Research paper

Stand Adaptabilities in an Ecological Afforestion Study on the West Coast of Taiwan

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【Summary】

The Taiwan Forestry Bureau initiated an ecological afforestation project on the west coast of Taiwan in 2004 in order to renew and improve existing windbreak forests there. To understand the influences exerted by adverse environmental stresses on the afforested costal stands, the status of stand adaptability was monitored by examining interrelationships among tree adaptability morphologies and environmental indicators. This study spanned the period from 2009 to 2011 and monitored a total of 15 plots in which stands were surveyed. To monitor growth measurements and tree morphological characteristics in the plots and collect soil and meteorological data, 17 parameters were recorded. These data were then subjected to statistical multivariate analyses of variance. The main factors and their factorial analysis in turn allocated the parameters into 5 categories of tree adaptation level indicators, including crown vitality, climatic influences, soil properties, tree growth, and blooming and fructification performance. These indicators were capable of explaining 80.7% of the total variability. Further application of discriminant functions to individual explanatory indicators allowed adaptation levels of the stand trees to be ranked. Mos's predictive grouping of stands produced a 90% fit; indicating a high degree of predictability based on these indicators. The overall results indicated that presently the afforested stands had good adaptation levels, and 9 of them had reached a good adaptation level. Only the stands at Wutiaogang and Taixi had moderately poor adaptation levels. Furthermore, regression analyses of stand adaptation levels and environmental factors indicated that the precipitation amount showed a linear correlation with tree performance. Apparently, at present, forest tending practices should focus on maintaining soil moisture to enhance the adaptation level of the stands. Through quantification of this indicator and in combination with on-site observations, a basic reference for a rapid adaptability sorting evaluation of coastal ecological afforestation stands can be established.

Key words: evaluation monitoring, coastal windbreak forest, factor analysis.

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研究報告

台灣西部海岸生態造林林分之適應性研究

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摘 要

林務局自2004年起於台灣西部海岸推動生態造林計畫，以更新改良現有防風林分，為探討海岸逆境對其造林林分之影響，經由林木適應形態與環境間之指標因素，以探討其造林林分之適應現況。本研究即自2009至2011年間針對該林分進行調查，共設置15處樣區，經由樣區林木生長量測與林木形態性狀，收集樣區土壤及氣象資料等17項介量，再將資料進行多變量變異數統計，以主成分分析及其因素分析，可將所有介量(參數)歸類成5種林木適應性指標，包括樹冠活力、氣候影響、土壤性質、林木生長、開花結實表現，可解釋總變異數的80.7%，再經鑑別分析之典型鑑別函數進行個別解釋指標之檢定，驗證林木適應指標之評等，選擇莫式法進行預測歸類獲得90.0%吻合率，顯示指標的預測率很高，結果顯示目前生態造林林分之適應良好，9個樣區已達適應值以上，僅雲林縣五條港及台西屬於中度不適應等級；再以林分之適應性受到環境因子的影響而進行迴歸分析，結果以降水量呈現線性相關，顯然目前林分宜從水分維護作業等，以提升林分之適應性。透過此指標的量化，結合於現場的觀測，可將海岸生態造林之林分進行適應分類鑑別，提供快速評估之參考依據。

關鍵詞：評估監測、海岸防風林分、因素分析。

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INTRODUCTION

Being an island surrounded by sea, coastal forests of Taiwan are subjected to variable marine climatic conditions. In the past, the founction of coastal stands was environmental safety, hence tending, protection, and renewal practices were rarely carried out. In addition, in the past, most coastal forests were planted with *Casuarina* spp. which grew rapidly and provided the capability of stabilizing wind-blown sand soon after establishment. However, these trees are not prone to natural regeneration, are susceptible to infestion by insects, and have very short life spans when grown in adverse environments. As a consequence, stands often degenerated within several a few decades. Since the 1980, research on the understory planting of various windbreak species was undertaken in order to renew coastal forests. In Yunlin County coastal areas of west-central Taiwan, afforestation of multiple-species mixed forests was quite successful (Gan and Chen 1987).

At present, coastal forests are narrowly distributed. It is unrealistic to expect them to provide long-term disaster-prevention functions, so this has become a daunting and challenging task for the government. To effectively resist various forms of coastal erosion and tidal damage, establishing ecologically based coastal windbreak forests is an urgent issue. In the meantime, the health of the forests has received increasing attention as well. Since 1990, the Forest Service and Environmental Protection Agency (EPA) of the US have mutually developed a monitoring program to meet the needs of enacting laws and setting policies (USDA Forest Service 1992). The program deployed large-scale systematic sampling to conduct health monitoring of national forest ecosystems, and obtain information on the current status, variations, and long-term trends of forest ecosystems (Wang and Chen 2002). The Taiwan Forestry Bureau initiated an administrative program of ecological afforestation along the west coast of Taiwan in 2004. The program aimed to renew and improve existing windbreak forests. Presently, these forests are gradually entering important tending periods, which reflect the need to implement various tending practices before the tree crowns of the stands close. In view of the long growth cycle of trees, particularly coastal forests which experience all kinds of adverse climatic conditions and environmental stresses, it is imperative to apply tending practices in a timely manner to foster healthy stands and hasten crown closure while hoping the trees will be of good form and quality to provide enhanced protective functions.

