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Land-Use and Land-Cover Change and Its Climatic Consequences — A Case Study of Xishuangbanna, China

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Abstract:

With the rapid development of economy, human activities have generated changes to some components of the climate system. LULCC have resulted in one important consequence for climate change. Xishuangbanna's rubber plantation area was more than 271 kha accounting for 27.1% of total China's rubber plantation, comparing its land area 2% of total china's land area, this rate was very high. This expansion of rubber plantation has causing large loss of primary forest, and has steadily increased and affected local climate. The annual mean temperature, in the past 50 years, Xishuangbanna annual average temperature was overall upward trend, the growth quantity of 0.252 centigrade for per decade, the annual increase rate of 0.13%; annual precipitation, relative humidity and foggy weather days were decreasing fast. In this paper, it will focus on exploring the climatic consequences of LULCC. Then using linear regression equation and climate tendency rate to find their changing trends, according the analysis and predict of variation tendency to give the corresponding suggestion that not to decrease primary forest from current conditions in order to conservation, reforestation and afforestation, furthermore to restore forest to be a healthy condition.

Keywords: *Land-use and land-cover change, Deforestation, Rubber plantation, Forest biomass.*

I. INTRODUCTION

The twenty-sixth session of the Conference of the Parties (COP 26) to the UNFCCC has hosted by the United Kingdom during Oct 31 to Nov 13 in 2021. The summit brought parties together to speed up action towards the goals of the Paris Agreement and the UN Framework Convention on Climate Change. Parties built a bridge between good intentions and measurable actions to lower emissions and provide much needed finance to achieve the rapid reductions towards the 1.5℃ goal.

It is clear that forests, as the main body of the earth's renewable natural resources and terrestrial ecosystems, play an irreplaceable role in the history of human survival and development. But with the rapid development of economy, human activities have generated changes to some components of the natural environment and ecosystem.

Land use and land cover change, especially deforestation which caused extremely serious harm to the natural environment, such as it would make the surface of the soil lack of vegetation protection, soil erosion, mountain floods, debris flow numerous; land desertification, aggravating the greenhouse effect, global warming and so on. In general, this could lead to a significant reduction in the area of land suitable for human habitation and arable land, resulting in a lack of food, poor living conditions and possibly even a threat to human survival.

LULCC have resulted in one important consequence for climate change. So the mitigation strategies have focused on reducing the CO2 emission, but the main source of CO2 emissions is deforestation that account 17% of all annual anthropogenic GHGs. [1] The large scale of deforestation and burning of forest have significantly affected the global carbon cycle even impacted climate.

Until recently, deforestation has only been a local or regional concern, but today we live in a globalized world in which the forests of Central and South America, Southeast Asia, and Africa are connected economically to consumers around the world. Growing global demand for agricultural commodities has led to increased tropical deforestation, which not only influences biodiversity and the livelihood of forest peoples but also contributes to global warming.

As all known that the forestry has significant mitigation potential in globally, but is estimated to account for 17.4 % of global greenhouse gas emissions. Asia-Pacific region is the main source of global forest-related emissions. China’s forest area is 206,861 kha that account 22% of China’s total land area, but primary forest area is only 11,632 kha which account 6% of forest area, 1.3% of China’s total land area. [2]

With the high demand of auto industry development, due to the very suitable climatic and geographic condition, rubber plantation was introduced and fast expanded in Xishuangbanna, rubber plantation started from 5.5 ha by 1955 to 271 kha by 2020 which accounting for 27.1% of total China’s rubber plantation--1,001 million ha in 2020, comparing its land area 2% of total china’s land area, this rate was very high. The high demand for rubber is not only affecting the loss of high diversity rain forest in Xishuangbanna but also causing the forest climatic regulation and water regulation.

Land-use and land-cover are directly related to climate and weather in complex ways and are critical contributions for modeling greenhouse gas emissions, carbon balance, and ecosystems. With the increasing levels of atmospheric CO_2 and methane, the local and global level of climate has constantly changed. Many experts have researched the relationship between Land use change and climate change, Zi(2019), Sun (2020), He (2021) and Xiao (2021) found that land cover and land use change, especially deforestation would caused large carbon emission which mainly impact local and regional climate. [3-6]

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In this paper, it explores the reasons why it is necessary to protect forest and the linkage between climatic impacts of declining deforestation and degradation. Finding ways not to decrease primary forest from current conditions in order to do that it is necessary to understand and know the impacts caused by land use changes on local climate. As other factors can also impact to climate, but this paper would like to focus on the impact of LULCC on local climate change, such as temperature, precipitation, evaporation, foggy days, et al. People in the developing countries mostly depend on natural resources for their living and land use changes impact not only geographic landscape but also ecosystem's goods and services. Therefore, it is clear to know the impacts from LULCC that it is possible to avoid the further increasing deforestation and degradation in. So finding the causes of climate change and creating the development strategies for the sustainable development is necessary and imperial.

