Research paper

Adaptations of *Casuarina* Windbreak Stands to Land Subsidence on the Southwestern Coast of Taiwan

Kuen-Yih Ho,[1,2] Wei-Je Tsai[1)]

【Summary】

In this study, we investigated the adaptive behavior of *Casuarina* windbreak stands along the southwestern coast of Taiwan to land subsidence. Based on surveys and measurements of 17 indicators, such as soil factors, the external appearance of individual trees, damage sustained by individual trees etc., we applied a maximum variance reciprocal matrix method of a factorial analysis to obtain sets of reciprocal matrices, together with weighting factor adjustments, and then we derived the state of health of the stands. The analytical results indicated that the vitality of the tree crowns, soil salinity, soil pH, tree diseases, tree flowering, and root damage were the 6 major factors affecting differences in the adaptive performance of *Casuarina* windbreak stands. Finally, the maximum variance reciprocal matrices of the factorial analysis identified 3 factors of tree status, crown vitality, and changes in the soil environment as influential indicators. Furthermore, the analysis indicated that there was a seasonal fluctuation in the tree health status with a decrease observed in summer and autumn compared to winter and spring. This study confirmed that coastal *Casuarina* windbreak stands of southwestern Taiwan have already been affected by land subsidence, and the adaptive characteristics of injured trees and a seasonal fluctuation of their health status were observed.

Key words: land subsidence, *Casuarina* sp., windbreaks stand, factorial analysis.

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[1)] Department of Forestry and Natural Resources, National Chiayi University, 300 Xuefu Rd., Chiayi 60004, Taiwan. 國立嘉義大學森林暨自然資源學系，60004嘉義市學府路300號。

[2)] Corresponding author, e-mail:kyho@mail.ncyu.edu.tw 通訊作者。

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研究報告

木麻黄防風林分對台灣西南海岸地層下陷適應性之影響

何坤益[1,2)] 蔡維哲[1)]

摘 要

本研究以台灣西南海岸地層下陷區木麻黃防風林分為對象，藉由土壤因子，林木外觀形態及林木受害程度觀測等17項指標，利用因素分析之最大變異轉軸法獲得相關轉軸矩陣，進行權重加權因素分析以求林分健康程度值。分析結果共選取出樹冠活力、土壤鹽分、土壤pH值、林木病害、林木開花及根部損傷等6項主要影響因素，顯現於木麻黃防風林之適應差異上。再利用最大變異轉軸法，歸納成林木狀態、樹冠活力及土壤環境等三項影響指標，結果顯示：林分適應特徵受地層下陷之影響，由林木生長、樹冠受害及土壤環境之變化，顯示夏、秋兩季的健康程度較冬、春季下降之季節變動情形。本研究確認台灣西南沿海木麻黃防風林分受到地層下陷之影響，並顯現受災林木適應之特徵及季節變動情形。

關鍵詞：地層下陷、木麻黃、防風林分、因素分析。

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INTRODUCTION

The southwestern coastal area of Taiwan often suffers damage from typhoons and torrential rains in summertime, while there are strong northeastely monsoons in winter, which create a rather adverse growth environment for coastal windbreak stands. Although *Casuarina* sp. possesses features of salt-tolerance and wind-resistance, and is an important coastal windbreak forest tree species in southwestern Taiwan, its growth and development are seriously stunted by increasing soil salinity from repeating inundation of sites by seawater, which in turn is the result of anthropogenic destruction of the environment and excessive withdrawal of water from underground aquifers (Chen et al. 2008). These impacts have caused degeneration of vital windbreak frontline trees along coastal areas.

Tree adaptation and the health status of forests are important components of forest management plans. Tree adaptations reflecting the growth and development of trees are particularly important to the management of plantations. On the other hand, the soundness of a forest's health condition has significant indicative functions for the success of forest establishment and tending. Hence, through surveys of forest tree adaptations and a forest's health status, we can understand the dynamic changes and future trends of a forest, thus enabling timely ameliorative actions to maintain the healthful development of forest ecosystems (Luo et al. 2008).

In recent years, European and North American foresters have engaged in research on forest health monitoring (FHM) to understand the influence of damages sustained by forest trees (Kolb et al. 1994). In the US, large-scale systematic FHM sampling plots of domestic forestland were established (Wang and Chen 2002). Through large-area surveys and monitoring of other environmental factors, information pertaining to processes of forest changes, the current status, and future trends can be established to facilitate execution of their FHM projects (Luo et al. 2009). Therefore, by means of long-term monitoring of indicators, the current status, changes, and long-term trends of a forest ecosystem can be comprehended (Conkling and Byers 2002, Smith 2002).

In this study, we investigated soil factors, tree external appearances, and the degree of damage sustained by *Casuarina* windbreak forest tree stands on the southwestern coastal region of Taiwan that is subject to land subsidence. We hope that through observations of a forest's health status, effective means of ameliorating the growth condition of these stands can be found and appropriate actions taken to rescue these important safeguards of our coastal lands.

MATERIALS AND METHODS

Establishment of test plots

Casuarina windbreak stands growing on land experiencing subsidence on the southwestern coast of Taiwan were the subject of this study. Seven test plots of *Casuarina* windbreak stands at Mailiao and Sihu of Yulin County; Dongshi and Xinwen of Chiayi County; Beimen and Jiangjun of Tainan County; and Chengsi of Tainan City were set up (Table 1 and Fig. 1). All test plots were located at the first line of littoral windbreak stands, and land subsidence of the areas has led to risks of seawater inundation in summer. We chose stands that were representative of the region's *Casuarina* forests to provide valid references for evaluations. Observations were carried out during January 2008 to January 2009. The size of each plot was 20×20 m square, representing an area of 0.04 ha.

