FOREST DISTURBANCE LEADS TO THE RAPID SPREAD OF THE INVASIVE *LEUCAENA LEUCOCEPHALA* IN TAIWAN

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ABSTRACT:

This study, based on different investigative documents and analytical methods, elucidates spatial distribution of habitats for major invasive exotic plants, *Leucaena leucocephala*, in Taiwan. Results show that *Leucaena leucocephala* is most harmful to broad-leaved trees and its invasion directly relates to changes in the physical environment. *Leucaena leucocephala* can bloom and bear fruits all year round and during the period of seeds sprouting and saplings, the invasion varies greatly among different soil types. *Leucaena leucocephala* prefers weakly acidic soil, though it grows well with other soil textures and nutrients as well. The average spreading rate of *Leucaena leucocephala* is 3.55 ha year^{-1} on abandoned farm land calculated from the aerial photographs taken in 1982, 1992, 2003, and 2007.

1. INTRODUCTION

Failure of human beings to effectively control exotic plants they introduce for their own benefit may affect the original ecological system in a short period of time, and may even lead to reduction in the variety of species. Once exotic plants succeed in invading and occupying a certain plot within an ecological system, no matter what methods we adapt to prevent and control them, much time and effort, even with eradication procedures, must be invested. It will cause major impact on the ecological system over a period of time; therefore, prevention, control, and research on the invasion of exotic plants have been given much attention (Moody and Mack, 1998).

The number of exotic plant species on Taiwan island has recently reached 4,516 (Lai, 1995). Most of them were imported via human economic activity; yet, the introduced plants were planted and bred intentionally, and humans failed to manage them properly as they multiply. Therefore, exotics may diffuse out to open fields, harm the ecological system and become invasive plants. In recent years, the detriment to the ecological system by *Leucaena leucocephala* has already spread over the island now 20010, and many plants cannot grow and develop effectively in their usual habitats because of this invasion. The invasion and diffusion (augmentation) of alien species have long been recognized highly complicated processes. The uncertainty of these intrusions has resulted both from their extremely complicated mechanisms and the lack of information on the range and detail of the invasive species. Fundamental information derived from long term inspection is necessary for understanding and clarifying this uncertainty. The comprehensive data will enhance the accuracy of a postulated invasive pattern. It has been shown lately that the stronger the interference the easier the invasion, especially for artificial disturbance caused by humans (Duggin and Gentle, 1998； Petren and Case ,1998). The invasive plants establish their domains at forest edges or road corridors when sufficient sunlight becomes available due to the formations of artificially developed segments, abandoned farm and fragmented terrain due to the construction of roads and buildings (Song et al., 2005; Hawbaker and Radeloff, 2004; Chung and Lu, 2006).

In this research we used different methods to investigate the *Leucaena leucocephala*, which seriously affect ecological environments in Taiwan. After analysis of the harmful effect on habitat, we review its special distribution and environmental impacts by means of global positioning system (GPS), geographical information system (GIS), remotely sensed data, and phonological study. The remote sensing technique is one of the best and widely method to investigate the damage area of exotic plants (Krumpe, 1972；Lonsdale, 1993; Bulman, 2000; David et al., 2000).

2. MATERIALS AND METHODS

2.1 The areas covered in this study

The climate of Taiwan includes both tropical and subtropical region. The southern area, north to Tropic of Cancer, has a tropical monsoon climate, and the northern area, south to Tropic of Cancer shows a subtropical monsoon. The climate over the entire island is characterized by high temperature, high humidity, and strong wind. There is a seasonal difference among all regions. The annual average temperature is about 20 ℃, while that for average rainfall is about 2,500 ㎜（highest during May to October, more in mountains than in flat land; more on the east coast than on the west coast；more in the north than in the south ） (King and Su,1993). High temperatures and humidity facilitate growth and spread of exotic plants. This research was conducted on the Kenting

National Park, Hengchun Area in Southern Taiwan (Fig. 1) to determine the invasive status of *Leucaena leucocephala*.

