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Dendroclimatic Response of Emergent Old–growth Cypress and Fir Natural Forest in Northeastern Taiwan

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The purpose of this study was to apply the dendroclimatology method on the analysis of the climatic and disturbance factors of Chilan alpine area on the tree rings of red cypress, yellow cypress, Taiwania, and Lunta fir in North Taiwan in order to establish a standardization chronology. The analysis ring width, along with the monthly mean temperature, monthly precipitation, and monthly radiation by applied correlation function and response function from 1936 to 2003 showed that there were positive correlation between the ring width indices of the 4 species and the monthly mean temperature of previous November and December, current January and March, and the monthly precipitation of the previous July, However, there was a negative correlation between the ring width indices with the previous monthly mean temperature of the previous July and the monthly precipitation of the previous September. Further, there was a positive correlation between the ring widths and the monthly radiation of March of the current year and a negative correlation between the ring widths and monthly radiation of the previous July. Thus, the ring widths chronology of 4 species were influenced by the monthly mean temperature of current March and the monthly precipitation of the previous July. Base on the standardization chronology, the analysis results showed that there is negative correlation between the ring width indices and the maximum wind speed within 10 minutes of the previous September and June of the current year and July (from 1950 thru 2003), if typhoons occurred in those months. The results also showed that the ring widths indices of the 4 species were not only influenced by climatic factors, but also by the disturbance of typhoons. This shows that typhoon frequency and disturbances are valuable in the reconstruction of a past climate.

Keywords: Dendroclimatology, Tree ring analysis, Soft–x–ray image analysis, Typhoon, Disturbance

INTRODUCTION

The characteristics of the tree–rings include width, density, cell structure, chemistry factors consistence (ex. Ca, Mg, K, etc.), and isotope ratio (O^{18}/O^{16}, D/H, C^{14}/C^{12}, C^{13}/C^{1}), which reflect the relationship between the complex physiology of the tree and its ecological environment. Climate plays an important role in affecting those characteristics. Tree–rings are one of the best proxy information sources of climate changes. In recent years, dendroclimatologist applied proxy information to establish the history of large–scale climate changes (Briffa *et al*., 1988, Meko *et al*., 1993). Records of reconstruction of past climate changes using dendroclimatology in Europe and Northern America area are already integral. But there are only a few habitats and species in Asia including China and Japan which have detailed data (Kojo, 1987; Sweda, 1994). The dendroclimatology researcher in Taiwan in recent years was written by Tsou *et al*. (1996) which reconstruction the changes of summer average temperature over past 300 yr in the Yushan area from the relationship between the tree–ring width of Abies Taiwanesis and the climate.

Tree–ring characteristics not only response climatic changes but also show different growth periods (youth, maturity, and age) and other inner and exterior disturbance factors. Inner disturbance factors include competition between trees caused by the gap dynamics of the forestland and the gene of trees. Forest fires, blights and insect diseases, logging, flood, air and soil pollution are exterior disturbance factors, and some short–term extreme climatic phenomena like frostbite, typhoon, and ice–up are related factors. Based on purpose and sampling designs, there are 5 subjects to be derived from different analysis of the tree–ring samples, as follows: dendrochronology, dendroclimatology, dendroecology, dendrohydrology, and dendrogeomorphology. Due to the world prevenance on climate changes, there is more research on dendroclimatology and dendroecology than on other subjects.

The seasonal disaster–typhoon is a special climatic form from tropical depressions in Taiwan which cause huge damage to lives and properties. Based upon the statistics from the Taiwan Central Weather Bureau (TCWB) (Hsieh *et al*., 2004), there were 374 typhoons in Taiwan

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from year 1897 to 1996, but there was only 1 yr (1941) that has no record of typhoon landfall, and the largest number in 1 yr was 10 typhoons, in 1959. The annual average value of typhoon landfall was 3.7, and the standard deviation value was ± 1.7, In past 54 yr (1950~2003), There were 134 typhoons landing which went through the Ilan area in Northern Taiwan, making thee annual average value a 2.5. typhoons are an important natural exterior disturbance factor (Lin *et al.*, 1999) that can cause forest dynamic ecological changes. The mechanical damages of trees caused by typhoons is not only broken branches and leaf loss, but also the function of the roots, especially the tiny absorbing–roots, which are broken by the strong winds of a typhoon. Leaves and roots injury to the physiological mechanism will drop the ratio of photosynthesis and bio–accumulation, and this effect will lead the tree to form narrow tree–ring widths with low average density.

