Applied Scenarios to Evaluate the Impact of Climate Change on Ecoregion in Taiwan

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ABSTRACT

In order to let us to evaluate the impact of Climate Change under the enviroment which CO_2 concentration in air is increasing, we use the Holdridge life zone classification mode, IPCC SRES scenarios and Forest-Grid to simulate and predict future site factor and ecoregion in Taiwan. We arrange temperature, rainfall and potential evapotranspiration ratio, cooperate with Forest Grid (Fong-Long, Feng, Wu, 2005) and Holdridge life zones. At SRES-A2, we know that the temperature rises, and the rainfall reduces. It caused the "Tropical Moist Forest" and "Tropical Dry Forest" of Holdridge life zones increase in western Taiwan. At SRES-B2, the temperature rises less than SRES-A2, but the rainfall increase. So the area of "Tropical Dry Forest" increase less than SRES-A2, and the reduced area of "Subtropical Lower Montane Moist Forest" of the mountain area is less too. With time, the Holdridge life zones of SRES-A2&B2 change and focus in the Northeast and the southwest in a short-term at the beginning, then changes expand to the whole Taiwan in medium-term and long-term. The changes of tropical forest life zones increase from low elevation to high elevation. The area of cool temperate and subtropical forest life zones reduce at high elevation. These data can offer information to assess impact of climate changes at the Taiwan ecological environment in the future.

【**Key words**】: Holdridge, SRES, Scenarios, Forest Grid

INTRODUCTION

We used Holdridge life zones to build Taiwan plant distribution, and used IPCC Special Report on Emission Scenarios to predict the changes of annual average temperature and annual rainfall in the background that CO2 thickness in the atmosphere will reach or over twice (280ppm before industrial revolution) in some period. Finally we could get the life zones change after climate change in the future.

By these steps, the purpose can assess impact on forest life zones after climate changes by scenarios. We hope to offer predictive information in the future and let correlate groups decide the tactic of climate changes for Taiwan.

Literature Reviw

Holdridge life zones

Holdridge (1967) integrates Biotemperature, Annual Precipitation and Potential Evaportranspiration Ratio (PET Ratio) with distribution of the global main ecosystem. Holdridge studies the relation about temperature, Precipitation and PET, and develop "Holdridge life zones" (Holdridge, 1967) that the whole world can use.

This life zones system decides the classification by two climate parameters: biotemperature, annual precipitation and a guide parameter: PET ratio, and it is made up in a triangular coordinate system by most hexagons.

By these three parameters, it equals to distinguish the triangular coordinate system into different types of life zones. Holdridge also considers the influence of the extreme climate. The frost line locates in critical temperature line of warm temperature belt and subtropical belt (annual average biotemperature is about 12~24℃) and cuts the classification area of the hexagon (Holdridge, 1967).

Under this consideration, the complete Holdridge divides into 37 life zones (Figure 1).

There are close relations in Holdridge model and plant about spatial distribution of different climate, and it can examine: (1) the interrelation of plant distribution and climate under different scale, (2) the climate change suitable ability of different plant or forest at some region. In scenarios of climate change with Holdridge model, It uses General Circulation Model (GCM) to predict climate changes and easily combines with Holdridge. So we use Holdridge model to estimate the life zones change after climate changes.

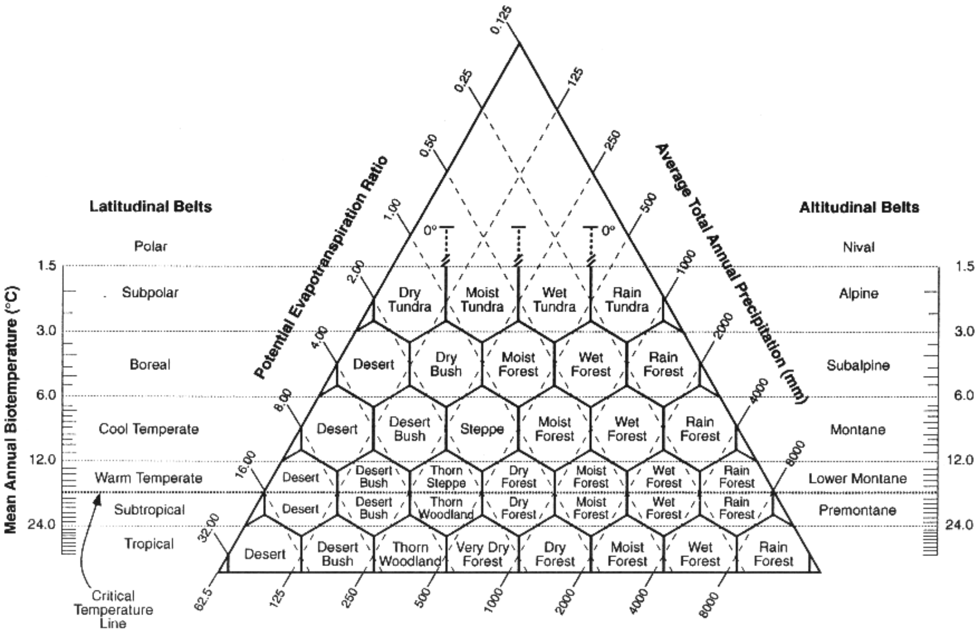

Fig. 1 Holdridge life zons model (Holdridge, 1967, Feng, 2001)

Scenario

Scenario is a rational and unanimous narration of future (IPCC, 1996). It is also called "the blueprint of future development". We use scenario method that IPCC (Intergovernmental Panel on Climate Change) set up to predict future climate change.