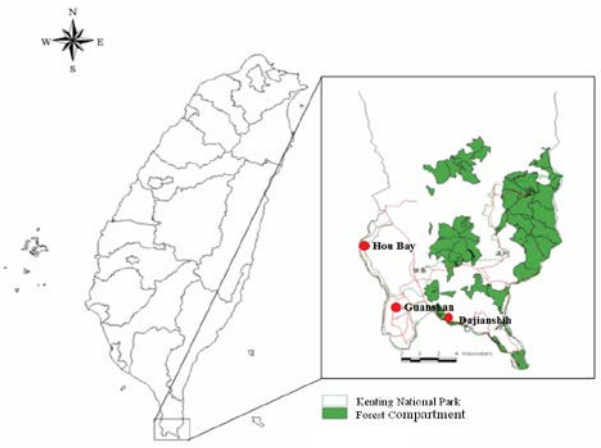

Fig. 1. The sampling sites of the Kenting Nationla Park and Hengchun area.

2.2 Eological habit of *Leucaena leucocephala*

Native to South America, *Leucaena leucocephala*, is a mimosaceae plant, 4-18 m. in height. Its legumen is flat, 14-26 cm long and 1.5-2.0 cm wide. Every pod contains15-30 brown and lustrous seeds, 6-10 mm long. In the Hengchun peninsula (the most southern part of Taiwan), there are three new varieties of *Leucaena leucocephala*: var. *glabrata*, var. *Leucocephala* and Peru type. Resulting from the interbreeding among these varieties, new types have already come into being （Lu and Chen, 2002）.The research investigated the phenological data and field study of *Leucaena leucocephal*. Numerous geographical data of Taiwan, are used for geographical analysis.

2.3 Research methods

2.3.1 Physical environment

The literature on floral development and distribution shows that for the habitat of plants, the primary conditions are seasonal distribution of rainfall and atmospheric humidity, whereas the secondary condition is terrain: altitude, slope, and aspect. The soil is usually affected by biology, rainfall, air temperature, geology, and terrain, and cannot be regarded as an isolated environmental factor of plant habitat (Ellenberg, 1968; Molles, 2002; Chapman & Reiss, 1999; Auerbach & Shmida, 1987). In large-scale ecological research, the physical environmental factors are ordinarily used to estimate the spatial ecological phenomena (Peterken and Game, 1984; Rossi and Kuitunen, 1996; King and Su, 1993).

2.3.2 The phenology of *Leucaena leucocephala*

While studying the phenology, we adopted the quantized manner of observation, and divided the acryl observation board of 10cm × 10cm into 100 panes of 1cm × 1cm. During field investigation, we marked every sampling point with the observation position and direction, and in every observation at the same position and direction, the phenological change of tree crown was observed. We used the observation board to count the occupied pane number in the extension of tree crown of every species (a) and of, *Leucaena leucocephala* in particular (b) a partial pane was counted as one. In this process, we took formula b/a × 100 as the abundance percent of *Leucaena leucocephala*. We quantized and recorded the abundance percent with Braun-Blanquet measure. The cycle of this research was one month, and 32 sampling points were selected in Hengchun Area, Kenting National Park.

2.3.3 Growth status of *Leucaena leucocephala* in different land-use

There are different land use types in Hengchun area, so the growth manners of *Leucaena leucocephala* after invasion are different. We designated totally 65 sampling plots in the following 7 habitat types of land: inner part of natural forest (4 plots), edge of natural forest (3 plots), mixed forest (26 plots), *Leucaena leucocephala* forest (11 plots), grass land (5 plots), bare land (10 plots), and plantation land (6 plots). All the sampling number in different habitat was suit to the invaded pattern and its circumstances. The size of each sampling plot was 3m × 3m, except that of those at the edge of natural forest: 5m × 5m the natural variance was under consideration. In every sampling plot, the number of *Leucaena leucocephala* of the following 3 heights was investigated and recorded: shorter than 30cm, between 30-120 cm, and taller than 120cm. The number of *Leucaena leucocephala*, taller than 120cm, was recorded in accordance with the following 5 diameter classes: less than 2.0 cm,2.0-4.0 cm,4.0-6.0 cm,6.0-8.0 cm, and larger than 8.0 cm. Sections were examined every 3 months and we transformed the number of *Leucaena leucocephala* of different height in every sampling section into tree number in every hectare area. This was used to analyze the growth state of *Leucaena leucocephala* on different land use types.

