Effects of Climate Factors on Normalized Difference Vegetation Index Taking from Satellite Remote Sensing at the Mt. Huangzui area of Taiwan

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Abstract

Eight sets of SPOT satellite images, covering nine years from 1994 to 2002 and equivalent to eight months, were used to monitor seasonal changes in the normalized difference vegetation index (NDVI) over the Mt. Huangzui area in the Yangminshan National Park of northern Taiwan. The grey system theory was applied to analyze the degree of contribution of the five climate factors on NDVI of four major vegetation types *Axonopus affinis*, *Miscanthus foridulus*, *Eurya crenatifolia* and broad leaf vegetation. Results from grey relational analysis showed that the contribution of climate factors to satellite NDVI can be ranked in order of monthly mean temperature＞daily cumulative irradiance＞daily insolation percentage＞monthly mean relative humidity＞monthly cumulative precipitation. It suggests that light and temperature-related climate factors play more important roles in determining the satellite NDVI than water-related climate factors in the Mt. Huangzui area.

Keywords: Climate factor, Normalized difference vegetation index, Satellite remote sensing, Mt. Huangzui area.

氣候因子對磺嘴山地區植被衛星遙測植生指數之影響

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摘要

本研究應用九個年度涵蓋四季分佈在八個月份之 SPOT 衛星遙測資料，監測陽明山國家公園磺嘴山植生指數(normalized difference vegetation index , NDVI)之季節性變化；並以灰關聯理論分析五種氣候因子(即累積降雨量、平均相對溼度、日照率、平均氣溫、與累積全天日射量)對類地毯草、五節芒、假柃木及闊葉林的衛星遙測植生指數之灰關聯性。灰關聯度與灰關聯序顯示，在磺嘴山這五種氣候因子對衛星遙測植生指數之貢獻度為：月均溫＞日射量＞日照率＞溼度＞降雨量。由此可知，光線及溫度對磺嘴山的衛星遙測植生指數之影響較水分重要。

關鍵詞：氣候因子、植生指數、衛星遙測、磺嘴山。

INTRODUCTION

Satellite remote sensing has been used in plant science research to monitor long-term and large-scale changes in vegetation (Oechel and Reid 1984, Jakubauskas *et al.* 1990), photosynthesis of terrestrial plants (Field *et al.* 1994), changes in canopy structure and density (Malanson and Trabaud 1987), recovery of primary production (Specht 1981, Tucker and Sellers 1986), regrowth rates and biomass production of the forest (Viedma *et al.* 1996), rates and models of recovery (Viedma *et al.* 1997), and other aspects of the ecological recovery processes.

The climate status－often associated with light, temperature, precipitation, relative humidity, wind, and so forth－is made up of fundamental forest parameters affecting the growth of vegetation. Significant progress has been made in the past three decades in the spectral identification and analysis of chlorophyll for the remote sensing of vegetation (Hsu *et al.* 2003). However, in nature, the upwelling radiance from the forest is a combined effect of all vegetation components in the forest affected by the complex climate status. Determining each individual climatic factors contribution to the total reflectance signal is crucial, but this cannot be done using traditional approadies of mathematics or statistics. However, it can be done using grey system theory.

The grey system theory, formulated by Deng (1982), is used for systems when some information is clear and some is not. With only limited data, the theory can effectively deal with the poor, incomplete, or uncertain problems of a system. It can be used to study the relationship between known and unknown information, and includes six methodologies, grey generation, grey relational analysis, grey modeling, grey prediction, grey decision making, and grey control (Deng 1982 and 1989). Since the system developed, researchers in various fields have applied the theory to the handling of their data. Grey relation analysis is generally used to describe the posture relationship between one main factor and all the other factors in a given system. The known information is based on standard patterns (reference or control patterns). The grey relational value thus is used to reflect the relationship between a reference condition and a test condition. With the analysis, the most important factor affecting a subject, can be identified such as a topological effect on an ecological environment (Che and He 1993), a serum marker's effect on the detection of liver fibrosis (Chen and Tan 1995), the relationship between lint yield and cotton fiber quality (Chen 1990), or the relationship between main quality and agronomic characters of wheat (Guo *et al.* 1991).

Recently, grey relational analysis was successfully used to compare the contribution of individual antioxidants to total antioxidative capacity or function in various measurement systems (Chao *et al.* 2001, Chu *et al.* 2003). Grey decision making was used to identify herb plants with the highest antioxidative capacity and function for marketing (Chung 2001). In this way, chlorophylls and their derivatives with less or non-polar chemical structures were found to contribute much more to the normalized difference vegetation index (NDVI) than those with more polarity. The former are located in the thylakoid membrane and the latter in the stroma of higher plant chloroplasts (Yang 2001). In a study on the recovery of a landslide-dammed lake of Chi-Chi earthquake-caused landslide, grey relational analysis showed that inorganic matter played a much larger role than organic matter did; and BOD, PO_4^-, NH_4^+, NO_3^-, and NO_2^- contributed the least of all physico-chemical variables (Wu *et al.* 2003). This is the first report to use a grey relational analysis to solve an important question in limnology unresolved by traditional mathematics and statistics.

