Taiwania, 57(3): 242-250, 2012

Forest Distribution on Small Isolated Hills and Implications on Woody Plant Distribution under Threats of Global Warming

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(Manuscript received 30 January 2012; accepted 25 April 2012)

ABSTRACT: Treelines have been found to be lower in small isolated hilltops, but the specific dynamics behind this unique phenomenon are unknown. This study investigates the distribution patterns of woody plants in Yangmingshan National Park (YMSNP), Northern Taiwan in search of the limitation mechanisms unique to small isolated hills, and to evaluate potential threats under global warming. Forests distributed between 200 to 900 m above sea level (ASL). Remnant forest fragments between 400 and 900 m ASL, have the highest species richness, and should be protected to ensure future forest recovery from the former extensive artificial disturbance. The lower boundary is threatened by urban and agricultural development. The lack of native woody species in these low elevation zones may cause a gap susceptible to invasive species. A consistent forest line at 100 m below mountain tops regardless of elevation suggests a topography-induced instead of an elevation-related limiting mechanism. Therefore, upward-shift of forests, caused by global warming, might be limited at 100 m below hilltops in small isolated hills because of topography-related factors. The spatial range of woody plants along the altitudinal gradient, thus, is likely to become narrower under the combined pressures of global warming, limited elevation, exposure-related stress, and artificial disturbance. Management priorities for forest recovery are suggested to include preservation of remnant forest fragments, increasing forest connectivity, and increasing seedling establishment in the grasslands.

KEY WORDS: Altitudinal gradient, forest line, global warming, species richness, Yangmingshan National Park.

INTRODUCTION

Global warming is a worldwide event that affects a wide range of species and ecosystems (Pounds et al., 1999; Germino et al., 2002; Walther et al., 2002; Hamann and Wang, 2006; Colwell et al., 2008; Harris et al., 2008; Botkin et al., 2007). Recent investigations show growing interests on the relationship of global warming and plant species response (Saxe et al., 2001; Laaidi et al., 2006; Song et al., 2010). The rising global temperatures in recent decades have prompted woody plant species to shift their distribution toward higher elevations or northern direction (Pounds et al., 1999; Colwell et al., 2008; Crimmins et al., 2011; Lenoir et al., 2011).

The poleward or upward shifting of species are particularly significant at the border of forests in high latitudes or high elevations (Harsch et al., 2009). Low soil temperature is usually the limiting factor that restricts tree growth at treelines (Korner, 1998; Korner and Hoch, 2006). However, forest boundaries are found not only in high latitudes or high mountain areas, but also in small isolated hills. A unique example is Northeastern Asia, where the forest limits are found around 1,000 m above sea level (ASL) at some small isolated hilltops (Wang, 2003; Kubota et al., 2004) as opposed to > 3,000 m ASL in non-isolated areas (Korner, 1998; Grace et al., 2002; Korner and Paulsen, 2004). This indicates unique mechanisms limiting tree establishment in isolated hilltops. However, such limiting factors unique to isolated hilltops and the threats of global warming in these areas are not documented in the scientific literature.

Forest ecosystems, especially lowland forests, face not only global warming but also artificial disturbances. Severe artificial disturbances directly remove original plant species, increasing the extinction risk of native plant species and threatening species richness (Brooks et al., 2002). Although some lowland areas were brought under protection through the establishment of preserve areas, and forest recoveries have progressed through the dispersal of plants from neighboring areas (Soons and Ozinga, 2005), global warming increases the uncertainty of plant species recruitment (Germino et al., 2002; Castro et al., 2004) and strongly influence the recovery of forests.