IPCC Special Report on Emission Scenarios predicts with the possible economy, population, industry and environment of future and proposes the trend that the greenhouse gas may discharge. Then it predicts corresponding climate changes by general circulation model.

Ching-pin Tung (2004) proposes scenarios of climate change can divide into four kinds: (1) Global circulation model predicting, (2) time analogy, (3) spatial analogy, (4) supposing. The first kind can use physical to assess the property of global warming after greenhouse gas enhancing through general circulation model.

IPCC predicts CO2 thickness will be among 540~970ppm in A.D. 2100 (Figure 2), and the global average temperature and sea level will all raise (IPCC, 2001). SRES predict atmospheric CO2 thickness will get twice or over twice in the future. Global average temperature will increase by 1.5 to 4.5℃ than A.D. 1990, and global rainfall will increase.

SRES considers possible conditions that may be devoted to economic development or sustainable use in the future, and the influence of global or regional development. IPCC issued the Special Report on Emission Scenario (SERS) in A.D. 2001. It divides four types by different scenarios: A1 (Rapid Global Growth Scenario), A2 (Regional

Growth Scenario), B1 (Global Service Economy Scenario), B2 (Increasing Population Scenario). It uses these to build future global develops models. In these 4 types of scenarios, "A" shows that focuses on economic development, "B" shows that precedes environment protection, "1" expresses that is suitable for the whole world, "2" express that is suitable for the region (Figure. 3).

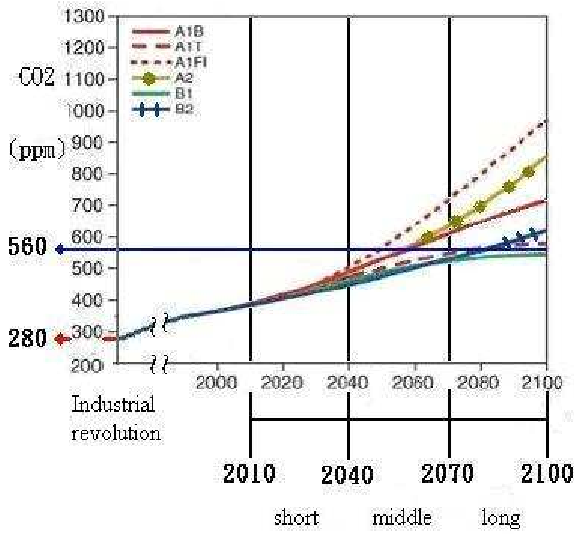

Fig.2 SRES predicts CO2 thickness will be among 540~970ppm in A.D. 2100 (Fixed from IPCC, 2001).

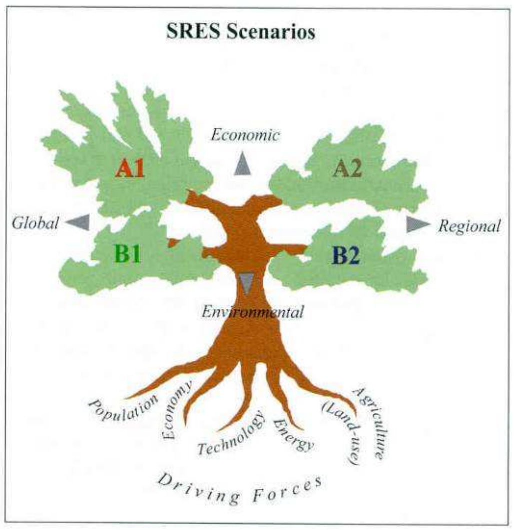

Fig.3 SRES Scenario（IPCC, 2001）.

Directing against the Taiwan regional in the whole world, we use A2 and B2 two scenarios between economic development and environmental protection. GCM model simulates global climate, so we must do "Downscaling" first.

Spatial Interpolation

By spatial Interpolation, it can improve estimating ability of nature various kinds and offer management of the natural resources (Chin-Cheng Huang, 1997). Spatial interpolation uses known observable points to estimate value of other unknown region of research zones (Burrough, 1986). Most materials of surface property can only precede point observation, so spatial interpolation is a useful and important technology.

1.Kriging

Rainfall estimation consulted "Applying Kriging interpolation model in precipitation properties mapping" by Fong-long, Feng and Kao, 1999 from Journal of the Experimental Forest of National Taiwan University. Because Kriging can be particular estimation and be used to do Rainfall estimation, we used it for my research.

Kriging is used popularly on soil science and geology research. It is a theory of regionalized variable because of region, and gets structure of regional spatial dependence after semi-variogram analysis. And by satisfying best linear unbiased estimate, we can use Kriging to estimate the data of unknown points and regions.

This research consults Chang-Ching Wu (2002) used Ordinary Kriging, Simple Kriging and Universal Kriging to estimate monthly rainfall and annual rainfall. He chosen model of the most suitable affect range by semi-variogram and decided best model by error value to take for fixed variable to build the data of monthly rainfall and annual rainfall.