In a previous study, combining the satellite data and grey system theory, we found that water-related climate factors, such as precipitation and relative humidity, played more important roles in satellite remote sensing brightness index (BRI) of carpetgrass in the Mt. Huangzui area than did temperature-related climate factors, such as insolation percentage, temperature, and irradiance (Huang *et al.* 2003). In this study, we further employ grey relational analysis to pinpoint the most important contribution or to compare the contribution degree of five climate variables determined on the ground to the NDVI of four vegetation types in the Mt. Huangzui area monitored by SPOT satellite in space.

MATERIALS and METHODS

Study Site

Mt. Huangzui is located in the eastern part of Yangminshan National Park in northern Taiwan and belongs to the Datun volcanic group, which consists of more than twenty volcanoes in the park. The geology is mainly andesite. Mt. Huangzui with its height of 912 m is a conical volcano. The peak of Mt. Huangzui is a wide area and forms a U-shape, the orifice of which points to the north (Fig. 1). It has a volcanic crater, around 500 m in diameter and 60 m in depth. It has been appointed as a conservation zone since 1983 owing to its primitive landscape and abundant biodiversity (Huang 2002).

Climate Data

The climate data covering the period from 1993 to 2002 and including monthly mean temperature, daily cumulative irradiance, mean insolation percentage, monthly cumulative precipitation, and monthly relative humidity, were obtained from the Central Bureau of Weather of Transportation Department. The weather data were recorded by the Chisingshan Station, around 7 km away from Mt. Huangzui.

Satellite Data

Eight sets of orthorectified SPOT satellite digital data of process level 10 were purchased from the Center for Space and Remote Sensing Research, National Central University at Chungli City, Hsin-Chu County, Taiwan. The data were collected on 12/11/1994, 1/6/1995, 3/15/1996, 5/15/1997, 7/22/1996, 8/17/1999, 11/14/1997, and 6/23/2002, equivalent to December, January, March, May, July, August, November and June in a year, respectively. All images were free of cloud. The ground investigation was conducted on 10/14/2002 to confirm the satellite remote sensing data.

Normalized Difference Vegetation Index

The reflectance index of vegetation used in this study was defined by the equation $(IR_{790\sim890} - R_{610\sim680})/(IR_{790\sim890} + R_{610\sim680})$, generally named the normalized difference vegetation index (Elvidge and Chen 1975).

Grey Relational Analysis

The five constituents of climate status were treated as a comparison or test series, and satellite NDVI was used as a reference series. The basic principle and method of grey relational analysis are as follows (Deng 1982 and 1989).

(1) Normalization of original data series:

Mean value normalization method is applied in the data series treatment. For example:

If the original data is $x_0(k) = (x(1), x(2), x(3),\ldots,x(k))$, then the initial normalization data series is $x_0^* = (\frac{x(1)}{x(1)}, \frac{x(2)}{x(1)}, \frac{x(3)}{x(1)}, \ldots, \frac{x(k)}{x(1)})$. If the mean value of the original data is $\overline{X}$, then the mean value normalization data series becomes $x_0^* = (\frac{x(1)}{\overline{X}}, \frac{x(2)}{\overline{X}}, \frac{x(3)}{\overline{X}}, \ldots, \frac{x(k)}{\overline{X}})$, where $\overline{X} = \frac{1}{n}\sum_{k=1}^{n} x(k)$.

(2) The grey relational coefficient γ is defined as follows :

$$\gamma(x_0(k), x_j(k)) = \frac{\min_j \min_k \left\| x_0(k) - x_j(k) \right\| + \zeta \max_j \max_k \left\| x_0(k) - x_j(k) \right\|}{\left\| x_0(k) - x_j(k) \right\| + \zeta \max_j \max_k \left\| x_0(k) - x_j(k) \right\|}$$

where

$j = 1, \ldots, m$; j is the identification coefficient; its value is taken as [0,1], usually,

$k = 1, \ldots, n$.

$\gamma = 0.5$.

x_0 is the reference data series.

x_j is the test data series.

$\left\| x_0(k) - x_j(k) \right\|$ is the absolute value (norm) of the difference between $x_0(k)$ and $x_j(k)$.

$\min_j \min_k \left\| x_0(k) - x_j(k) \right\|$ is called the secondary minimum difference which is selected in all j.

$\min_k \left\| x_0(k) - x_j(k) \right\|$ is called the first minimum difference which is selected in all k.

all the same as *max max*.

(3) The grey relational grade $\gamma^*(x_0(k), x_j(k))$ is

$$\gamma^*(x_0(k), x_j(k)) = \frac{1}{n}\sum_{k=1}^{n}\gamma(x_0(k), x_j(k)) .$$

(4) Rearrangement of grey relational grade from large value to small value in a series.

The grey relational grade has the following characteristics:

a. $0 \le \gamma^* \le 1$.

b. The more similar the test data $x_j(k)$ is to the reference data $x_0(k)$, the larger the grey relational grade value γ^*.

c. Only if the reference series $x_0(k)$ is exactly equal to the test series $x_j(k)$, does the grey relational grade value $\gamma^* = 1$.

