,000 ha (TFB 2009). Besides the national forest areas supervised by TFB, national parks comprise nearly 10% of Taiwan's land, and are almost forested mountain areas. National parks (i.e. Kenting, Sheipa, Taroko, Yangmngshan and Yushan) are managed by the Park Service, Ministry of Interior, to achieve the following goals: 1) to enhance environmental, ecological and cultural sustainability; 2) to promote scientific researches and environmental educations; 3) to provide quality recreational opportunities (Lu *et al.* 2001; National Parks of Taiwan 2009). The ownerships and management responsibilities of the remaining forest lands falls on diverse organizations and institutes (**Table 2**), including the Forest Development Agency, Taiwan Forest Research Institute, Taiwan Power Company even universities (TFB 1996; Lu *et al.* 2001). Privately owned forestlands occupy roughly 9% of the total forest area and are usually located in the low elevation regions (Lu *et al.* 2001).

LANDSLIDES AND VEGETATION DYNAMICS

A catastrophic earthquake results from a sudden release of energy in the Earth's crust that creates seismic waves. The main effects include shaking and ground rupture, princepally resulting in the alterations of landscapes, more or less

Table 2 The key managers and their responsibilities of forests at their respective levels of Taiwan (Modified from Lu *et al.* 2001).

Agencies	Responsibility
National Government Level	
The Council of Agriculture	Owner of Taiwan's forest land and resources; financial and technical support; promotional and advisory role
Park Service, Ministry of Interior	Conservation and protection of forest ecosystems within National Parks
Provincial Government Level	
Taiwan Forestry Bureau (TFB)	The developer and executive of forest management policies; upland forest management
Taiwan Forestry Research Institute (TFRI)	Forestry and watershed management research
Reservoir Administration Offices	Forests and forestry watershed management within their respective reservoir catchment areas
Taiwan Power Company	Forests and watershed management within their own areas
The Soil and Water Conservation Bureau	Slope stabilization and land conservation
Water Conservancy Bureau	Channel protection and improvement works
Universities	Forestry research and environmental education

Table 3 Comparisons for the Areas (ha) (relative percentage, %) of Normalized Difference Vegetation Index (NDVI) classes at Lienhuachi Experimental Forest, Fushan experimental forest, Mt. Jiujiufong areas among prior- and post- natural disasters.

Natural disaster	Reference	Date	Study site	Mean NDVI
Typhoon Herb	Lee *et al.* 2008	06/30/1996 (Before)	Lienhuachi Experimental Forest, Nantou, Taiwan	0.89
		08/18/1996 (After)		0.82
Chi-Chi Earthquake	Chen *et al.* 2005	06/24/1999 (Before)	Mt. Jiujuifong areas, Nantou, Taiwan	0.61
		09/27/1999 (After)		0.37
Typhoon Bilis	Kang *et al.* 2005	08/10/2000 (Before)	Fushan Experimental Forest, Ilan, Taiwan	88% cells with value 0.58 ~ 0.67
		09/05/2000 (After)		79% cells with value 0.56 ~ 0.63
		07/01/2001 (After)		90% cells with value 0.58 ~ 0.67
Typhoon Toraji	Chen *et al.* 2005	07/25/2001 (Before)	Mt. Jiujuifong areas, Nantou, Taiwan	0.54
		06/20/2002 (After)		0.45
Typhoon Mindulle	Chen *et al.* 2005	07/10/2003 (Before)	Mt. Jiujuifong areas, Nantou, Taiwan	0.47
		07/12/2004 (After)		0.40