The Yangmingshan area is in the northern part of Taipei city, northern Taiwan. The natural vegetation were largely destroyed by crop cultivation, logging and urban colonization with the development of Taipei city (Wang, 2003). The establishment of Yangmingshan National Park (YMSNP) in 1985 provided chances for forests recovery, in which originally cultivated land or forest recreation areas were re-colonized by native plant species (Huang et al., 1988; Chen and Kuo, 1989; Wang, 2003). However, forest recovery through the establishment of native plant species may face threats from global warming. The rising temperature shifts the spatial core of plant distribution ranges to higher altitudes (Lenoir et al., 2011), but in YMSNP, where elevation is mostly below 1,000 m ASL, the chances for woody plants to distribute upward is highly limited. Although the vegetations have been widely investigated in this area (Chen and Kuo, 1989; Wang, 2003; Yang, 2007), a comprehensive study of species diversity and distribution along the altitudinal gradient is lacking. Scientific studies to evaluate the threats of global warming to forest ecosystems are therefore urgently needed.

In this study, a large dataset recording the species composition, species richness and spatial pattern of plant species distribution along the altitudinal gradient was collected to analyze the potential dynamics driving treeline in YMSNP. The potential risks under threats of global warming were evaluated, and priorities for management strategies assessed.

MATERIAL AND METHODS

Study site

The YMSNP is located near Taipei city in northern Taiwan (121° 32′ E, 25° 10′ N), and was established to preserve its unique post-volcanic landscape. The area of YMSNP is approximately 11,455 hectares. Elevation within the park ranges from 200 to 1,120 m ASL. Forests are found below 1,000 m ASL, and are dominated by broad-leaved forests. Grasslands are frequently found in areas above 800 m ASL and are dominated by Silvergrass (*Miscanthus* spp.) and dwarf bamboo (*Pseudosasa usawai* (Hayata) Makino & Nemoto).

The YMSNP has been disturbed by social development since 100 years ago, and the lower altitudinal part is fully colonized by villages. Large areas were logged and reforested in the early 20th century. Crop lands, recreation areas, tea gardens, and farmlands were developed in many parts, with native woody plants finding refuge in remnant forest fragments. After the establishment of YMSNP in 1985, most of the areas were freed from the artificial disturbances. Since then, natural forests expanded their ranges through the re-establishment of native plants.

The climate of YMSNP is characterized by its moisture and wind (Chen and Tsai, 1983). Typhoons and northeast monsoons bring heavy rainfall and fog in summer and winter, respectively (Chen and Tsai, 1983). Mean annual precipitation recorded by the weather station near Datunshan averaged 6,799 mm from 2001 to 2009. Mean annual temperature averaged 7.1ºC. Mean monthly temperature was highest in July (31.6 ºC) and lowest in January (-0.9 ºC).

Field investigation and data analysis

Sample plots were placed in three regions in the southern part of YMSNP defined by three major mountain peaks: Huangzueishan (912 m ASL), Chihsingshan (1120 m ASL), and Datunshan (1092 m ASL). The northern parts of YMSNP were not studied because the lower elevations were largely developed with few remnant of natural lands available for investigation, whereas the higher elevations were either too steep for field work, or were restricted military lands.

Woody plants were studied and recorded from May to November, 2008 along fourteen major mountain trails and three main roads crisscrossing the above-mentioned regions (Fig. 1). Sample points were placed every 200 meters along the trails or roads, and the woody plants within a radius of 20 meters around each point were recorded with their species name, location (latitude and longitude) and elevation. Rare or threatened species were recorded whenever they were found on the trails. Because of their scarcity, rare and threatened species located more than 20 m from the trails were also recorded when they were identifiable through telescopes.

Species composition of the three regions and changes in species richness along elevation were evaluated using the relative frequency of woody plants. The distribution ranges of each plant species was estimated from the abundance of each species along the elevation gradient. Only the species with a relative frequency higher than 1.0 were presented in this paper to evaluate the influence of environmental factors on forests recovery.

RESULTS

Species composition

A total of 12,425 woody plant individuals including 183 angiosperm trees and 100 shrubs species were recorded in this field investigation. The Datunshan area, with 216 woody plant species, had slightly higher species richness than the other two areas.