This study aim to apply the dendroclimatology method to tree–ring widths of 4 long–live species in Chilan area, Ilan county, northern Taiwan to research whether or not tree–ring width is not only affected by the climatic factors (temperature, precipitation, and counter–glow), but also influenced by the typhoons, another important seasonal exterior factor. It is really helpful to reconstruct the historical data of past climatic factors, especially the extremely climatic factor of typhoons, by parsing the influence level of every seasonal climatic and disturbance factor that causes changes in tree–ring width. The data reestablishment makes for an understanding of ancient climatic changes.

Most dendroclimatology research rebuilds models of the climate from long–range annals established by tree–rings obtained from trees close to the forest–line area. Hence, trees standing at the edge of ecological niches will change first, and the effects from exterior disturbance factors are also distinct when we evaluate changes in tree growth and ecological balance caused by global warming.

Typhoons are a special climatic form, stemming from tropical depressions in the Western Pacific area, but are also called hurricanes when they form in Eastern Pacific and Atlantic area. The ratio of distribution of global typhoons in the Northern Pacific area (of which Taiwan is a part of), is 36% higher than the ratio of hurricanes, which is 16% (Chil, 1978). According to research written by Hsieh *et al.* (2004) about typhoons that have hit Taiwan over the past 100 yr, typhoons named as "invaded typhoons" when averaged for maximum wind speed over a 10 minute period, achieved a category 7 (13.9 m s^{-1}) with a gust level reaching category 11 (2.5 m s^{-1}). These were surveyed by the station for the Central Weather Bureau located at the plain in Taiwan.

We can put typhoons into 4 different categories depending on their wind speed as super, strong, medium, and mild typhoon. Based upon Shieh *et al.* (2004), there are 9 different paths that typhoon will take to hit Taiwan.

Typhoons that directly passed through the Chilan mountain area, Northern Taiwan, followed the second most path, numbering at 12.3%; the most numerous were the first and sixth path which were 27.6%. The number of typhoons on the third and ninth paths depended on the radius of the typhoon. The total percentage of the first, second, and sixth paths were about 40% (Fig. 1). The invasion ratio of the typhoons in northern and northeast Taiwan was very high, about 2.5 times per yr. The high frequency of typhoon disturbances could cause harmful effects on the long–term growth of trees (Lin *et al.*, 1999).

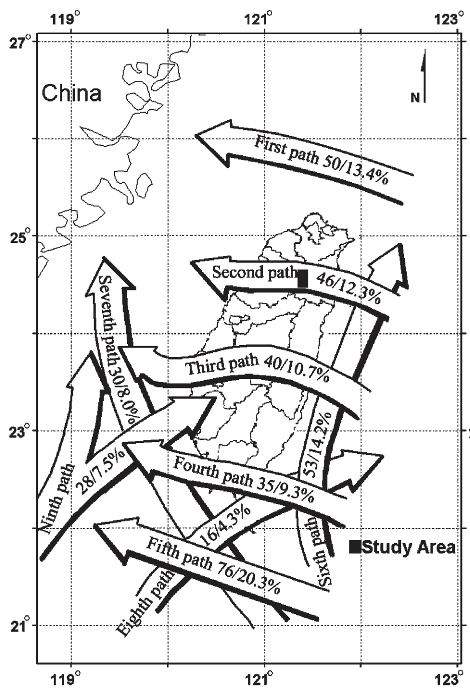

Fig. 1. Pathways and disturbance frequency of typhoons that hit Taiwan from the B.C. 1897 to 1996 (modified from Hsieh *et al.*, 2004).

The effect of forest ecosystems disturbed by typhoons could be scrutable from Lin *et al.* (1999) who researched the LAI index of the canopy of broad–leaved forest at the Fushan Long–Term Ecological Station as follows: 5 typhoons during July to September in 1994 caused the value of the LAI index at the eastern ridge of Fushan watershed to drop 2/3rds; annual average frequency of typhoon interference at the station was a 2, and resulted in large energy loss in disturbances in the same or next year. However, the researches on typhoon affecting Forest Ecosystem are not many (Hong *et al.*, 1995; Lin, 1995; Mabry *et al.*, 1998).