RESULTS and DISCUSSION

Mt. Huangzui and Vegetation

Mt. Huangzui was formed by a volcanic eruption approximately 600,000-800,000 years ago. It was formed by the molten lava and pyroclastic rock at the volcanic crater, located at the peak of the mountain. A U-shaped volcanic crater that surrounds the east, west, and south edges, was also formed during the volcanic eruption. Around twenty buffaloes were found to inhabit the Huangzui Pond and swamp and barren area during the ground truth investigation of 10/14/2002 in the volcanic crater. A big shallow puddle and barren area were also found on the east edge, and it is likely that the puddle may become a big shallow lake during the rainy season (Fig. 2).

The largest patch of vegetation in the Mt. Huangzui area is made up of *Axonopus affinis*, *Miscanthus foridulus*, *Eurya crenatifolia,* and broad-leaved plants (Fig. 2). Today's carpetgrass *A. affinis* in the area was imported for the purpose of raising buffalo when the Japanese occupied Taiwan after 1895. Before this transplantation, the major vegetation *M. foridulus* was cut off from the edges and/or in the volcanic crater (Huang *et al.* 2003 and its Chinese references).

Apparently, the carpetgrass covered land on the three edges and in the center area of volcanic crater can be remotely sensed by SPOT satellite from more than 800 km in space. The distribution of *M. foridulus* was illustrated as a light-green color in a satellite image (Fig. 1). The carpetgrass covered land at the west and south edges is about 500 m long and narrow while land at the east edge is similarly long but wider. This might be caused by the steepness of the west and south edges and the flat top at the east edge. A big patch of *A. affinis* can be observed at the corner of the west and south edge.

Climate Status

The climatic data cited in this study was recorded from 1993 to 2002 and included the monthly mean temperature, daily cumulative irradiance, daily mean insolation percentage, monthly relative humidity, and monthly cumulative precipitation. Among the five climatic factors, the former three showed a similar annual pattern. In the middle of winter they started to gradually increase, and then they dramatically increased at the end of winter and in spring, and reached maximum levels during the summer; they gradually decreased in autumn, and then reached their minimum levels in winter. The daily insolation percentage was less volatile than these other two factors (Fig. 3A-C). The pattern of monthly relative humidity was the opposite of the three factors mentioned above. However, the monthly relative humidity always remained at a high level, of between 87% and 94% (Fig. 3D). The average monthly cumulative precipitation between January and September within the nine years was always more than 250 mm. November and December are the rainy seasons in the Mt. Huangzui area, and the average precipitation reached 524 mm and 427 mm, respectively (Fig. 3E).

Normalized Difference Vegetation Index (NDVI)

The spatial distribution of vegetation's NDVI revealed several characteristics in the Mt. Huangzui area (Fig. 4 and 5).

First, the U-shape contour pointing to the north and surrounded by the west, south, and east edges can be easily distinguished from other vegetation areas all year round, especially during the May-November period (Fig. 4C-G). The Huangzui Pond and its surrounding swamp and barren area are located in the central part of the volcanic crater. A shallow puddle also be found at the east edge, all year round. The image forming the horseshoe is the carpetgrass *A. affinis* propagating along the three edges.

Second, the vegetation's NDVI in each pixel always varies seasonally or periodically, forming an annual cycle (Fig. 4 and 5A). The NDVI for the entire winter, which is from December to February (Fig. 4H and 4A); and early spring in March (Fig. 4B) was minimal, under 0.1, while the NDVI during the May-August period (Fig. 4C to F) was maximal, exceeding 0.5.

Third, for both total vegetation and individual vegetation such as broad leaf, *A. affinis*, *M. foridulus*, and *E. crenatifolia*, a graph of changes in their NDVI is consistently parabolic (Fig. 5), like the curve of monthly mean temperature, daily cumulative irradiance, and the daily insolation percentage (Fig. 3A-C). In other words, the NDVI is always maximal in the May-August period and minimal in the December-March period. Except during the winter, the NDVI of broad leaf is much greater than that of *A. affinis*, *M. foridulus,* or *E. crenatifolia*. Among the latter, the NDVI of *M. foridulus* slightly exceeds that of *E. crenatifolia*, which in turn slightly exceeds that of *A. affinis*. In summer, while the NDVI of broad leaf is at 0.55, the NDVI of other vegetation is around 0.45, causing the NDVI of total vegetation to be 0.5. In winter, no apparent difference was found among the NDVI of any types of vegetation.

Fourth, a comparison between the curve patterns of climatic factors (Fig. 3) and that of total or individual vegetation NDVI (Fig. 5) suggests that the monthly mean temperature and the daily cumulative irradiance are more closely related to the NDVI of total or individual vegetation than the daily insolation percentage, which in turn is more closely related than the monthly relative humidity and the monthly cumulative precipitation.