The dominant tree species are *Machilus thunbergii* Sieb. & Zucc., *Prunus phaeosticta* (Hance) Maxim., *Ardisia sieboldii* Miq., *Schefflera octophylla* (Lour.) Harms and *Mallotus japonicus* (Thunb.) Muell.-Arg. (Table 1). Abundant shrub species are *Ilex asprella* (Hook & Arn). Champ., *Hydrangea angustipetala* Hayata, and *Rhododendron oldhamii* Maxim. *H.*

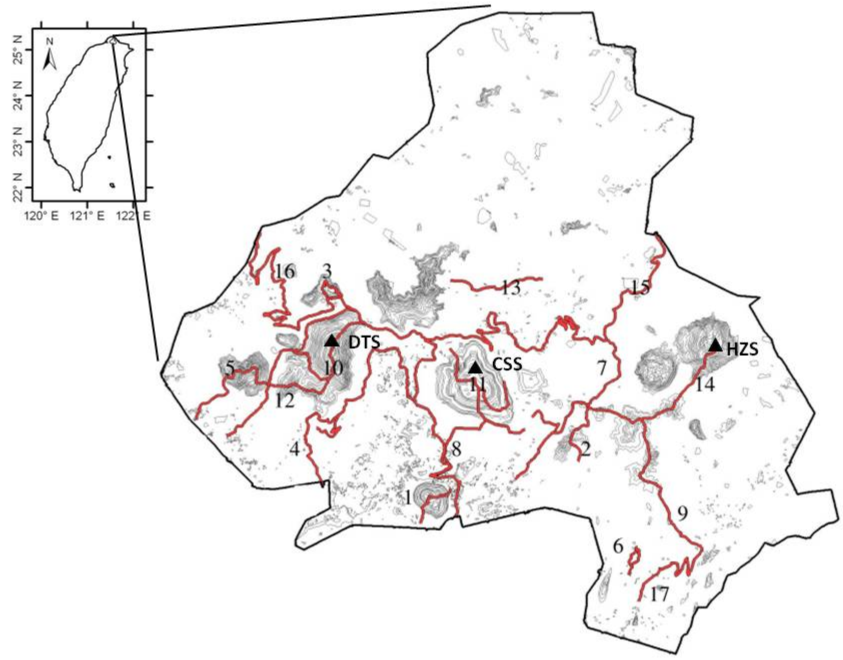

Fig. 1. The 14 major trails and 3 main roads surveyed in this study. The three mountain peaks that define the regions are: Huangzueishan (HZS), Chihsingshan (CSS), and Datunshan (DTS). The three main roads are Yangjing road (15), Balaka road (16), and Wanshi road (17).

angustipetala is common along the roadside, while *R. oldhamii* is characteristically found at the upper boundary of forests at about 1,000 m ASL. These two shrubs are often found at the forest edge. *Cyathea lepifera* (J. Sm.) Copel. is the most abundant tree fern common in YMSNP area and constitute the second canopy layer in the forests.

Five woody plants were considered rare species: *Rhododendron longiperulatum* Hayata, *Rhododendron nakaharae* Hayata, *Rhododendron rubropunctatum* Hayata, *Maackia floribunda* (Miq.) Takeda, and *Bretschneidera sinensis* Hemsl. These plants were all restricted within a narrow distribution range.

Species richness patterns along the altitudinal gradient

The total woody species richness presents bimodal distribution along elevation in YMSNP. The number of woody plant species is higher between 400 and 800 m ASL (Fig. 2). Lower species richness was found at 500 m ASL because of large recreation area in this altitudinal range. The trend of decreasing plant species richness from 700 to 1,100 m ASL suggested increasing stress on the growth of woody plants.

In Chihsingshan, the species richness of woody plants presented a unimodal distribution along the altitudinal gradient, with woody plants distributed between 400 m and 700 m ASL (Fig. 2).

The species richness patterns in Datunshan and Huangzueishan, however, presented a bimodal distribution pattern along the elevation gradient (Fig. 2). A large gap in woody plant distribution was found from 500 to 600 m ASL in both areas. Grasslands were the dominant ecosystem in Huangzueishan, whereas recreation area was designed in Datunshan areas.