Soil indicators

From each plot, 4 sampling points were selected, and the topmost (O horizon, OB) layer (< 10 cm) and subsoil (B horizon, BC) layer (< 45 cm) soils were excavated. Soils from each plot were then thoroughly mixed, air-dried, and sieved through a 20-mesh screen (0.84 mm) before analysis. The following soil indicators were determined.

1. Soil texture: Soil texture was determined using the Bouyoucos hydrometer method (Bouyoucos 1962).
2. Soil salinity: Saturated soil solutions comprised of soil: distilled water = 1: 2 were prepared. After 48 h of standing, the soil salinity was determined by filtering the solution and using a salinity meter to measure electrical conductivity of the solution (USDA Salinity Laboratory 1954, Revised 1983).
3. Soil pH value: the same as described above, a saturated soil solution was prepared, and after 48 h of standing, was filtered. The pH of the filtrate was then measured (APHA et al. 1998).

External appearances (morphology) of trees

In this study, changes in the external appearance of trees in the test plots were used to demonstrate the stress of trees, and hence the stress indices of the trees (Li 2005, Liu 2005). The observations comprised the following indices.

1. Crown density: This consisted of the percentage of the tree crown area shielding light from penetration, including the main trunk, branches, and leaves in the crown (USDA Forest Service 2002, Wang and Chen 2002). This indicator is also called foliage density. The visual crown density eval-

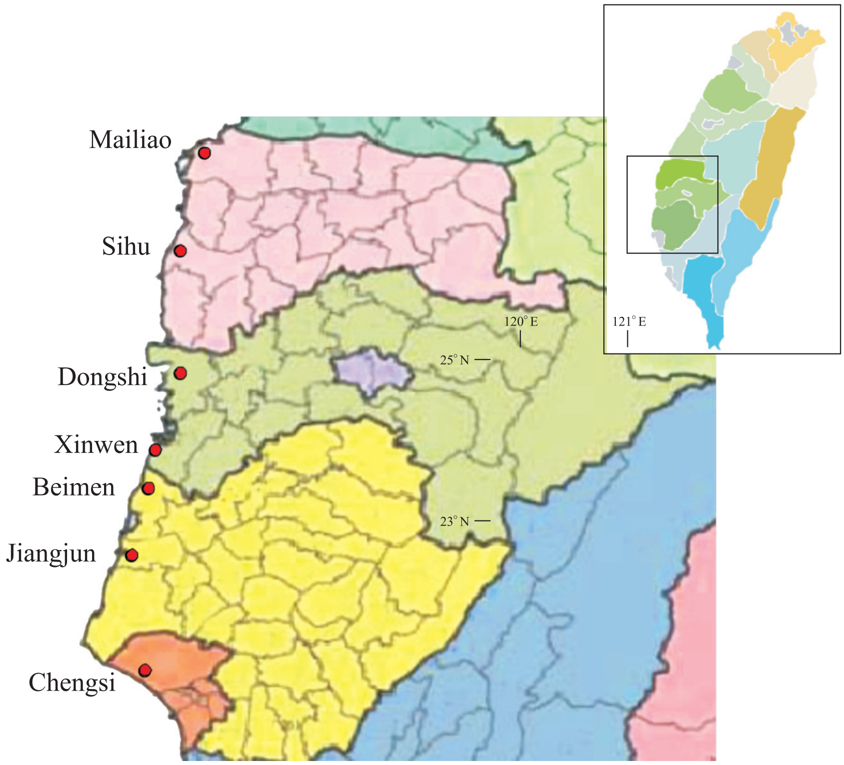

Fig. 1. Locations of the test plots.

Table 1. Basic information of the sampled plots

Plot	Site	Elevation (m)	Location
Mailiao	Yunlin County	0.6	23°48’, 120°14’
Sihu	Yunlin County	0.5	23°40’, 120°09’
Dongshi	Chiayi County	0.5	23°27’, 120°08’
Xinwen	Chiayi County	0.5	23°20’, 120°07’
Beimen	Tainan County	0.7	23°18’, 120°06’
Jiangjun	Tainan County	0.6	23°13’, 120°05’
Chengsi	Tainan City	0.6	23°02’, 120°04’

uation was based on schematic diagrams provided by the USDA Forest Service.

2. Crown light transmittance: This consisted of the percentage of the tree crown that let light penetrate. This was determined according to reference graphs provided by the USDA Forest Service (Metzger and Oren 2001, March 2002). It also served as the bases of the crown density evaluations.
3. Crown dieback: This is consisted of the percentage of branch tips in a crown that had withered or died. The results were evaluated by scores of 0~5, with 0 designating no dieback, 1 indicating a dieback rate of 1~25%; 2, a dieback rate of 26~50%; 3, a dieback rate of 51~75%; 4, a dieback rate of 76~89%; and 5, a dieback rate of 90~100%.

4. Crown ratio: This consisted of the percentage of the live crown to the total tree height (USDA Forest Service 2002), calculated by the equation: crown ratio = (tree height - height to the lowest live branch)/tree height.
5. Tree crown taper coefficient: This consisted of the ratio of tree height to diameter at breast height (dbh) used to estimate the tree shape factor.

Damage sustained by the trees

Visual estimation is universally used to determine tree adaptability, in which a survey of leaves, branches, bark, and root status provides indications as to the stress sustained by the trees (Wang and Chen 2002, Redfern and Boswell 2004). Variables of the survey consisted of the following items.

