PATTERN ANALYSIS ON THE DISPERSAL OF *LEUCAENA LEUCOCEPHALA* IN HENGCHUN PENINSULA USING REMOTE SENSING AND GIS

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ABSTRACT: Invasive species such as *Leucaena leucocephala* have disturbed the forest ecosystem in Hengchun Peninsula, Taiwan. This study applies remote sensing and GIS to analyze the landscape pattern of *Leucaena leucocephala* dispersal in Hengchun Peninsula. The research processes include (1) applying remote sensing and GIS to generate the land use map of Hengchun Peninsula and the distribution map of *Leucaena Leucocephala* in 1994 and 2006; (2) analyzing the landscape pattern of *Leucaena Leucocephala* based on landscape structure indices; (3) monitoring the effect of *Leucaena Leucocephala* dispersal on Hengchun Peninsula landscape from 1994 to 2006 using Shannon diversity t-test. The result is as follows. The land use map and the distribution map of *Leucaena Leucocephala*g in 1994 and 2006, generated by remote sensing and GIS techniques, are acceptable after accuracy assessment. From the generated distribution map of *Leucaena Leucocephala* and the calculated landscape indices, obviously the dispersal of *Leucaena leucocephala* continues to expand from 1994 to 2006. However, the dispersal effect of *Leucaena leucocephala* on the landscape of Hengchun Peninsula is not significant according to the result of Shannon diversity t-test. The above result is concluded that the integration of remote sensing and GIS is a timely and useful technique to study the pattern analysis of *Leucaena leucocephala* dispersal. Meanwhile, the result obtained from this study can be a reference for Forest Unit or National Park to monitor and control the dispersal of *Leucaena Leucocephala* in Hengchun Peninsula, Taiwan.

1. INTRODUCTION

In Taiwan, *Leucaena leucocephala* has caused a serious impact on forest ecosystem (Huang and Ohashi, 1993). Therefore, the issue of invasive species has been growing concerns recently. Three species (i.e., Salvador, Peru, and Hawaiian) were introduced into Taiwan for living and economic purposes in 1645 and 1976 (Chen and Hu, 1976). *Leucaena leucocephala* could oozed Mimosine (Chou and kuo, 1986) and become pure forest because of allelopathy. Due to the characteristics of growing fast and spreading widely, it has disturbed and impacted Taiwan forest ecosystem, particularly in Penghu area and Henchun Peninsula. For this reason, the ecologists and related organizations are concerning about the issue of the monitoring and controlling of *Leucaena leucocephala*. For example, monitoring the pattern structure, the dispersal trend, and landscape change of *Leucaena leucocephala.*

There are several papers related to the study of *Leucaena leucocephala* in the Hengchun Peninsula (Lee, 2003; Chung and Lu, 2006; Kuo, 2008). However, those studies focus on the Allelopathic research of *Leucaena leucocephala* and the generation of spatial distribution for *Leucaena leucocephala* using remote sensing. In this study, the objective focuses on pattern analysis of *Leucaena leucocephala* dispersal in Henchun Peninsula using remote sensing and GIS.

2. MATERIALS AND METHODS

2.1 Study Area and Materials

2.1.1 Study Area: Henchun peninsula is located in the south of Taiwan. The study area includes Kenting National Park and Hengchun National Forest. The total area is about 314.27 square kilometers and distributed with low mountains, hills or terraces. The coastal plains in the west of the peninsula are the center of population distribution.

2.1.2 Materials: The first and second national land-use survey maps produced by Taiwan Survey and Mapping Center in 1994 and 2006 are used as the basic material (Figure 1a and 1b). The map includes seven land-use types (i.e., forest land, water, grassland, agricultural land, waste land, bare land, transport and settlement). However, there is no information about *Leucaena leucocephala* in the national land-use map. Therefore, SPOT satellite image (Figure 1c and 1d) is then used to extract the spatial distribution map of *Leucaena leucocephala*. To coincide with the year of national land-use survey data, two kinds of SPOT images are collected. One is SPOT-2 image on 11/12/1994 including green, red, and near- infrared bands. The other is SPOT-4 image on 11/22/2006 including green, red, near-infrared, and shortwave infrared bands. The spatial resolution of each pixel for both images is 20 m × 20 m.