II. STUDY MATERIALS AND METHODS

2.1 Study Area

Xishuangbanna (21 ° 09 '-22 ° 33'N, 99 ° 58 ' -101 ° 50'E) is Dai Autonomous Prefecture, covers 19,150 km^2, in Yunnan Province, China. Xishuangbanna is belonged to the Southern Yunnan Canyon South which is the extension part of the Hengduan Mountains. (Fig 1) Lancang River runs through the whole prefecture, then southward through Myanmar, Laos, Thailand, Cambodia and Vietnam into the Pacific Ocean known as the Mekong River. Mountain area accounts for 95.1% of the total area, the basin accounts for 4.9% most of the areas. Its population reached 1.235 billion in the end of 2020, population of per square kilometer is 57.5, rural population accounts 79.4% of total population.

It is the only preserved largest area of tropical rainforest geographical distribution except Taiwan and Hainan Island in China, which is a tropical and subtropical regions located in the bring of North Earth's Tropic of Cancer.

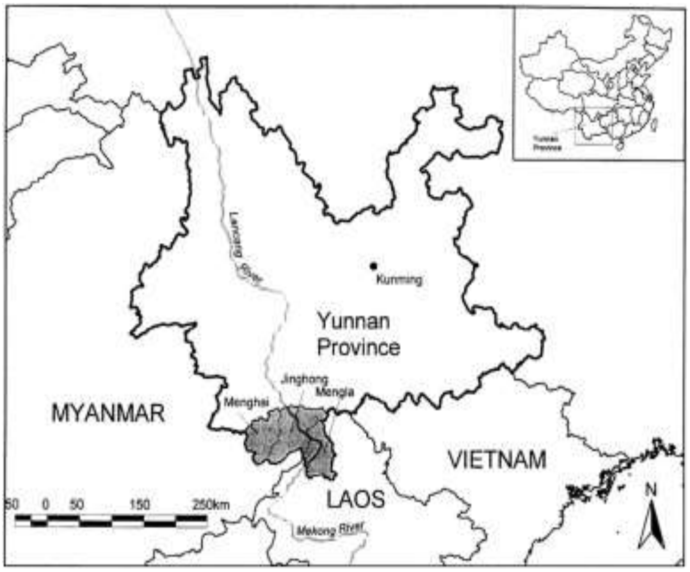

Fig 1: The location of study area

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2.2 The Data Collection

For the LULCC information, it mostly depended on the secondary data. Since 1955, related local government departments, such as Xishuangbanna Forestry Bureau, Xishuangbanna Land and Resource Department, have recorded the statistical data on LULCC and forestry. Through the data collection and analysis, it is clear to find the land use and land cover information.

Carbon sequestration and release vary by the forest types, although generalizations can be made about the three major forest biomes which are boreal, temperate, and tropical forests. TABLE I shows the global average carbon levels in the vegetation and soils for several major terrestrial biomes.

Forest biomass carbon density estimation of in Xishuangbanna were conducted by a research group in Xishuangbanna Tropical Botanical Garden based on the forest inventory data and other vegetation biomass carbon data (TABLE II).

TABLE I. Average carbon stocks for various biomes

Carbon in tons of CO_2/ha

Biome	**Area**	**Plant carbon**	**Soil carbon**	**Total carbon**
	10^6 ha	Carbon in tons of co2/ha		
Tropical forests	1.76	442	450	892
Temperate forests	1.04	208	352	561
Boreal forests	1.37	236	1,260	1,496
Tundra	0.95	23	467	490
Croplands	1.60	7	293	300
Tropical savannas	2.25	108	430	538
Temperate grasslands	1.25	26	865	892
Deserts/semi-desert lands	4.55	6	154	160
Wetlands	0.35	157	2,357	2,514
Weighted average across total area	15.12	113	488	601

Source: Intergovernmental Panel on Climate Change. 2000 [7]