In this study, we investigated the growth adaptability of stands in a coastal ecological afforestation program. Data on various influential factors at the sites were collected, and their effects on the stands were analyzed. We hope that by surveying the status of the forest belts, proper tending measures can be established, and these should provide a method for stand health evaluation of ecologically afforested forests of Taiwan.

MATERIALS AND METHODS

Setups of the plots

The west coastal stands of an ecological afforestation program implemented by the Taiwan Forestry Bureau in 2004 were studied in 2009~2011. Permanent sample plots were selected 90~980 m from the first line of coastal windbreak forests at several locations (Caota, Baishatun, etc.) which are good representations of areal forests in general (Table 1). Each plot consisted of a tract of a stand 10

Table 1. Basic information on the permanent plots

Sample plot	County/township	Coordinate position	Distance to sea (m)	Presence of a sea wall (height, m)
Caota	Taoyuan/Guanyin	25°04’N, 121°08’E	980	N
Baishatun	Taoyuan/Guanyin	25°03’N, 121°06’E	230	N
Haibin	Hsinchu	24°51’N, 120°56’E	110	Y 3m
Maoerding	Hsinchu/Zhubei	24°50’N, 120°55’E	210	N
Guogang	Miaoli/Houlong	24°36’N, 120°43’E	110	Y 3m
Haikou	Miaoli/Tongxiao	24°30’N, 120°40’E	130	Y 3m
Tongping	Miaoli/Yuanli	24°27’N, 120°38’E	160	Y 3m
Fangnan	Miaoli/Yuanli	24°25’N, 120°36’E	90	Y 4m
Wanggong	Changhua/Fangyuan	23°58’N, 120°19’E	180	Y 5m
Wutaiogang	Yunlin/Taixi	23°48’N, 120°09’E	150	N
Taixi	Yunlin/Taixi	23°46’N, 120°10’E	160	Y 4m
Aogu	Chiayi/Dongshi	23°29’N, 120°09’E	590	N
Xinwen	Chiayi/Budai	23°12’N, 120°04’E	190	Y 5m
Chengxi	Tainan/Annan	23°02’N, 120°05’E	120	Y 4m
Anping	Tainan/Anping	22°59’N, 120°08’E	75	N

N, no; Y, yes.

x 20 m, and 15 plots in total were established (Table 1, Fig. 1).

Growth survey

A survey of tree growth provides information on the growth vitality. The items of inventory survey included diameter at breast-height (DBH), basal diameter, tree height, and the below-crown height to the first live branch (HCB).

Soil analyses

At each plot, 4 soil sampling points were selected, and top soil (0~20 cm in depth) and base soil (20~40 cm in depth) pedons were separately dug up. Each soil sample was thoroughly mixed, air-dried, and sieved through a 20-mesh (0.84-mm holes) screen before analysis, in accordance with the procedures of Bouyoucos (1962). The soil salinity and pH were determined according to a grading rule of the USDA Salinity Lab (1954) using salinity and pH meters to measure saturated solutions (Table 2). In addition, the ammonium acetate method was also used (Rafahi 1982). A Hitachi P-4010 inductively coupled plasma (ICP) atomic emission spectrometer (Tokyo, Japan) was used to measure the soluble and

Fig. 1. Locations of the permanent plots.

Table 2. Soil salinities and pH values

Plot	Soil Depth (cm)	Conductivity (mmhos/cm)	Salinity level	pH value	Result
Caota	0~10	1.60±0.09	Very low	6.63±0.08	Neutral
	10~20	1.30±0.14	Very low	6.89±0.19	Neutral
Baishatun	0~10	1.80±0.02	Very low	7.51±0.06	W. alkal.
	10~20	1.90±0.07	Very low	7.23±0.08	Neutral
Haibin	0~10	1.40±0.03	Very low	6.96±0.28	Neutral
	10~20	1.50±0.03	Very low	7.29±0.05	Neutral
Maoerding	0~10	3.20±0.05	Low	7.71±0.21	W. alkal.
	10~20	3.60±0.21	Low	7.11±0.08	Neutral
Guogang	0~10	1.00±0.12	Very low	8.01±0.04	M. alkal.
	10~20	0.15±0.01	Very low	7.37±0.23	W. alkal.
Fangnan	0~10	3.90±0.25	Low	7.66±0.13	W. alkal.
	10~20	2.90±0.08	Low	7.25±0.02	Neutral
Haikou	0~10	1.10±0.47	Very low	7.55±0.15	W. alkal.
	10~20	1.80±0.23	Very low	7.32±0.05	W. alkal.
Haikou	0~10	1.10±0.04	Very low	7.33±0.51	W. alkal.
	10~20	1.60±0.14	Very low	6.98±0.04	Neutral
Wanggong	0~10	3.10±0.10	Low	7.53±0.07	W. alkal.
	10~20	2.40±0.34	Low	7.40±0.06	W. alkal.
Wutaiogang	0~10	15.70±0.17	High	7.65±0.02	W. alkal.
	10~20	19.20±0.21	Very high	7.34±0.21	W. alkal.
Taixi	0~10	41.00±0.10	Very high	7.46±0.12	W. alkal.
	10~20	45.80±1.27	Very high	7.02±0.04	Neutral
Aogu	0~10	10.80±0.36	High	7.78±0.15	W. alkal.
	10~20	12.20±0.21	High	7.43±0.02	W. alkal.
Xinwen	0~10	1.10±0.15	Very high	7.43±0.04	W. alkal.
	10~20	1.60±0.15	Very high	7.55±0.16	W. alkal.
Chengxi	0~10	2.10±0.25	Low	7.53±0.04	W. alkal.
	10~20	1.80±0.45	Very low	7.20±0.08	Neutral
Anping	0~10	4.00±0.37	Medium	7.36±0.15	W. alkal.
	10~20	5.80±0.18	Medium	7.31±0.32	W. alkal.