1. Survival: We visually assessed whether the trees were alive or dead, with 0 indicating a live trees, and 1 indicating a dead tree.
2. Root damage: We observed the damage status of tree roots with 0 indicating normal roots, 1 indicating exposed and undamaged roots, and 2 indicating exposed and damaged roots.
3. Bark damage: The portion of tree bark beneath the first living branch was visually checked for the degree of damage. A grade of 0~5 was designated with 0 indicating no damage; 1 1~25% damage; 2 26~50% damage; 3 51~75% damage; 4 76~89% damage; and 5 90~100% damage.
4. Flowering: We visually observed whether trees in the plot were flowering, and recorded these data.
5. Fruiting: We visually observed whether there was fruit (cones) present among trees in the plot, and recorded these data.
6. Shoot withering: As in the case of bark damage, shoot withering was observed and designated in 6 grades with 0 indicating no shoot withering; 1, 1~25% of the shoots had withered; and so forth.
7. Leaf falling rate: This consisted of the percentage of falling leaves of the total number of leaves in a tree crown. It was rated in 6 categories from 0~5, with designations identical to those of the above items.
8. Leaf coloration: We observed the color of leaves (twiglets) in the tree crown, with 0 indicating a pale-green color; 1, yellowish-green color; 2, brown color; and 3, other colors, and recorded these data.
9. Natural regeneration: Natural regeneration is a vital factor for the perpetual existence of a forest stand. A survey was conducted to observe whether there were new seedlings in the surrounding area to assess the regeneration status of the stands.

Statistical analyses

A factorial analysis was applied to establish suitable morphological indicators that assisted in making the assessments. Then a discrimination analysis was carried out to differentiate the indicated variables with strong discriminating efficacies that enabled a greater differentiating capacity of the forest health monitoring and accuracy of the forecasts.

Factorial analysis

A factorial analysis examines a number of significant variables in order to find common factors affecting the original dataset among a group of interrrelated information (Shen 2007). The functions are shown as follows:

$X' = (X_1, X_2, \ldots\ldots, X_k)$, where X' is the set of common factors for the significant variables $(X_1, X_2, \ldots X_k)$;

$Y' = (Y_1, Y_2, \ldots\ldots, Y_k)$, where Y' is the set of common factors for the significant variables $(Y_1, Y_2, \ldots Y_k)$;

$\sigma' = (\sigma_1, \sigma_2, \ldots\ldots, \sigma_k)$, where σ' is the set of interrelated information $(\sigma_1, \sigma_2, \ldots \sigma_k)$ common factors; and

$$A = \begin{pmatrix} \sigma 11\ \sigma 12 \ldots\ \sigma 1k \\ \sigma 21\ \sigma 22 \ldots\ \sigma 2k \\ \sigma k1\ \sigma k2 \ldots\ \sigma kk \end{pmatrix}.$$

Through this analysis and deduction, the results provided a culling of the independent variables. When weighting factors to individual variables were applied and the data normalized, the individual sample tree yielded a weighting factor score (X'), which was then used for the forest tree health status analysis. The status was graded into 5 classes: grade V with $x' < -2$ indicating a tree was extremely unhealthy, grade IV with $-2 \leq x' < -1$ indicating an unhealthy tree, grade III with $-1 \leq 0$ indicating a degraded tree, grade II with $0 \leq x' < 1$ indicating a healthy tree, and grade I with $x' > 1$ indicating a very healthy tree. Finally, upon summation and averaging of all trees (in a plot), the X' value produced a health status indication of the entire stand.

Discrimination analysis

A discrimination analysis was conducted to investigate indicators with the greatest influence on the adaptation of forest trees and to provide factors contributing to the degradation of a stand. The functions are shown as follows:

$A = f(X_1, X_2, \ldots\ldots, X_k)$

A: Health status of the stand,

$$\text{with } A = \begin{cases} \text{I: Stand is very healthy,} \\ \text{II: Stand is healthy,} \\ \text{III: Stand has sign of degradation,} \\ \text{IV: Stand is unhealthy,} \\ \text{V: Stand is extremely unhealthy;} \end{cases}$$

where, $X_1, \ldots\ldots, X_k$ are k analytical explanatory variables. In the function, A is a reactive variable which belongs to the visual assessment classification. The discriminant function, discriminating probability, and predicted classification of individual trees and stands were estimated. The explanatory capacity of the discriminating function on each independent variable was applied to screen the independent variables step by step and to ultimately derive a numeric variable that reflected an optimal classification.

RESULTS AND DISCUSSION

Soil indicators

Soil texture

According to results of the Bouyoucos hydrometer measurement, the region's soils were mainly sand particles except the soil of Dongshi, which was sandy loam (with a composition of sand: clay: silt of 3: 1: 2). The water permeability, soil porosity, and the ratio of silt and clay contents at Dongshi were obviously greater, with a thicker layer of litter deposit on the top, which indicated that the soil permeability had affected the formation of the O horizon (humus layer). A characteristic of sandy soil is a high proportion of sands in the soil, with a loose texture that does not clump. The interstices among the soil particles are large and possess good water permeability and good aeration. The good permeability also leads to poor accumulation of organic matter, and hence lowers the humus content. This type of soil has poor water and fertilizer retention, causing the soil to lack nutrients needed for tree growth (Chen et al. 1998). Coastal windbreak forests are mostly located on sandy soils which have a better soil component texture (Liu 2005) than other soil types. However, the high permeability of the soil allows the organic matter to move downward to the bottom layer. In addition, a well-aerated soil is subjected to erosion and oxidation (Malo et al. 1974, Schimel et al. 1985). The good drainability of sandy soils also allows the soluble organic matter to leach and be removed by rain (Lin et al. 2005). Furthermore, strong tidal winds and flying sand can often damage the vegetation growing in situ; land subsidence worses the problem, making these sites quite inhospitable as growing environments for trees (Chen et al. 2008).