TABLE II. Forest carbon density estimation in Xishuangbanna

Land use/land cover	**Mean biomass carbon density** (Mg Carbon ha^{-1} ±S.E.)	**Land use/land cover**	**Mean biomass carbon density** (Mg Carbon ha^{-1} ±S.E.)
Forest type (elevation range)		Conifer forest	
Inside nature reserve (mature forest)		Young	28.39± 3.03
Tropical seasonal rain forest (<800 m)	121.74 ± 6.99	Intermediate	36.85 ± 3.46
Mountain rain forest	116.24 ± 3.83	Mature	51.44 ± 5.00

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(800–1000 m)			
Subtropical evergreen broadleaf forest (>1000 m)	105.24 ± 3.99	Mean carbon density	37.19 ± 2.77
Conifer forest	31.54	Rubber plantation	
Outside nature reserves		<800 m	61.48
Tropical seasonal rain forest and mountain rain forest		800–1000 m	35.09
Young	29.23 ± 3.05	>1000 m	15.31
Intermediate	56.06 ± 3.75	Mean carbon density	30.47
Mature	75.17 ± 4.18	Bamboo	10.02
Mean carbon density	49.84 ± 3.13	Shrublands	14.56
Subtropical evergreen broadleaf forest		Grasslands	5.32
Young	32.15 ± 2.64	Tea garden	14.26
Intermediate	54.73 ± 1.89	Shifting Cultivation	3.81
Mature	71.00 ± 3.04	Paddy	5.41
Mean carbon density	53.22 ± 2.13		

Source: Li *et al.*, (2008) Remark: 1 Mg=10^6 gram [8]

When natural forests were cleared to create agricultural areas or other land use types, stored carbon was released back into the atmosphere as CO_2. Clearing forests not only impacts the area's capacity as a carbon sink that is currently sequestering CO_2 but also impacts future climate stabilization [9].

For the collection of detail climate data, it must to take long meteorological monitoring and data logging. In Xishuangbanna, there are three meteorological stations, Jinghong station was built in 1953, Menghai station and Mengla station were built in 1958, so these stations have supplied this related data. The information in the three stations is not fully grasping the details of local climate changes, but it is a good representation of the study climate change in Xishuangbanna region.

2.3 Statistical Analysis

According the collected climatic data, for the changing trend was conducted by linear regression equation. Using x_i to present a climate variable of sample size of n, and using t_i to correspond x_i, then use a linear regression to create the relationship of x_i and t_i:

$$x_i = a + bt_i\left(i = 1,2,\ldots,n\right) \tag{1}$$

Where, a is regression constant, and b is regression coefficient. $b \times 10$ is the climate tendency rate, unit is centigrade/10a or mm/10a. Then using this regression equation to calculate the correlation coefficient (r).

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Formula of computation as follows:

$$b = \frac{\sum_{i=1}^{n} x_i t_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} t_i\right)}{\sum_{i=1}^{n} t_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2} \tag{1}$$

$$a = \bar{x} - b\bar{t} \tag{2}$$

$$r = \sqrt{\frac{\sum_{i=1}^{n} t_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} t_i\right)^2}{\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2}} \tag{3}$$

Where, $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $\bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i$

b reflects the climate variable trend, the number of b reflects the increase or decrease rate. $b > 0$ explained that showing an increasing trend within t's increase; $b < 0$ explained that showing a decreasing trend within t's increase.

This research given significance level: $\alpha = 0.05$, then get r_α, $t_{\alpha/2}$, and F_α, if $|r| > r_\alpha$, $|t| > t_{\alpha/2}$, $|F| > F_\alpha$, thus explain that x's variation tendency with the time t change is significant, and regression parameters and regression variance are significant.

III. THE RESULTS

3.1 Land Use/ Land-cover Change

Since 1970s, Xishuangbanna's primary forest cover has dramatically changed because of deforestation. The principal changes in primary forest cover are shown in above. The major primary forest cover change has occurred between 1978 and 2020 because of the opening of forest sector into the private sector due to the economic reform after 1978. From then to the present, primary forest cover has gradually decreased further.

In recent years, the increasing rubber plantation has caused the significant reduction of primary forest in Xishuangbanna year by year. The cover rate of primary forest had been reduced from 70% by1976 to 50% by 2003, furthermore to 35% by 2010. The most reduction was caused by rubber plantation. The rubber started plantation from the 1950s, its expansion from 2.55 kha in 1971 to 271 kha in 2020, the average growth rate was 10.5% during 1971-2020; especially in the beginning of the 21th century, the

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rubber plantation expanded 1 fold in short 10 years time (TABLE III).