severe damage on human infrastructures and even the initiations for all types of landslides (Jibson 1996; Lin *et al.* 2005). The impacts of earthquake on forests usually associate with the direct losses of forestry lands and vegetation cover caused by landslides or ground rapture. The combined effects of steep slope, weak geological formations, typhoons with heavy rain and earthquakes (Chen 2005; Lin *et al.* 2006) can trigger landslides in Taiwan more often. The 921 Chi-Chi Earthquake that occurred on September 21, 1999, caused massive landslides in central Taiwan. According to airborne sensing data and field surveys conducted by Taiwan's Soil and Water Conservation Bureau in 2000, the Chi-Chi earthquake resulted in approximately a total area of 15,980 ha of landslides (Lin *et al.* 2005). Most landslides occurred at the areas adjacent to steep slopes that prone to collapse. Lin *et al.* (2001) and Wang *et al.* (2000) also indicated that the Chi-Chi Earthquake brought several larger-scale landslides such as the slope-land within the Da-Chia River basin, Tasoling, the mountain areas in Chiai county, as well as Chiufenershan and the Jiujiufong Mountain area in Nantou county. The landslide at the Jiujiufong area was especially serious, which caused a total area of 1,025 ha landslides within several forest compartments (Huang 2002; Chen 2005).

In order to better understand the relationships among vegetation change and multiple natural disturbances (i.e. Chi-Chi earthquake, Typhoon Toraji, Typhoon Mindulle), Chen (2005) introduced the Normalized Difference Vegetation Index (NDVI) to detection the vegetation changes for overall Jiujiufong Mountain area and Jiujiufong Nature Reserve. NDVI is one of the most popular methods for vegetation monitoring (Teillet *et al.* 1997). Higher NDVI indicates a greater level of photosynthetic activity (Sellers 1985). Chen (2005) used seven SPOT images through 1999 to 2004 for the area containing the 8th to 20th forest compartments of the Puli Forestry District. The results indicated that the vegetation flourished with the NDVI value of 0.61 prior to the earthquake, the value reduced to 0.37 immediately after the earthquake because of severe landslides. Under stable weather conditions, the vegetation recovered gradually for nearly two years and the NDVI value increased to 0.54 prior to Typhoon Toraji. For the three-year period between Typhoon Toraji of July 2001 and Typhoon Mindulle of July 2004, the NDVI values fluctuated widely with weather conditions at the mean value of 0.45, as a result of land erosion from rainfalls (**Table 3**). Lin *et al.* (2005) also incorporated with multi-temporal satellite images and GIS models to assess the vegetation recovery rate (VRR) for similar areas. They found that the VRR can reach 58.93% in certain landslide areas over 2 years, and one of the most important environmental factors to control the recovery rate may be soil moisture. However, the landside of Chi-Chi earthquake, which mainly occurred within the Jiujiufong Nature Reserve, is the major factor leading to forest degradation and land loss. The species composition of plant communities also changed. The pioneer species became dominant after Chi-Chi Earthquake (Chen 2005). Although the forest vegetation cover did recovered slightly after the earthquake, the soil was still not stable enough to resist the erosion due to heavy rainfall that associated with the typhoons afterward.

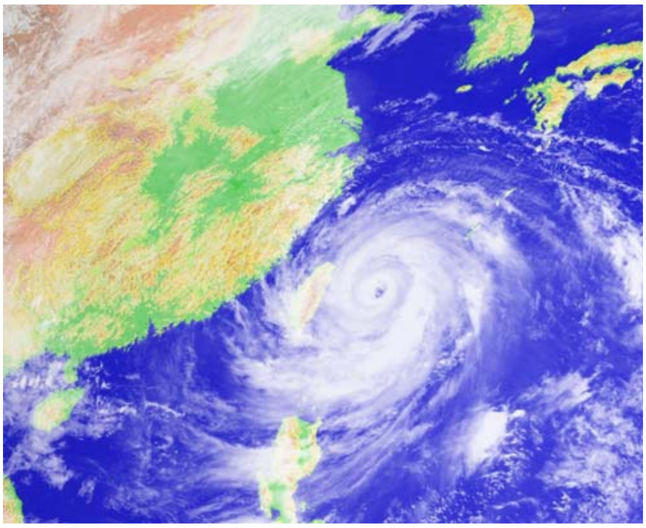

Fig. 2 Image of Typhoon Herb approaching Taiwan on July 31, 1996. Typhoon Herb was one of the most intense typhoons to strike Taiwan in the second half of the 20th century. The strong wind and heavy rainfall associated with it caused widespread flooding and major damage on the subtropical forests in northern Taiwan. Image source: The Digital Typhoon project: http://www.digital-typhoon.org