Contribution

It is known that the field of traditional statistics cannot quantify the extent to which an individual factor contributes to a subject. However, grey system theory is able to compensate for the weakness of traditional statistics. We, therefore, applied grey relational analysis to determining the degree of contribution of five climatic factors to the NDVI of several vegetation types that were remotely monitored by SPOT satellite.

The seasonal change in the NDVI of the four vegetation types, *A. affinis*, *M.*

foridulus, *E. crenatifolia*, and broad-leaved plants, and five climatic factors were first mean-normalized, according to the theory of grey relational analysis (Table 1). The satellite NDVI was treated as a reference series, and the five constituents of the climate's status were used as a comparison or test series.

The grey relational values were further calculated on the basis of mean normalization results (Table 2). Whether we are calculating total or individual vegetation, the grey relational values are: monthly mean temperature＞daily cumulative irradiance＞daily insolation percentage＞monthly mean relative humidity＞monthly cumulative precipitation. This also represents their grey relational order and degree of contribution. Therefore, the monthly mean temperature plays the most important role in the NDVI of total or individual vegetation in the Mt. Huangzui area. The daily cumulative irradiance is second, and the daily insolation percentage is third. The monthly mean relative humidity is fourth. The monthly cumulative precipitation is always of the least importance.

This data was the complete opposite of the data for the effects of the same climatic factors on the satellite brightness index (BRI) of carpetgrass *A. affinis* in the Mt. Huangzui area (Huang *et al.* 2003). This may be because the ecological or physiological implications of the NDVI and BRI are contrary to each other. Therefore, different climatic factors make different contributions to the satellite NDVI. However, temperature and light make the most important contribution to the vegetation index among the five climatic factors. Furthermore, it seems that cumulative irradiance plays a more important role than insolation in the satellite NDVI, and that relative humidity and cumulative precipitation are even less significant.

Since the daily cumulative irradiance and the daily insolation percentage apparently affect the temperature and are related to sunlight; and the monthly mean relative humidity and the monthly cumulative precipitation are related to water, which is abundant year round in the Mt. Huangzui area; temperature and sunlight obviously make a greater contribution to the vegetation's NDVI than water. In other words, the temperature-related climatic factors, including the insolation percentage, temperature, and irradiance, play more important roles in all satellite remote sensing NDVIs of all vegetation in the Mt. Huangzui area than the water-related climatic factors such as precipitation and relative humidity (Huang *et al.* 2003).

Vegetated areas generally yield higher values on the NDVI because of their relatively high NIR reflectance and low visible reflectance. In contrast, rock and bare soil areas show similar reflectance in R and NIR bands, and result in a vegetation index near zero. Although the NDVI is preferred for monitoring vegetation growth conditions, a number of factors may influence the NDVI calculation that are unrelated to vegetation conditions. Photosynthetic pigments such as chlorophyll a and b and carotenoids have been found to be highly correlated to the values of NDVI calculated by mimicking the broad-band of ground-measured leaf reflectance as the SPOT satellite data, which are calculated by green band XS1 (500-590 nm), red band XS2 (610-680 nm), and infrared band XS3 (790-890 nm) (Hsu 2003, Hsu *et al.* 2003, Elvidge and Chen 1995). Therefore, the seasonal alteration of the satellite NDVI of total and individual vegetation was affected by seasonal changes in their photosynthetic pigments.

From the viewpoint of adaptation of a plant to its environment, the four major vegetation types in the Mt. Huangzui area may have completely adapted to light-related factors like irradiance, insolation percentage, and temperature. In other words, the vegetation may have better adapted or completely adapted to water-related factors such as relative humidity and cumulative precipitation. Therefore, the growth of vegetation in the Mt. Huangzui area is more easily affected by light-related factors. The environmental temperature was regulated by cumulative irradiance and the insolation percentage of sunlight.

The climate of the Mt. Huangzui area is classified as temperate heavy moist, because the relative humidity fluctuates between 86 % and 94 % during the whole year (Table 1). So, the vegetation here enjoys a sufficiently wet environment. In other words, water-related factors are not limiting factors for the growth and development of vegetation.

Marked changes in the daylight spectral distribution take place by the selective actions of various factors during passage through the atmosphere. The proportions of sunlight and skylight, both forming the daylight, in the total spectrum vary according to cloud conditions. Therefore, it is reasonable that the variation caused by the amount of daylight reaching the Mt. Huangzui area is the most important climatic factor influencing the growth and development of vegetation, according to the grey system theory. Blue, red and far-red radiations are the most significant spectral regions regulating plant morphogenesis. No data of the spectrum of sunlight in the Mt. Huangzui area has been collected over the past several decades. Therefore, it is impossible at present to evaluate the significance of each light regime.

It is still unknown whether our ranking of each climatic factor’s contribution to vegetation growth and development is exclusive to the Mt. Huangzui area or is applicable throughout Taiwan or even worldwide. This requires more research to be conducted.

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Table 1. The NDVI of total and individual vegetation and five climate factors according to the data of Figs. 3 and 5.