W. alakl., weakly alkaline; M. alkal., moderately alkaline.

replacable calcium, magnesium, and sodium concentrations.

Collection of meteorological information

Meteorological information was provided by observation stations of the Central Weather Bureau (CWB) next to the plots. These included the Guanyin, Hsinchu, Wanli, Lugang, Houanliao, Aogu, and Tainan Stations. Pertinent information was selected from the 2000~2011 period, including average temperature, precipitation, hours of sunshine, maximum instantaneous wind speed, etc.

Evaluation of the growth morphological characteristics of trees

The evaluation was done according to the Canadian Tree Growth Morphology method

(USDA Forest Service 2002).

The crown diameter was measured, and the average width of the tree crown was defined by the lateral branch extensions in various directions.

The crown ratio is the ratio of the live crown to the living tree height, in other words, crown ratio = (tree height – height of the first live branch)/tree height.

The crown density is the areal ratio in percentage of the crown that is impenetrable to sunlight to the entire crown area.

The see-through degree of the crown is the areal ratio of the tree crown that allows light penetration, in percentage.

The crown branch tip dieback consists of horizontal branches of the tree crown that show persistent dieback toward the stem, or dieback from the tree top downward. It is often present in the upper portion of a tree crown and the outer portion of the middle-upper crown.

Statistical analyses

The variables monitored were analyzed using a statistical software package of SPSS 12 (Liu 2005, Shen 2007).

Main factor analysis

A correlation matrix of individual variables was calculated to estimate their commonality. The common factors with eigenvalues of > 1, those with eigenvalues of < 0, and the extracted factors which could explain 75% of the variation were retained to determine the number of factors, $X' = (X_1, X_2, \ldots, X_k)$.

Factor 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:

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

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

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

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

Upon axis rotation of the determinant factors of the stand adaptation level, the explanatory quantity of the eigenvalues were weighted, and weighted factor (x) scores were calculated. Normalization of these gave x' values. Summing x' values of the sample trees in each plot and dividing by the number of sample trees produced the average adaptation level indicator (y). Multiplying y by √n gave Z_0 values; which when √n was subtracted became Z_1 values; subtracting √n from Z_1 gave Z_2 which equaled $Z_0 - 2\sqrt{n}$. Finally, a single-tail stand health determination was carried out in which a Z_0 value of < 1.645 indicated a healthy stand; Z_0 of > 1.645 denoted a slightly unhealthy stand; Z_1 of > 1.645 indicated a moderately unhealthy stand; and when $Z_2 > 1.645$, the stand was very unhealthy.

Discriminant analysis

The independent variables were screened step by step by re-evaluating the explanatory capacity of each independent variable with regard to its discrimaint function so as to derive the significance of each variable. A forward stepwise discriminate analysis was carried out, and a set of optimal classification numerical variables was selected.

Regression analysis of environmental factors and adaptability

Climatic and soil data of the plots were normalized, then a regression was run with the stand adaptation levels of the plots. Correlations among environmental factors and tree adaptability of the plots were analyzed. The significance of the factor analysis and environmental factors was analyzed.

RESULTS

Growth analysis of trees

Results of the net tree growth survey are shown in Table 3. The Taixi plot showed the greatest net tree height growth of 0.98 m. The plot also showed the greatest basal diameter growth of 2.34 cm. The Chengxi plot, on the other hand, exhibited the greatest DBH growth of 2.65 cm. The greatest net area of crown growth was also observed at the Taixi plot, reaching 2.01 m^2. Furthermore, the Fangnan plot had the greatest height to the first live branch of 1.81 m.

Analysis of soil factors

Salinity

Table 2 shows soil salinity determinations of the plots. The soil salinity of most plots was low. At Wutiaogang, Yunlin County, the base soil had the highest salinity, while Guogang, Miaoli County, had the lowest salinity. The topsoil at Wutiaogang was also extremely saline. In contrast, the Guogang plot had the lowest topsoil salinity of 1.00 ± 0.12 mmhos cm^{-1}.

Soil pH

Soil pH values of the test plots are also shown in Table 2. In general, soils of the plots were neutral to moderately alkaline, indicating that soils of the coastal belt contained water-soluble salt ions. Among the plots, the Guogang topsoil had a moderately alkaline pH which was the highest among all plots.