Lin *et al.* (2006) incorporated landscape metrics analysis, remote sensing data, multivariate statistical analysis and spatial autocorrelation to assess the complex effects of the Chi-Chi Earthquake and afterward typhoons on landscape patterns in the central Taiwan. Their study indicated that all patches, including forested lands, were not only moderately fragmented with patches of other land cover types, but also isolated from patches of their own groups across the whole landscape after Chi-Chi earthquake. After Typhoon Xangsane, forest patches exhibited slightly changed fragmentation, shape, and isolation, but showed the different patterns of interspersion with what occurred after the Chi-Chi earthquake. After Typhoon Toraji, forest patches exhibited a narrower range of patch sizes, and were less convoluted, but more fragmented. The results also suggested that the earthquake does strongly influence the level of fragmentation, isolation, size, and shape complexity of overall patches at the landscape level. After the earthquake, typhoons with different paths and magnitudes variously affected the landscape patterns and the variations, but Typhoon Toraji may have brought more impacts on them than Typhoon Xangsane.

Furthermore, Kang *et al.* (2005) detected the changes of NDVI to assess the vegetation dynamics due to typhoon disturbances at the Fushan Experimental Forest. Following Typhoon Billis, the NDVI decreased 4.8%, but subsequently increased back to similar levels prior to typhoon by July 2001 (**Table 3**). There was a positive correlation between the rates of NDVI decrease caused by typhoon Bilis and the post-typhoon recovery rate of vegetation. The NDVI tended to be higher at high elevations and east-facing slopes than at lower elevations and slopes of other aspects. Lee *et al.* (2008) also found that the greatest NDVI losses caused by Typhoon Herb took place at higher elevations and on west-facing (i.e. windward) slopes near Lienhuachi Experimental Forest (**Fig. 2**). In other words, locally the spatial pattern of NDVI change in relation to typhoon disturbance may be largely influenced by the topography and its interaction with typhoons (Boose *et al.* 1994; Bellingham and Tanner 2000; Lee *et al.* 2008).

In addition, both elevation and directional variability of NDVI decreased after typhoon Herb at LHCEF, suggesting that the typhoon had a homogenizing effect on vegetation cover. The mean NDVI decrease associated with typhoon Herb was from 0.89 to 0.82 (**Table 3**). Unlike other studies in North and Central America as well as northeastern Taiwan that found greater typhoon/hurricane damages in even-aged conifer stands than in native hardwood forests, NDVI decrease associated with Typhoon Herb was greater in the natural hardwood forest (0.08) than the conifer plantation (0.06) at LHCEF. The results infer natural hardwood forests are not necessarily less vulnerable to typhoon disturbances.

FOREST STRUCTURE DAMAGE AND THE LIGHT ENVIRONMENT

Frequent typhoon disturbances have had major impacts to forest ecosystems in Taiwan. The direct impact of typhoons on forest ecosystems usually associate with high winds (Kang *et al.* 2005). The effects are not limited to physical damage of forest structure including uprooting of trees to form forest gaps, as well as increasing litter fall and change the understory light regimes (Lin 1997; Chang 2001; Kang *et al.* 2005; Lin *et al.* 2010). Particularly high winds, which combine with salt stress, making forests largely defoliated (Xu *et al.* 2004; Lin *et al.* 2010). Trees can be blown down or branched snapped off by strong winds, even the events lasting only couples of seconds (Xi *et al.* 2008a; Bettinger *et al.* 2009). When the maximum resistive bending moment for the tree stem or roots surpasses by the applied bending moment, the tree breakage or even windthrows will occur (Mayer 1987). Generally, the structure and dynamics of both temperate and tropical forests are affected by tree death and canopy gap formation (Runkle 1982; Canham and Loucks 1984; Sousa 1984; White *et al.* 1985; Mabry *et al.* 1998; Xi *et al.* 2008a). Both shape tolerant and pioneer species require a gap for successful regeneration (Hartshorn 1980; Denslow 1985; King *et al.* 2000; Lin *et al.* 2003). Gaps are also considered as an important factor to maintain the species diversity (Orians 1982; Denslow 1985; Kang *et al.* 2005; Xi *et al.* 2008b).