Month	NDVI					Climate factors				
	Total	Individual				Insolation (%)	Humidity (%)	Precipitation (mm)	Irradiance (Mj/m^2)	Temperature (℃)
		A. affinis	*M. foridulus*	*E. crenatifolia*	Broad leaf					
1	0.143	0.214	0.143	0.200	0.224	19.9	91.7	269.9	164.5	10.3
3	0.136	0.152	0.130	0.124	0.176	20.5	89.6	271.6	249.5	13.4
5	0.523	0.437	0.484	0.474	0.558	18.6	87.1	305.3	314.0	19.4
6	0.503	0.467	0.498	0.472	0.531	20.8	87.1	266.1	320.0	22.2
7	0.486	0.377	0.453	0.374	0.542	29.0	86.1	269.1	386.9	23.1
8	0.492	0.444	0.467	0.445	0.518	29.9	87.2	321.7	379.6	22.8
11	0.422	0.438	0.407	0.405	0.515	15.8	92.2	524.1	147.2	15.2
12	0.131	0.181	0.106	0.155	0.218	11.8	93.2	427.2	129.2	12.0

Table 2. The mean normalization value of the NDVI of total and individual vegetation and five climate factors according to the data of Figs. 3 and 5.

Month	NDVI					Climate factors				
	Total	Individual				Insolation	Humidity	Precipitation	Irradiance	Temperature
		A. affinis	*M. foridulus*	*E. crenatifolia*	Broad leaf					
1	0.403	0.632	0.426	0.604	0.546	0.958	1.027	0.813	0.629	0.597
3	0.384	0.449	0.387	0.374	0.429	0.985	1.004	0.818	0.955	0.773
5	1.475	1.290	1.440	1.431	1.360	0.894	0.976	0.920	1.201	1.120
6	1.419	1.379	1.482	1.425	1.294	1.000	0.976	0.802	1.224	1.282
7	1.371	1.113	1.348	1.129	1.321	1.396	0.964	0.811	1.480	1.338
8	1.388	1.311	1.390	1.344	1.263	1.437	0.9767	0.969	1.452	1.319
11	1.190	1.293	1.211	1.223	1.255	0.760	1.033	1.579	0.563	0.881
12	0.370	0.534	0.315	0.468	0.531	0.570	1.044	1.287	0.494	0.691

Table 3. Grey relational grade and order of the effects of climate factors on the total and individual vegetation in Mt. Huangzui area. The numbers in parentheses are the grey relational order.

Vegetation	Climate factors				
	Insolation	Humidity	Precipitation	Irradiance	Temperature
Total	0.648(3)	0.534(4)	0.497(5)	0.704(2)	0.734(1)
Individual					
Broad-leaf	0.613(3)	0.518(4)	0.495(5)	0.699(2)	0.777(1)
A. affinis	0.577(3)	0.526(4)	0.511(5)	0.682(2)	0.720(1)
M. foridulus	0.625(3)	0.526(4)	0.498(5)	0.680(2)	0.718(1)
E. crenatifolia	0.579(3)	0.531(4)	0.501(5)	0.677(2)	0.712(1)