TABLE III. Rubber plantation area of Xishuangbanna, 1971-2020 (Area Unit: kha)

Year	Area	Year	Area	Year	Area	Year	Area	Year	Area
1971	2556.125	1981	22880	1991	42159.69	2001	86701.25	2011	135561.5
1972	4754.813	1982	26465.88	1992	45612.5	2002	87875.81	2012	150724.4
1973	5919.75	1983	26527.44	1993	48400.19	2003	87667.38	2013	162325.2
1974	7966.625	1984	19907.63	1994	57713.81	2004	91837.31	2014	177945.3
1975	9058.063	1985	20035.19	1995	64892.38	2005	101311.3	2015	195111.6
1976	14769.63	1986	21367.94	1996	72253.38	2006	116967.1	2016	223848.3
1977	15973.25	1987	27973.31	1997	76405.81	2007	127674.9	2017	228839.3
1978	17394.25	1988	28956.56	1998	80850.25	2008	134233.4	2018	240381.1
1979	18273.19	1989	32991.69	1999	84247.81	2009	131025.4	2020	254351.9
1980	21433.81	1990	37452.19	2000	85621.13	2010	132312.6	2020	271308.7

In the past, Xishuangbanna was completely covered by primary forest, the total biomass carbon would have been approximately 212.70 Tg C. By 1976 the total biomass carbon stocks for all land-use and land-cover types in Xishuangbanna decreased to 86.95 Tg C, and it was 74.57 Tg C by 2010. The annual carbon emissions rate was 0.49 Tg C /year during 1976-2020. If rubber plantation are permitted to expand as this rate, the total biomass of carbon stocks in Xishuangbanna will decrease to 50.07 Tg C in 2060.

3.2 Climate Consequences

In the past 50 years, Xishuangbanna annual mean temperature was overall upward trend (Fig 2). In the early 20th century, the Earth's mean surface temperature has increased by about 0.8 centigrade, with about two-thirds of the increase occurring in 1980s. In Xishuangbanna, during 1960-2020, the temperature growth quantity of 0.252 centigrade per decade, the annual increase rate of 0.13%, its annual mean temperature has increased by about 1.26 centigrade, it is very higher than global level. If at this increasing rate, the temperature will increase 3 centigrade in 30 years.