MATERIAL AND METHODS

Site description and climate data

Many dendroclimatological studies focused on building a tree–ring chronology and simulating or reconstructing long–term climate in the past or future according to the core samples obtained from trees close to the forest–line area. Trees at the edge of ecological niches grew sensitive to the changing weather and always reacted to the impact of exterior disturbance factors by recording such evidences in the trunk. Hence, the environmental researchers usually apply tree–ring data collected from special ecozones to assess global warming impacts on tree growth and ecological changes. This paper follows the concept. Chilan Mountain is the highest alpine peak in northeastern Taiwan and is next to the Snow Mountain cordillera. Chilan Mountain is famous for its natural vegetation resources and has been designated as Chilan Natural Reserve (CNR) by the Act of Cultural Properties Protection. Lanyang River and Dahang River originate from the Chilan Mountain and flow along the valley of the east and west side of the ridge. Topographically, the east of the Chilan Mountain is a pocket form that opens to the northeast and is usually filled with mist from late morning. CNR was chosen because many valuable old–growth stands of cypresses and firs grow naturally here and high–frequency typhoons have visited. These 2 particularly biophysical and environmental characters of the site and dendroclimatological research match very well.

The climate in Taiwan depends significantly on the effects of terrain relief. The distribution of vegetation around the island changes with the climate. Botanists in Taiwan have mentioned such significant differences and hence divided the island into several geo–climatological zones according to climate and vegetation.

Chilan Mountain locates right at the climatic ecozone between the northeast ever–moist zone and the rainy summer zone. This mountain's rainy season is from May to November with precipitation of about 200 mm mo^{-1}, and dry season is from December to April with precipitation below 200 mm mo^{-1}. The average monthly temperature is 7.5 °C in January and 19.5 °C in July, each representing winter and summer, respectively. The annual average temperature is 13.5 °C.

In the past decades, TCWB did not construct any permanent weather stations around the Chilan alpine area while Taiwan Forest Bureau (TFB) had tried to make a temporary experiment there from 1961 to 1967. A temporal station was set up in Taiping, Chilan. Fig. 2 shows such valuable monthly records of temperature and precipitation of Chilan and Ilan stations. Fig. 2A and 2B indicate that the monthly average temperature (real line) and precipitation (bars) of Chilan station coincide with those of Ilan station. This means that these 2 stations have homogeneous climate; particularly, the simple correlation for the precipitation and temperature of these 2 weather stations is 0.71 and 0.98, respectively. Consequently, the representative weather observations of the study site were collected from Ilan station of the TCWB at the following position: longitude of 121°44'52.55"E and latitude of 24°45'56.04"N. Available data include monthly average temperature (°C), monthly cumulative precipitations (mm), radiation or light hours (hrs) and wind speed (m sec^{-1}), and frequency of typhoon invasion from 1936 to 2003. Yearly pattern of cumulative average light–hour variations is shown in Fig. 2C. The monthly strongest momentary wind speed and invaded typhoons frequency are shown in Fig. 3. Those data will be used to examine the relationships between the tree–ring width and climate factors, i.e., precipitation, temperature, light hour, and typhoons disturbance.

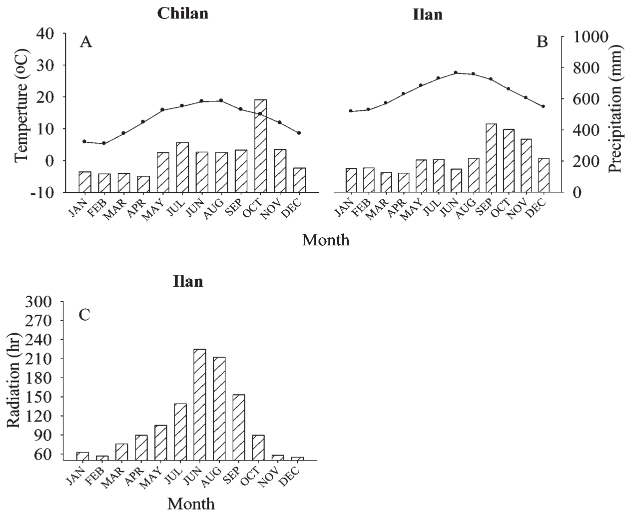

Fig. 2. Weather records of Chilan and Ilan stations around the study site. A and B respectively show the monthly average temperature (stacked line) and monthly precipitation accumulation (clustered column) of Chilan and Ilan stations. Cumulative average light–hour variations from Ilan weather station by month (C).

As explained by TCWB, invaded typhoon happens when the average strongest wind speed in 10 minutes reaches category 7 ($\geq$ 13.9 m sec^{-1}) or gust of wind speed approaches category 11 ($\geq$ 28.5 m sec^{-1}) measured at the sea level. According to the weather records of Ilan station, the highest records of average monthly strongest momentary wind speed from 1950 to 2003 were in July, August, and September, which were 17~18 m sec^{-1}, equal to category 8~9 mild–strength typhoon as in Fig. 3A. In total, the frequencies of typhoons that attacked Ilan were 35 times in August, 32 times in September, 27 times in July, and 16 times in June. Typhoons attacked Ilan the most from June to September and the least in April, May, October, and November (Fig. 3B).