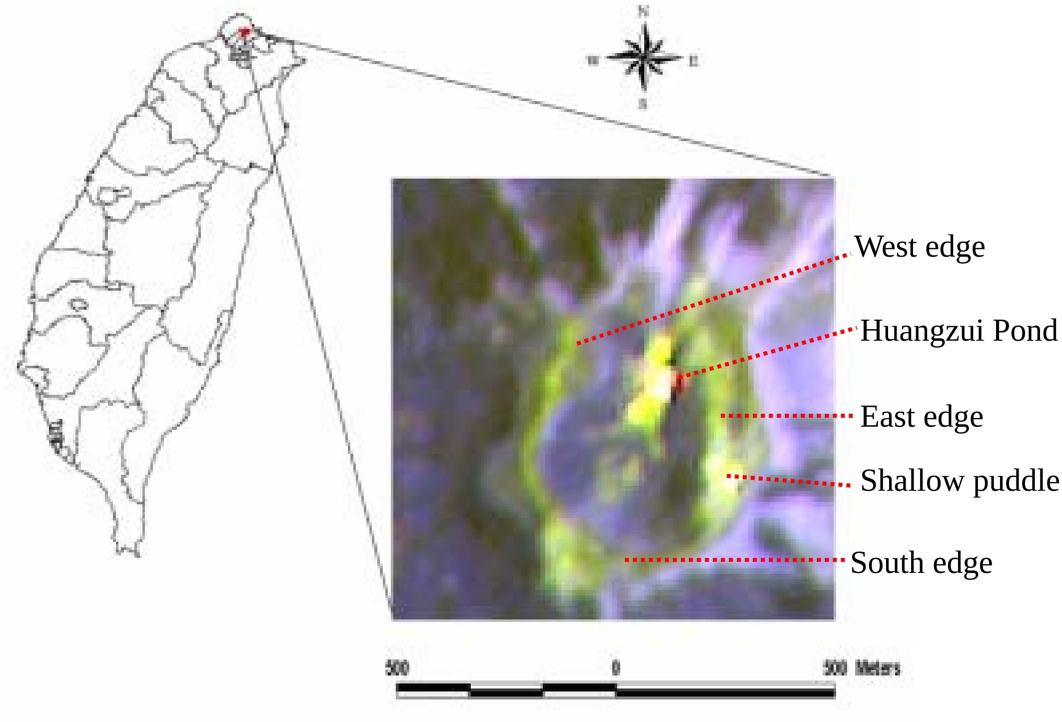


Figure 1. Geographic location of the Mt. Huangzui area in the Yangminshan National Park in northern Taiwan. The satellite image was taken on 6/23/2002. The light-green imagery on the edge is the carpetgrass land. The east, west, and south edges form a U-shaped volcanic crater, the orifice of which points to the north. The white and yellow in the center is the Huangzui Pond and a nude area surrounds it..

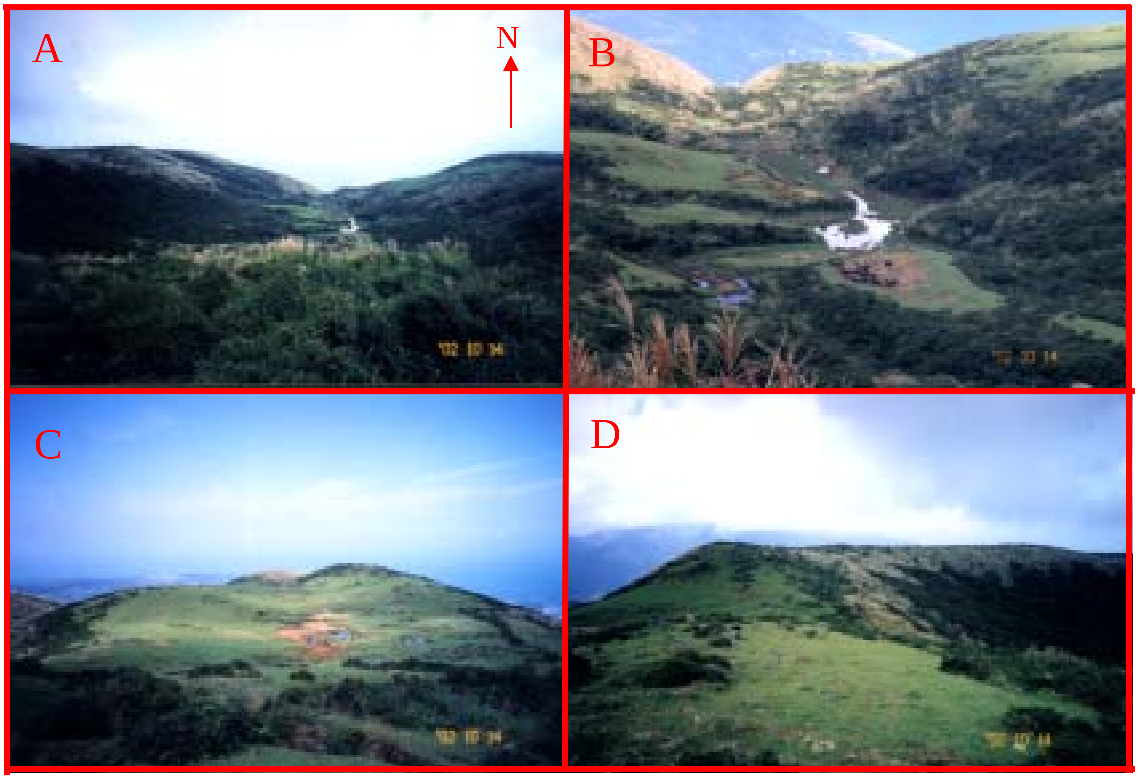


Figure 2. Color photo of the Mt. Huangzui. All the pictures were taken on 10/14/2002 during the ground truth investigation. (A) An U-shaped volcanic crater surrounded by the east, west, and south edges; (B) The Huangzui Pond and swamp and nude area in the volcanic crater; around twenty buffalo habitat in this area; (C) The carpetgrass, shallow puddle and naked area in the east edge; (D) The carpetgrass in the west edge.