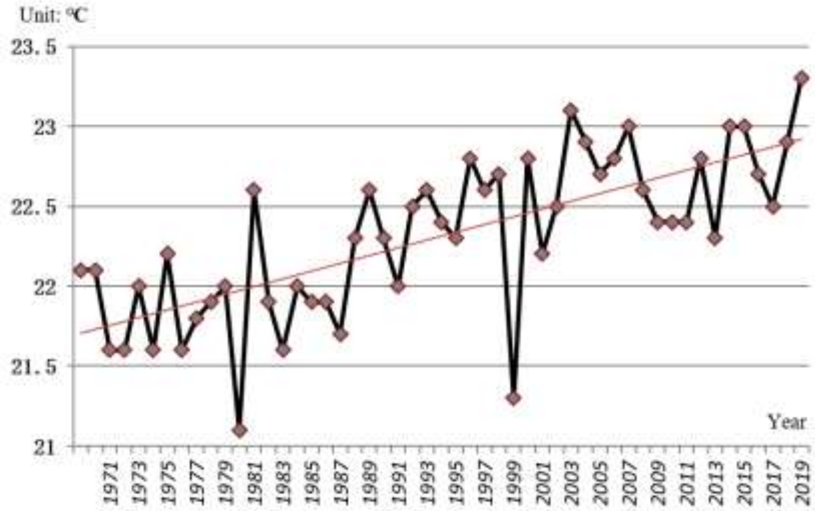

Fig 2: Xishuangbanna annual mean temperature (centigrade) 1971-2020

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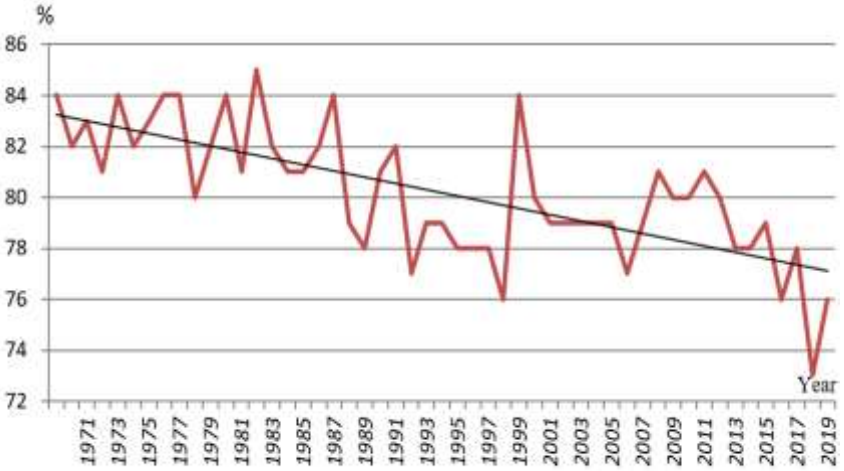

Fig 3: Xishuangbanna annual mean relative humidity (%) during 1971-2020

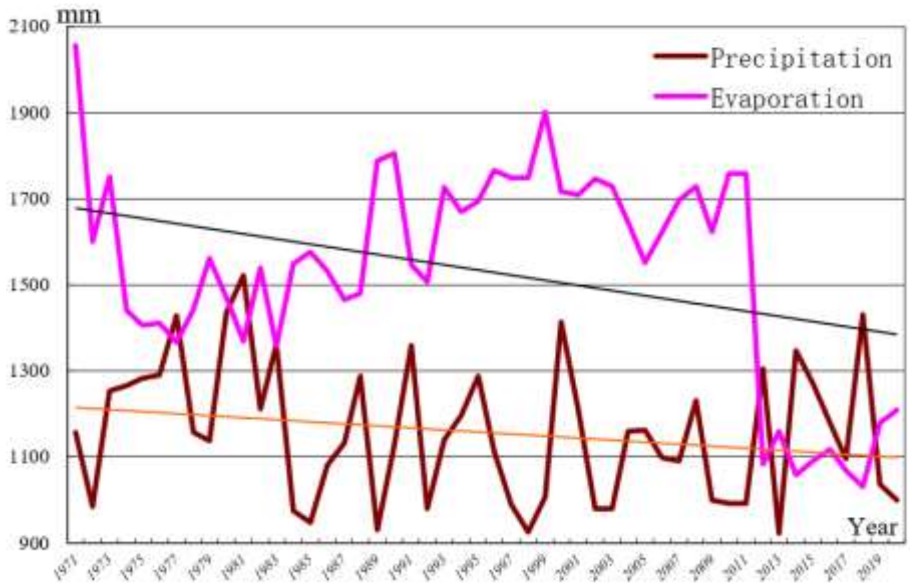

Fig 4: Xishuangbanna annual precipitation &annual evaporation (mm) during 1971-2020

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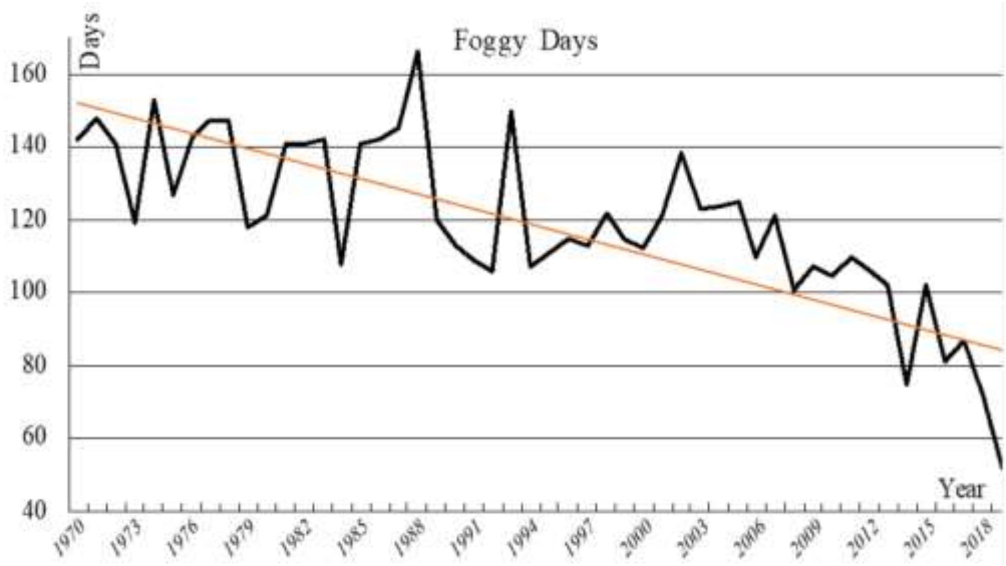

Fig 5: Xishuangbanna annual foggy days during 1971-2020

With the temperature increasing, the relative humidity was decreasing by year, the decreasing quantity of 1.215 for per decade, the annual decline rate of 0.15% (Fig 3). Annual precipitation was overall downward trend, the decline quantity of 23.96 mm for per decade, the annual mean decline rate of 1.18% (Fig 4).