2.3.4 Analysis of the land-use change and invasion and dispersion speed of *Leucaena leucocephala*

There was no human interference in Kenting National Park area after 1982. We selected four period aerial photographs: 1982, 1992, 2003 and 2007 to monitor the temporal and spatial land-use change over the past 25 years in 3 sampling sites Hou Bay, Guanshan, and Dajianshih Mountain of Kenting National Park (Fig 1). In order to determine the invasion and dispersion speed of *Leucaena leucocephala*, we used the traditional aerial photographs to demarcate the current distribution scope of *Leucaena leucocephala*. By using the manner of Lonsdale （1993）, to judge and calculate the distribution scope of *Leucaena leucocephala*, and estimated its invasion and dispersion speed. All the aerial photos were processing with image geometrically corrected and coordinate fixed.

2.3.5 The relationship between the distribution of *Leucaena leucocephala* and physical and chemical properties of soil

The field investigation data was converted to a digital geographic theme and overlaid with the soil map to construct a map of the relationship between *Leucaena leucocephala* sampling points and physical and chemical properties of soil. The soil map was made by Agriculture and Forestry Bureau of Taiwan in 1986, all the soil characteristics were analyze and mapping on this soil map. The examination collected data on physical-chemical properties of soil to a 20cm depth, which included 11 items: sand content, silt content, clay content, pH value, organic matter, cation, aggregate stability, dispersion ratio, free iron, exchangeable K, and available P. We used all factors to analyze and discuss the relationship between the

distribution of *Leucaena leucocephala* and physical and chemical properties of soil.

3. RESULTS AND DISCUSSION

3.1 The invasion status of *Leucaena leucocephala*

3.1.1 The phenology of *Leucaena leucocephala*

We started to investigate the phenology of *Leucaena leucocephala* in October, 2001, and continued for 15 months until December, 2002. Fig. 2 shows the results after quantizing every phenology with Braun-Blanquet measure method. *Leucaena leucocephala* in Hengchun area has a short life cycle and the following phenomena were observed all year round: flower budding, blossoming, fruit setting, fruit ripening, and fruit falling. According to phenology, the florescence of *Leucaena leucocephala* should be sub-annual; therefore, it must have at least two florescence phases in a year. With adequate moisture, it can blossom all the year round. Before the dropping off of the old legumens, the new legumens appear. Contrasting the result of phenological investigation with meteorological data, the phenology of *Leucaena leucocephala* is mainly affected by precipitation.

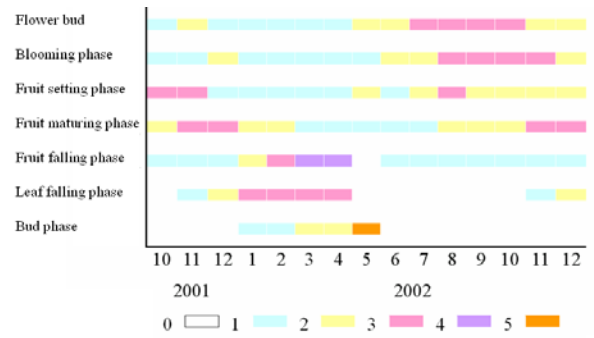

Fig. 2. The phenology of *Leucaena leucocephala* in study area

3.1.2 Growth status of *Leucaena leucocephala* on lands of different use types

Since December, 2001, we began to investigate, quarterly, the growth status of *Leucaena leucocephala* in lands of different use types. In every sampling section, the number of trees was recorded according to the following height categories: less than 30 cm, 30-120 cm, and higher than 120 cm. Trees of taller than 120 cm were recorded in accordance with 5 DBH (diameter at breast height) categories: less than 2.0 cm, 2.0-4.0 cm, 4.0-6.0 cm, 6.0-8.0 cm, and greater than 8.0 cm. The recorded data were transformed into the number of trees per hectare (Table 1). Table 1 shows *Leucaena leucocephala* can not only be found in pure forest, but also frequently appears at the edge of natural and mixed forests. Its growth status varies in lands of different land use types due to environmental differences.