2.Trend

Trend is the simplest way that describes changing gradually and a large scale changing. It uses a least square method with known data point by a multinomial regression analysis. If Trend becomes wave to rise and fall, it can use a multinomial to express. Trend use a linear multinomial regression to describe large range parameter gradually and decide a multinomial through a least square method by data (Fong-Long, Feng and Huang, 1997). Jian-Tai, Kao (1999) proposes that it can use a linear multinomial on temperature estimation.

So this research uses Trend to do spatial interpolation of Taiwan temperature distribution.

MATERIALS & RESEARCH APPROACH

Materials

1.Annual average temperature: We consulted 25 weather station data of Central Weather Bureau.

2.Annual rainfall: We took rainfall data of 818 rainfall station.

3.Topography: 40m*40m raster

4.SRES-A2, SRES-B2 temperature and rainfall estimate. We used CGCM2 data of general circulation mode from IPCC SRES and find three zones that include Taiwan by CGCM2 global 96*48 zones. Then we used downscaling with CGCM2 data on Taiwan zones by figure 4~5.

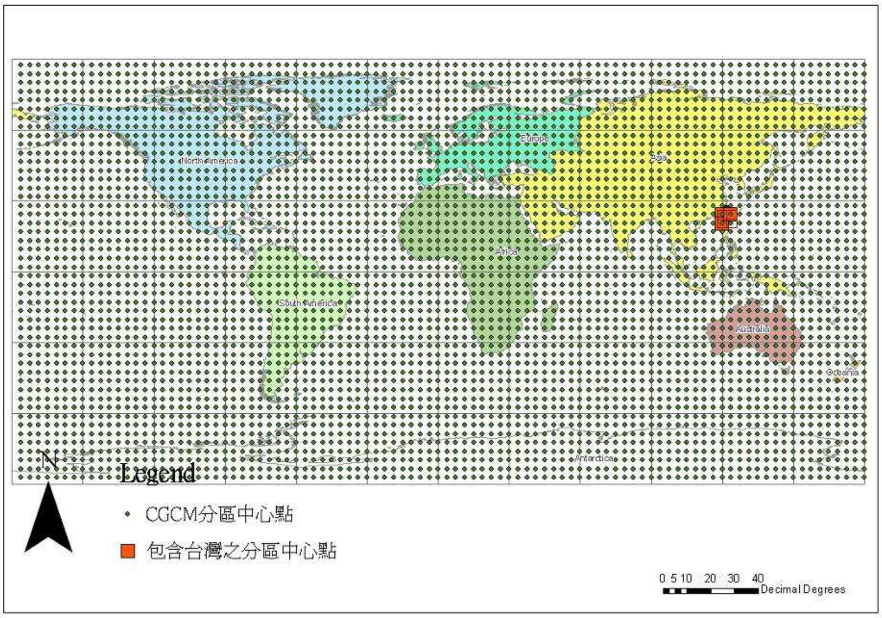

Fig.4 GCM2 model in global.

Research approach

We used the materials offered by IPCC SRES and set up temperature and rainfall scenario tables. Then we divided the base-line for recently 30 years (1960~1989), short period (2010~ 2039), middle period (2040~2079) and long period (2070~2099). By base-line materials, we simulated average annual temperature and annual rainfall of every period. We chosen materials of A.D.1961~1989 for standard because rainfall estimating result of Chang-Qing Wu (2002) can be close in A.D.1961~1990.

We used ArcGIS software to do spatial interpolation of Trend for temperature by the materials offered from IPCC. Then we precede elevation correction and estimated spatial distribution of Taiwan average annual temperature in base-line, SRES-A2 and B2. We used ArcGIS software to do spatial interpolation of Ordinary Kriging, Simple

Kriging and Universal Kriging for annual rainfall. Potential evapotranspiration ratio is calculated by average annual temperature and annual rainfall (Holdridge, 1967).

The formula is :

$$\text{Potential evapotranspiration ratio} = \frac{58.93 * \text{Average annual temperature}}{\text{Annual rainfall}}$$

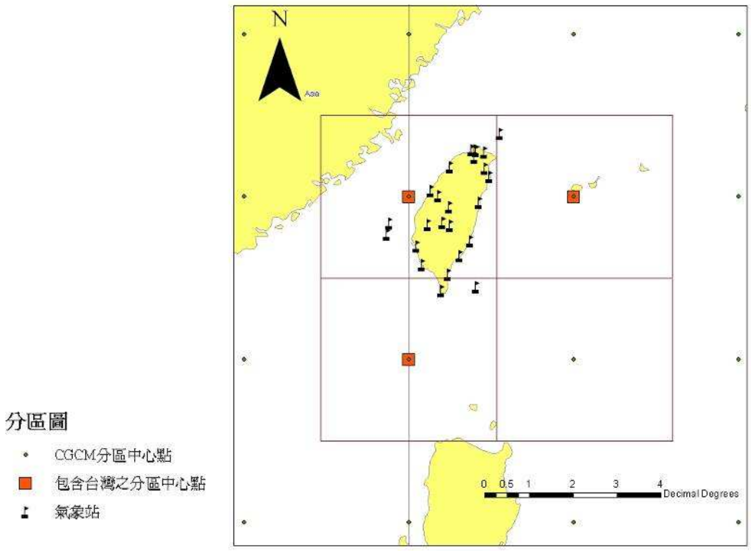

Fig. 5 The location of Taiwan in CGCM2 zone.