Fog is an important measurement of forest water regulation function. The primary forests have long been recognized as contributing to water-soil protection and in several countries this has been translated into systems that pay for these services [10]. However, the capacity of forests to fulfill this role may be affected by the changing conditions. In Xishuangbanna, during the period of 1971-2020, foggy days are decreasing fast, and closed to vanish in 21th century, the annual decline quantity of 1.18 days, especially in the first ten years of 21th century, its annual decline quantity of 5.2 days which was three folds of that in the period of 1971-2020 (Fig 5). If at the decline rate of 2010-2020, the foggy days will vanish in short 10 years. Depending on the statistical analysis, get the climate tendency as the following Table IV.

TABLE IV. Climate tendency and linear regression equation

Items	**Climate tendency rate** (unit/10a)	**Regression equation**	**Correlation coefficient**
Mean temperature	0.252	y = 0.0252x + 21.672	0.73
Relative humidity	-1.215	y = -0.1215x + 83.199	0.69
Precipitation	-23.962	y = -2.3962x + 1218.6	0.52
Evaporation	-59.778	y = -5.9778x + 1683.8	0.55
Fog days	-11.758	y = -1.1758x + 149.72	0.75

Remark: x: climate factors; y: correlation coefficient

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IV. DISCUSSION

In this paper, it is difficult to make accurate data of annual LULCC including carbon stocks estimation, because there are many uncertainties. But through the analysis of climatic tendency trend can help us understanding the ecosystem service of forest, such as water regulation and climate regulation.

The fast growth of population and the rapid economic development are the main drivers of LULCC and have led to significant impacts on environment in Xishuangbanna. In recent years, large-scale rubber plantations is the predominant cause of deforestation. [11] Rubber as an exotic species was introduced in to Xishuangbanna and large-scale planted and expanded in the past few decades. Since the first rubber tree was planted in Xishuangbanna of 1950s, the plantation area has reached 271 kha by 2020, especially in the first ten years of the 21th century, the net growth was 13.5 kha/year, this has caused large loss of primary forest. It is predicted that at this trend the rubber plantation will expand to 600 kha in less 10 years. This means will convent half of the rest primary forest to rubber plantation in the coming years and will seriously damage the forest biodiversity and complexity ecosystem function, even cause inevitably catastrophic effect.

The rubber plantation not only converted the forestland to agricultural land or other land use, but also affected the loss of high diversity rain forest and the ecosystem services[12], the carbon dynamics even caused the climate change.[13-16] So the rubber presents a double threat to natural primary forests [17]; the analogy of the most vivid is that “rubber plantation act a water pumps in tropical China” [18], rubber plantations are much higher water consumer than native rain forests, and it as an exotic species gain competitive advantage under well-watered conditions, this will sensitively cause drought. In the spring season of 2010, there was a large-area drought covering Southern Yunnan province, Northern Myanmar, Laos, Thailand and Vietnam, most experts criticized that the rubber plantation’s expansion was the main origin.

V. CONCLUSION

The high demand and price of natural rubber by the auto industry will mostly cause to an increasing expansion of rubber plantation in Xishuangbanna. But the climatic consequences of LULCC to the livelihoods of people in Xishuangbanna are not well known.

People in Xishuangbanna are mostly depending on natural resources and agriculture for their living and daily income. For making human in harmony with nature, it is necessary and imperative to make people understanding the climatic consequences of LULCC, and policy-makers must design a long-term sustainable plan and implement appropriate policy that can integrate society development, economic development and environmental sustainability in the future. According the above findings, we suggest that not to decrease primary forest from current conditions in order to conservation, reforestation and afforestation, furthermore to restore forest to be a healthy condition.

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Acronyms and abbreviations:

CO_2	Carbon dioxide
℃	Centigrade.
FAO	Food and Agriculture Organization (of United Nations)
GHGs	Greenhouse gas emissions
Gt	Giga tones
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
Kha	Kilo hectares
LULUC	Land Use, Land-Use Changes
Mg	Mega grams
Tg	Tera grams

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