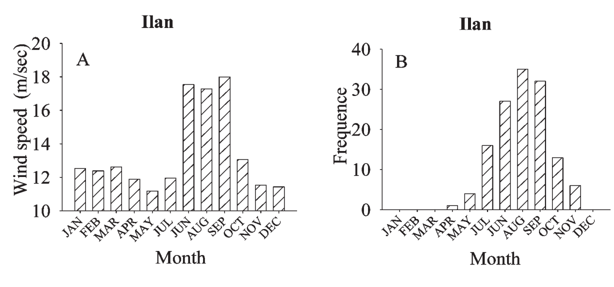

Fig. 3. Monthly strongest momentary wind speed (A) and frequency of invaded typhoons in Ilan station from 1950 to 2003 (B).

Sampling

The forest is mainly covered by old–growth cypresses and firs in the study site. *Chamaecyparis obtusa* var. *formosana* (yellow cypress), *Taiwania cryptomerioides* (Taiwania fir), and *Cunninghamia konishii* var. *konishii* (Luanta fir) are the dominant species with canopies occupying mostly the upper story space of the

Table 1. Site condition and tree information of sampling trees

Sample ID	Species	Longitude	Latitude	DBH (cm)	Cores (trees) Included	Altitude (m)	Aspect
YC1	Yellow cypress	24°31'42"	121°22'31"	156.00	2(1)	1878	E
YC2	Yellow cypress	24°31'42"	121°22'31"	200.60	2(1)	1868	E
YC3	Yellow cypress	24°31'42"	121°22'31"	183.60	2(1)	1865	E
YC4	Yellow cypress	24°31'42"	121°22'31"	178.60	2(1)	1860	E
YC5	Yellow cypress	24°40'17"	121°25'35"	299.36	2(1)	1646	SE
RC1	Red cypress	24°31'35"	121°22'22"	164.00	2(1)	1919	N
RC2	Red cypress	24°31'35"	121°22'22"	155.00	2(1)	1910	N
RC3	Red cypress	24°35'23"	121°25'26"	283.43	2(1)	1684	SW
RC4	Red cypress	24°35'23"	121°25'26"	258.40	2(1)	1680	SW
RC5	Red cypress	24°35'20"	121°25'28"	321.65	2(1)	1684	NW
RC6	Red cypress	24°35'24"	121°25'36"	261.15	2(1)	1670	SE
RC7	Red cypress	24°35'24"	121°25'36"	258.17	2(1)	1670	SE
TF1	Taiwania fir	24°40'06"	121°25'30"	267.52	2(1)	1559	NE
TF2	Taiwania fir	24°40'06"	121°25'30"	321.66	2(1)	1559	NE
TF3	Taiwania fir	24°40'06"	121°25'30"	315.20	2(1)	1550	NE
TF4	Taiwania fir	24°40'06"	121°25'30"	274.89	2(1)	1559	NE
LF1	Luanta fir	24°35'23"	121°25'36"	166.60	2(1)	1661	SE
LF2	Luanta fir	24°31'41"	121°22'32"	165.00	2(1)	1859	NE
LF3	Luanta fir	24°31'41"	121°22'32"	129.00	2(1)	1859	NW
LF4	Luanta fir	24°31'41"	121°22'32"	110.00	2(1)	1859	NW

stand. This is evident along line 170 forest–road (Wang 2000). The average height of these 3 species is about 30~35 m, and diameter breast height (DBH) averages around 1.5~2.0 m. Although close to the mountain ridge or on steep gradient areas, a few species such as *Tsuga chinensis* var. *formosana*, *Pinus Taiwanensis*, and *Pinus morrisonicola* can be found mixing with the main species. *Chamaecyparis formosensis* (red cypress) is another dominant species especially at CNR where a coniferous old–growth stand that mixed with red and yellow cypresses has been the focus of forest conservation and sustainable management issues. Broad–leaved trees, with height ranging from 15 to 25 m, dominate the second layer of the stand and the DBH of the bigger trees is about 1 m.

Because of the sensitive reaction of emerging species to extreme climatic factors such as typhoons, the most dominant coniferous species in this layer, i.e. red cypress, yellow cypress, Taiwania fir, and Luanta fir, were chosen as samples. All of the tree cores were taken from the sites along the forest road and from the giant tree garden at an altitude ranging between 1540~1900 m. ATrimble GPS receiver with an original 10–m range error was applied to locate the geographic coordinates of those samples. Two cores were extracted from each tree with a HaglоF device 1.3 m above ground, including one core toward the east or west and the second one toward the north or south. Table 1 shows the detail attributes of the sample cores.