Altitudinal distribution of individual woody plant species

Most of the woody plants were distributed below 900 m ASL, suggesting a woody plant upper-limit at 900 m ASL (Fig. 3). Only herbaceous species could be found above 1,000 m ASL. The elevation at which the upper forest boundary occurred, however, varied among the three regions, but was always approximately 100 m below the mountain peak, regardless of its elevation. The dominant members of grasslands above 900 m were Silvergrass and dwarf bamboo.

All of the woody plants in YMSNP were distributed over the whole altitudinal range of YMSNP, except a few species. In Huangzueishan, from 600 to 700 m ASL, there is a wide gap where is covered by grasslands and therefore with few woody species (Fig. 2).

Three species were found to have restricted distribution across all sites. *Eurya crenatifolia* (Yamamoto) Kobuski (EURCRE) grew from 600 to 900 m ASL. The species was usually found in the grassland along the forest edge where strong winds cause perennial stress. *Bretschneidera sinensis* (BRESIN), an endangered

Table 1. Species composition of the three areas in YMSNP represented by relative frequency

Species code	Species	Huangzueishan		Chihsingshan		Datunshan	
		Total individuals	Relative frequency	Total individuals	Relative frequency	Total individuals	Relative frequency
ACACON	*Acacia confusa*	28	0.97	40	0.90	57	1.12
ACEKAW	*Acer kawakamii*	51	1.76	36	0.81	46	0.91
ARDSIE	*Ardisia sieboldii*	72	2.49	83	1.86	116	2.29
AURUSA	*Arundinaria usawai*	1	0.03	50	1.12	24	0.47
BLACOC	*Blastus cochinchinensis*	32	1.11	55	1.23	15	0.30
BRESIN	*Bretschneidera sinensis*	40	1.38	4	0.09		
CALFOR	*Callicarpa formosana* var. *formosana*	40	1.38	71	1.59	101	1.99
CLECYR	*Clerodendrum cyrtophyllum*	40	1.38	44	0.99	9	0.18
CLEJAP	*Cleyera japonica*	20	0.69	53	1.19	69	1.36
CYALEP	*Cyathea lepifera*	76	2.63	128	2.87	148	2.92
CYAPOD	*Cyathea podophylla*	66	2.28	83	1.86	20	0.39
DAPGLA	*Daphniphyllum glaucescens* subsp. *oldhamii*	32	1.11	61	1.37	36	0.71
DENDEN	*Dendropanax dentiger*	24	0.83	52	1.17	53	1.05
DOPMOR	*Diospyros morrisiana*	30	1.04	63	1.41	6	0.12
EURCRE	*Eurya crenatifolia*	55	1.90	37	0.83	46	0.91
EURLOQ	*Eurya loquaiana*	30	1.04	82	1.84	97	1.91
EUSJAP	*Euscaphis japonica*	15	0.52	52	1.17	42	0.83
GLORUB	*Glochidion rubrum*	12	0.41	31	0.69	88	1.74
FICERE	*Ficus erecta* var. *beecheyana*	33	1.14	112	2.51	190	3.75
FICFIS	*Ficus fistulosa*	47	1.62	18	0.40	10	0.20
HYDANG	*Hydrangea angustipetala*	72	2.49	123	2.76	136	2.68
ILEASP	*Ilex asprella*	78	2.70	114	2.55	72	1.42
ITEPAR	*Itea parviflora*	32	1.11	82	1.84	63	1.24
LIQFOR	*Liquidambar formosana*	20	0.69	53	1.19	31	0.61
MACJAP	*Machilus japonica* var. *kusanoi*	24	0.83	19	0.43	64	1.26
MACTHU	*Machilus thunbergii*	115	3.98	193	4.32	296	5.84
MAEJAP	*Maesa japonica*	43	1.49	29	0.65	27	0.53
MAEPER	*Maesa perlaria* var. *formosana*	65	2.25	91	2.04	108	2.13
MALJAP	*Mallotus japonicus*	40	1.38	95	2.13	80	1.58
MALPAN	*Mallotus paniculatus*	24	0.83	46	1.03	22	0.43
MELCAN	*Melastoma candidum*	70	2.42	88	1.97	34	0.67
MORAUS	*Morus australis*	29	1.00	15	0.34	48	0.95
OREPED	*Oreocnide pedunculata*	50	1.73	95	2.13	168	3.31
PREMIC	*Premna microphylla*	9	0.31	16	0.36	66	1.30
PRUCAM	*Prunus campanulata*	1	0.03	56	1.25	88	1.74
PRUPHA	*Prunus phaeosticta*	74	2.56	129	2.89	220	4.34
RHOOLD	*Rhododendron oldhamii*	58	2.00	17	0.38	325	6.41
RHOMAR	*Rhododendron mariesii*	0	0.00	115	2.58	0	0.00
RUBCOR	*Rubus corchorifolius*	74	2.56	120	2.69	44	0.87
RUBSUM	*Rubus sumatranus*	27	0.93	60	1.34	49	0.97
RUBSWI	*Rubus swinhoei*	32	1.11	52	1.17	95	1.87
SAMCHI	*Sambucus chinensis*	12	0.41	32	0.72	57	1.12
SARGLA	*Sarcandra glabra*	43	1.49	15	0.34	10	0.20
SAUTRI	*Saurauia tristyla* var. *oldhamii*	34	1.18	59	1.32	75	1.48
SCHOCT	*Schefflera octophylla*	61	2.11	104	2.33	106	2.09
STYFOR	*Styrax formosanus* var. *formosanus*	14	0.48	73	1.64	39	0.77
TROARA	*Trochodendron aralioides*	7	0.24	53	1.19	63	1.24
TURFOR	*Turpinia formosana*	34	1.18	29	0.65	85	1.68
VIBLUZ	*Viburnum luzonicum*	30	1.04	32	0.72	28	0.55
WENFOR	*Wendlandia formosana*	36	1.24	42	0.94	34	0.67
	Others	941	32.53	1261	28.21	1363	26.89
	Total	2893	100.00	4463	100.00	5069	100.00