Table 1. The number of *Leucaena Leucocephala* invasion in different landuse type.

Land use	trees	SE	%
Plantation	159	102.54	0.20
Grass land	205	108.75	0.26
Bare land	852	225.42	1.07
Natural forest	1624	287.12	2.05
Edge of natural forest	13524	2033.06	17.05
Mixed forest	20416	1358.56	25.74
Leucaena Leucocephala	42543	10443.49	53.63
Total	79323		100.00

3.1.2.1 Natural forest

We found no *Leucaena leucocephala* taller than 30cm survived in any natural forest. Natural forest in Taiwan normally has high crown density, unless natural hazards, such as typhoons, north-east monsoon. If large gaps are created in the crown level, then plenty of sunlight will penetrate. Lacking sunlight when they reach a certain height will kill these trees. From the fact stated, it is quite difficult for *Leucaena leucocephala* to invade into the natural forest with integrated tree crowns, unless the natural forest community is badly destroyed.

3.1.2.2 Edge of natural forest

Table 1 shows that, for *Leucaena leucocephala* in the natural forest, if its height is either taller than 120 cm, between 30cm and 120 cm, or less than 30 cm, the average proportion of tree number per hectare is about 1.0, 3.5,or 4.5 respectively. It is obvious that the number of seedling trees is many times that of grown trees in this area, because there is plenty of sunlight at the edge. Although *Leucaena leucocephala* has hardy renewal ability at the edge of natural forest, it is quite difficult for *Leucaena leucocephala* to penetrate into the inner part of natural forest, unless the edge of natural forest is continually destroyed or the number of *Leucaena leucocephala* is too high to have an allelopathic effect to restrain the renewal and growth of other seedling trees (Chou and Chen, 1976; Chou, 1980; Chou and Kuo, 1986).

3.1.2.3 Mixed forest

From Table 1, the average number of *Leucaena leucocephala* per hectare in the mixed forest is1.0, 1.7, and 5.3 respectively for those trees of three heights: less than 30cm, between 30-120 cm, and taller than 120cm. In this specific area, although *Leucaena leucocephala* may increase its dispersive chances by the germination of a jillion seeds, there are not many trees taller than 30cm, resulted from the fact that *Leucaena leucocephala* not only scramble for nutrient with other species, but also competes within the same breed.

3.1.2.4 *Leucaena leucocephala* forest

In *Leucaena leucocephala* forest, the crown cover can obstruct the sunlight, making the trees compete for nutrient and space. The growth of *Leucaena leucocephala* seedling becomes comparatively difficult. In every hectare, the average number of *Leucaena leucocephala* is about 1.0, 5.0, and 15.2 (Table 1), which is according to tree height: lower than 30cm, between 30-120 cm, and higher than 120cm. It shows that the number of

seedlings (lower than 30cm) is far more than that in mixed forest and that at the edge of natural forest. However, there is only one that can grow into 120cm or higher among 15 seedlings.

3.1.2.5 Grass land

Most of the grass lands are formed because of animal husbandry, and *Leucaena leucocephala* is the best feed for the flocks and herds in Hengchun area. When *Leucaena leucocephala* is hardly germinating the flocks and herds enjoy it and therefore it's difficult for *Leucaena leucocephala* to break into the grown forest. Once the browsing stops, without seeds of *Leucaena leucocephala* being trampled and eaten by the flocks and herds, the *Leucaena leucocephala* will break into the grassland and gradually grow into forest.

3.1.2.6 Bare land

Following the wind, the seeds of *Leucaena leucocephala* can spread to the bare land given up to cultivation, and germinate easily. After 3 months, the seedlings become taller than 30cm, and the DBH can be measured 6 months-to-one year later. As for the bare land selected in Chart 3, its forming time is not very long, so there are not too many *Leucaena leucocephala* seedlings, whose DBH is mostly smaller than 120cm. It is appropriate to check, remove, and prevent the invasion of *Leucaena leucocephala* every half a year.