Tree–ring analysis

Tree–ring samples were immersed in 98% methanol solution replacing the distillation until the solution was clean. Samples were fixed with glair gel and cut into 2–mm thick, 5–mm wide with a high, accurate plane–table saw. The moisture of tree–ring samples was adjusted to 12~15% in the thermostat that also has stable humidity. X–ray images were then taken for image processing and analysis. The soft X–ray machine (HP CABINE X–ray system series, 43855B model) used in this study was made by Hewlett Packard. Two requests were made for the shooting: (1) X–ray shooting distance was set to 62.5 cm from the samples; the range of the negative film was 35×43 cm (13×16 in) (KODAK Industrex M100 film, ready pack Ⅱ); (2) the power of X–ray was set to 9 PkeV, 3 mA, for 50 minutes. Finally, X–ray images were used to analyze tree–ring width and density of the cores samples by using 5 software programs: Image Pro Plus 4.5.0.29® version for Windows, Sigma Plot 2001 for Windows Version 7.0, and Tree Ring X–ray 32 (Nobori, 1989).

Growth–ring dating was performed by incorporating the visioning method and statistic program analysis. Visual dating was done by using the skeleton plot process and Image–Pro Plus. Ring widths were measured with a 0.02 mm precision at an 800 dpi image. Afterward cross–dating of the tree–ring series was achieved by using dendrochronology program CDendro. This program has been well used to detect ring–width measurement and cross–dating error, and cores containing such errors were corrected or removed from the data set.

The purpose of standardization was to transfer the originally nonstationary tree–ring width series into a new stationary series with a fixed mean μ and a constant variance σ^2 ring width. Each tree grows naturally with different ages and is influenced by non–climatic factors such as age, competition, blight, insect diseases, fires, etc. Varying growth rate can be found in response to tree ages. Non–climatic factors may result in disturbance effects and cause different growth tendencies for the trees

(Cook, 1985; Holmes *et al*., 1986). Ring–width series standardization transforms those non–stationary effects into a long–term averaging series suitable for examining radial growth of the trees. In this study, standardization of ring–width series was done by using the program ARSTAN (Cook, 1985). This involves fitting the observed ring–width series to a "detrend" curve and computing the tree–ring width index.

It = tree ring index, Rt = tree ring width, Gt = Expected value.

Gt estimate using deterministic models methods. The b_1, b_2, b_3 parameter were regression coefficient, T is time.

$$It = Rt/Gt \quad (1)$$

$$Gt = b_1 T^{b2 \cdot e^{b3 \cdot T}} \quad (2)$$

$$Ii = Xi/Xio \quad (3)$$

Responses function and correlation on climatic factors

Correlation function and response function are well–used methods for examining the relationship between tree–ring width changes and climatic factors (Fritts, 1976). Correlation function shows the simple relation between tree–ring width annals and data of precipitation, temperature, radiation (light hours), and maximum wind speed. On the other hand, response function is more complicated and theoretically similar to the principal component regression analysis, which integrates and transforms multiple factors into eigenspace and finally forms principle components (PCs) as independent variables for regression analysis. In the regression, the stepwise selection criteria were applied to refine suitable PCs and each regression coefficient of the components. Those coefficients were then substituted by the original climatic factors to get the final coefficients representing the radial growth changes of tree rings in response to the variation of climatic factors.

The dependent variable is annual ring width. There were 36 monthly climatic independent variables for both the correlation and response function analyses which stand for the monthly values of average temperature, accumulated precipitation, and accumulated light hours for July to December (state the specific year here) and January to June (please state year here). The available data are from 1936 to 2003 (n=68). Also in the case of intense climate, the dependent and independent variables are annual ring width and monthly values of maximum momentary wind speed while only 54 observations (from 1950 to 2003) were available for regression analysis. The software PRECON–K (Fritts, 1994) was used to do such correlation and factor response analysis.

$$Wi = \sum_{j=1}^{J} a_j T_{ij} + \sum_{k=1}^{k} b_k p_{ik} + \sum_{l=-m}^{-1} c_l w_l \quad (4)$$

Wi = tree ring width index in i year
a_j = Temperature var coefficient
Tij = Temperature data in i year
b_k = precipitation var coefficient
P_{ik} = precipitation var in k year
w_l = tree ring width for n year $c_t = w_i$

$$W = Xb \quad (5)$$

$W = N$ step stadization tree ring width $N \times 1$ step vector
$X = N \times q$ $(q = J + K + m)$
$b = q \times 1$ step response function regression vector

RESULTS

Tree–ring characteristic

Division between the sapwood and heartwood in red cypress is obvious, and their colors are a little more light reddish than yellow cypress. Sapwood is narrow with yellow–gray colors and heartwood is red–yellow to brown. The earlywood of red cypress advances to the latewood gradually with obvious differences between them. Red cypress has marked tree–rings. The average tree–ring width is about 0.99 mm. The ratio of the earlywood and latewood is almost the same – about 0.50 mm – but its average density value is 538.14 kg m^{-3}, the lowest among the 4 species. Table 2 shows these characteristic values.