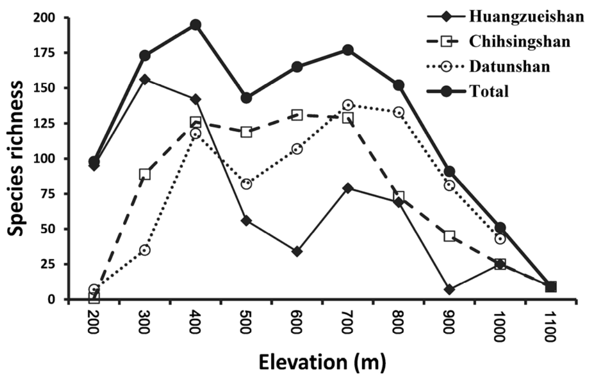

Fig 2. Woody plant species richness along altitudinal gradient in YMSNP

species, was found to be distributed from 390 to 550 m ASL, and is found only in sites exposed to wind and sun on mountain ridges or grasslands. *Rhododendron mariesii* Hemsl. was found to be restricted within altitudinal range from 380 to 450 m, and was restricted on the mountain cliff.

In Huangzueishan, a significant gap in woody plant distribution was found between 600 and 700 m ASL, from which most woody plant species were absent (Fig. 3A). This gap was caused by an interruption by grassland. Only one shrub species, *E. crenatifolia*, was found within the grasslands. This phenomenon is particular in Huangzueishan area. In contrast to the other two areas, woody plant richness were high between 600 to 700 m ASL, and luxuriant forests were found among this altitudinal range.

In the Chihsingshan region, most of the woody plants were distributed higher than 500 m ASL, with few reaching above 1,000 m ASL (Fig. 3B). One species, *Rhododendron mariesii*, was restricted to the lower elevation range. Although this species is generally not rare in Taiwan, it was rarely found in YMSNP, with only a total of 115 individuals recorded.