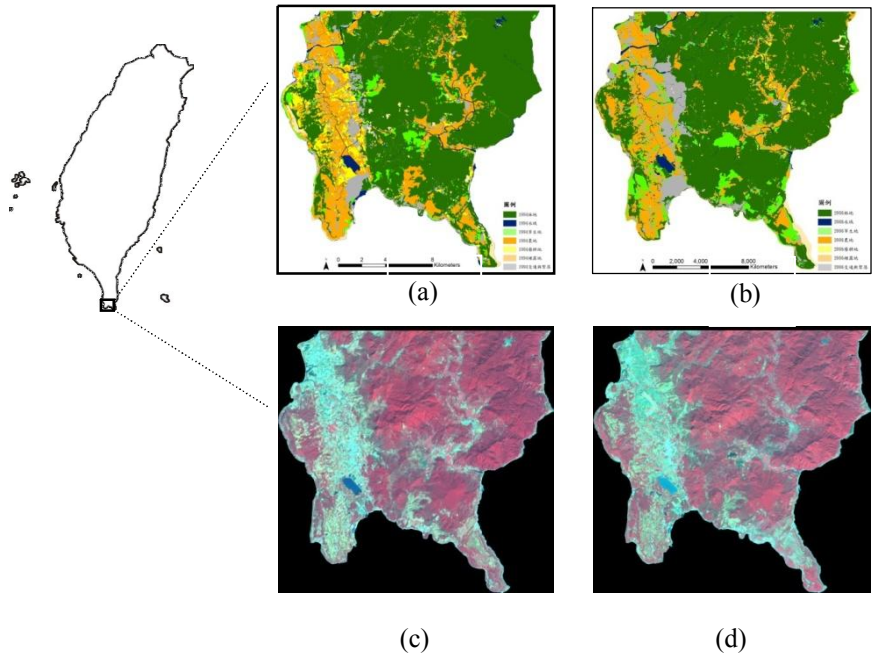


Figure 1: (a) First land-use survey map in 1994. (b) Second land-use survey map in 2006. (c) SPOT-2 image in 1994. (d) SPOT-4 image in 2006.

2.2 Methods

2.2.1 The Generation of Land Use Classification Map including *Leucaena leucocephala*: The national land-use survey data produced by Taiwan Survey and Mapping Center includes seven land types. They are forest land, water, grassland, agricultural land, waste land, bare land, transport and settlement. As mentioned in the material, there is no information about *Leucaena leucocephala* in the national land-use survey data. To generate an updated land use classification map including *Leucaena leucocephala,* the forested area in the national land-use survey data is extracted and used to cut the SPOT image. Then supervised and unsupervised classification approaches are integrated to classify SPOT image in 1994 and 2006. The steps are as follows. (1) Use unsupervised approach to generate different clusters such as *Leucaena leucocephala,* non-*Leucaena leucocephala* and shadow. (2) Select train areas from the above unsupervised result with the assistance of color ortho-photos (scale 1/5000), and accomplish the supervised classification of forested areas using Gaussian maximum likelihood classifier. (3) Test areas are selected to assess the classification accuracy.

After generating the classification map from SPOT image, the classification output including *Leucaena*

leucocephala is then converted into vector data and overlaid with the national land-use survey data to produce an updated land-use map with *Leucaena leucocephala*.

2.2.2 Calculation of Landscape Indices: the GIS software (ArcGIS 10) and the spatial pattern analysis program of FRAGSTATS (McGarigal and Marks, 1995) are applied to calculate landscape indices according to the above updated land-use map with eight land types. The purpose is for pattern analysis on the dispersal change of *Leucaena leucocephala*. In this study, two kinds of indices are selected. One is class-level indices such as Class Area (CA), Number of Patch (NP), Patch Density (PD), Mean Patch Size (MPS), Shape Index (SI). The other is landscape-level indices such as Patch Richness (PR), Shannon Diversity Index (SHDI), Shannon Evenness Index (SHEI). The equation for each index is as follows. The detailed description please refers to McGarigal and Marks (1995).

(1) Class area (CA)

$CA = \Sigma (a_{ij} / 10000)$

where a_{ij} = area (m^2) of patch ij, and $CA > 0$, without limit.

(2) Number of Patches (NP)

$NP = n_i$

where n_i = number of patches in the landscape of patch type (class) i, and $NP \geq 1$, without limit.

(3) Patch Density (PD)

$PD = n_i (1000000) / A$

where A = total landscape area (m^2), and $PD > 0$, constrained by cell size.

(4) Mean Patch Size (MPS)

$MPS = \Sigma Aij /[(Ni) (10000)]$; $MPS > 0$

where Aij = area of patch j in the patch of class i and Ni = number of patches in class i.

(5) Shape Index (SI)

$SI = p_{ij} / \min p_{ij}$

where p_{ij} = perimeter of patch ij in terms of number of cell surfaces and $\min p_{ij}$ = minimum perimeter of patch ij in terms of number of cell surfaces.