3.1.2.6 Plantation land

In the previous 5-time investigations on the plantation land, no *Leucaena leucocephala* seedling was recorded. We found in the sixth investigation, however, that *Leucaena leucocephala* had invaded and grown. In the early days of managing a plantation, the interspace of woodlands is usually large. That makes it the best habitat for *Leucaena leucocephal*., The most possible reason is the some-years lagging of tending treatment after plantation has completed in Taiwan. From what we learned in the process, the importance of forest tending and upbringing for controlling the invasion of *Leucaena leucocephala* is clearly stated.

3.1.3 The relationship between the dispersal of *Leucaena leucocephala* and physical and chemical properties of soil

We used the IKONOS satellite image (2001) with resolution of 1m × 1m, to demarcate the distribution scope of *Leucaena leucocephala*. After counting and clearing up the result, we found that the distribution area of *Leucaena leucocephala* was 3,354 hectare，which occupied 15.7 % of the investigated area, 21,363 hectare，and was distributed in belt or block shape (Figure 3).

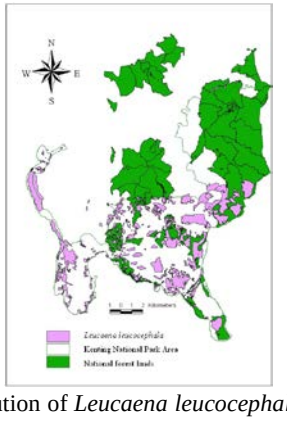

Fig. 3. The distribution of *Leucaena leucocephala* in Hengchun area.

In order to analyze the relationship between the distribution of *Leucaena leucocephala* and the physical and chemical properties of soil, we converted and overlaid the investigation data onto the soil map in GIS processing, while 249 points were selected and the soil depth of 20cm was designated as the benchmark. We used 11 soil component factors to analyze and discuss the relationship between the distribution of *Leucaena leucocephala* and the properties of soil. The result in Table 2 shows that 11 physico-chemical properties of soil can be concluded into 3 components. Component one includes: sand, silt, clay, aggregate stability, organic matter content, free iron, cation exchange energy, and the amount of variation is 54.8 %. Component two includes: dispersion ratio and available phospherous, and the amount of variation is 14.6 %. Component three includes: pH value and exchangeable potassium with 11.4 % as the amount of variation.

Table 2. Structural Matrix of *Leucaena leucocephala* dispersal and physical&chemical properties of soil

	1	2	3
Sand content	-.984	.115	.125
Silt content	.984	-.082	.027
Aggregate stability	.960	-.255	-.077
Clay content	.870	-.162	-.383
Organic matter	.800	-.050	.212
Free iron	.757	.022	.147
Cation Exchange Capacity (Cec)	.723	-.026	-.275
Dispersion ratio	-.229	.859	-.232
Available P	-.047	.852	.221
pH value	-.502	-.129	.680
Exchangeable K	.582	.272	.643

Combining the analytical data and field survey results, we understand that the physico-chemical properties of soil components, decides whether a habitat fits the growth of *Leucaena leucocephala*. Besides the degree of soil acidity(in the whole sampling area, the pH values for soil is always lower than 7），the characteristics and nutrient condition of non-acidic soil is favorable for *Leucaena leucocephala*. The main reason for *Leucaena leucocephala* to spread widely is its vigorous life force and special genes.

3.1.4 Analysis of the invasion and dispersal speed and landuse change of *Leucaena leucocephala*

In order to analyze the dispersion speed of Leucaena leucocephala, we chose at the beginning an aerial photograph taken in 1982 to select 3 sites with most abundant Leucaena leucocephala, and caompared carfully the aerial photograph of the same sites taken in1992, 2003, and 2007. Fig. 3 shows that Leucaena leucocephala began to invade every sampling area from 1982, and sampling sites Dajianshih Mountain, Guanshan and Hou Bay presented: 18.58, 35.35, and 15.2 % of the general distribution area respectively in 2007. Across 25 years, the annual average dispersion speed of Leucaena leucocephala in the three sampling sections was about 3.35 ha year-1(Table 3 and 4). Using regression analysis to estimate Leucaena leucocephala's dispersion curve on different area and time, we found that the dispersion speed approximately appears as a quadratic curve, with a correlation coefficient of 0.979.