Soil salinity

According to the classification system of the USDA Salinity Laboratory (1954), soil salt contents of the sampling sites ranged from low to high salinities as shown in Table 2. The results showed that the electrical conductivities of the soils had a minimum value of 1.34±0.89 mmhos/cm and a maximum value of 12.68±0.436 mmhos/cm. Soil electrical conductivity of the test plots changed with the seasons. At Dongshi and Chengsi, a significant decrease in electrical conductivity occurred during summer and autumn, whereas there were notable increases in winter and spring. Figures 2 and 3 show the seasonal changes in soil electrical conductivity. Soil conductivity was lower in summer and autumn compared to that in winter and spring. The changes were due to the heavy rain in the previous season, and the rainy season in the above regions mainly occurred in summer and autumn. During the experimental period, typhoons and plum rains often brought torrential rains, causing the soils in the region to be flooded, sometimes lasting for 1 mo or longer (Chen et al. 1996). The precipitation and flooding may have dissolved salts from the soils, which could have lowered the electrical conductivity. Winter and spring are the dry season, during which small amounts of precipitation and flooding are unable to remove salts from the soils, thus causing higher electrical conductivity compared to the summer and autumn seasons.

Soil pH values

Table 3 show the results of soil pH values, and pH values ranged 6.82~8.17 which indicated the soils were neutral to strongly alkaline. Among the test plots, topsoil at Sihu had a pH of 6.82, which is neutral to slightly acidic, whereas there was a significant difference between its top and bottom soils. Other test plots had negligible differences between

Table 2. Soil salinity and electrical conductivity of the sampled sites

Plot	Soil	Conductivity ($mmhos\ cm^{-1}$)	Salinity	Electrical conductivity				
				Jan-08	Apr-08	July-08	Nov-08	Jan-09
Mailiao	Top	2.01±0.954	low	0.82	5.36	0.90	1.05	1.95
	Base	1.45±0.958	none	0.79	3.95	0.84	0.80	0.90
Sihu	Top	2.16±0.614	low	3.55	1.94	1.33	0.52	3.45
	Base	1.65±0.641	none	2.52	1.13	0.97	0.60	3.02
Dongshi	Top	12.68±0.436	high	14.06	16.70	8.47	5.83	19.24
	Base	7.68±0.362	middle	6.69	8.40	6.29	4.91	12.13
Xinwen	Top	3.75±0.255	low	4.11	4.81	3.59	2.23	4.02
	Base	2.93±0.297	low	2.60	2.49	2.45	2.63	4.48
Beimen	Top	1.34±0.893	none	2.44	2.85	0.42	0.47	0.53
	Base	1.40±1.047	none	1.38	3.95	0.62	0.58	0.48
Jiangjun	Top	1.66±0.533	none	2.52	2.71	0.93	0.92	1.21
	Base	1.74±0.526	none	2.54	2.85	1.29	0.70	1.31
Chengsi	Top	7.97±0.447	middle	8.85	12.38	2.95	6.21	9.48
	Base	6.57±0.245	middle	7.33	7.21	5.15	4.67	8.50

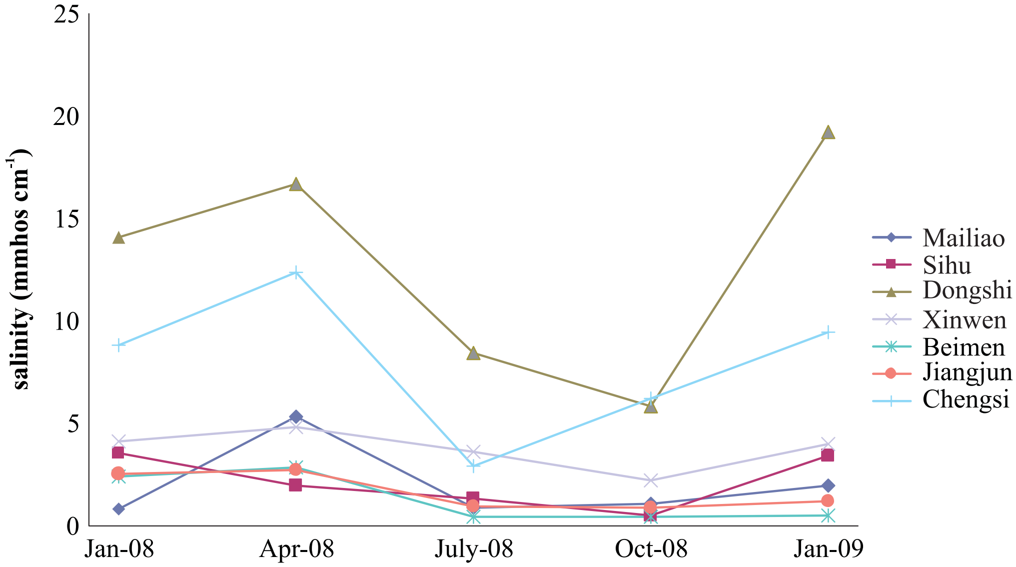

Fig. 2. Soil salinity curves of the OA layer.