(6) Patch Richness (PR)

$PR = m$

where m = number of patch types (classes) present in the landscape excluding the landscape border if present, and $PR \geq 1$, without limit.

. (7) Shannon Diversity Index (SHDI)

$SHDI = -\Sigma (pi * \ln pi)$

where P_i = proportion of the landscape occupied by patch type (class) I, and $SHDI \geq 0$, without limit.

(8) Shannon Evenness Index (SHEI)

$SHEI = [-\Sigma (p_i * \ln p_i)] / \ln m$

where P_i = proportion of the landscape occupied by patch type (class) i and m = number of patch types present in the landscape excluding the landscape border if present. In addition, the range is $0 \leq SHEI \leq 1$.

2.2.3 Monitoring of Landscape Change using Shannon Diversity t-test: To monitor the landscape change of Hengchun Peninsula, the Shannon diversity t-test (Magurran, 1988) is applied to examine if there is a significant landscape change due to *Leucaena leucocephala* dispersal. The equation of Shannon diversity t-test is as follows.

$$t = \frac{(H_1 - H_2)}{(VarH_1 + VarH_2)^{1/2}}$$

where H_i is the Shannon diversity index of i time; Var H_i is the variance; and df is the degree of freedom.

$$H_i = -\sum_{i=1}^{m} p_i \times \ln(p_i) - \frac{m-1}{n_i}$$

$$VarH_i = \frac{\sum_{i=1}^{m} p_i (\ln(p_i))^2 - \left(\sum_{i=1}^{m} p_i \times \ln(p_i)\right)^2}{n_i} + \frac{m_i - 1}{2n_i^2}$$

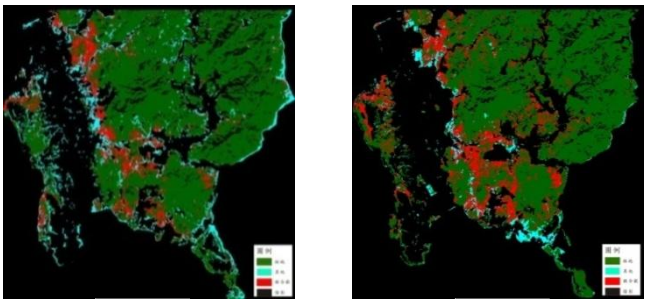
$$df = \frac{(VarH_1 - VarH_2)^2}{\frac{(VarH_1)^2}{n_1} + \frac{(VarH_2)^2}{n_2}}$$

3. RESULTS AND DISCUSSIONS

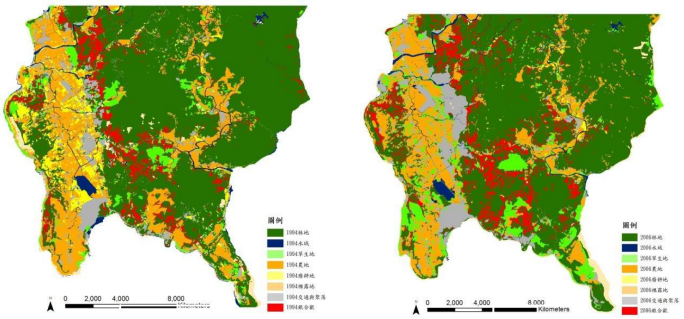
3.1 Land Use Classification Map including *Leucaena leucocephala*

As mentioned in the method, supervised and unsupervised classification approaches are integrated to classify SPOT image in 1994 and 2006. The result is shown as Figure 2(a) and 2(b). To assess the classification accuracy, 11 test areas including *Leucaena leucocephala,* non-*Leucaena leucocephala* and shadow are selected to produce a classification error matrix. The result of overall accuracy in 1994 is about 98%, while the result in 2006 is about 96%.

The classification map including *Leucaena leucocephala* is then converted into vector data and overlaid with the national land-use survey data to produce an updated land-use map as Figure 2(c) and 2(d).



(a) (b)



(c) (d)

Figure 2: Land use classification map including *Leucaena leucocephala*. (a) SPOT-2 image classification in 1994. (b) SPOT-4 image classification in 2006. (c) First land-use map updated by *Leucaena leucocephala*. (d) Second land-use map updated by *Leucaena leucocephala*.