One of the potentially important impacts produced by typhoons on the forest structure is the increase of availability to the understory light floor as a result of gap formation and defoliation. In general, light levels beneath undisturbed forest canopies are typically low. Additional sunlight penetrating the canopy may increase the growth and survival rate substantially for both of shade-tolerant and shade-intolerant tree seedlings, which can benefit the long-term dynamics of forest succession (Chazdon and Fetcher 1984; Canham 1989; Whitmore 1989; Yamamoto and Tsutsumi 1985; Oliver and Larson 1996; Kang *et al.* 2005). King *et al.* (2000) investigated the typhoons' impacts on Fushan forest ecosystem by examining the leaf area index (LAI). LAI can be used as an indicator for photosynthesis conducting forest canopy and provides a more general estimate of primary productivity of a given forest ecosystem (Waring and Schlesinger 1985). Defoliation or loss of canopy leaves and formation of gaps through knockdown of trees were direct damages to the forests at this study site. Canopy LAI decreased sharply and immediately following with typhoon hits. For example, King *et al.* (2000) found out that the LAI was 4.47 prior to typhoon season in 1994 and dropped dramatically to 1.47 after the forest was struck by 6 typhoons within the same year (Lin *et al.* 1999). Although the LAI bounced back to nearly 2.3 in the following spring, it was still 40% less than the previous year at the same season. The change of the LAI in response to typhoon was just one effect of the typhoon on ecosystem. Boles of trees are often snapped and trees uprooted in areas where strong winds were experienced. Hurricane Hugo caused 9% of trees to be uprooted and 11% of tree boles snapped when the storm struck Puerto Rico in 1989 (Walker 1991). However, Fushan forest responded to the typhoon impacts on stand density differently from hurricane impacted tropical forest. The stand density of the Fushan forest decreased only 4.2% after the series of typhoon in 1994 (Mabry *et al.* 1998) as compared to 39% wreaked by the 1989 Hurricane Hugo to the Luquillo forest (Fu *et al.* 1996). This suggested that response of stand density to storms varied with intensity, frequency and pattern of storms, local physical environments plus tree species composition of forests.

The germination of seeds below the forest floor, in addition to the growth and survival of understory vegetation have been suppressed as canopy tree shading took place. Through alteration of understory, light regimes by changing the LAI and creation of snapping trees and can affect structure, composition, regeneration and functions of the forest ecosystem. Light may be an ultimately limiting factor for the growth of seeding and sapling for many forests, which lack the frequent visits of typhoons. However, light may not be a major limitation for a frequent disturbance ecosystem such Fushan forest (King *et al.* 2000; Lin *et al.* 2003). The regular defoliation caused by the reoccurring typhoons and low stature of the forest (mean canopy height of 10.6 m), results in 9-30% higher light levels beneath the opened canopy than those found in most tropical and temperate forests (Lin *et al.* 2003).