In Datunshan, the woody species were mostly distributed higher than 500 m ASL (Fig. 3C), because agriculture and urban development have expanded into the lower altitudinal areas of this region. As a result, some species, for example *Premna microphylla* Turcz. and *Trochodendron aralioides* Sieb. & Zucc., were widely distributed across the elevation range in other regions but were found only in the higher elevations in this region.

DISCUSSION

Rising global mean temperatures have caused the spatial core of altitudinal distribution range of plant species to shift upward to higher elevations over the past 100 years (Pounds et al., 1999; Colwell et al., 2008; Crimmins et al., 2011; Lenoir et al., 2011). At the predicted temperature rise of 1.5 to 6.1ºC for the 21st century (IPCC, 2007) and a lapse rate of 0.6ºC per 100 m change in elevation, this may imply a 250 to 1,000 m elevation shift of current vegetation. That the woody plant species were distributed between 200 and 900 m ASL in YMSNP indicates a lower forest boundary at 200 m and an upper forest boundary at 900 m. These two boundaries, however, are the consequences of different causal factors, and thus may face different threats under global warming trends.

In the lower elevations, urban and agricultural developments have tenaciously cleared away natural vegetation. As a result, species richness was low below 300 m ASL, and natural vegetation was absent below 200 m ASL. This may open a large gap for invasive species to move in.

The upper boundaries, on the other hand, are more likely caused by natural environmental factors. In high elevation or high latitudes, the forest boundaries are usually limited by low soil temperature (Korner and Paulsen, 2004). However, our findings show a consistent forest boundary at approximately 100 m below summits or mountain ridges regardless of their altitude suggests that the upper forest boundary in small isolated hills to be limited by similar factors that are related to topography but not elevation, and the mechanisms may be different from the forest lines in high mountains or high latitudes, which are usually located at a similar altitudinal range. Climate monitoring studies have identified wind speed and soil moisture to be the factors significantly different between the forest stands and non-forest ecosystems in YMSNP (Cheng, 2010; Poo and Liao, 2010). These strong winds increase evapotranspiration rates, decrease water contents in the soil, and result in frequent and severe soil drought in dwarf bamboo grasslands (Poo and Liao, 2010). Strong winds and typhoons have been found to limit seedling survival in small hills outside YMSNP (Guo, 2009). It is therefore likely that the combined effects of strong wind and soil drought suppressed seedling growth and establishment (Heiligman and Schneider, 1974; Tamasi et al., 2005), and prevent the expansion of forest.

Whereas rising global mean temperatures have caused the spatial core of altitudinal distribution range of plant species to shift upward to higher elevations in most regions (Pounds et al., 1999; Colwell et al., 2008; Crimmins et al., 2011; Lenoir et al., 2011), the low elevation of small isolated hills in YMSNP provides limited opportunity for upward migration. If the topography-implied limitations suggested by our results are true, this would impose dire consequences for the