RESULT

Impact assessment of Holdridge life zones by scenarios. We used the factors of average annual temperature, annual rainfall and potential evaporation ratio to make out the Holdridge life zones of different scenarios. We used temperature factor and rainfall factor mainly to find out the suitable life zones. After life zones classification, we could find out the suitable zones and some kind that can't be classified. We called the unable classified area is "none".

The Holdridge life zones of the base-line.

By the average annual temperature and annual rainfall of the base-line with potential evaporation ratio, we could make the Holdridge life zones of the base-line. The following picture 6 and table 1:

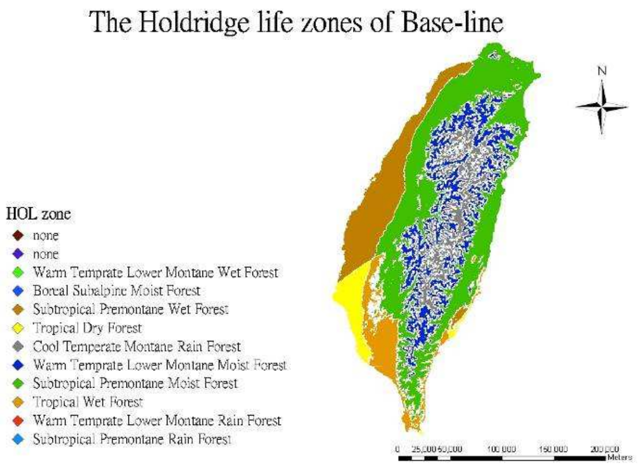

Fig. 6 The Holdridge life zones of Base-line.

Table. 1 The area of Holdride life zones at Base-line (unit: km^2).

Temperature(℃)	Rainfall (mm)	Classification	Area
1.5↑	**2000~4000**	none	1.41
24↑	**1000 down**	Tropical Very Dry Forest	
1.5~3	**2000~4000**	none	23.48
6~12	**1000~2000**	Cool Temperate Montane Moist Forest	
12~18	**1000~2000**	Warm Temperate Lower Montane Wet Forest	0.17
1.5~3	**4000~8000**	none	
3~6	**2000~4000**	Boreal Subalpine Moist Forest	391.34
18~24	**1000~2000**	Subtropical Premontane Wet Forest	4859.96
24↑	**1000~2000**	Tropical Dry Forest	1577.60
6~12	**2000~4000**	Cool Temperate Montane Rain Forest	3811.67
3~6	**4000~8000**	none	
12~18	**2000~4000**	Warm Temperate Lower Montane Moist Forest	7279.37
6~12	**4000~8000**	Cool Temperate Montane Rain Forest	
18~24	**2000~4000**	Subtropical Premontane Moist Forest	15031.09
24↑	**2000~4000**	Tropical Wet Forest	3006.27
12~18	**4000~8000**	Warm Temperate Lower Montane Rain Forest	4.16
18~24	**4000~8000**	Subtropical Premontane Rain Forest	16.66
24↑	**4000~8000**	Tropical Moist Forest	
18~24	**8000** up	Tropical Rain Forest	
Total area			36003.18

By Fig. 6 and table 1, we could know "Subtropical premontane moist forest" of middle above sea level mountain area is most large in the Holdridge life zones of the base-line, nearly have 15031.09km^2; there are 4859.96 km^2 of "Subtropical premontane Wet Forest" area in the nothe to west and along the coast. "Tropical dry forest" and "Tropical moist forest" are mainly in the west-south to south; "Subtropical premontane moist forest" and "Subtropical premontane wet forest" are located at high elevation. "Warm temperate lower montane moist forest" is located at over 3,000 meters of the central mountain. "Warm temperate Lower montane rain forest" and "Subtropical premontane rain forest" are located at the east-north. Some parts of unable classified area of Holdridge life zone: 1 is temperature under 1.5 degrees Centigrade, and the rainfall is 2000mm- 4000mm. It has 1.41km^2; 2 is temperature among 1.5℃ and the rainfall is 2000mm- 4000 mm. It has 23.48km^2. Both of these areas are unable to classify by Holdridge system and mainly located in north and northern mountain area about over 3600m above sea level of Taiwan, other located under 3000 meters above sea level.

Changes of the base-line with SRES-A2 short period, middle period and long period.

In SRES-A2, it can be found out change situation in the base-line, A2 short period, A2 middle period and A2 long period from Fig. 7 from the southwest and Northeast change at the beginning firstly, and the end is the whole Taiwan finally.

In the base-line to the A2 short period, we could see that "Tropical wet forest" increases at southwest, and it covers "Tropical dry forest". But tropical dry forest also expands upward along western; it lets the area of "Subtropical premontane wet forest" reduce substantially. In addition, the area of "Warm temperate lower montane rain forest" increase at northeast and south, and "Subtropical premontane rain forest" appears at northeast.

In the A2 middle period, it can see that "Tropical very dry forest" appear in the Taiwan middle coast; "Subtropical premontane wet forest" reduces more; "Tropical dry forest" is almost located at the low elevation in the west, and the area of "Tropical wet forest" increase more at the low and middle elevation in the west, and at east and south.