The annual average dispersion speed of *Leucaena leucocephala* is related to the lands of cultivation abandon.

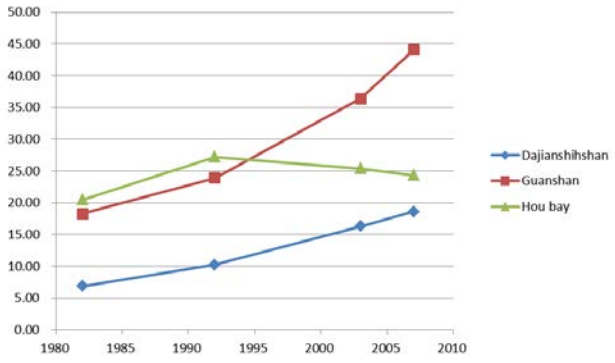

Fig. 3. *Leucaena Leucocephala* distributed in each study area of different year

4. CONCLUSION

Leucaena leucocephala is one of important invasive plants in Taiwan, and the damage often results in territorial disintegration of biodiversity, which makes the ecosystem expenditure piles up every year to prevent their invasion. The results showed it have strong adaptability to the environment. Once the environment has been disturbed to a certain degree, the ecosystem deterioration occurs. The effect of manpower prevention is usually trivial. On the contrary, *Leucaena leucocephala* could not invade easily in the close canopy of woods. They cannot cause a big endangerment area even if several can grow. Keeping the forest integrated is therefore the most important policy to prevent their entrance. As for the prevention work in disastrous areas, cut off the *Leucaena leucocephala* seedlings every half a year, to prevent them from extending is most important.

Table 3 *Leucaena Leucocephala* distributed in each study area of different year

study area	1982		1992		2003		2007		Distributed speed (ha year^{-1})
	area	%	area	%	area	%	area	%	
Dajianshihshan	49.13	6.87	73.25	10.24	116.5	16.29	132.82	18.58	3.35
Guanshan	104.79	18.26	137.13	23.89	208.76	36.37	252.76	44.03	5.92
Hou bay	99.4	20.45	132.21	27.20	123.49	25.41	118.24	24.33	0.75
Total	253.32	14.27	342.59	19.30	448.75	25.28	503.82	28.38	

Table 4. Landuse change and *Leucaena Leucocephala* distribution from year 1982 to 2007.

Study area	Land-use type	1982		1992		2003		2007	
		Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)
Dajianshih Mountain	Agriculture Land	135.00	18.88	141.4	19.80	243.5	34.07	284.3	39.77
	Forest	326.17	45.62	308.35	43.13	297.7	41.64	264.38	36.98
	Leucaena leucocephala	49.13	6.87	73.25	10.24	116.5	16.29	132.82	18.58
	Grass Land	204.50	28.61	191.6	26.81	57	7.97	33.3	4.66
Guanshan	Agriculture Land	442.25	61.87	460.04	64.36	388.42	54.34	334.93	46.86
	Forest	105.47	14.75	90.28	12.63	76.45	10.69	104.95	14.68
	Leucaena leucocephala	104.79	14.66	137.13	19.18	208.76	29.20	252.76	35.35
	Grass Land	62.31	8.72	27.35	3.83	41.18	5.76	22.17	3.10
Hou Bay	Agriculture Land	549.05	76.86	439.39	61.50	382.03	53.48	419.61	58.73
	Forest	13.93	1.95	88.48	12.37	176.65	24.71	173.83	24.31
	Leucaena leucocephala	99.40	13.90	132.21	18.49	123.49	17.27	118.24	16.54
	Grass Land	52.00	7.28	54.3	7.60	32.21	4.51	2.71	0.38
Total	Agriculture Land	1126.30	52.53	1040.83	48.55	1013.95	47.29	1038.84	48.45
	Forest	445.57	20.78	487.11	22.72	550.8	25.69	543.16	25.33
	Leucaena leucocephala	253.32	11.82	342.59	15.98	448.75	20.93	503.82	23.50
	Grass Land	318.81	14.87	273.25	12.74	130.39	6.08	58.18	2.71

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