Litterfall and nutrient inputs

Decomposition of plant litter refers to the physical and chemical processes involved in reducing litter to simpler chemical constituents (Van Vuuren *et al.* 1993; Aerts and De Caluwe 1997; Lin *et al.* 2003; Xu *et al.* 2004). Such litterfall plays a critical role in the nutrient cycling of most forest ecosystems with its rates of litterfall and subsequent decomposition affecting nutrient availability to vegetation (Santa Regina and Gallardo 1989; Santa Regina and Tarazona 2001). The environmental conditions, the chemical composition of the litter and the distribution of soil organisms are important factors that control litter decomposition rates (Lin *et al.* 2003; Xu *et al.* 2004). Typhoon may bring numerous amounts of litterfall, which consist mainly leaves, twigs, branches, broken boles, even entire trees. Such massive input of fresh organic debris alters the nutrient status of the forest as compared to normal major annual falling of senescent plant parts of the ecosystem. For example, typhoon disturbance strongly affected annual fine litterfall and related nutrient inputs in the subtropical forest on Okinawa Island, contributing an average of 30% of the annual litterfall mass, from 30% to 39% (for different nutrient elements) of annual total nutrient inputs. The results also indicated that typhoon-driven maintenance of rapid cycling of P and N and their high availability in soil appears to be an important mechanism to maintain productivity for this subtropical forest ecosystem (Xu *et al.* 2004). In the Taiwan Fushan forest, the input of organic debris of non-typhoon ranges from 3.8 tons per ha to 5.6 tons per ha, while 12.0 tons per ha of litterfall was accumulated by six typhoons in 1994 (Horng *et al.* 1995; Lin 1997; King *et al.* 2000).

Compared with litterfall derived from old plant parts, litterfall generated by typhoon disturbances is not only greater in amount but also richer in concentrations of certain nutrient, particularly mobile elements such as N, P, K. Greater amount and higher level of fresh organic debris caused by typhoons to forest floor affected budgeting and the efficiency of nutrient cycling, which in turns determined the productivity of forests. It was found that the annual input of nutrient to forest floor was 84 to 54% higher in 1994 than of the previous non-typhoon year of 1993 in the Fushan forest (Lin 1997). According to Lin's estimation, the amounts of litterfall N input to forest floor was 177 kg/ha in 1994 (i.e. six typhoons/year), while the amount appeared much lower as 85 kg/ha in 1993 (non-typhoon year), respectively. For P, it was 9.8 and 4.9 kg/ha, for K, it was 32 and 16 kg/ha, respectively.

Similarly, Lin *et al.* (2003) found that litterfall was significantly higher in years with strong typhoons than in years without typhoons, and the number of strong typhoons explained 82% of inter-annual variation in litterfall statistically. Nutrient-use efficiency (dry mass/nutrients in litterfall) was high for N, but low for P compared with other tropical forests. Lin *et al.* thought that the results may be associated with the initial condition of nutrient availability, which indicated the study forest is P limited but not N limited. Nutrient loss via litterfall represents a large percentage of above ground biomass, especially during years with strong typhoons (e.g., 19–41%, 15–40%, 5–12%, for N, P, and K, respectively). Furthermore, Lin *et al.* (2003) pointed out that forests under infrequent wind disturbance (e.g., temperate or boreal forests) can gradually regain any lost nutrients prior to the next disturbance. However, this differs from the situation observed in Fushan Experimental Forest. The pattern of not responding to typhoons with a flush of new growth appears to be an adaptation to frequency with which there are multiple typhoons affecting the forest in a single year. Nutrient loss in litterfall caused by frequent typhoon disturbances appears to limit tree growth and contributes to the very low canopy height of the Fushan Experimental Forest.

Impacts on wildlife

Some interesting phenomena of wildlife communities, which were related to natural disturbance events, have been observed and investigated. The 1994 typhoons dramatically defoliated the forests in Fu-shan area. Abnormally abundant population of caterpillars (e.g. *A. helicona*) was found to occur in the following spring. Some research assumed that new growth of leaves was more palatable and preferred by foliage-feeding caterpillars under fair weather conditions. Additionally, many caterpillars were killed by groups during the 1994 typhoon. However, no specific statistics was recorded (King *et al.* 2000).