Exchangeable cations

The survey found that soil concentrations

Table 3. Growth performances of trees in the sample plots

Plot	Height (m)	Basal diameter (cm)	DBH (cm)	Crown area (m^2)	HCB (m)
Caota	0.345	1.220	0.898	0.122	0.011
Baishatun	0.109	0.463	0.714	0.270	0.126
Maoerding	0.487	1.258	0.750	0.860	0.136
Haibin	0.461	0.997	0.315	0.895	0.037
Guogang	0.237	0.972	0.338	0.388	0.048
Haikou	0.382	0.943	1.209	0.615	0.049
Tongping	0.392	0.706	1.309	0.345	0.001
Fangnan	0.358	0.964	1.225	0.678	0.181
Wanggong	0.473	1.578	1.623	0.831	0.089
Wutaiogang	0.222	0.871	0.266	0.795	0.012
Taixi	0.976	2.337	1.499	2.005	0.033
Aogu	0.665	1.038	1.541	0.265	0.115
Xinwen	0.408	1.948	0.477	0.589	0.061
Chengxi	0.307	1.325	2.646	0.569	0.042
Anping	0.163	0.153	0.146	0.954	0.006

DBH, diameter at breast-height; HCB, below-crown height to the first live branch.

of Ca^{2+} of the plots were between 1.38±0.05 and 8.77±0.45 cmol (+) kg^{-1} as shown in Table 4. Its concentrations in the sample plots were notably higher than those of other cations. Concentrations at Taixi, Maoerding, and Wutiaogang were the highest. Soil concentrations of Mg^{2+} were between 0.23±0.08 and 1.91±0.04 cmol (+) kg^{-1}. Aogu and Guogang had the highest and lowest Mg^{2+} concentrations, respectively. The highest salinity of 45.80±1.27 mmhos cm^{-1} observed at Tasi belonged to the extremely high salinity class, while the 1.00±0.12 mmhos cm^{-1} salinity of Guogang was the lowest.

Compilation of weather data

Weather data were collected from weather stations nearby the research sites. Among the items, those deemed to affect tree growth such as temperature, precipitation, maximum instantaneous wind speed, and hours of sunshine were analyzed according to the latitudinal distribution of the plot sites. The weather information is presented in Table 5.

Evaluation of stand adaptability

By measuring tree growth and morphological characteristics, and collecting soil and weather data, 17 parameters for the test plots were established. These were subjected to a main factor analysis, and factors were extracted through a factorial analysis. Accordingly, factors having a commonalty of < 0.01 (correlation coefficient < 1%) were rejected from further analysis (Table 6).

By turning the matrix axis, the main factor with higher weighting values were grouped together, and 5 indicators with significant effects on tree adaptability were obtained as shown in Table 7. Combining these indicators could explain 80.74% of the total variations, indicating they had good explanatory capacity, and could render the adaptability factor of a majority of trees in the stands. Thus, they were good forecasters of stand adaptation levels. When named according to their factor structural matrix, these indicators included crown vitality, climatic influences, soil properties, tree growth, and blossoming

Table 4. Cation concentrations in the soil

Plot	Concentration of exchangeable cations (cmol (+) kg^{-1})		
	Ca^{2+}	Mg^{2+}	Na^{+}
Caota	1.34±0.08	0.67±0.05	1.85±0.03
Baishatun	4.63±1.96	0.82±0.17	1.83±0.08
Maoerding	8.47±0.97	0.76±0.05	1.97±0.07
Haibin	1.89±0.15	0.36±0.03	1.77±0.04
Guogang	1.98±0.71	0.23±0.08	1.81±0.03
Haikou	2.98±1.13	0.43±0.07	1.82±0.07
Tongping	2.01±0.12	0.64±0.02	1.91±0.04
Fangnan	1.38±0.05	0.39±0.01	1.76±0.04
Wanggong	3.92±0.41	0.66±0.03	1.85±0.07
Wutaiogang	8.77±0.45	1.69±0.10	4.42±0.13
Taixi	8.15±0.71	1.31±0.09	2.78±0.10
Aogu	6.18±1.56	1.91±0.04	2.91±0.05
Xinwen	6.17±2.69	0.44±0.02	1.88±0.11
Chengxi	5.56±1.14	0.68±0.07	1.76±0.06
Anping	5.49±1.64	0.75±0.01	2.17±0.53

and fructification performances.

Adaptation levels of the stands

Evaluation of adaptation levels of the stands was based on a synthetic indicator of tree external morphological characteristics. Thus, explanatory capacities of the eigenvalues obtained upon axis rotation of the adaptability indicator causal factors matrix were weighted for the evaluation, and then the

Table 5. Weather data of the sample plots

	Average temperature (℃)	Precipitation (mm mo^{-1})	Hours of sunshine	Maximun instantaneous wind speed (m s^{-1})
Caota	16.4	72.1	73.1	12.1
Baishatun	16.3	71.0	83.3	12.4
Maoerding	16.5	58.1	76.5	17.5
Haibin	16.5	56.4	95.1	17.9
Guogang	16.6	46.4	162.0	14.9
Haikou	16.7	40.2	163.3	15.2
Tongping	16.6	37.3	164.0	15.5
Fangnan	16.8	36.2	165.5	15.8
Wanggong	17.2	17.9	166.9	16.1
Wutaiogang	17.8	16.6	162.5	18.3
Taixi	17.9	18.0	162.8	17.6
Aogu	17.5	29.8	159.1	14.2
Xinwen	17.2	24.6	160.8	12.3
Chengxi	18.6	21.5	165.2	18.1
Anping	18.7	20.7	165.6	18.7