3.2 Pattern Analysis of Landscape Structure

According to the above updated land-use map, the FRAGSTATS program is applied to calculate the class-level indices and landscape-level indices for pattern analysis of Henchun peninsula. Table 1~ 2 are related to the class-level indices while Table 3 is the landscape-level indices. From Table 1 and Table 2, it is clear that the difference of class-level indices between 1994 and 2006 exists among eight land use types, particularly for the type of *Leucaena leucocephala.* For example, the area of *Leucaena leucocephala* (CA) increases about 818.84 ha from 1994 to 2006. The reason may result from the dispersal of *Leucaena leucocephala* because number of patches (NP) and patch density (PD) are also increased. In addition, the increase of mean patch size (MPS) and shape index (SI) implies that the patch of *Leucaena leucocephala* may clump together and form into an irregular shape due to the dispersal from 1994 to 2006.

As for the landscape-level indices of Henchun peninsula in 1994 and 2006, Shannon diversity index (SHDI) increases from 1.4189 to 1.4340 while Shannon evenness index (SHEI) slightly increases from 0.6823 to 0.6896. Obviously, both indices increase from 1994 to 2006 although patch richness (PR) in 1994 and 2006 is unchanged. This result indicates that the landscape pattern of Henchun peninsula from 1994 to 2006 is getting more diversity and evenness due to the dispersal of *Leucaena leucocephala.*

Table 1: Difference of class-level indices between 1994 and 2006 for eight land use types in Henchun peninsula.

Index / Land type	CA	NP	PD	MPS	SI
Water	-80.92	243	0.77	-0.12	0.15
Grassland	952.24	436	1.38	-0.25	10.37
Agricultural land	-402.72	237	0.75	-2.03	4.26
Waster land	-1370.40	-615	-1.96	-0.99	-23.19
Bare land	-16.56	-163	-0.52	3.63	-3.90
Transport and settlement	894.44	998	3.16	0.08	-3.44
Non-Leucaena leucocephala	-759.52	43	0.13	-1.21	5.53
Leucaena leucocephala	818.84	415	1.31	0.17	10.40

(* CA=Class Area, NP=Number of Patch, PD=Patch Density, MPS=Mean Patch Size, SI=Shape Index)

Table 2: Class-level indices of *Leucaena leucocephala* in 1994 and 2006.

Year	CA	NP	PD	MPS	SI
1994	1881.52	1641	5.23	1.15	51.54
2006	2700.36	2056	6.54	1.31	61.94

Table 3: Landscape-level indices of Henchun peninsula in 1994 and 2006.

Year	PR	SHDI	SHEI
1994	8	1.4189	0.6823
2006	8	1.4340	0.6896

(* PR=Patch Richness, SHDI=Shannon Diversity Index, SHEI=Shannon Evenness Index)

3.3 Monitoring of Landscape Change using Shannon Diversity t-test

To monitor landscape change in Henchun peninsula, Shannon diversity t-test is calculated according to the landscape pattern of eight land-use types. The result is shown as Table 4. Clearly the t value (=1.0688) obtained from SHDI in 1994 and 2006 is less than the table value (=1.96) under the significance level of 5%. Meanwhile, the probability of t-test (=0.1428) is greater than 0.05. This result indicates that the landscape change in Hengchun

Peninsula is not significant from1994 to 2006 although the SHDI slightly increases due to the effect of *Leucaena leucocephala* dispersal.

Year	PR	NP	H_i	Var H_i	t value	d.f	Probability of t-test
1994	8	9973	1.4182	0.0001	1.0688	508	0.1428
2006	8	11567	1.4333	8.5E-05			

Table 4: Landscape change analysis of Hengchun Peninsula using Shannon diversity t-test.
(*H_i=Shannon Diversity Index, Var H_i=variance of H_i)

4. CONCLUSIONS

This study applies remote sensing and GIS technique to generate an updated land use map of Hengchun Peninsula in 1994 and 2006, which includes the distribution map of *Leucaena Leucocephala*; to analyze the pattern structure of Hengchun landscape according to the calculated landscape indices; and to monitor landscape change from 1994 to 2006 using Shannon diversity t-test. The objective is pattern analysis on the dispersal of *Leucaena Leucocephala* in Hengchun Peninsula using remote sensing and GIS. The results are concluded as follows:

(1) The integration of remote sensing and GIS is a timely and useful technique to study the pattern analysis of *Leucaena leucocephala* dispersal because it can quickly generate a land use map for analyzing pattern structure and monitoring landscape change.
(2) Based on landscape indices and Shannon diversity t-test, the landscape change of Hengchun Peninsula is not significant from 1994 to 2006 although the SHDI slightly increases due to the effect of *Leucaena leucocephala* dispersal.

The result obtained from this study can be a reference for Forest Unit or National Park to monitor and control the dispersal of *Leucaena Leucocephala* in Hengchun Peninsula, Taiwan.

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