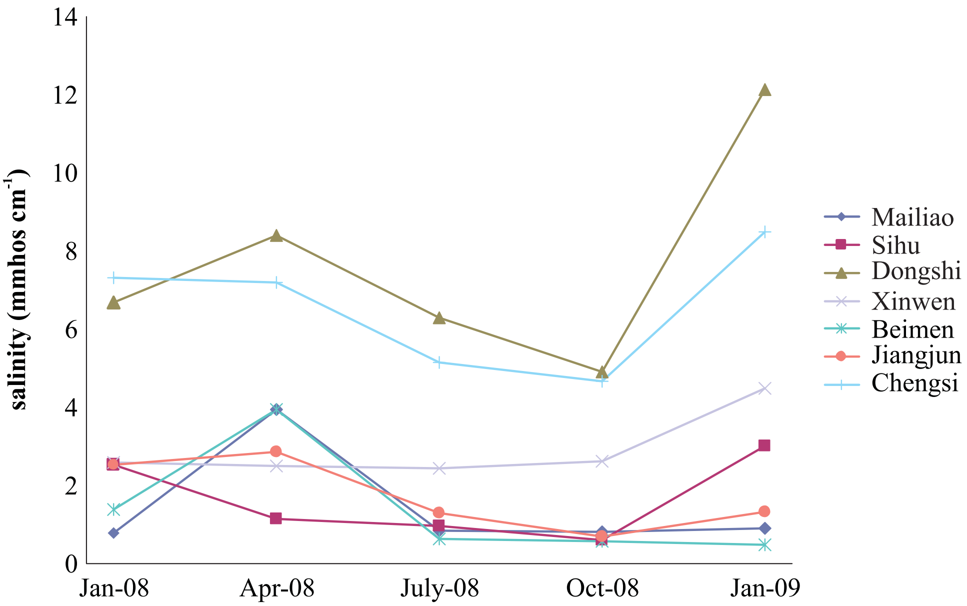

Fig. 3. Soil salinity curves of the BC layer.

the top and bottom soils, except that the top (OA) layer soils were all slightly more acidic than the bottom (BC layer) soils. However, in the Sihu area, the BC layer had a pH of 7.46, and the pH tended to increase in the deeper soil. According to Chen et al. (1998), their survey of soil nutrients in the coastal forest indicated that coastal sand dunes had a high ground temperature, and the humus of the organic litter decomposed faster. Dur-

Table 3. pH values of the soils at the sampled sites

Plot	Soil	Soil pH					Average
		Jan-08	Apr-08	July-08	Nov-08	Jan-09	
Mailiao	Top	8.35	7.79	7.22	7.58	6.78	7.78±0.072
	Base	8.43	7.76	7.42	7.55	6.88	7.87±0.501
Sihu	Top	5.98	7.65	7.55	7.48	6.81	6.82±0.204
	Base	8.14	6.78	6.93	7.86	7.45	7.46±0.169
Dongshi	Top	8.30	7.52	7.24	7.67	6.85	7.69±0.050
	Base	8.16	7.71	7.26	7.84	7.82	7.71±0.057
Xinwen	Top	8.42	7.91	7.85	7.82	7.86	8.17±0.056
	Base	8.20	8.12	8.01	8.12	8.05	8.16±0.009
Beimen	Top	8.19	7.65	7.12	7.78	8.15	7.65±0.068
	Base	8.24	7.54	7.25	7.65	8.13	7.67±0.048
Jiangjun	Top	8.40	7.83	7.42	7.70	7.81	7.88±0.055
	Base	8.51	7.82	7.87	7.89	7.89	8.07±0.027
Chengsi	Top	8.40	7.89	7.47	7.92	8.49	7.92±0.054
	Base	8.40	7.92	7.51	7.94	8.53	7.94±0.052

ing the decomposition process, humic acid or other organic acids tended to accumulate in the topsoil (OA layer), causing the soil pH to become acidified. This trend was observed to decrease with soil depth.

Adaptation of forest trees

Evaluation of tree adaptation is an abstract concept which must be defined through observing various external morphological characteristics or damage sustained, then applying a factorial analysis and discrimination analysis. The results were further deduced and weighed to reduce artificial subjective factors and abnormal events to derive a status of forest tree adaptation (Wang and Chen 2002, Redfern and Boswell 2004).

The SPSS 12.0 software package was applied in this study to analyze the grading of morphological variables related to the tree crown status and damage factors of the stands to differentiate the ranking of the variables. The analytical method extracted primary factors from a large pool of morphological and damage status variables, i.e., the 17 items of observations, by excluding those with a commonality of < 0.01 (the maximum correlation coefficients of < 1% after factoring). Finally, 15 highly correlated variables were obtained, which were tree crown density, crown light transmittance, crown dieback, leaf falling rate, bark damage, soil salinity, subsidence, soil texture, soil pH value, natural regeneration, diseases, fruiting, leaf coloration, flowering, and root damage. All variables had a correlation between tree adaptation and damage sustained of > 1%, and should be considered as survey items for future coastal *Casuarina* forest adaptation studies. The results are summarized in Table 4.

In order to enhance the explanatory capacity of the factorial analysis, an inversion of the maximum variance reciprocal matrix axis was undertaken. The inverted matrix had its own factor matrix member belonging to one or a few original factors, so as to reduce the inter-factor complexity, which greatly simplified the explanation of the factor. Interrelationships between factors and potential factors were also delineated, and the results

Table 4. Extraction of factors by a reciprocal matrix transformation

Component	Initial eigenvalues		
	Total	% of variance	Cumulative %
Crown density	3.176	18.685	18.685
Crown light transmittance	2.727	13.364	32.048
Crown dieback	1.462	8.601	40.649
Leaf falling rate	1.223	7.195	47.845
Bark damage	1.088	6.399	54.543
Soil salinity	1.036	6.096	60.398
Subsidence	0.982	5.778	66.117
Soil texture	0.924	5.438	71.556
Soil pH value	0.899	5.286	76.841
Natural regeneration	0.866	5.096	81.937
Disease	0.805	4.733	86.670
Fruiting	0.726	4.268	90.938
Leaf coloration	0.665	3.914	94.852
Flowering	0.340	2.000	96.852
Root damage	0.280	1.649	98.501
Survival	0.153	0.899	99.399
Shoot withering	0.102	0.601	100.000

of the reciprocal matrix are shown in Table 5. In total, 6 major highly correlated factors were deduced which simplified the original external morphological status and damage sustained into 6 major indicators, renamed as: 1) tree crown vitality indicator; 2) soil salinity; 3) soil pH value; 4) extent of tree diseases; 5) tree flowering; and 6) extent of tree root damage. The cumulative explanatory power of these 6 major indicators could explain > 98% of the adaptive performance of the plots, indicating their high explanatory capacity and could replace the 15 tree adaptive factors established in the factorial analysis.