Table 6. Total variance explained

Component	Initial characteristic value		
	Total	Variance (%)	Cumulative (%)
Crown dieback	4.478	26.343	26.343
Foliage falling	3.778	22.225	48.568
Foliage withering	2.656	15.625	64.193
Transmittance	1.670	9.823	74.016
Crown density	1.143	6.725	80.741
Precipitation	0.736	4.330	85.071
Hours of sunshine	0.613	3.603	88.675
Wind speed	0.462	2.716	91.391
Temperature	0.348	2.050	93.441
Na cation	0.316	1.858	95.299
Salinity	0.247	1.454	96.752
Mg cation	0.210	1.238	97.990
Crown area	0.151	0.889	98.879
Tree height	0.125	0.735	99.615
Stem base	0.047	0.277	99.891
Blossoming	0.011	0.062	99.954
Frucitification	0.008	0.046	100.000

Table 7. Matrix structure of axis factors

	Composition				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Crown dieback	0.912	-0.006	-0.025	0.001	-0.029
Foliage falling	0.875	0.029	0.052	0.039	-0.011
Foliage withering	0.870	0.035	-0.035	-0.017	-0.043
Transmittance	0.799	0.073	0.084	-0.318	-0.097
Crown density	-0.783	-0.082	-0.045	0.361	0.105
Precipitation	-0.103	-0.965	-0.131	-0.139	-0.021
Hours of sunshine	0.110	0.897	0.080	0.058	-0.010
Wind speed	0.090	0.795	-0.360	0.034	0.082
Temperature	-0.145	0.727	0.259	0.287	0.007
Na cation	0.042	0.107	0.972	0.104	-0.017
Salinity	0.099	0.091	0.943	0.077	-0.040
Mg cation	-0.034	-0.053	0.887	0.103	0.105
Crown area	-0.088	0.098	0.066	0.910	0.026
Tree height	-0.088	0.128	0.080	0.893	0.154
Stem base	-0.212	0.227	0.186	0.803	0.142
Blossoming	-0.118	-0.021	0.085	0.013	0.840
Fructification	-0.041	0.083	-0.051	0.239	0.751

health status of individual stands was evaluated accordingly. Four grades were obtained, with grade I denoting good adaptability (good); grade II, slightly maladapted (fair); grade III, moderately maladapted (poor); and grade IV, heavily maladapted (very poor). Grades of the test plots along the coast are shown in Table 8. From our observations of the health status of the west coast windbreak forests, stand adaptation levels varied from good to moderately poor (Table 8).

Most test plots showed good adaptation; whereas stands at Wanggong, Aogu, Chengxi, and Anping were graded as slightly maladapted. Wutiaogang and Taixi in Yulin County were moderately maladapted. During our survey at the Taixi plot, we noted that the wind exerted tremendous influences. The dilapidated wind fence there had resulted in the demise of many trees. In addition, the 2 sites have extremely high-salinity soils which further hindered tree growth. The afforestation plot of Aogu is right next to the coast, and summertime inundations are frequent which also lead to high soil salinities and retarded tree growth. The slight maladaptation at Wanggong, Changhua County, was deemed to be due to strong monsoon winds in wintertime, coupled with the fact that the plot was next to a river without on embankment. Whenever there are torrential rains, inundations take place. Tree mortality at Baisatun, Taoyuan County was the lowest among all plots. There are intact wind fences which are supplemented by timely weeding practices. The 6 species planted there all showed very good growth.

Discriminant analysis

When the stepwise regression discriminating method was applied to the influential variables and stand adaptation levels, typical discriminant functions were derived. *F*-tests of the typical discrimiant functions all pro-

Table 8. Adaptation levels of the plots

Plot	No. of trees (*n*)	Mortality	x’	Y	$\sqrt{n}$	Z_0	Z_1	Z_2	Grade
Caota	39	0.33	-54.7	-1.40	6.24	-8.76	-15.01	-21.25	I
Baishatun	130	0.03	-119.5	-0.91	11.40	-10.48	-21.89	-33.29	I
Maoerding	45	0.08	-47.7	-1.06	6.71	-7.12	-13.83	-20.53	I
Haibin	57	0.21	-45.8	-0.80	7.54	-6.06	-13.61	-21.16	I
Guogang	88	0.27	6.8	0.07	9.38	0.73	-8.64	-18.02	I
Haikou	84	0.20	-21.6	-0.25	9.16	-2.35	-11.52	-20.68	I
Tongping	97	0.34	-21.9	-0.22	9.84	-2.22	-12.07	-21.92	I
Fangnan	45	0.31	8.5	0.18	6.71	1.26	-5.43	-12.14	I
Wanggong	71	0.11	82.3	1.15	8.42	9.76	1.34	-7.08	II
Wutaiogang	53	0.22	76.3	1.44	7.28	10.48	3.21	-4.07	III
Taixi	34	0.26	53.7	1.58	5.83	9.21	3.38	-2.44	III
Aogu	45	0.06	22.5	0.50	6.71	3.35	-3.35	-10.05	II
Xinwen	93	0.22	-10.3	-0.11	9.64	-1.07	-10.71	-20.36	I
Chengxi	72	0.31	16.5	0.23	8.48	1.95	-6.53	-15.01	II
Anping	59	0.10	29.9	0.51	7.68	3.89	-3.78	-11.46	II