Distribution and assemblage of bird population is usually influenced by the vegetation physiognomy and composition of plant species communities (Rotenberry 1985; Bersier and Meyer 1994). Forest structure can be defined by the complexities of vertical vegetation layers as well as horizontal patch distributions. The more complicated the landscape structure, the higher the bird species biodiversity (MacArthur and MacArthur 1961; Karr and Roth 1971; Wilson 1974). Natural disasters such as earthquakes and typhoons are important functions to alter forest structure. In other words, it also affects bird population. For example, a study of a dominant bird species, the forest-gray-checked fulvetta (*Alcippe morrisonia*) in the Fushan forest revealed that population of juveniles decreased significantly but its adult population was not affected (Chou 2000). Lin *et al.* (2003) investigated the relationship among number of birds, species diversity and vegetation recovery after earthquakes and found that the number of birds and community composition would keep stable relatively at the undamaged forestry habitats compared with landslide sites.

Torrential rainfall associated with typhoon rapidly increase stream level. Different Species of fresh water fish decreased dramatically but restored about two weeks after storms when streams remained wild and was not disturbed by humans. Another interesting finding was a troop of Formosan macaques (*Macaca cyclopis*), which inhabited the forests and lived mainly on leaves of hardwood forest, disappeared from the forest after 6 typhoons struck in 1994, and then returned after one year (King *et al.* 2000).

IMPLICATIONS OF FOREST MANAGEMENT AND RESTORATION

Post-disaster implications can usually be executed more efficiently if government organizations can established more guidance or regulations that associate with responding emergencies due to natural disasters (Lu *et al.* 2001; Bettinger *et al.* 2009). For example, the Maryland Board of Public works carried out several acts after the strike of Hurricane Isabel in 2003, which included determining the authority for repair and replacement of damaged structures. According to the statistic reports of Taiwan's COA, the government invested USD $ 3.97 billion within 3 years (i.e. from 2002 to 2004) to mitigate the damage caused by typhoons and to conduct new infrastructure for preventing future disasters (Yu and Chen 2009). About 77% of forestlands in Taiwan are owned by COA but managed by TFB. In other words, TFB plays the key role in defining strategies of property recovery and forest restoration after natural disasters. Taiwan's national forests are usually located in high elevation areas, which include the upstream of water catchment areas. Considering the mountainous topography and fragile geological conditions, TFB suggested that the slope stabilization should be the primary strategy for post-disaster mitigation (TFB 2009). It proposed the slope land restoration, re-planting plan towards high mountain forests and the windbreak forest reforestation in the coastal areas.

In order to restore the equilibrium of forest succession, TFB (2009) conducted a strategic framework of forest management: "*Implementing new policy of reforestation, regenerating natural green surroundings*". Under this framework, TFB carried out the operation on stand towards the mountain area that emphasizes regenerating and establishing forest resources in nature. Similarly, Huang (2001) suggested policies of forest ecosystem management should take in the concepts of adaptive management toward the diverse forest types. The silvicultural objective should focus on restoring the forests naturally, such as reducing human tending in the restoring stands or replant the forests with the native plant species (Huang 1999). Moreover, the policy of forest landscape restoration also promotes from both perspectives of industry economics and ecology landscapes.

Through the basic framework, TFB have achieved several objectives of national forest management and post-disaster restorations. However, soil liquidation, landslides and debris flows due to the impacts of frequent typhoons, heavy precipitation or earthquakes often occur at upstream forestry lands and sometimes cause tremendous losses of forest resources and human properties. In order to enhance post-disaster forest restoration, in addition to protecting forests from future natural hazards, TFB setted up basic principles of restoration implications. When replanting productive forests, operation and development plans should be set up and performed by following succession rules of forest ecosystems. Instead of only containing a single vertical layer of trees, replanting stands should have the structural varieties for retaining the species diversity.

According to different altitude of forests, TFB promotes the development and regeneration of natural forests at mountain areas above 1,500 m. On the other hand, management of low and medium elevation forests would focus on their growth of timber quality and forest resource enrichments by stand tending. TFB also facilitated the grading and zoning system on forestry lands to reinforce suitable management and restoration practices toward different types of land and forest resources (Huang 2000; TFB 2009). For instance, designated forest management regions at lower elevations (i.e. below 1500 m) may focus on enhancing the fixation of green house gas (i.e. CO_2) by constant stand tending. At potential high risk areas (e.g. 150 m buffer zone along with streams, reservoir water-catchment areas), TFB provides a redemption plan to retrieve leased forest land for reinforcing management practices.