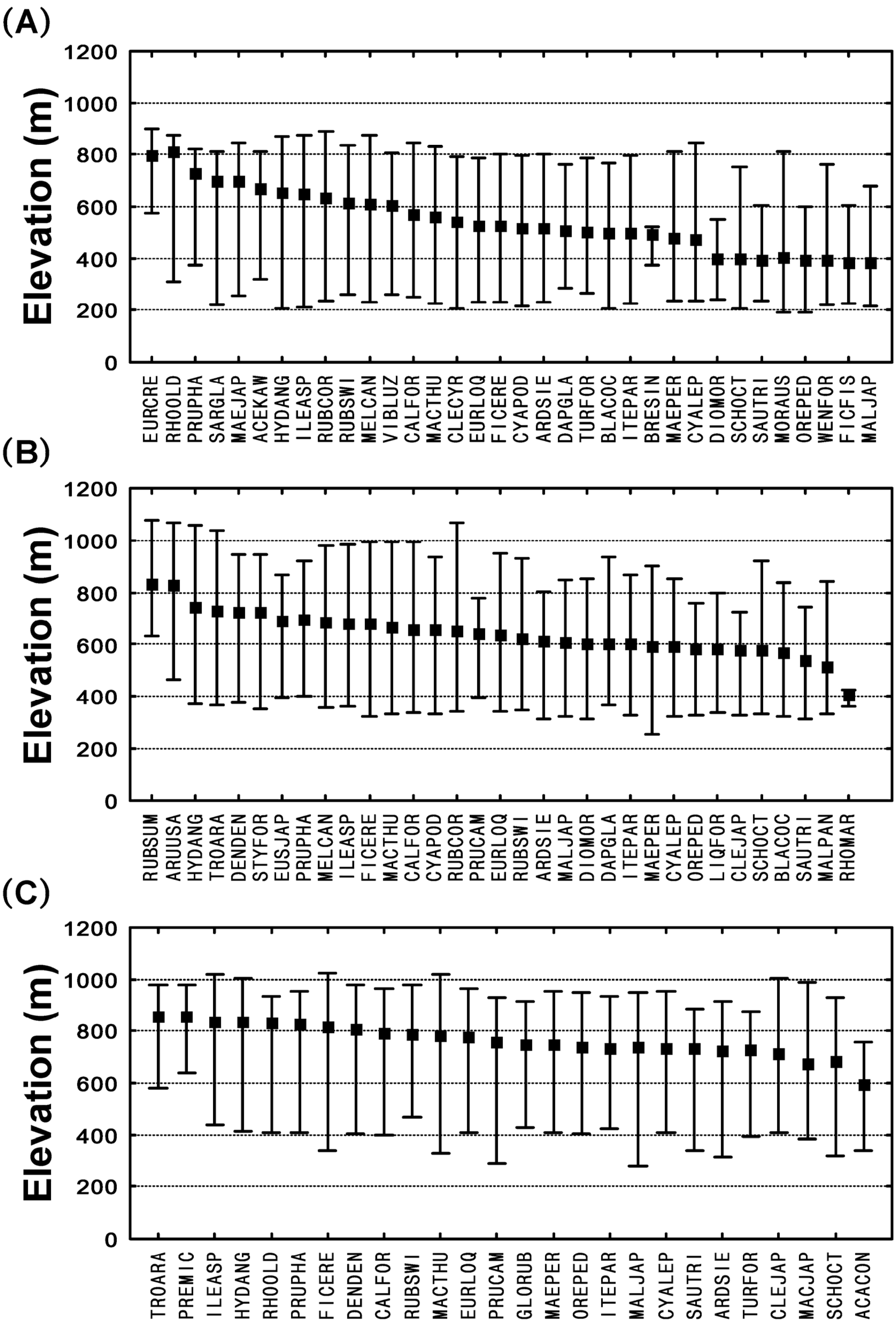

Fig. 3.The spatial patterns of woody plant species represented their highest and lowest elevations in (A) Huangzueishan, (B) Chihsingshan, and (C) Datunshan. The species codes are listed in Table 1.

woody species in YMSNP because the 100 meter wind and drought suppressed zones around the mountain summits will not be suitable for colonization, thus further compacting the area available for woody species distribution.

The grasslands in the middle altitudes of Huangzueishan suggest other potential sources of threat. Artificial disturbance via grazing have been suggested to be the driving force behind the formation of these grasslands (Hsu, 2006). Although grazing pressures have declined in the past few decades, the grasslands have not been recolonized by adjacent forests. The grassland was exposed to constant wind from the northeast monsoon. Wind blow can decrease soil moistures (Heiligmann and Schneider, 1974) and suppress seedling growth (Heiligman and Schneider, 1974; Tamasi et al., 2005). Due to the exposure to wind, tree seedlings on the grassland in Huangzueishan are subject to death and in turn forests are ceased from recovery. The high amounts of visitors may further disturb and decrease woody plant seedling recruitment. Therefore, when faced with temperature rise, the grassland gap in the middle altitudes of Huangzueishan may be persistent, and cause interruption to the upward migration of plant species, endangering the forests above the grasslands.