Y, average of indicator; *n*, number of sample trees; $Z_0 < 1.645$ denotes “good” adaptability (grade I); $Z_0 > 1.645$ denotes “fair” adapatability (grade II); $Z_1 > 1.645$ denotes “poor” adaptability (grade III) and $Z_2 > 1.645$ denotes “very poor” adaptability (grade IV).

duced *F*-values of < 0.05, indicating a significant level for the influential variables. Thus, all influential variables have an explanatory capacity. Subsequently, the typical discriminant functions derived from the 17 variables were tested for their Wilks’ lambda values, all of which had *p* values of < 0.05, indicating that all the coefficient of the discriminant functions had significant explanatory power. Subsequently, a Fisher linear discriminant function was applied to observe the discriminating capacity of individual variables of the stand health status. Coefficients of the functions are shown in Table 9.

In this study, Mos’s method of predicting classification was applied and compared to the original classification as shown in Table 10. In the original grading probabilities, the average fit was 90.0%; upon the cross-validation in which each observed value was classified according to a function of all other observed values, a 88.8% correct ratio was obtained.

Regression analysis of environmental factors and stand adaptability

In our investigation of stand tree adaptability, in addition to the conditions of tree crown growth and stress damage, influential factors of the ecological environment should also be included. Thus, regressions between environmental factors (climatic and soil) and stand adaptation levels were run, and their coefficients of determination (R^2) are shown in Table 11. Among the factors, precipitation showed the highest linear correlation with the normalized adaptation scores, while Ca cation and wind speed showed the lowest (Fig. 2).

DISCUSSION

Evaluation of stand tree adaptability is an abstract concept; as a consequence, its

Table 9. Coefficients of the Fisher linear discriminant function

	Adaptation level			
	Good	Fair	Poor	Very poor
Tree height	-1.57	-1.13	-0.17	1.34
Stem base	-3.05	-2.06	-1.77	-0.98
Crown area	0.63	1.51	1.36	2.04
Crown density	16.68	16.08	15.73	14.68
Crown transmittance	14.30	14.67	14.93	14.70
Crown dieback	0.34	0.77	0.93	1.10
Foliage withering	-0.19	0.36	1.06	1.97
Foliage falling	0.34	0.94	1.58	2.44
Blossoming	-4.11	-1.12	5.24	6.06
Fructification	5.45	10.21	19.94	21.25
Salinity	-4.69	-7.26	-2.33	5.29
Temperature	2.26	3.24	2.21	2.18
Precipitation	6.16	5.02	-1.96	-9.01
Hours of sunshine	4.02	4.37	-0.34	-4.25
Wind speed	0.88	2.84	3.19	1.52
Mg cation	-1.49	0.07	0.25	1.74
Na cation	4.02	9.11	7.61	3.07
(constant)	-82.11	-85.62	-96.95	-114.99

Table 10. Results of adaptation levels of the cross-validated classification

	Adaptation level	Prediction				Total
		Good	Fair	Poor	Very poor	
Original probability	Good	94.5	5.5	0.0	0.0	100.0
	Fair	0.4	88.6	11.0	0.0	100.0
	Poor	0.0	16.8	77.9	5.3	100.0
	Very poor	0.0	0.0	21.8	78.2	100.0
Cross-validation probability	Good	93.7	6.3	0.0	0.0	100.0
	Fair	0.9	88.2	11.0	0.0	100.0
	Poor	0.0	18.9	73.7	7.4	100.0
	Very poor	0.0	0.0	23.6	76.4	100.0

Table 11. R^2 values of environmental factors

Climatic factors	R^2	Soil factors	R^2
Temperature	0.455	Salinity	0.390
Precipitation	0.803	pH value	0.220
Hours of sunshine	0.667	Ca cations	0.206
Wind speed	0.223	Mg cations	0.251

embodiment must adopt visual observations of various morphological features and minimize the influence of subjective factors (Ho and Tsai 2011). Therefore, in this study, a main factor analysis was conducted with regards to morphological characteristics of stand trees. Then through a factor analysis,

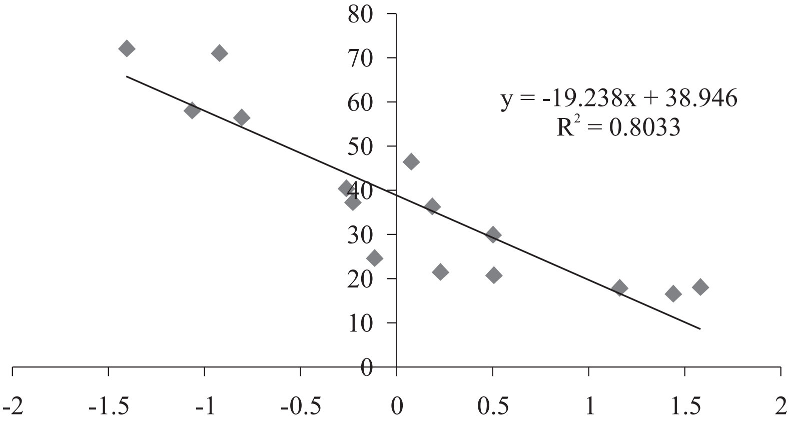

Fig. 2. Dspersal diagram of precipitation and adaptation factor scores.