Factors 1~6 were extracted from a reciprocal transformation of the original factor matrix and were further transformed to derive 3 major influential factors which are shown in Table 5. These 3 factors were named the tree status indicator, crown appearance indicator, and soil influence indicator. We regard these 3 factors as major factors that affect the health status of trees in the windbreak stands in the land subsidence regions. The definition and significance of the 3 factors are discussed here.

Component I: The tree status indicator

According to data of the factor extraction (Table 6), component (I) had a high degree of correlation with factor-indicators 1 (vitality of the tree crowns), 3 (soil pH), and 5 (tree flowering). Comparing the extraction results and by selecting factors of high commonality, we named component I the tree status indicator. Because the region suffers from the adverse effects of land subsidence, trees are often inundated with seawater for long periods of time and have to cope with high soil salinities, which exert a certain degree of influence on the growth and physiology of the trees. When the roots are inundated and suffer from a lack of oxygen, damage is exhibited and the uptake of nutrients and water is adversely affected. Root damage is often reflected in tree

Table 5. Structure of the matrix after a reciprocal transformation of the axis factors

Tree health indicator	Factor					
	1) Tree crown vitality indicator	2) Soil salinity	3) Soil pH value	4) Degree of tree diseases	5)Tree flowering	6) Degree of tree root damage
Crown density	**-0.818**	-0.137	0.186	0.271		
Crown light transmittance	**0.808**	0.150	-0.162	-0.304		
Crown dieback	**0.783**	0.181				0.177
Leaf falling rate	**0.759**	0.124	0.102		-0.110	0.194
Bark damage	0.425		0.412	0.259	0.180	
Soil salinity	-0.161	**0.833**	-0.116		0.201	
Subsidence	-0.290	**0.776**	0.128		-0.206	
Soil texture	-0.165	**0.665**	-0.492	0.187	0.295	-0.145
Soil pH value	-0.182	**0.542**	**0.535**	-0.221	-0.331	0.120
Natural regeneration			0.483	-0.342	-0.115	
Diseases	0.263		0.342	**0.525**	0.159	-0.282
Fruiting	-0.158	0.126		0.460	-0.456	0.349
Leaf coloration	0.302	0.113	0.253	0.363		-0.234
Flowering	-0.193		0.390	-0.316	**0.500**	
Root damage				0.126	0.476	**0.640**

Table 6. Results of the second matrix axis factor extraction

Second matrix axis factor extraction	Component		
	1. Tree status indicator	2. Crown appearance indicator	3. Soil influence indicator
Factor 1) Tree crown vitality indicator	**0.667**	**0.735**	-0.108
Factor 2) Soil salinity	0.419	0.317	**0.821**
Factor 3) Soil pH value	**0.926**	-0.143	-0.048
Factor 4) Degree of tree diseases	0.101	**-0.957**	0.021
Factor 5) Tree flowering	**0.949**	0.194	0.175
Factor 6) Degree of tree root damage	0.228	0.387	**-0.854**

crown morphologies as well as the health status of the trees. In addition, in lieu of normal flowering, trees endangered by environmental stresses often flower out of season when the tree attempts to propagate. Therefore, when trees are under stress, they often flower en masse, which becomes a symptom of the distress suffered by the trees. Based on these considerations, we named component I the tree status indicator.

Component II: The crown appearance indicator

The original factors that had a commonality of > 0.5 with component II were factors 1 (vitality of tree crowns) and 4 (the degree of tree diseases). Because of land subsidence problems, coupled with the effects caused by typhoons and torrential rains, crown dieback, wind tossing and tearing, and even stem breakage were often observed, causing gaps to appear in the crown layer of the stands and indirectly affecting the health status of the stands. Eventually, degradation of the stands ensued. When the roots or trunks of the trees are inundated or damaged, the growth status of the trees is initially affected. The roots are unable to provide sufficient nutrients and water, leading to signs of distress in tree crowns (USDA Forest Severice 2005). Damage such as a decrease in the crown densities, branch dieback, and wind-torn crowns caused lower values of the tree crown vitality indicators (Alexander and Palmer 1999). Hence, component II significantly emphasized the crown density and crown dieback of trees, and we named it the crown appearance indicator.

Component III: The soil influence indicator

The emphasis of component III of the double-extracted factor was mainly on the environmental status of the growing sites of the stands. The main factors affecting the stands were soil salinity, soil pH, and severity of land subsidence. Under the interactions of these factors, significant influences were exerted on tree adaption and the health status and were liable to cause a decline in tree growth. The problem of land subsidence is a result of overexploitation of land and underground aquifers. The problem of seawater inundation often leads to a danger of salination of the soil and underground water. Formation of saline soil might ensue with accumulation of soluble salts (such as sodium and chloride ions). High amounts of soluble salts exert their influence through osmotic pressure and root absorption which eventually endanger and limit tree growth, causing trees to weaken, or even become snags or dead. Furthermore, because windbreak forests are mostly sited in littoral areas, wind breakage or inundation are also factors affecting the health status of the forest. Hence, we named component III the soil influence indicator. Thus, component III was mostly shaped by the environment, and was able to cause serious stand degradation and even death, suggesting that the health status of the forest is subject to deep environmental control.

Tree adaptation and the health status are generalized tree growth performances and not really amenable to be analyzed by a few factors. Therefore, when the interrelated factors underwent matrix axis transformation, the eigenvalues provided weighting factors to explain the evaluation of the health status of trees (Table 7). The post-transformation factor matrix accorded the respective eigenvalue weighting factor X (Table 7), the normalization of which yielded the weighted score, X'. Finally, the weighted factor scores, X's, were applied for the health status evaluation of each stand, to derive the health status of the *Casuarina* windbreak forests (Table 8, Fig. 4).