In the A2 long period, we could see "Subtropical premontane moist forest", "Cool temperate montane rain forest" and "Warm temperate lower montane moist forest" reduce to the high elevation; "Tropical dry forest" spread all over the western; "Subtropical premontane wet forest" is close to disappearing, and "Warm temperate lower montane rain forest", "Subtropical premontane rain forest" and "Tropical moist forest" are disappearing completely. "Tropical very dry forest" increases a little than A2 middle period.

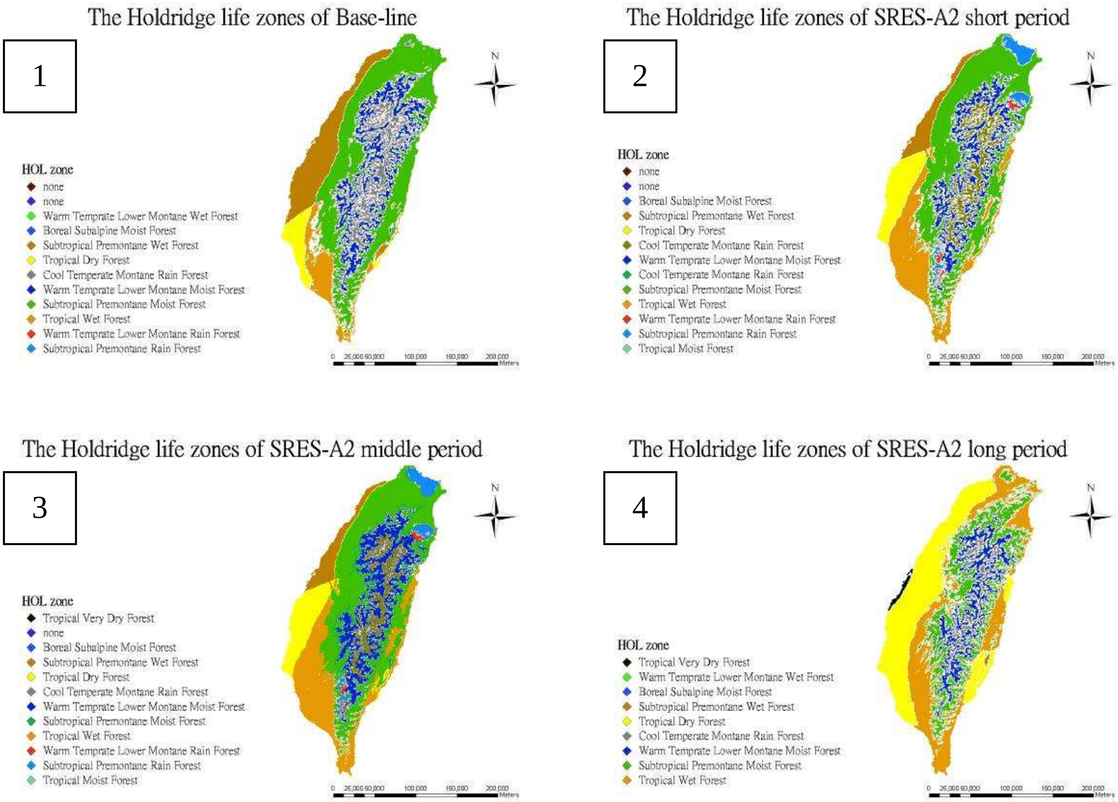

Fig.7 The changes of Holdridge life zones of the base-line and SRES-A2. In this fig, 1 is base-line; 2 is SRES-A2 short period; 3 is SRES-A2 middle period; 4 is SRES-A2 long period.

By table 2, we could see the changes of area of every life zone in different section.

The area of “Tropical dry forest” increases substantially from 1577.6km^2 to 10292.74km^2 and locate at western to the low and middle elevation mountain. "Subtropical premontane wet forest" reduces from 4859.96km^2 to 265.95km^2."Tropical wet forest" increases from 3006km^2 to 9670km^2.

Changes of the base-line with SRES-B2 short period, middle period and long period.

In SRES-B2, we could know the changes of base-line, SRES-B2 short period, middle period and long period by figure 8. By the result of scenario of "base-line to B2 short period", "Tropical wet forest" increases at southwest and east and covers the area of "Tropical dry area" and "Subtropical premontane moist forest". "Tropical dry forest" spreads upward along western, and covers "Subtropical premontane wet forest"; "Subtropical premontane rain forest" appears at northeast.

Table. 2 The area of Holdride life zones at SRES-A2 (unit: km^2).