factors reflecting the status of stand tree adaptability were extracted. Through axis turning of the factor matrix, factors with higher weighting scores were grouped together to derive 5 indicators of stand tree adaptation levels. These indicators were capable of explaining 80.74% of the total variation; suggesting that they were fairly self-explanatory and were representative factors of stand tree adaptation levels. They were also deemed capable of forecasting growth adaptation of trees. Based on the factor structural matrix, these indicators were named accordingly and included crown vitality, climatic influences, soil properties, tree growth, and blossoming and fructification performance.

The aforementioned adaptability indicators for ecological afforestation of Taiwan's west coast, of which crown density, transmittance, crown dieback, foliage falling, and foliage wither belonged to the crown vitality indicator, reflected the growth vigor and variation of tree crowns. Soil inundation and salinity directly or indirectly affect tree crowns and growth of foliage. Liu (2005) used a tree crown coverage factor as an important indicator of plantation tree growth conditions. Thus, damage due to environmental stresses is reflected by the degree of vitality which a tree crown exhibits, and the status of tree growth is directly or indirectly reflected by the growth of crowns; particularly the condition of branch tip dieback. This often appeared on the upper portion of a crown or the ends of lateral branches. Withering of foliage and early falling of foliage also portend decreases in crown growth vigor which also leads to decreased crown area percentages.

Factors represented in the climatic influences indicator included 4 items of average precipitation, average hours of sunshine, maximum instantaneous wind speed, and average temperature. Influenced by different environmental climatic conditions, tree growth tends to differ. Lee et al. (1993) mentioned the climatic conditions of their experimental site, in which except for June, transpiration rates were greater than precipitation. The condition was particularly serious during the northeasterly monsoon season. Wind speeds were higher during the period from October to March which also adversely affects tree growth conditions. In view of these situations, the indicator was named climatic influences.

The soil property indicator was based on soil salinity possibly affecting the soil status and the dynamics of soil nutrient variations. Exchangable cations in the soil, which are also effective nutrients usable to plants, and a lack of some ions often lead to dysfunction in nutrient uptake. Chen et al. (1996, 1998) pointed out that old-growth sandy coastal forests often gradually become enriched along with tree growth. An increase in tree age is accompanied by accumulation of litter on the ground, and mineralization of the forest bed organic matter often produces humic acid upon its decomposition, causing pH values of the top layer of soil to decrease (Horng and Cheng 1993, 1996). Hence, this indicator was named soil properties. Our survey also indicated that pH values of the plots were between 6.63 ± 0.08 and 8.01 ± 0.04 and there was no distinctive difference between the top and bottom soils. We surmised that this was because the soils were supporting newly planted trees with scanty sapling cover, and there were still large amounts of accumulated litter on the ground. The low humus content of the surface soil caused there to be only minor differences between the soil layers (Table 2). Thus, the soils were lacking humic substances, and tree growth might have been adversely affected at this stage. In addition, soil conditions were not conducive to retaining water and nutrients. Upong further tree growth, however, the soil environment should gradually improve.

The tree growth indicator included 3 factors of crown area, tree height, and basal diameter. Basic tree growth status information is directly reflected by height growth, diameter growth, and crown area. Lin and Tang (1999) in their investigation noted that due to impacts of the northeasterly monsoon, the windward basal diameters and tree heights of plantation species were inferior to those of leeward ones. Accumulation of litter was also less on the windward side than on the leeward side. Thus, the status of tree growth is also an important indicator. In addition, the blossoming and fructification performance indicator which encompassed the appearance of flowers and fruits was mainly influenced by the innate flowering and fruiting seasons. However, in littoral regions, where trees are subjected to immense environmental stresses, and when faced with decline or demise, trees often undergo large-scale flowering and fruiting as a mechanism to produce progeny. In addition, Lin et al. (2009) also noted that these plantations have flowering or fruiting phenomena, indicating that these endemic species-based plantations have a self-regeneration capability. In choosing afforestation species, such species should be prioritized.

Summation of the weighted factor scores from the factor analysis gives an indicator of individual stand adaptability. And the discriminant analysis provides grading of their status differentiation. When factors were extracted with a commonality of > 0.01 in the factor analysis (i.e., with a maximum correlation coefficient of > 1%), then using the varimax function of the discriminant analysis obtained by turning the matrix axis, the inter-factor explanatory power was increased, and the turned factor matrix has each indicator pegged to one or a few factors. The complexity among the indicators was simplified, and the quantities of explanation were simplified as well. The correlations between factors and hidden factors became more prominent in the meantime. In addition, the relative importance of the monitored items was directly reflected in the coefficients of the discriminant functions.