Table 7. Generalized tree adaptation and health status of the Mailiao *Casuarina* windbreak stands

Mailiao	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	(X)	X'
	3.176	2.272	1.462	1.223	1.088	1.036		
1	0.858	-1.088	-0.353	-0.347	1.449	0.111	0.908	0.742
2	0.105	-0.720	-0.804	0.050	0.144	3.474	-1.658	-1.356
3	0.028	-0.794	-0.642	0.118	2.002	3.694	0.308	0.252
4	-0.065	-0.305	-0.644	0.674	0.221	-3.233	-1.335	-1.092
5	-0.875	-1.300	-0.350	0.847	0.101	0.400	-5.032	-4.116

Note: Due to the large dataset of sampled trees, the listed data represent an abstraction.

Table 8. Health level by season of the *Casuarina* windbreak plot stands

Plot	Average	Health level	Health level by season				
			Jan-08	Apr-08	July-08	Nov-08	Jan-09
Mailiao	-1.715	IV	-1.646	-0.204	-1.719	-3.377	-1.581
Sihu	-3.867	V	-2.784	-4.211	-4.253	-4.192	-4.044
Dongshi	2.280	I	3.109	2.339	1.901	1.202	2.763
Xinwen	0.584	II	2.058	0.345	-0.737	1.376	-0.610
Beimen	-1.156	IV	-0.204	1.075	-2.045	-2.959	-1.896
Jiangjun	-0.501	III	0.866	-0.557	-0.496	-1.239	-0.931
Chengsi	1.962	I	4.711	2.065	0.309	1.188	1.755

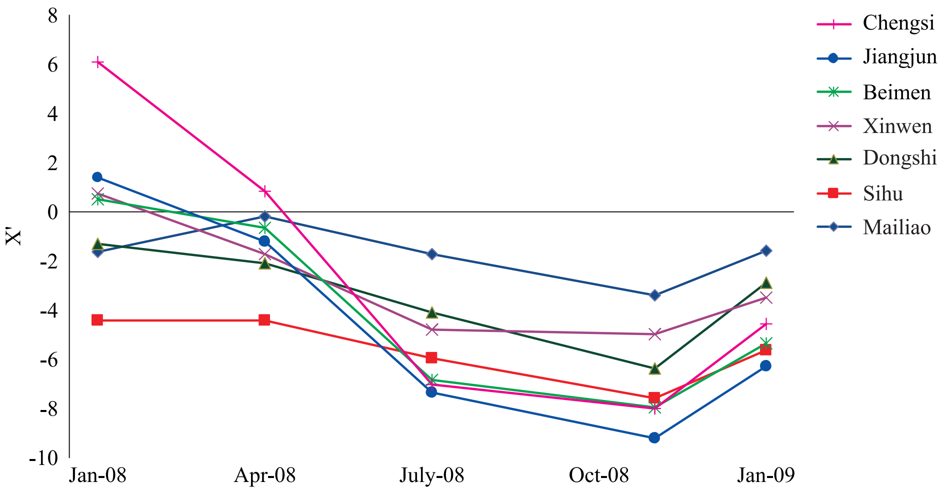

Fig. 4. Seasonal health curves of *Casuarina* windbreak stands on the southwestern coast of Taiwan.

The health status and trends of the *Casuarina* windbreak stands in Yulin, Chiayi, and Tainan Counties and Tainan City indicated that there were seasonal variations in their health conditions. At all test sites, stand health was poorer in summer and autumn than it was in winter and spring. This result points out that weather (in particular, typhoons) and amounts of precipitation are critical to the health of the stands. In addition, the trends of the health status at different test sites suggested that even though there was overall degradation, the degree differed by site. However, degeneration of coastal *Casuarina* windbreak stands is a symptom that needs immediate attention and management.

Figure 4 shows the seasonal health status of the sample sites. These curves of health status obviously changed seasonally. The health status of all stands in summer and autumn was less healthy, especially stands at Jiangjun which were extremely unhealthy. Furthermore, there was a recuperating trend for the stands in winter and spring. Except for an indistinct recovery degree at the Hsingwen stand, all other stands showed significant recovery from the more-adverse conditions in summer and autumn.

The health status of the stands also differed due to the degree of land subsidence and season. Variations in those factors directly or indirectly influenced the health status of the stands. We postulated that in summer and autumn, the decline in the stand health status was significantly influenced by a sites location in land-subsidence zones, caused by torrential rains brought by typhoons in the summer and autumn, and the inundation of surging seawater These factors caused forest sites to be waterlogged and have greater amounts of entrained salts. Long-term submergence rendered the trees susceptible to environmental stresses, and coupled with the osmotic pressure problem of the root systems, the trees might suffer from dehydration or the roots from anoxic conditions, that are detrimental to a tree's health. However, in winter and spring, retreating water levels caused trees to sustain less environmental harm, hence the tree health status recovered and showed better grow vigor than in summer and autumn.

According to the results of the analysis, the purposes of the discrimination analysis are to use graphic or algebraic means to describe the characteristics of differences among the datasets, so as to seek a differentiation function of the dataset that maximizes among-set differences. The estimated discrimination functions probe the relationship between the dependent or responsive variables and the explanatory variables (Table 8), and predict the probability of event occurrence. From the discrimination function, one can derive the grouping of responsive variables, create within-sample predictions, evaluate the goodness of fit of a model and prediction based on extrapolating the sample data, and explore the best sorting of the observed data (Shen 2007).

With regard to the windbreak forest stands at land-subsidence sites, to effectively retard the decline of *Casuarina* stands, active reforestation and forest compositional improvement measures should be undertaken. Long-term studies exploring the feasibility of establishing mixed stands and planting salt-tolerant, waterlog-resistant tree species to reduce environmental impacts and foster biodiversity of the ecosystem should be conducted. These actions are needed in order that the windbreak forests in land-subsidence zones of Yulin and Chiayi Counties can be sustainable.