Temperature(℃)	Rainfall (mm)	Classification	Base line	A2 short	A2 middle	A2long
1.5 ↓	2000~4000	none	1.41	0.18		
24 ↑	1000 down	Tropical Very Dry Forest			68.08	188.53
1.5~3	2000~4000	none	23.48	9.65	0.16	
6~12	1000~2000	Cool Temperate Montane Moist Forest				
12~18	1000~2000	Warm Temperate Lower Montane Wet Forest	0.17			9.36
1.5~3	4000~8000	none				
3~6	2000~4000	Boreal Subalpine Moist Forest	391.34	258.29	51.15	9.83
18~24	1000~2000	Subtropical Premontane Wet Forest	4859.96	1630.49	431.44	265.95
24 ↑	1000~2000	Tropical Dry Forest	1577.60	2631.79	7669.19	10292.74
6~12	2000~4000	Cool Temperate Montane Rain Forest	3811.67	3331.35	2159.75	1346.69
3~6	4000~8000	none				
12~18	2000~4000	Warm Temperate Lower Montane Moist Forest	7279.37	6412.31	6101.36	5338.03
6~12	4000~8000	Cool Temperate Montane Rain Forest		28.77		
18~24	2000~4000	Subtropical Premontane Moist Forest	15031.09	13710.41	10746.55	8881.12
24 ↑	2000~4000	Tropical Wet Forest	3006.27	6309.92	8480.67	9670.92
12~18	4000~8000	Warm Temperate Lower Montane Rain Forest	4.16	410.46	11.87	
18~24	4000~8000	Subtropical Premontane Rain Forest	16.66	1261.56	250.49	
24 ↑	4000~8000	Tropical Moist Forest		8.00	32.45	
18~24	8000 up	Tropical Rain Forest				
Total area			36003.18	36003.18	36003.18	36003.18

In the B2 middle period, "Tropical wet forest" and "Tropical dry forest" continue to spread, and the area of "Subtropical premontane wet forest" reduces.

In the B2 long period, ""Subtropical premontane wet forest" disappears, and the area of "Subtropical premontane moist forest" reduce; "Tropical wet forest" at north and nortseast" and "Tropical dry forest" increase. "Tropical very dry forest" still exists at middle part coast from B2 middle period, but the area are not more than A2 scenario and less than B2 middle period.

By table 3, we could know the change of SRES-B2 life zones. "Tropical wet forest" and "Tropical dry forest" increase mainly. "Tropical wet forest" increases from 3006.27km^2 to 10726.89km^2; "Tropical dry forest" increases from 1577.6km^2 to 5778.58km^2. "Subtropical premontane moist forest" reduces from 15031.09km^2 to 10502.14km^2.

In this scenario result, "Subtropical premontane wet forest" reduces from

4859.96km^2 to disappear. The areas that Holdridge can not classify located at north and Middle Mountain and reduce with time.

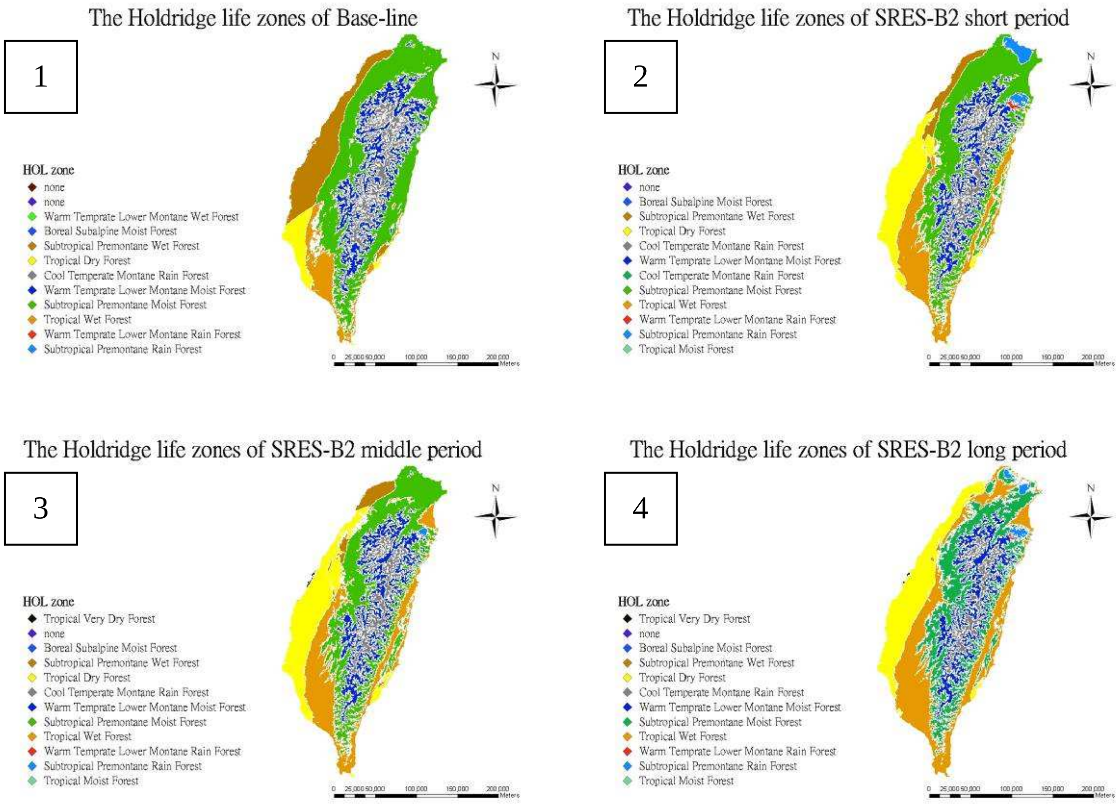

Fig.8 The changes of Holdridge life zones of the base-line and SRES-B2. In this fig, 1 is base-line; 2 is SRES-B2 short period; 3 is SRES-B2 middle period; 4 is SRES-B2 long period.

SRES-A2 is compared with SRES-B2 result

We compared SRES-A2 with SRES-B2 result.