The colors of the sapwood and heartwood in yellow cypress are visible, but the division between them is not clear. The sapwood of yellow cypress is light red with yel-

Table 2. Physical characteristics of the tree–rings for the studied species

Species Names	Yellow Cypress	Red Cypress	Taiwania Fir	Luanta Fir
Site				
Altitude (m)	1646–1919	1540–1919	1559	1661–1859
Measurements				
Number of tree	5	7	4	4
Ring width				
Means width (mm)	1.03	0.99	2.23	0.95
Earlywood width (mm)	0.54	0.53	1.13	0.50
Latewood width (mm)	0.49	0.47	1.10	0.45
Wood density				
Mean density (kg m^{-3})	694.43	538.14	528.94	572.12
Earlywood density (kg m^{-3})	591.43	462.59	469.95	480.10
Latewood density (kg m^{-3})	770.00	618.94	585.58	667.33
Min. density (kg m^{-3})	563.46	390.10	429.35	432.40
Max. density (kg m^{-3})	803.74	662.05	662.23	759.59

low and white but the heartwood is light red with yellow to yellow–brown. Its tree–ring width is extremely narrow, and the earlywood moves toward the latewood gradually and disappears. It does not have any resin channel, and the average tree–ring width is about 1.03 mm, almost the same as the value of red cypress. The ratio of the earlywood and latewood is almost the same. The average density is 694.43 kg m^{-3}, the highest among these 4 species.

There are obvious differences between the sapwood and heartwood in Luanta fir. The heartwood is light yellow–brown or yellow–brown with a purple edge, but this will turn into pure purple. The sapwood is light yellow. At times, the tree–ring is wide but sometimes narrow. The average tree–ring width is about 0.95 mm. The width of the earlywood is about 0.50 mm and that of the latewood is about 0.45 mm. The average density is 572.12 kg m^{-3}, which is greater than that of red cypress but less than that of yellow cypress. Obvious divisions can also be observed between the sapwood and the heartwood in Taiwania fir. Its sapwood is light red with yellow and a yellow or yellow–red color with purple–brown edges in its heartwood. The tree–ring is obvious but narrow in this species. The average tree–ring width is about 2.23 mm and the width of the earlywood and latewood is about 1.10 mm. The average density is 528.94 kg m^{-3}.

Standardization

By using the techniques of X–ray image analysis, 550–y series annals of tree–ring width index from 1450 to 2003 were established. Fig. 4A shows such long–term ring–width index annals while Fig. 4B highlights the ring–width changes in response to the available observations between the years 1936 and 2003. Horizontally scale enlarged annals are suitable for cross checking the effects of regular and extreme climate on radial growth. The tree–rings were getting wider from 1996 to 1998 but went narrower after 1999.

Though the correlation of species individuals, signal–noise ratio, and the first eigenvector may vary with the method adopted for standardization, Table 3 shows the statistic abstraction of the standardization annals of this research. On average, it is clear that the ring–widths are relatively low sensitive to climate changes because of the low values of mean sensitivity and standard deviation.