CONCLUSIONS

In this study, we conducted a forest health monitoring survey plan at 7 locations of *Casuarina* windbreak forests. Through visual observations and grading of certain external growth morphology and degree of damage sustained, then by means of a main component factorial analysis, we managed to reduce the original 17 parameters to a grouping of 6 forest tree adaptation indicators: 1) crown vitality indicator; 2) soil salinity; 3) soil pH value; 4) degree of tree diseases; 5) tree flowering; and 6) degree of tree root damage. These 6 major factors affecting the tree adaptation accounted for > 98% of the total variance, meaning the 6 adaptation indicators had fairly strong explanatory power. We further extracted the 6 indicators using reciprocal matrix transformation to derive 3 major components, which were tree status, crown factors, and environmental effect factors. Thus, in addition to intrinsic tree growth, the effects of the external environment on the tree health status should not be neglected. Therefore, we transformed our visual survey results into quantifiable indicators and variables that can actually be measured to evaluate the tree health status. In addition, we focused on soil property analyses of windbreak forest stands and found that salt contents of the soils have significant effects on the growth and health trends of the trees.

LITERATURE CITED

Alexander SA, Palmer CJ. 1999. Forest health monitoring in the United States: first four years. Environ Monitor Assess 55:267-77.

APHA, AWWA, and WPCF. 1998. Standard methods for the examination of water and wastewater. 20th ed. Vol. 2 Baltimore, MD: United Book Press Inc. p 2-46-7.

Bouyoucos, GJ. 1962. Hydrometer method improved for making particle size analysis of soils. Agron J 54:464-5.

Chen TH, Chiu TY, Chen JS. 2008. Soil characteristics for the coastal forest at low wetland in Yunlin Sihhu. Chin Seasonal J For Sci 41(4):483-92. [in Chinese with English summary].

Chen TH, Sheu BH, Chang CT. 1996. Nutrient contents and inputs of precipitation, stemflow and throughfall in Shihu coastal Casuarinas stands, central Taiwan. Taiwan J For Sci 14(4):419-35. [in Chinese with English summary].

Chen TH, Sheu BH, Chang CT. 1998. Investigation on the nutrition amount for Casuarina forest at the coast of Sihhu. Taiwan J For Sci 13(3):225-35. [in Chinese with English summary].

Conkling BL, Byers GE. 2002. Forest inventory and analysis national core field guide. USDA Vol. 1. Field data collection procedures for phase 2 plots. Ver.1.6. 100 p.

Kolb M, Innes JL, Kaufmann E. 1994. Reliability of differing densities of sample grids used for the monitoring of forest condition in Europe. Environ Monitor Assess 29:201-20.

Li WZ. 2005. Study on the Casuarina forest health monitoring in northeastern coast of Taiwan [master's thesis]. Ilan, Taiwan: Department of Natural Resources, National Ilan Univ. 94 p. [in Chinese with English summary].

Lin CP, Chen TH, Chiu TY. 2005. Space and seasonal changes for soil enzyme activity at sand dune in the coast of Miaoli Houlong. Taiwan J For Sci 20(2):157-66. [in Chinese with English summary].

Liu LH. 2005. Study on the assessment method for health indices of coastal security forest – examples from north and middle part of Taiwan [master's thesis]. Pingtung, Taiwan: Department of Forestry Science, National Pingtung Univ of Science and Technology. 68 p. [in Chinese with English summary].

Liu LH, Yeh CL, Wang CH. 2007. Health indexes of coastal protection forests in northern and central Taiwan. J Exp For Natl Taiwan Univ 21(2):147-60.

Luo SF, Chen YT, Sha HC, Chen CT. 2008. Validity analysis and development for the index of tree health. Q J For Res 30(3):41-52.

Luo SF, Wei CH, Lee CC, Chen CT. 2009. Forest health inventory by remote sensing technology for the *Cryptomeria* plantation forest in Chitou area. Q J For Res 31(1):37-54.

Malo DD, Worchester BK, Cassel DK, Matzdort KD. 1974. Soil-landscape relationship in a closed drainage system. Soil Sci Soc Am J 38:813-8.

March GT. 2002. Phase 3 field guide-crowns: measurements and sampling. Asheville, NC: Southern Research Station USDA. 21 p.

Metzger JM, Oren R. 2001. The effect of crown dimensions transparency and the assessment of tree health. Ecol Appl 11(6):1634-40.

Redfern DB, Boswell RC. 2004. Assessment of crown condition in forest trees: comparison of methods, sources of variation and observer bias. For Ecol Manage.188:149-60.

Schimel DS, Stillwell MA, Woodmansee RG. 1985. Biogeochemistry of C, N and P in a soil catena of the short-grass steppe. Ecology 66(1):276-82.

Shen ML. 2007. Appractical multivariable analysis. Taipei, Taiwan: Jeou Chou Book Co. 608 p.

Smith WB. 2002. Forest inventory and analysis: a national inventory and monitoring program. Environ Pollut 116:233-42.

USDA Salinity Laboratory. 1954. Diagnosis and improvenment of saline and alkali soils. Washington: US Department of Agriculture (USDA) handbook. 160 p.

USDA Forest Severice 2002. Forest inventory and analysis national core field guide. USDA: phase 3 field guide-crowns: measurements and sampling. Washington: US Department of Agriculture (USDA). 21 p.

USDA Forest Severice 2005. Forest inventory and analysis national core field guide. National core field guide. Version 3. Washington: US Department of Agriculture (USDA). 203 p.

Wang ZH, Chen ZY. 2002. Creation for assessment method of forest health indices - examples from the old mature trees in Chilan. No. 91-6 Study series. Taipei, Taiwan: Forestry Bureau, Council of Agriculture, Executive Yuan. 47 p.