In "Tropical dry forest", SRES-A2 increases to 10292.74 km^2, but SRES-B2 increases to 5778.58 km^2; In "Tropical wet forest", SRES-A2 increases to 9670.92km^2, but SRES-B2 increases to 10726.89km^2. Though "Subtropical premontane wet forest" completely disappears in SRES-B2, but it still has 265.95km^2 in SRES-A2. Some life zones still exist or disappear in SRES-A2, like "Warm temperate lower montane rain forest", "Tropical moist forest". "Warm temperate lower montane moist forest" and etc, still exist in SRES-B2 result and have even more area. By "Tropical dry forest" and "Tropical wet forest", SRES A2 that develops for economic will let these two life zones spread and effect plant distribution and association possibly. If we use SRES-B2 that develops for environmental protection, "Tropical dry forest" and "Tropical moist forest" still spread, but not serious like SRES-A2 in "Tropical dry forest". By the result of the above, we could find "Tropical dry forest", "Tropical wet forest", "Subtropical premontane wet forest" and "Subtropical premontane moist forest" are the most obvious. We do the above change of area of four life zones into a histogram, such as Figure 10~11.

Table. 3 The area of Holdride life zones at SRES-B2 (unit: km^2).

Temperature(℃)	Rainfall (mm)	Classification	Base line	B2 short	B2 middle	B2long
1.5 以下	2000~4000	none	1.41			
24 以上	1000 down	Tropical Very Dry Forest			13.33	3.21
1.5~3	2000~4000	none	23.48	2.98	0.78	0.16
6~12	1000~2000	Cool Temperate Montane Moist Forest				48.61
12~18	1000~2000	Warm Temperate Lower Montane Wet Forest	0.17			
1.5~3	4000~8000	none				
3~6	2000~4000	Boreal Subalpine Moist Forest	391.34	150.71	101.77	110.07
18~24	1000~2000	Subtropical Premontane Wet Forest	4859.96	1223.86	1162.21	
24 以上	1000~2000	Tropical Dry Forest	1577.60	4532.60	5915.36	5778.58
6~12	2000~4000	Cool Temperate Montane Rain Forest	3811.67	2923.39	2595.93	2111.86
3~6	4000~8000	none				
12~18	2000~4000	Warm Temperate Lower Montane Moist Forest	7279.37	6531.10	6446.76	6004.61
6~12	4000~8000	Cool Temperate Montane Rain Forest		0.50		
18~24	2000~4000	Subtropical Premontane Moist Forest	15031.09	13161.26	12348.56	10502.14
24 以上	2000~4000	Tropical Wet Forest	3006.27	6565.73	7283.31	10726.89
12~18	4000~8000	Warm Temperate Lower Montane Rain Forest	4.16	115.68	21.93	60.34
18~24	4000~8000	Subtropical Premontane Rain Forest	16.66	793.30	113.01	521.78
24 以上	4000~8000	Tropical Moist Forest		2.07	0.24	134.93
18~24	8000 up	Tropical Rain Forest				
Total aera			36003.18	36003.18	36003.18	36003.18

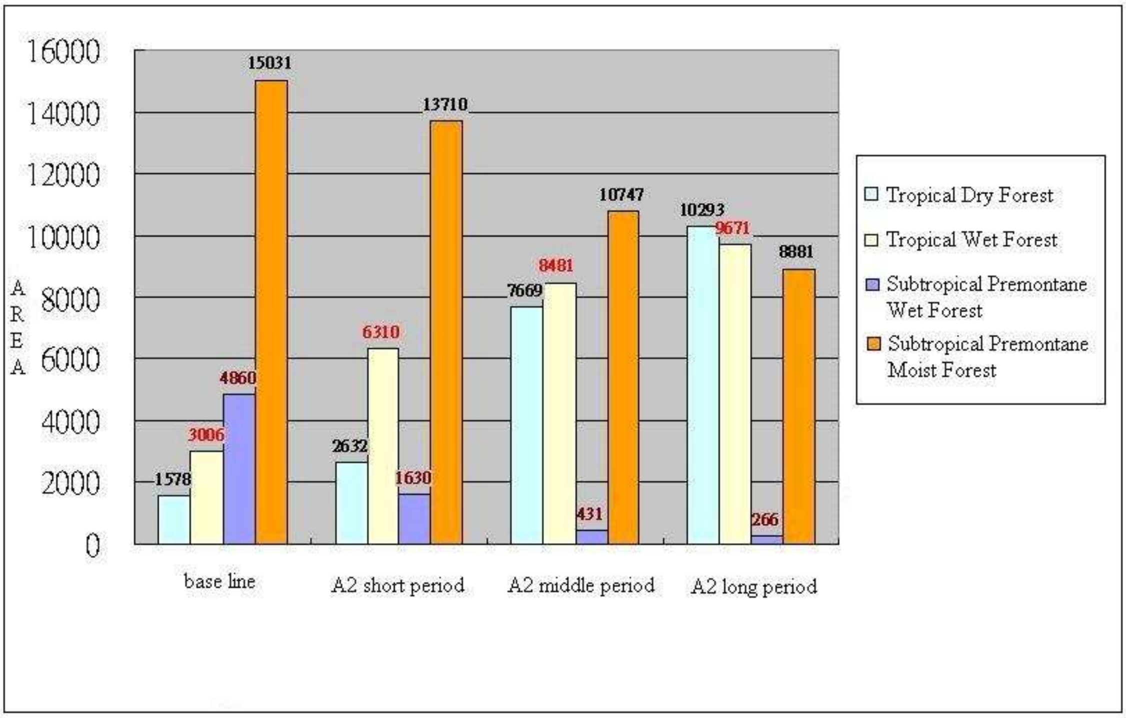

Fig.10 The changes of major Holdridge life zones' area of the base-line and SRES-A2 (unit: km2)