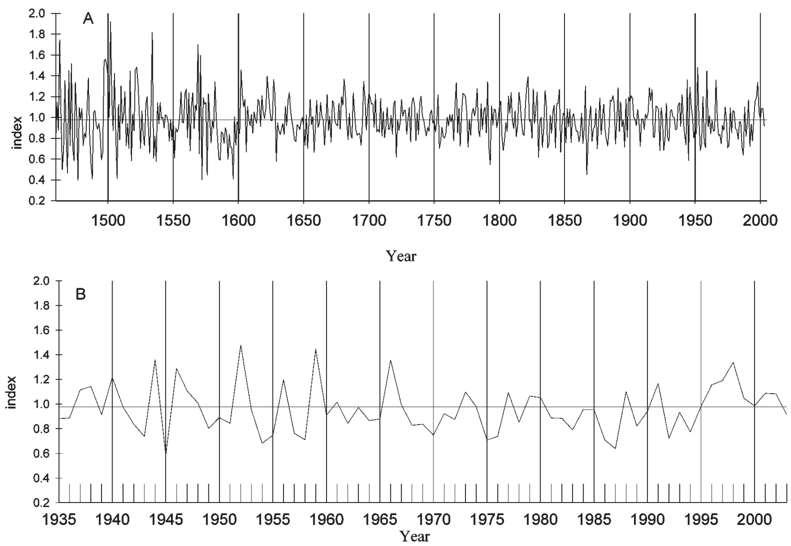

Fig. 4. The standardization chronology of tree–ring width index 4 species at Chilan mountain area. The least samples in each annals are 2 trees. (A) The annals established from year 1450 to 2003. (B) The duration enlarged from year 1935 to 2003 in Fig. A.

Table 3. Table of typhoon numbers in every month and its frequency analysis thru 1950 to 2003 (Data form Taiwan Central Weather Bureau 2004)

Month	Frequency				total
	Super typhoon	Strong–strength typhoon	Mid–strength typhoon	Mild–strength typhoon	
4				1	1
5	1		1	2	4
6	1	2	9	4	16
7		11	11	5	27
8	3	14	9	9	35
9		16	12	4	32
10			10	3	13
11		4	1	1	6
total	5	47	53	29	86

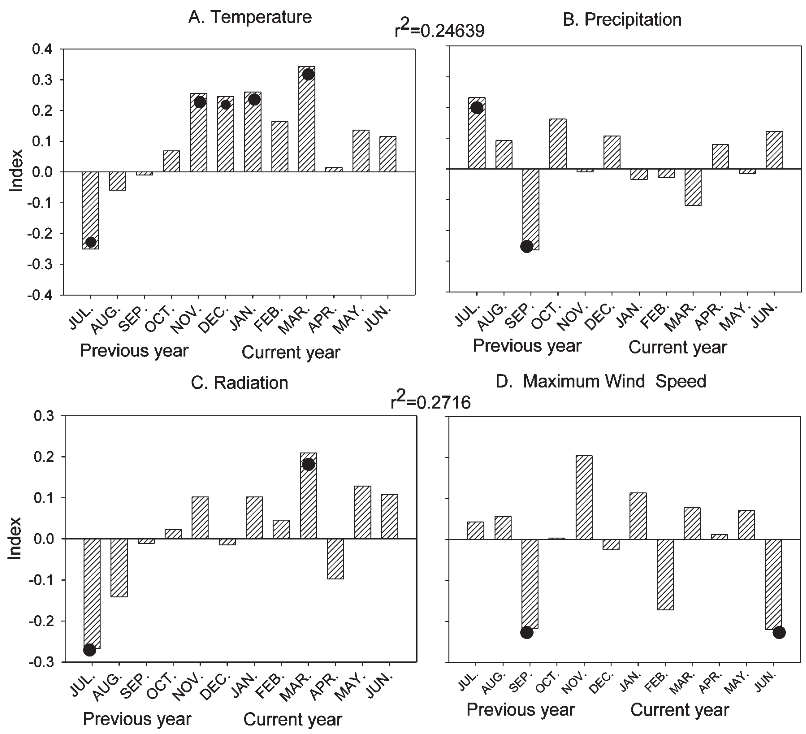

Fig. 5. Response function (bars) for the standardization chronology of conifer old–growth cypress and fir at the Chilan Shan. The values are the weights of the regression equation of the response function. r^2 is squared multiple correlation coefficient of regression equation of the response function. Circle indicate significance of variables ($p<0.05$). Data used for analysis are 1936–2003 and 1950–2003 for general climatic factors and maximum wind speed, respectively.

Climatic response function and correlation

Fig. 5 shows how the climatic factors influence the radial growth of the trees at Chilan Mountain Area. The correlation coefficient (r) and regression coefficient (b) of variables were depicted simultaneously and vertical bar and real line represent coefficients r and b, respectively.

Ring width is negatively correlated with the average temperature of July (please state year here) while it is positively correlated with November (please state year here) and December (please state year here) and January (please state year here) and March (please state year here). The correlation coefficients for those monthly variables are statistically significant at 0.05 levels indicating that temperature contributes to tree growth in both warm and cold season. Information from Fig. 5A can be easily interpreted. The tested species, red cypress, yellow cypress, Taiwania fir, and Luanta fir natively grow in cold–warm temperature climatic region and prefer cold atmosphere. In conclusion, the positive and negative correlations link to the winter and summer temperature, respectively, and the result makes sense.