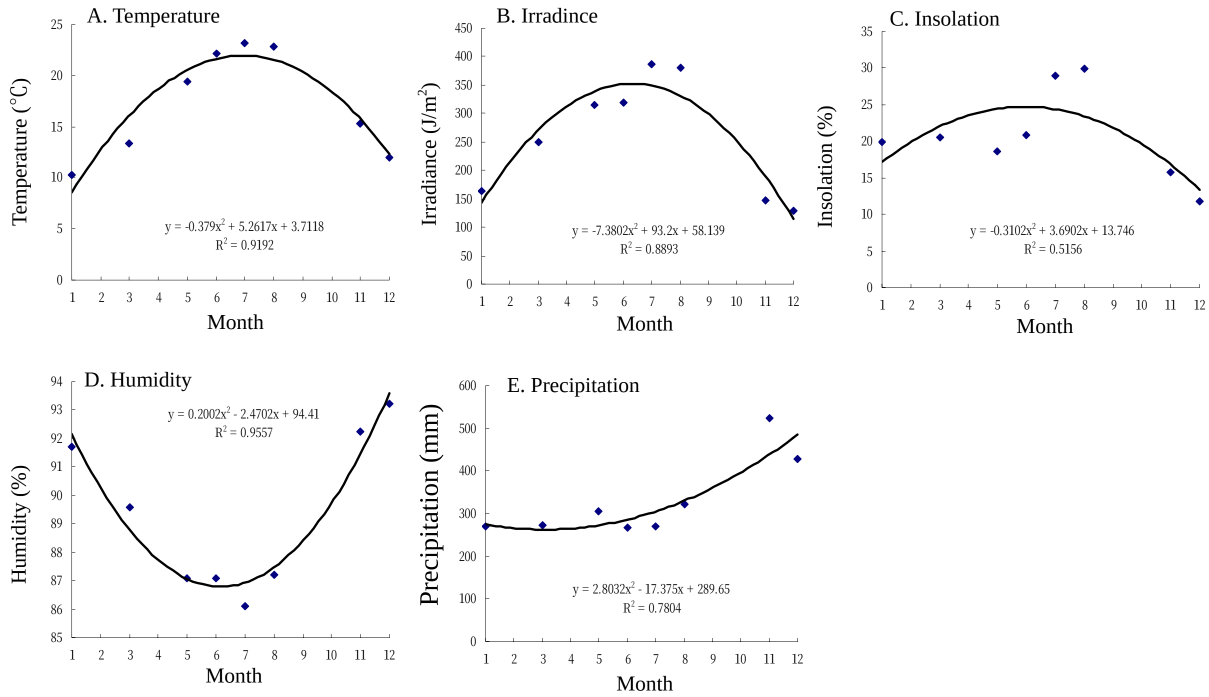
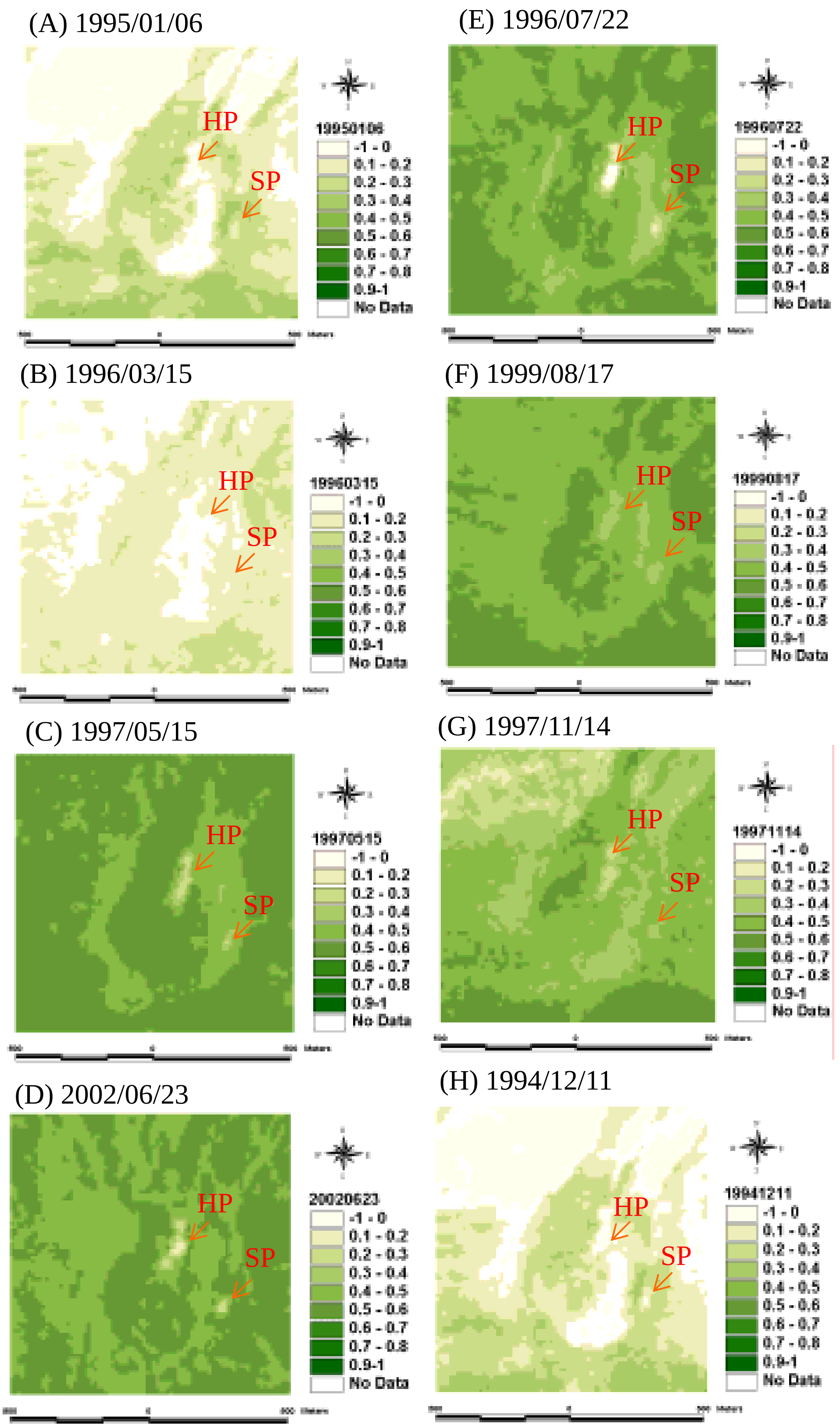