Furthermore, TFB also granted rewards to the private forestland owners, who incorporated their restoration strategies with TFB's guidelines (Huang 2000). At coastal areas, replanting of wind breaking forests not only provides protection against future typhoon's strikes, but also regenerates green environments along the seashores. Planting new trees can retain soil by roots to reduce soil losses. The bamboo forests usually collapse easily and may lead to landslides after typhoons due to the shallow rooting. Planting woody plants in bamboo forests can improve the soil stability, especially at steep slopes, selective cutting operations would be used to advancing regeneration and improve productivity for current bamboo forests.

Land scarcity and favorable economic conditions for development have resulted in difficulties for managing forest resources within upstream watersheds. However, the upstream watersheds represent the important catchment areas and sources of public drinking water (Lu *et al.* 2001; Cheng *et al.* 2002). The headwater areas where river and streams originate are usually steep, fragile geologically and subject to heavy rainfall, which may prone to erosion and landslides. To maintain and protect forests at water-catchment areas, soil erosion control studies and regular monitoring measures should be conducted (Lu *et al.* 2001). TFB continues to enhance protection regulations as well as restoration of national forests within water-catchment areas. The practices are based on the comprehensive managing concept for water-catchment areas, such as the flexible priority rules on the implementations toward various cases as well as introducing the framework of bioengineering alternatives for watershed management (Lu *et al.* 2001; TFB 2009).

Additionally, concepts of ecological environment protection should be taken when deriving the restoration implementations. Sustainability of forest resources and human well-being should be concerned equally, not only from an aspect of ecological conservation but also at a context of forest restoration after natural hazards. For example, bioengineering construction can provide more effective and eco-friendly alternatives for stabilizing slopes and channels (Huang 2000; Lu *et al.* 2001). Moreover, Huang (1999) suggested that forest restoration within natural reserve areas should avoid human disturbances. Human disturbances may alter the natural cycle of forest succession. In other words, natural resilience would be the best alternative from the view of conservation purposes. Overall, effective implications of post-disasters forest management and restoration should not only consider of public well fare but also promote sustainability of forest ecosystems (Yang and Lin 2002).

FUTURE DIRECTIONS AND NEEDS

The goal of post-disaster forests and watershed management in Taiwan is to meet diverse needs of people in addition to restoring forests naturally. Achievement of this goal may face several challenges. More accurate prediction of natural disasters will be needed. Accurate prediction will significantly optimize the decision making process for both prior-event preventions and post-event recoveries (Wu and Kuo 1999; Tsai and Liao 2005; Xi and Peet 2008). For example, improved understanding of circulation dynamics for typhoons and their interactions with Taiwan terrain will provide useful information for determining the potential impact level due to particular categories of typhoons (Wu and Kuo 1999). Implementations of advance remote sensing techniques (e.g. Airborne LIDAR) and GIS database can provide the useful methods to as assess spatial information from distant damaged forests. It can save time, expenses and human efforts.

Because several agencies hold the stewardships of forestlands in Taiwan, complications may occur while operating management practices. For example, a protection forest policy exists, but cannot be implemented in isolation from policies governing use and management of all watershed lands (Lu *et al.* 2001). As the role of TFB in watershed management is still not well defined, even though it is responsible for managing the majority of forest watersheds on the island. In order to achieve the objectives of forest management and policies, either some sort of coordinating third-party organization should be formed or a clear cooperation guideline should be legislated, permitting a particular agency with the responsibility. The decision and its implementation should be made at the higher levels of government, but with active public participation. An evaluation tool should be applied to monitor and assess the outcomes for operations of forest restoration after disasters.

The ultimate goal of management and restoration on forestry land is to achieve equilibrium between development of economics and existence of forest ecosystem. In order to sustain forest resources and environments, future challenges must seek optimized ways for post-disaster forest management and restoration.

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