In using a typical discriminant method to conduct statistical models and test explanatory variable hypotheses, the discriminating power of individual explanatory variables are weighted, and ones with the grestest explanatory power are chosen. These are used to establish a predictive probability function and are subjected to a cross-validation process to assess their accuracy. Usually the degree of fit is evaluated. The higher the degree of fit, the greater is the predictive capacity. In this study, Mos's method was employed to generate predictive grading and original grading. In the original grading, the average degree of fit was 90.0%; while for cross-validation, each observation was graded according to a function of all other observations; and an 88.8% cross-validation degree of fit was obtained. Hence, Chiou (2003) also concluded that the adaptability of stand trees should belong to a graded reaction variable, using a discriminant analysis to examine influential factors and find related variables. In evaluating tree vitality differentiation of a coastal protective forest, in addition to monitoring all risk factors of the existing stand, its potential adaptation performance should also be predicted. Furthermore, through the use of Fisher's method to grade the observation data, or to predict to which grade the observations belong, the observation data are pegged to the grading function of the adaptation grades and compared to the function values. The greater the function value is, the better is the observations' adaptation. The equation can provide a rapid grading of stand conditions during coastal forest surveys. When used in conjunction with stand adaptation level grades established earlier, a stepwise regression procedure can be used to obtain typical discriminant functions. Chiou (2003) was the first researcher to apply typical discriminant functions and found good predictive capability for west-coast forests of Taiwan. Chiou (2003) studied stand tree adaptability grading based on original observational variables, and obtained a good fit between the predictive grading and actual grading. Hence, discriminant functions have good predictive capability to effectively differentiate health grades of afforested saplings in the west littoral regions of Taiwan. Through establishing discriminant functions, valuable evaluation information on coastal forest stand health can be constructed. These will be helpful in the future to provide a basis for tree growth adaptability evaluations by overseeing organizations. In view of the limitations of fieldwork capability and funding, we can gradually apply the concept of discriminant analysis to select indicators with good differentiating ability and reduce the number of survey items in fieldwork so as to increase efficiency of manpower while still attaining accurate predictions.

Stand adaptability evaluation adopts a synthetic indicator based on the external morphological features of trees. Therefore when the causal factor matrix was turned along its axis, the resulting eigenvalues served as a weighting of the explanatory power. These in turn were used to deduce the adaptability of the stand in each plot and its adaptation level. The interrelationship among environmental factors and stand adaptability indicated that precipitation exerted a linear effect with $R^2 = 0.803$. Because of the extended range of coastal forests and the predominant sandy soils of the plots, drainage is rapid, and water retention is problematic. Figure 2 shows that the amount of precipitation was linearly correlated to the y-axis (adaptation levels); in other words, the heavier the rainfall, the healthier the stand became. The rainfall amount thus has a certain importance to a newly planted forest. On the west coast of Taiwan, northern parts have more precipitation. The plant communities are consistently battered by monsoons, high temperature in summertime, and salty fogs. The health of stands suffers severe challenges there.

In our observation of the health status of west-coast windbreak forests, the stand adaptation levels were from good to moderately poor (Table 8). Most test plots showed good adaptation; whereas stands at Wanggong, Aogu, Chengxi, and Anping were graded as slightly maladapted. Wutiaogang and Taixi in Yunlin County were moderately maladapted. During our survey at the Taixi plot, we noted that wind exerts tremendous influences. The dilapidated wind fence there had caused the demise of many trees. In addition, the 2 sites have extremely high-salinity soils which further hindered tree growth. The afforestated plot at Aogu is right next to the coast, and summertime inundations are frequent which also lead to high soil salinities and retarded tree growth. The slight maladaptation at Wanggong, Changhua County, was deemed due to strong monsoon winds in wintertime coupled with the fact that the plot was next to a river without an embankment. Whenever there are torrential rains, inundations take place. Tree mortality at Baishatun, Taoyaun County was the lowest among all plots. There are intact wind fences which are supplemented by timely weeding practices. The 6 species planted there all showed very good growth.

CONCLUSIONS

Since 2004, the Taiwan Forestry Bureau has implemented an ecological afforestation program on the west coast of Taiwan. By surveying tree growth and morphological features, collecting soil and weather information in the test plots, we carried out a main factor analysis of a multivariate analysis of variance and factor analysis to group all parameters into 5 stand tree adaptability indicators, including crown vitality, climatic influences, soil properties, tree growth, and blossoming and fructification performance. The results indicated that at present, most of the ecological afforestation tracts have adapted well, with 9 plots showing scores above an adequate adaptation level; only the Wutiaogang and Taixi plots were moderately maladapted. A further discriminant analysis generated typical discriminant functions to test individual explanatory indicators, and ascertained the adaptation level grading. Then Mos's method was selected and indicated that the predictive grading had a 90.0% fit, suggesting that the indicators had high predictive accuracies. Regression analyses among stand tree adaptation levels and environmental factors indicated a linear correlation between precipitation and adaptation levels. Thus, at present, water retention practices for stands are critical for enhancing stand adaptability. In addition, quantification of the 5 indicators combined with field observations should enable proper grading of coastal afforestation sites and provide a basis for the rapid evaluation of a stand's status.

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