Figure 3. Climate data of the Mt. Huangzui area, covering 1993 to 2002. The data were the average of (A) monthly mean temperature, (B) daily cumulative irradiance, (C) daily insolation percentage, (D) monthly mean relative humidity, and (E) monthly cumulative precipitation.



(A) 1995/01/06
HP
SP
19950106
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(E) 1996/07/22
HP
SP
19960722
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(B) 1996/03/15
HP
SP
19960315
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(F) 1999/08/17
HP
SP
19990817
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(C) 1997/05/15
HP
SP
19970515
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(G) 1997/11/14
HP
SP
19971114
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(D) 2002/06/23
HP
SP
20020623
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data
(H) 1994/12/11
HP
SP
19941211
-1 - 0
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
0.9-1
No Data

Figure 4. The spatial distribution of NDVI in the Mt. Huangzui area monitored by eight sets of SPOT satellite data taken from 1994 to 2002. The red arrows point to the Huangzui pond (HP) and shallow puddle (SP) in the volcanic crater and east edge, respectively.

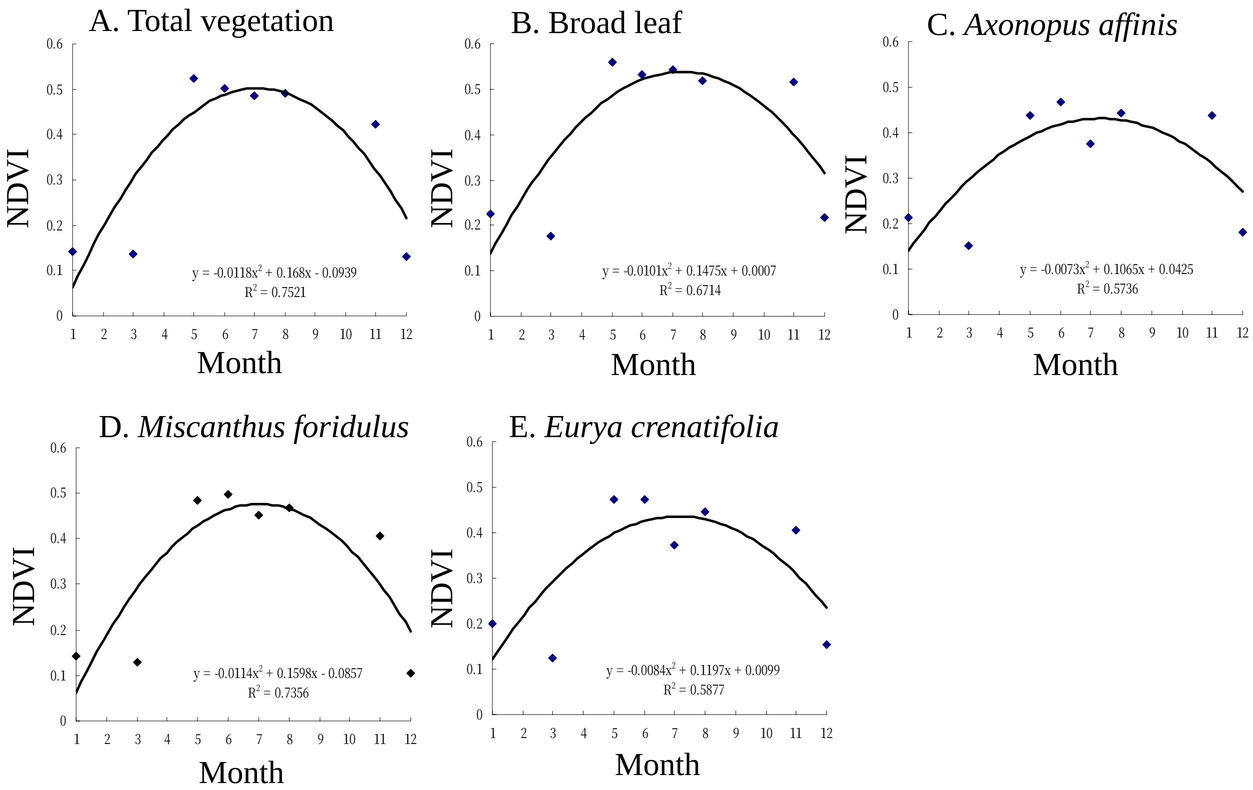


Figure 5. The seasonal change in the NDVI of total and individual vegetation in the Mt. Huangzui area.