Rare plant species may be under higher risk of extinction than the abundant plants. The restricted distribution of rare plant species suggests that they have specific environmental demands. Small isolated hills provided low chance for them to migrate to suitable environments under global warming. Investigations on the environmental factors for these rare species were crucial, providing information of management strategies for their preservation.

Artificial perturbation usually creates many habitat fragments where native plant species could be preserved (Hobbs, 1992; Zobel et al., 2011), and these natural habitat fragments largely affect the recovery of local species richness (Cornell and Lawton 1992; Caley and Schluter 1997; Bartha and Ittzes 2001). In YMSNP, the highest species richness was preserved in forest fragments between 400 and 900 m ASL. These fragments have been the source of colonizers in the reforestation of previous croplands, will continue to be the source of colonizers for the species migration movement. Therefore, these species rich fragments should be protected to ensure future colonization of natural forests. Further studies will be needed to understand the survival of these seedlings and the succession or recovery processes of these forests to decrease the threatening of strong wind, soil drought and global warming.

The YMSNP is under protection to provide chances for forest recovery after severe artificial disturbances. The remnant forest fragments preserve the native woody plants and play important roles on the recovery of forests. However, local environmental change on an isolated small hill was determined increase the risk of woody seedlings mortality. Woody seedlings were not able to establish on the upper forests limits and in the grasslands because of stressful environments caused by these exposed areas. Upward of forest expansion were prohibited and spatial distribution ranges of woody plants along elevation were suppressed. Investigations on the forest recovery and management planning to increase the survival rate of woody seedlings are needed under the threatening of global warming. Management priorities for forest recovery are suggested to include preservation of remnant forest fragments, increasing forest connectivity, and increasing seedling establishment in the grasslands.

ACKNOWLEDGEMENT

The authors would like to thank many students of the Department of Life Science, Chinese Culture University who helped collect data in the field work. We are also grateful to Dr. Wak-Kim Poo in the Department of Life Science, Chinese Culture University, for providing valuable comments. This work was funded by the Yangmingshan National Park, Construction and Planning Agency Ministry of the Interior, Executive Yuan, Taipei, Taiwan, Republic of China.

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獨立低山丘陵的森林樹木分布及全球變遷的影響

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(收稿日期: 2012 年 1 月 30 日; 接受日期: 2012 年 4 月 25 日)

摘要：造成獨立低山丘陵形成森林界限的原因並不清楚，對於木本植物在全球變遷壓力下所受到的威脅也沒有相關研究的探討。本研究主要在瞭解獨立低山丘陵的木本植物分布，推測森林界限形成的原因，並評估全球變遷下木本植物所受到的威脅。陽明山國家公園是位在台灣北部獨立的低山丘陵，此地區的森林主要分布在海拔 200 至 900 公尺之間，殘存較大面積的森林介於海拔 400 至 900 公尺之間，需要積極的保護，維持物種多樣性，使得森林能夠由過去的大面積人為干擾之後進行復育，並保證有充分的種源。國家公園低海拔地區由於長久的都市發展及開拓墾殖，木本植物種類多樣性相當低，使得此地區受到外來種入侵的可能性相對增高；較高海拔的部分，山頂或稜綫的下方 100 公尺處常會出現森林界限，可見木本植物的分布受到地形因子的影響，而非海拔。因此，全球溫度上升造成木本植物遷移的過程，在獨立低山丘陵會受到地形效應的影響而非溫度，並且植物往高海拔遷移的過程可能會被限制在稜綫下方約 100 公尺處。因此，低山丘陵的植物分布，在人為干擾、海拔限制、地形效應及全球變遷的多重影響下，海拔分布範圍將會受到壓縮。因此低山丘陵的森林復育過程，需要優先考量保育現有的原生森林、增加殘存森林之間的連結、增加木本植物小苗在草原上建立的可能性。

關鍵詞：海拔梯度、森林界限、全球暖化、物種多樣性、陽明山國家公園。