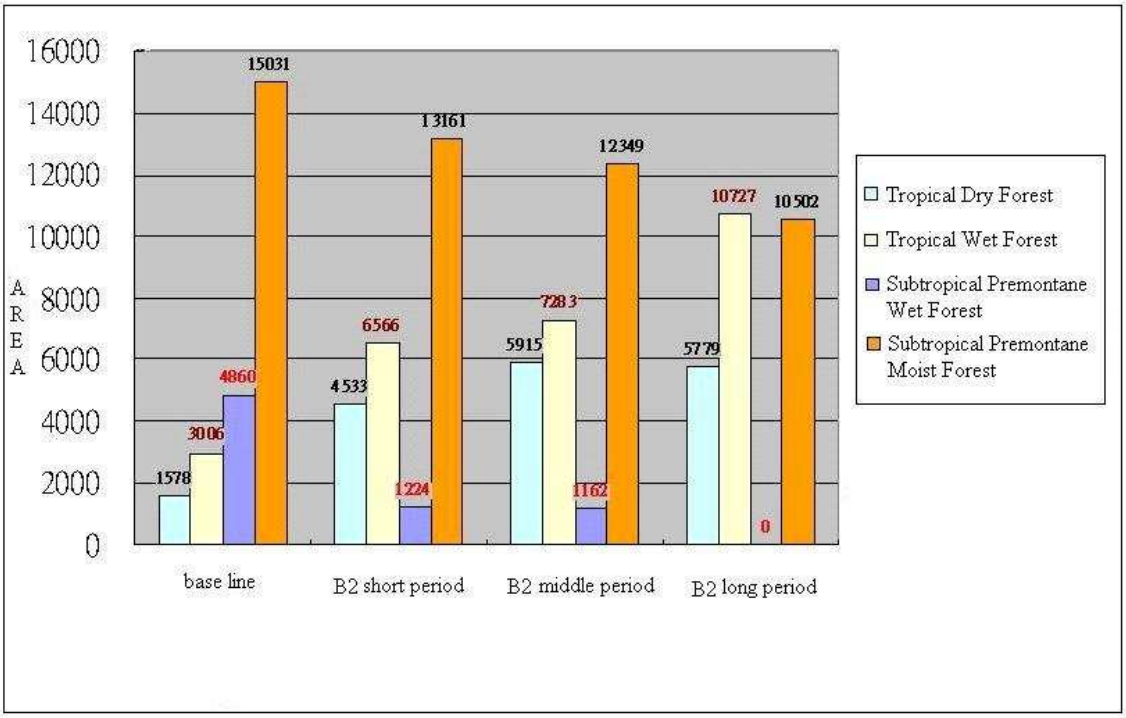

Fig.11 The changes of major Holdridge life zones' area of the base-line and SRES-B2 (unit: km2)

CONCLUSION

By the above result, we first can know that under the SRES-A2 scenarios, temperature and rainfall change more than SRES-B2 scenarios. In the SRES-A2 scenarios, the temperature rises, and the rainfall reduces. these cause the "Tropical moist forest" and "Tropical dry forest" increase substantially in the Holdridge life zones system. In the SRES-B2 scenarios, the temperature rises, but the range of rising is relatively small, and the rainfall increases. For these reasons, the area of "Tropical dry forest" increase less than SRES-A2, and the area of "Tropical moist forest" in the mountain reduce less. From Holdridge life zones, we can know these results of scenarios, the increase of "Tropical moist forest" and "Tropical dry forest" will be the main reason to effect low and middle elevation forest. It's a future research that what tree will be effected to disappear, move, and suit this change.

By scenarios, we can know the area of tropical dry and moist forest expand, and life zones change by temperature rising annual rainfall reducing clearly. If we use this scenario with habitat index to assess ecological site quality, we also can assess some tree's site quality. IPCC SRES scenarios can offer future possibility temperature and rainfall to predict the site quality and production. SRES is an old predict mode(IPCC, 2001), if we want more meticulous to predict future temperature and rainfall to study the life zones change and influence assessing, we need more meticulous future predict mode and a better spatial interpolation, and then we carry on the Holdridge life zones and influence assessment of the species and some rare trees. Directing against the uncertainty of climate change scenarios, it is still an important subject for research of the future that how to reduce it; In addition we can use other climate predict mode that IPCC offer to compare in the future and find out a node that it is relatively suitable for Taiwanese.

This scenario predicts climatic change in A.D. 2010 - 2099 years of future, and it need time to can bring to prove whether the plants were influenced during this section. We need continuous newer predict mode and plant investigating, so we can clear understand what changes in the future plants. Though this research use present data and IPCC SRES to predict future, this result could offer the climate change effect caused toward forest life zones of Taiwan, and it can let us to assess and consult.

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