It is interesting for the case of precipitation result. Fig. 5B shows the monthly cumulative rainfalls in July are beneficial to tree growth while rainfalls in September cause obviously reverse impacts. Influences of rainfalls of other months are not statistically significant. July is the first rainy season and it does major contribution to tree growth. However, large amount of rainfall in the following September causes negative influences. These are supposed to be the additional influences induced by typhoon. The extra rainfall seemed to be brought by typhoons. Correlation between ring width and accumulative light hours in a month is only significant for July (please state year here) and March (please state year here) in Fig. 5C. The phenomenon is identical to the effects of temperature. Though light offers energy for tree photosynthesis, excessive quantity of light hours may result in higher temperature that normal tree needs. It may happen in hot season, especial in July.

DISCUSSION

Standardization

False rings were easy to read in the X–ray negative films under a 100X microscope. There were only 3 false tree–rings found in this research. The same changes of the normal intra–annual density fluctuations were also easy to read from the X–ray negative films (Kaennel and Schweingruber, 1995).

Compared with the correlation of individuals' ring–width index (0.14~0.26) and variance in the first eigenvector (26%), those statistics imply that the width of individual tree–ring changes smoothly year by year with higher autocorrelation. Such phenomena are also found in other researches (Cleaveland, 1986; Kienasr *et al.*, 1987; Schweingruber *et al.*, 1978).

Climatic response function and correlation

The response function is sensitive to the confidence interval (CI) of regression coefficients, eigenvectors, and climatic parameters (Blasing *et al*., 1983). Response function considered the response of multiple climatic factors in examining the tree growth, but it usually estimated the regression coefficients with narrow intervals which may probably overemphasize the influences of some climatic factors. Therefore, when trying to explore the relationship between tree growth and climatic factors, the simple correlation function is usually adopted for easy calculation and understanding. Correlation function is only used to examine single factor's effects on ring width. Even though the narrow confidence interval may happen in response function, it was still applied to current study and integrated with correlation function to explore the relationship between growth rings and climatic factors.

The relation between those general climatic factors and ring width is consistent with Tsou's finding in 1998 for the species *Abies kawakamii* at Yushan in central Taiwan. However, the precipitation in May was negatively correlated with annual growth of *Abies kawakamii*. This is because the climate of central Taiwan is different from the current study site, northeastern Taiwan. The general climatic factors might change along with the local environments, such as latitude, terrain relief, and land covers. Results also suggest tree–ring width is more sensitive to monthly accumulative precipitation than to temperature and light hours. This conclusion is similar to Schweingruber's research in 1988 for the species *Pinus sylvexstris* at Xanten, eastern Germany, which showed that tree–ring width responds sensitively to the amount of precipitation in winter and spring.

CONCLUSION

The correlation of the monthly average strongest wind speed corresponded to the tree–ring width annals shown in Fig. 5. The tree–ring width mainly reflected the negative correlation of the momentary strongest wind speed of the previous September and of the current June. The period where typhoons invaded northeast Taiwan was from June to October during 1950 to 2003. To analyze the frequency of typhoon categories above mid level as shown in Table 3, there were 28 instances in September at most; 26 in August, 22 in July, 12 in June and 10 in October. After typhoon invasion, the amount of branches were different according to the intensity of typhoon. The branch amount increases after the invasion and big branches that usually hold onto the tree will also fall down from mechanism reaction.

The influence of the typhoon intensity on the tree growth as studied by Lin (1997) showed there were 2 peaks of litterfall in every year: one in spring (March thru May) and another during typhoon season (July thru September). The cause of such a large amount of the in spring was that lots of old leaves were being replaced by new leaves at that time, but depended on typhoon invasion during the typhoon season. There were 5 mid–strength typhoons invading the research area thru July to October in 1994 and these formed 2 huge amount of litterfall during July and August. Research in the same area by Hong *et al*. (1995) showed litterfall increases twice as much during typhoon invasion. According to the report on litterfall in Fushan area written by Hong *et al*. (1995) the amount caused by typhoons in 1994 was 5000 kg ha^{-1} and the total amount was 8000 kg ha^{-1}, although there was only 3000 kg ha^{-1} in 1993 without any typhoon invasion. Hence, typhoons cause huge damage to leaves and branches.

The reason that the study showed tree–ring width reflecting the negative correlation to typhoons in previous year could be related to the mitosis of the cambium. According to Sander *et al*. (1995) said that the tree–ring width can be explained by cambium cell division and tree–ring density could be explained by cell dissension. The changes in tree–ring width in the current year while September typhoons were coming were very small, but showed lots changes in the next year, and would narrow in width. It also showed that negative correlation in June was probably related to cambium cell division and tree–ring width increase.

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